Investigation into the need for Additive Manufacturing personalisation of handheld assistive devices

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ABSTRACT

As people become older, they are prone to suffer physical and cognitive deterioration due to diseases and the ageing process itself. These disabilities affect their daily activities but the usage of an assistive device may provide the necessary support and increase their quality of life. However, sometimes these products do not provide a solution to everybody, as they are standard versions offering the same characteristics to all users; for this reason, it is useful to think about the production of personalised options that could solve particular needs. The creation and built of tailored devices may have as a result a better match between the user and the product, improving their fit and performance; these characteristics can be achieved via additive manufacturing since this technology is able to produce cost-effective and complex organic forms adapted to a user.

This study has the aim of assessing the potential of additive manufacturing in the production of personalised assistive devices, evaluating whether it is worth or not use this technology to personalise assistive products.

Through a combination of literature searching and focus group sessions, a walking stick handle was identified as a suitable case study device which would have the potential to impact a high number of people across a range of illnesses associated with ageing.

This study has shown, via user trials, that an ergonomic shape as opposed to the more traditional “crook” style, was a preferred option because its form adapts better for the user’s hand, there is more support due to its wider surface and pressure is exerted over the whole hand; also, it could provide a more comfortable position for hand and wrist.

Most users also preferred some kind of additional texturing on the handle because they could provide a degree of roughness to the surface, causing an anti-slippery effect and providing a better grip, but the exact texture they preferred varied between users. This suggests that there may be a benefit to allowing users a choice of different textures at the point of purchase.

Personalisation of an ergonomic-shaped handle did not appear to provide a significant benefit, with participants generally preferring the standard shape. This suggests that (for the majority of people) the overall shape may have more of an influence on the user's preference than any small changes to enable conformance to the individual.

However, further work is needed to define a suitable and accurate method of capturing user data in cases where personalisation may be more relevant, for example, where someone has a disability that affects their ability to grab the handle.

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CONTENTS

NOMENCLATURE

3D	Three-dimensional
3D CAD	Three-dimensional Computer Aided Design
AD	Anno Domini
AdAM	Centre for Advanced Additive Manufacturing
ADL	Activities of Daily Living
Al	Aluminium
AM	Additive Manufacturing
AMA	American Medical Association
ARMS	Adherence to Refills and Medications Scale
AT	Assistive Technology
ATA2004	Assistive Technology Act of 2004
BC	Before Christ
BI	Barthel Index
CAD	Computer Aided Design
CATCH	Centre for Assistive Technology and Connected Healthcare
cm^3	Cubic centimetre
CNC	Computer Numerical Control
CVD	Cardiovascular Disease
DFA	Design for Assembly
DFDR	Design for Disassembly and Recyclability
DFE	Design for Environment
DFLC	Design for Life Cycle
DFM	Design for Manufacture
DFMt	Design for Maintainability
DFQ	Design for Quality
EEC	European Economy Community
EMG	Electromyography

EVA	Ethylene-vinyl acetate
FEA	Finite Element Analysis
FDM	Fused Deposition Modelling
FO	Foot orthoses
g	Gram
HECoS	Higher Education Classification of Subjects
IADL	Instrumental Activities of Daily Living
ICS	International Continence Society
ICF	International Classification of Functioning, Disability and Health
IGES	Initial Graphics Exchange Specification
IVDs	In vitro diagnostic medical devices
K	Kilogram
KI	Katz Index
L	Litre
LS	Laser Sintering
Lb	Pound
MHRA	Medicines and Healthcare Products Regulatory Agency
MIT	Massachusetts Institute of Technology
mm	Millimetre
NHS	National Health Service
O&P	Orthoses and Prostheses
PA	Polyamide
PAEK	Polyaryletherketone
PIADS	Psychosocial Impact of Assistive Devices Scale
PS	Polystyrene
PSI	Policy Studies Institute
PVC	Polyvinyl chloride
RA	Rheumatoid Arthritis

RCAI	Restorative Care of America Incorporated
RNIB	Royal National Institute of Blind People
SLA	Stereolithography
SLM	Selective Laser Melting
STL	Standard Tessellation Language
SXCT	Spiral X-ray Computed Tomography
Ti	Titanium
TPE	Thermoplastic elastomers
UAV	Unmanned aerospace vehicle
UCD	User-Centred Design
UK	United Kingdom
UV	Ultraviolet
V	Vanadium
~	Approximately equal
°C	Degrees Centigrade
ø	Diameter
µm	Micrometre
±	Plus or minus

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1 INTRODUCTION

Many people suffer physical deterioration during their lives, especially at advanced age; some of the consequences are reductions in their ability to move, the speed at which they move and their capabilities. The elderly population may require an assistive device or an extra support to help them to perform their daily activities. Currently, there are apparatus to cover these needs that are developed in standard sizes, such as handles for cutlery, whereas others are manufactured in different sizes like grab rails for bathrooms. Other designs encompass a broader segment of people having adjustable features, for example, canes or stool-chairs which are manufactured to be used by people of different heights. None of these alternatives provide solutions to the whole population because individuals have special requirements; these could be solved through personalisation. Producing personalised and individual devices with conventional manufacturing methods such as milling, injection moulding or casting is not economically feasible because those processes were planned to follow a continuous flow using bespoke tooling or moulds. Using these methods for the manufacture of unique solutions would result in high cost parts; however, there exists a potential solution to create single devices with a lower price. Additive manufacturing (AM) technology has the potential to be used to produce suitable products, taking advantage of the personalisation level achievable in order to help the elderly population to perform their everyday activities.

1.1 The elderly population in the UK

The elderly population is prone to suffer illnesses due to the natural ageing process. These illnesses can lead to both physical problems and cognitive decline resulting in limitations in a person's ability to carry out daily activities.

The document "Later Life in the United Kingdom", published by the charity Age UK, establishes that there are 11.4 million people over 65 years old in the UK, which represents 17.5% of its total population, estimated to be 64.5 million on 30 June 2014 [1]. Considering complications, there are many documented cases in the UK of people who suffer limitations; according to the investigation "Bigger Picture" [2], in England, 4.3 million people over 65 years old live with limited day-to-day activities because of a long-term health condition or disability, and over 2 million of them have difficulties performing daily activities. The document "Later life in the United

Kingdom", establishes that two thirds of National Health Service (NHS) users are 65 years old and over but only two fifths of NHS funds are allocated to them [3]. Based on these sources, this work will focus on people over 65 years old.

As we age, the human body tends to suffer deterioration that can be supported by the use of assistive devices. These types of products are created to alleviate users' difficulties but, unfortunately, not all assistive devices are effective for the whole population as some users may have special requirements due to particular needs. For this reason, there exist personalised products that according to literature, bring emotional and physical benefits to the user.

Through the identification and analysis of a suitable case study device, this thesis will investigate the potential benefits of personalisation of assistive devices through the use of AM.

1.2 Aims and objectives

The aim of this research is: *"to evaluate the potential of additive manufacturing for personalised assistive devices"* through the following objectives:

- Identifying and analysing an assistive device for which personalisation has the potential to make the most impact on users.
- Identification of key aspects of the assistive device in order to create different options/versions for comparison and evaluation.
- Definition of how to conduct the personalisation process.
- Evaluate the user's perception and preferences concerning personalised and non-personalised versions of the selected case study device.
- Perform overall analysis of potential benefits and/or disadvantages of personalising.

1.3 Thesis structure

This thesis encompasses 9 chapters. The following two chapters will be related to the background information and literature review of core topics such as diseases, activities, assistive devices, personalisation and additive manufacturing. Later, the study is divided into two parts; the first one discusses the planning and selection of an assistive device that would have a high impact if it is personalised; the second part will start with a chapter where there will be an analysis of the selected assistive device as well as a plan about how to personalise it and complete the AM process of different versions, from their design up to their post-processing. Following this, the experiment phase will be conducted through individual interviews with participants. After Part 1 and Part 2, the results and discussion from these tests will be analysed and the last chapter includes conclusions and further work recommendations. Figure 1.1 establishes the organisation of this research.

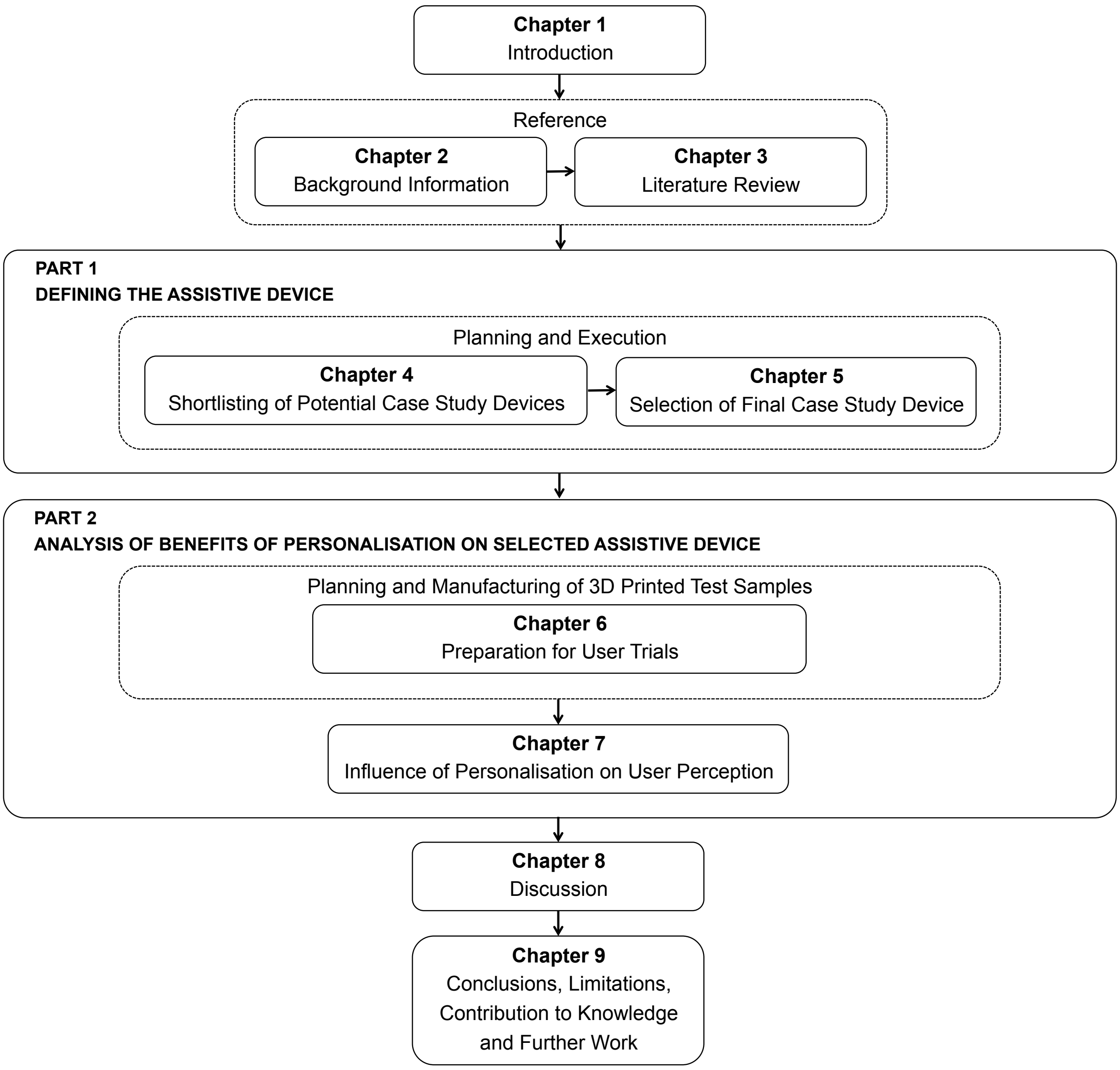

Figure 1.1 - Thesis structure

2 BACKGROUND INFORMATION

This investigation is based on the relation of five core topics such as diseases, activities, assistive devices, personalisation and AM. The first two, diseases and activities are interconnected because illnesses may cause interruption of daily occupations, while assistive devices can support activities when people suffer from limitations, and AM may have the potential to be used to personalise them. The possibility of improvement in the user will be investigated in this study. Details and technical data about the topics previously mentioned will be shown in this chapter and the information will be used to help identify a case study assistive device based on its potential level of impact.

2.1 Diseases

Diseases are prone to appear in the elderly population, and one single illness could present a variety of symptoms with different intensity in different people; for example, arthritis is an impairment that, in some people, can cause pain in the hands, and in others is manifested as painful knees. In order to identify areas where assistive devices could help it is important to know all the characteristics of the illnesses and the limitations a person could suffer.

The diseases discussed here are based on the illnesses mentioned in the document "Later Life in the United Kingdom" [3].

2.1.1 Arthritis

Arthritis is a type of rheumatic disease characterised by inflammation, which can cause loss of function in one or more structures of the body such as joints, tendons, ligaments, bones and muscles.

Arthritis is one of the most common diseases that causes long-term impairment in the UK population; it is a "term for a range of conditions which cause pain and swelling of the joints. These conditions occur as a result of damage or wear and tear on the body and are more prevalent over time" [4]. In the UK, around 10 million people of all ages suffer from this illness and it represents an expenditure of around £5 billion for NHS and social services in England [5]. Around 4.74 million people over 65 years old suffer from arthritis in the UK [5] [6].

The symptoms include stiffness, pain, swollen joints, decreased range of motion, loss of height over time, a stooped posture, increased risk of bone fracture, balance problems, painful muscle cramps, cognitive dysfunction, bladder dysfunction and breathing problems due to kidney damage, depression and sleep disturbances.

2.1.2 Osteoporosis

According to the International Osteoporosis Foundation, osteoporosis means: "porous bone is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [7]. The process of losing bone density is progressive and people with osteoporosis have a higher likelihood of bone fractures if a fall occurs.

Around the world, an estimated 200 million people have osteoporosis [8] and nearly 3.2 million people in the UK suffer from this condition. There are approximately 2.41 million people over 65 years old in the UK with this disease [9] and there are around 230,000 fractures each year due to osteoporosis [3]. 1 in 2 women and 1 in 5 men (50 years old and over) could suffer a fracture due to this illness [3].

The symptoms of osteoporosis include pain, decreased range of motion, loss of height over time, a stooped posture, a bone fracture occurred in unexpected situations (fractures produced by a small impact, cough or sneeze) and balance problems.

2.1.3 Dementia

This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10].

According to Age UK, dementia is one of the most common causes of impairment in people over 65 years old, even more common than other illnesses such as cancers, cardiovascular problems and stroke. In 2015, there were around 850,000 people affected by dementia in the UK [11]. In 2013, the total number of cases was 815,827, of which 773,502 were in people aged 65+ [11]. According to a forecast, the total of cases will increase to 1 million by 2025 and more than 2 million by 2051.

The number of cases of dementia is related to age [11]. According to Alzheimer's Society figures (2013), symptoms can start, in an early-onset scenario, in people from 30 to 64 years old, representing 5% of the total of cases, meanwhile the other 95% are people over 65 years old. Therefore dementia is a disease that largely occurs in the elderly population.

The main type of dementia is Alzheimer's, this is a physical progressive illness that damages the brain; in the UK, around 520,000 people suffer from it [12]. In this disease, proteins form plaques and skeins that cause lack of connections in nerve cells and eventually they, and brain tissue, die. Alzheimer's disease is present in 62% of the occurrences of dementia, and vascular dementia is positioned in second place with 17% (Approximately 150,000 cases in the UK) [11]. Vascular dementia is "caused by a range of cardiovascular or cerebrovascular conditions that may lead to ischemic, hypoperfusive, or hemorrhagic brain lesions that are characterised by loss of cognitive functions" [13]; some of its symptoms are memory loss, but unlike Alzheimer's, this is not usually presented in the early stages of vascular dementia; its most common symptoms in early phases are difficulties with planning, making decisions, concentration and reduction in the thinking process [14].

The symptoms of dementia are cognitive dysfunction, gradual loss of memory, difficulty with thinking and reasoning, reduction of communication skills, disorientation, visual hallucinations, tremors, balance problems, stiffness in joints, decreased range of motion, depression, bladder dysfunction and sleep disturbances.

2.1.4 Parkinson's disease

Parkinson's is a disease in "which part of the brain becomes progressively damaged over many years" [15]. According to the Parkinson's Foundation, more than 10 million people worldwide suffer from this illness [16]. Around 4% of cases are diagnosed before age 50 [16]. In the UK, in 2009, there was an estimated figure of 127,000 people who suffered from this disease; from this group the male population was higher than the female, with approximately 70,000 cases in men and around 57,000 in women, and the total of people over 60 years old was roughly 118,000. There is a prediction published by Parkinson's UK of about 162,000 cases developed by 2020 [17].

In 2009, the highest rate of Parkinson's cases in the UK was in the group of people aged between 75-79 years old with around 26,000 incidences, followed by the groups of 80-84, 85+, 70-74 and 65-69 years old; meanwhile, the lowest prevalence was in groups <60-64 years old, with around 14,000 occurrences and decreasing with the age. According to these numbers, there is an increment of Parkinson's cases concerning to become older.

The main symptoms of Parkinson's disease include involuntary tremors, decreased range of motion, stiffness, pain, a stooped posture, painful muscle cramps, spasms, balance problems, cognitive dysfunction, depression, sleep disturbances, bladder dysfunction, constipation, problems with odour identification and decreased appetite [15].

2.1.5 Urinary incontinence

According to the International Continence Society (ICS), urinary incontinence is: "the complaint of any involuntary urinary leakage" [18] and it can be the result of abnormalities in the lower urinary tract or other diseases. It is classified in 3 types shown in Table 2.1 [19]:

Symptom	Description
Stress	Leakage with physical exertion or when sneezing or coughing.
Urge	Leakage with a strong and urgent desire to void.
Mixed	Combination of stress and urge.

Table 2.1 - Types of urinary incontinence [19]

In the UK, approximately 3.2 million people over 65 years old have urinary incontinence [20], women are more prone to this condition. Its causes depend of the type of urinary incontinence. For stress incontinence, the cause can be damage of the muscles of the pelvis or the urethral sphincter. The cause for the other type, urge incontinence, is the over-activity of the detrusor muscles that control the bladder. [21] Other situations that may cause incontinence include pregnancy, obesity, former cases of incontinence in family and age.

The symptoms of urinary incontinence are: balance problems, sleep disturbances such as nocturia: "waking to void one or more times per night" [22]; bladder dysfunction that encompasses storage symptoms such as urgency, frequency; voiding symptoms such as slow stream, intermittent stream, hesitancy, straining, terminal dribble and post-micturition symptoms, this includes an incomplete emptying and the post-micturition dribble, which is related to the leakage of urine a few moments after going to the bathroom [22].

2.1.6 Heart disease and strokes (cardiovascular diseases)

Cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23]. In the UK, approximately 150,000 people have a stroke each year [23]. In 2012, there were 17.5 million deaths worldwide caused by cardiovascular disease, of this figure, 7.4 million were due to heart attacks and 6.7 million were due to strokes [24]. There are approximately 2.94 million people over 65 years old [25] with a cardiovascular condition in the UK.

A lot of factors can influence having a CVD, according to the NHS they are: high blood pressure, smoking, high blood cholesterol, diabetes, not exercising, a former CVD case in the family, being obese, alcohol and stress handling [26]. The symptoms are swelling due to a heart failure, it may cause swelling in feet, ankles, legs and abdomen; pain caused by coronary heart disease in the chest (angina), in the neck, jaw, throat, abdomen and back; pain due to a heart attack in the chest, upper back and neck. Other symptoms are painful muscle cramps, spasms, balance problems, cognitive dysfunction, depression, sleep disturbances, indigestion, heartburn, nausea and vomiting, fatigue, breath problems, palpitations, visual impairment, poor visual acuity, poor depth perception and visual field loss.

Table 2.2 summarises the number of people affected by the six previous diseases:

Diseases	Population in the UK (million)	Age
Arthritis	4.74	65+
Osteoporosis	2.41	65+
Dementia	0.77	65+
Parkinson's disease	0.12	60+
Urinary incontinence	3.2	65+
CVD	2.94	65+

Table 2.2 - Number of cases per disease in the UK

Besides the diseases previously mentioned, the ageing process itself may cause other illnesses that will be described in the following section.

2.2 Ageing

"Aging, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].

As mentioned before, the number of elderly people in the UK is 11.4 million [3], which is almost 18% of the entire population.

In addition to specific diseases, ageing itself causes difficulties such as: sarcopenia and dynapenia, which refer to the loss of muscle mass and the muscular strength, respectively, with age [28]; joint deterioration that increases with age and starts to limit the variety and range of the movements that the limbs can perform, affecting flexibility as well [29]; a decline of bone strength, as people become older they start losing bone mass and bone density, this is due to the lack of calcium and other minerals [29]; a reduction of coordination and motor skills because when a person becomes older, there is a decline in synapses and neurons and besides this, the nervous system starts to deteriorate [30].

As a result, symptoms can be clumsiness, tremors, less flexibility, a decline of sensibility to heat, pain and pressure, swelling, stiffness, loss of height over time, a stooped posture, a bone fracture, balance problems, cognitive dysfunctions, sleep disturbances, reduction of communication skills and fatigue.

Besides all the problems mentioned before, there is a decrease of the sensory system [31] that will be described in the following section.

2.2.1 Sensory impairment

Sensory impairments may also have limitations during ageing; there could be a loss of vision, hearing, sense of smell, taste and touch. Their symptoms are poor visual acuity, poor contrast sensitivity, poor depth perception, visual field loss, inability to know where noise is coming from, hearing a buzzing or whistling in the ears, lack of sensation of external stimuli, problems with odour identification, decreased appetite and problems with flavour identification.

Visual impairment represents a restriction in one or more of these areas: sharpness of vision, visual field and colour [32]. This impairment can lead to specific symptoms such as decreased range of motion, balance problems, reduction of communication skills, poor visual acuity, contrast sensitivity, depth perception and visual field loss. According to the Royal National Institute of Blind People (RNIB), there are 1.87 million people in UK with sight loss affecting in an important way their daily lives [33]. 77% are over 65 years old, which equates to near 1.44 million people [33].

A hearing impairment does not allow a person to receive sounds [34], it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "heredity (genetics), aging, loud sound exposure, diseases and infections, trauma (accidents), or ototoxic drugs (drugs and chemicals that are poisonous to auditory structures) [35]". The symptoms of a hearing impairment are balance problems, reduction of communication skills, disorientation, fatigue, being unable to tell where the noise is coming from and hearing a buzzing or whistling in the ears. In the UK there are 11 million people with hearing loss [36], of which 6.4 million are people over 65 years; and 685,000 cases of this figure are considered as severe/profound [3].

A tactile impairment represents deterioration in the sense of touch, which avoids perceiving pain, temperature, pressure, vibration and body position through skin, muscles, tendons, joints and internal organs [37]. Since the person is not aware of pain, temperature, pressure and vibration, their symptoms involve pain, balance problems and lack of sense of external stimuli [37].

Anosmia is the loss of the sense of smell, this sense is related to enjoyment, safety and social interaction and it allows detecting danger [37]. This sense could decrease after the age of 70 due to losing nerve endings and reduced mucus production, smoking or breathing harmful particles. The symptoms of people who suffer from anosmia are: problems with odour identification and decreased appetite.

Ageusia represents taste impairment due to a decline of taste buds and dried mouth. Taste bud reduction often occurs after 60 years old and the sensitivity to five tastes can be reduced; also, the production of saliva declines with age, and causes a dry mouth and that affects the sense of taste [37]. Therefore, its symptoms can be problems related to identification of flavours and decreased appetite.

The following sections will examine the potential activities, which may be affected by the diseases mentioned before.

2.3 Classification of activities

Quality of life measures the wellbeing of the physical and mental health; these states are associated with the actions that people perform during their regular routines, and the lack of ability to execute a task can be frustrating; this can be caused by different illnesses present in most cases in the elderly population like the ones mentioned in the previous section. By analysing these activities alongside the illnesses discussed in the previous sections, it is possible to identify the activities which might most benefit from personalised assistive devices.

The activities performed can be used as a measurement of physical and mental health in older people. With this intention, these activities have been classified in two groups in order to measure different aspects. The first group to consider is called activities of daily living (ADL) and is related to self-care and mobility [38] and the second one is instrumental activities of daily living (IADL), which includes the analysis of functions that are required for living independently in a society [39].

Several standards have been developed for each category (ADL and IADL); in the following sections these standards will be analysed in order to select the most used and include their activities into this study, this final list will help to review how the activities are affected by the diseases previously mentioned.

2.3.1 Standard of activities of daily living

For the ADLs, there are several standards [38], the two more frequently used are: the Barthel Index (BI) and the Katz Index (KI). The BI was created for evaluating the functions of patients with neuromuscular or musculoskeletal impairments; the KI was developed for assessing activities of people who suffer from hip fractures, on the elderly and on chronic patients.

The BI encompasses ten points that evaluate the ability to accomplish activities: "feeding, moving from wheelchair to bed and returning, doing personal toilet, getting on and off toilet, bathing self, walking on level surface, ascending and descending stairs, dressing, controlling bowels and controlling bladder" [38]. On the other hand, the KI analyses the performance in six ADL: "bathing (sponge, shower or bathtub), dressing, going to the toilet, transference, continence and feeding" [38].

There are some papers that advise the use of the Barthel Index, for example, it has been suggested by the Royal College of Physicians for evaluating the performance of the elderly population: "The Barthel ADL Index probably reflects existing informal assessments and formalises existing activities" [40]. The BI "offers a simple, clinically relevant way of identifying most important physical disabilities, and of measuring its overall extent" [41]. On the other hand, there are other publications that support the KI, mentioning this "is valid for the retrospective assessment of basic ADL by informants, with optimal reliability" [42].

For the purpose of this research, the Barthel Index was chosen because it contains all the activities of the Katz Index plus other specific actions, thus a more complete evaluation is created.

2.3.2 Standard of instrumental activities of daily living

The instrumental activities of daily living are activities more complex than the ADL and are used to maintain independence in a community [43].

According to literature, there is no universal IADL standard used, or an agreement related to specific activities involved in this assessment: "As IADL is culturally and environmentally determined it seems reasonable that no one assessment will ever meet the needs of all patients groups" [39] and some centres have created their IADL evaluations to analyse precise needs of patients [39]. The same idea is stated in the article "Measurement of Instrumental Activities of Daily Living in stroke": "Although there is a conceptual understanding of IADL, there is no agreement as to the exact categories or items to be included" [44]. One clear example of this is the action of making tea, which can be considered essential in the UK and it is present in some IADL indexes but in other countries it lacks importance and is neglected.

However, there is one measurement that is the most used in the elderly population, the Lawton IADL scale [45] [46]. It includes eight activities for assessment: ability to use telephone, shopping, food preparation, housekeeping, laundry, mode of transportation, responsibility for own medications and ability to handle finances [46]. The accomplishment of this set of activities can demonstrate a level of independence in the person and people who cannot execute them could experience frustration because their autonomy is threatened. As the activities encompass relevant areas of daily life, the Lawton scale will be used for this study.

ADLs have been established as basic activities and including them in the study will cover essential actions that a person needs to perform. On the other hand, IADLs cover the needs that people require for being active within a society. Therefore, including both types of activities in this investigation will cover many relevant areas in people's lives and their accomplishment will bring a sense of fulfilment and independence.

People who suffer from diseases could struggle with the execution of ADLs and IADLs; for this reason, assistive devices will be reviewed in the next section in order to find which could be used as a method of helping.

2.4 Assistive devices

According to the Technology-Related Assistance for Individuals with Disabilities Act [47], assistive devices can be defined as: "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities"; these can be positioned in different parts of the body: inside, outside or separated from it [48]. This definition includes products that were created thinking of people with impairments, but, also, it encompasses items designed not initially for people with disabilities; for example, a microwave for general purposes can be an assistive device for people with cognitive problems unable to use a regular stove [47].

2.4.1 History of assistive devices

Throughout human history there have been people that were either born with a form of disability or that became disabled due to accidents or war, thus a need arose to help them improve their quality of life and capabilities. Records prove that the first assistive devices were invented by the Egyptians: a prosthetic for the big toe of the right foot made of leather was found in the mummy of a priest dated about 1500 BC [49], the first sort of eyeglasses were created about 1000 BC, while the first head-worn eyeglasses were not made until 1285 [50]. The first prosthetic leg is believed to be dated about 300 BC [51] and the first prosthetic hand was used in battle in 218 BC by Roman General Marcus Aurelius after losing his hand in battle and using one made out of iron to be able to hold his shield [49]. One of the most iconic and widely used assistive devices, the wheelchair, makes its first appearance around 525 AD in China [52].

As time passed, the complexity of assistive devices increased together with scientific and technological development, for example in 1508 a prosthetic hand was built that had some movement using springs, later that century Ambroise Paré made several improvements in the field of prosthetics like adding adjustable harnesses, knee lock control and other engineering features that are still used today [51]. Around 1588 the first hearing aids were created of wood and with the form of the ears of animals that have acute hearing [53], later in 1595, an improvement of the wheelchair was created for the king of Spain who had gout [52]. In 1824 Louis Braille created the system that has his name to help blind people to read [50] and by 1871 the wheelchair was almost in its present form missing only the steel wheels since at that time wooden wheels were still in use [52].

Assistive devices keep changing as technology does and a big breakthrough was achieved with the help of electronic devices, for example the "talking" reading machines by Ray Kurzweil in 1975 that allows people with sight impairments to listen to written information; in the 1970s, Gregg Vanderheiden created the communication device "Auto-Corn" for people who suffer from speaking problems [50]. In some countries such as United States, there was an increment in the development of assistive devices originated by the Second World War, where prosthetics and sensory aids were created. Later in the 20th century there was an increase to try the inclusion of disabled people in society with the implementation of curb cuts, ramps, wheelchair lifts installed on buses; and access to information and communication by means of telephone, voice-recognition systems, voice synthesisers, screen readers and computers [50]. As time has gone on, the idea of personalisation of devices to meet individual needs has come about.

2.4.2 Classification of assistive devices

It is relevant to know the classification of the assistive devices because each category should follow regulations for being approved and commercialised.

Assistive devices can be also known as assistive technology [54]. The UK Government utilises this last term and they describe it as: "products or systems that support and assist individuals with disabilities, restricted mobility or other impairments to perform functions that might otherwise be difficult or impossible" [55].

The assistive devices/assistive technology can be classified as a) an aid for daily living, or b) medical devices; these are established as products used for relieving an injury, handicap or disease or to substitute a physical function [55].

Not all assistive technology products are considered as medical devices. The definition of medical devices establishes "a direct link between the corrective function of the product and the individual using the product" [55]; and, for example, products such as shower chairs are used mainly for personal hygiene, rather than mobility or medical purposes.

Examples of medical devices are:

- Mobility aids such as wheelchairs, walking aids, external limbs prostheses
- Communication and hearing aids
- Posture management (from regular cushions to elaborate support systems)
- Pressure management (pressure redistribution, relief cushions and mattresses)
- Moving and handling systems such as hoists, slider boards and bath lifts

Examples of aids for living but not medical devices are:

- Acoustic signals such as traffic lights
- Bariatric chairs and stools
- Personal alarm systems

- Portable ramps
- Shower chairs
- Stair lifts
- Toilet equipment such as toilet seats, shower seats and commodes

This study will be focused on assistive devices that are classified as medical devices since the product will have a direct connection between the user and the corrective function.

2.4.3 Types of medical devices

One of the ministerial departments of the UK Government is the Department of Health; it manages different bodies and one of them is the Medicines and Healthcare Products Regulatory Agency (MHRA) who is in charge of regulating the medicines and medical devices [56].

The different types of medical devices established by the MHRA are [57]:

- Active implantable medical devices
- In vitro diagnostic medical devices (IVDs)
- General medical devices

1. Active implantable medical devices

These devices are located inside the body such as cardiac pacemakers, implantable defibrillators, leads, electrodes, nerve stimulators, bladder stimulators, among others.

2. In vitro diagnostic medical devices (IVDs)

Examples of these types of devices are: reagent, calibrator, control material/kit/instrument/apparatus, equipment used in vitro to analyse material such as tissue or blood donations, pregnancy tests and hepatitis B tests.

3. General medical devices

These cover almost the rest of the medical devices, examples include first aid bandages, hip prostheses, X-ray equipment, heart valves, dental materials, among others.

Medical devices are also classified according to their level of risk. For “active implantable devices” and “general medical devices” the categories are [57]:

- Class I: Low risk
- Class IIa: Medium risk
- Class IIb: Medium/high risk [58]
- Class III: High risk

This classification will depend on these factors:

- Time of usage of the device
- If the device is invasive or not
- If the device is implantable or active
- If the device contains a substance or not

“General Medical Devices” are led by The Medical Devices Directive 93/42/EEC (European Economy Community) and in its document “COUNCIL DIRECTIVE 93/42/EEC of 14 June 1993 concerning medical devices” [59], Annex IX mentions the classification criteria. According to the 1.1 Rule 1, assistive devices such as splints, walkers, relief pads or walking sticks are Class I; rule 1 establishes: “all non-invasive devices are in Class I, unless one of the rules set out hereinafter applies” [59] and none of the other 17 rules points out other applicable criterion.

Having defined the classification as General Medical Devices-Class 1 of the potential assistive device for this study, the concerning regulations will be followed.

As mentioned earlier, assistive devices relieve or support parts of the body and some of them should be in direct contact with the limbs, therefore, it is relevant to investigate how it is possible to obtain a better fit, and what advantages it could provide; this fit in assistive devices can be achieved through personalisation that will be described in more detail in the following section.

2.5 Personalisation

Personalisation is the adaptation of a whole product or certain specific aspects of it to the user in order to fulfil his/her individual requirements. Several stakeholders such as manufacturers, marketers and public health services are involved in the creation of these types of products, however, the investigation will focus on the user.

2.5.1 Advantages of personalisation

The use and growth of personalisation is related to the benefits that it can provide. From the standpoint of the user, the benefits of personalisation in general can be:

- Personalisation results in a better adjustment of a product, this causes an enhancement in the efficiency of the device because the user could have a suitable grip or control over it; also, the force exerted by a person to an object can reach its maximum value avoiding loss of energy, this can be seen in personalised shoes used in high impact activities.
- With a better adjustment in a product, people are more comfortable and this could avoid an injury to the user or fatigue when it is utilised; also, there can be an improvement in the emotional attachment to a product avoiding its abandonment such as splints, canes or assistive devices which are in direct contact with a part of the body, or simply because a fitted product could be more comfortable or appeal to a person.
- The development of the product is focused on the user from the beginning to the delivery of the solution; therefore, the person participates actively in many stages receiving individual attention.
- A company that creates bespoke devices may have a high level of expertise in the field; in this case, the result is a robust solution utilising experience, research and technology.
- Satisfaction and customer loyalty. A personalised device is focused on solving the needs of one person; hence, the solution creates a unique benefit that may not be found in another company. This specialisation results in user satisfaction, and, as a consequence, the person may use the same service for further requisitions.
- Personalisation of products can help to show the user's identity.
- Facilitating a purchase since staff provide personalised customer attention.
- In some cases, there is a faster delivery compared to products built using other manufacturing methods.
- It could provide a better experience, preference match, product, service and communication [60].

2.5.2 Limitations of personalisation

Not only is important to mention the potential advantages of personalisation, but also its disadvantages in order to know if there is a creation of value for the user [60]. The disadvantages are:

- Additional time. A personalised device needs the creation of a well-established methodology to guide the process, also, it requires research, materials, spare parts, feedback from the user, take measurements or data and testing; the implementation of these aspects results in an investment of time and a larger process of development of a product.
- Additional payment. A company should make an economic investment in order to acquire adequate equipment such as software and hardware, training staff about how to use it and their constant preparation to have a competitive knowledge.

More details about disadvantages and personalisation applied to products and assistive devices can be found in chapter 3.2.

Personalisation can provide a positive relationship between the user and the product because it creates a broad range of options in terms of design, size, colour or a better adaptation to the body through additional features enhancing the preference match. For this study there is an intention to obtain a better adjustment in assistive devices in this way, the user can perceive an improvement in comfort, control and performance of the device.

2.5.3 Methods for capturing personalisation data

One of the purposes of personalising products is to achieve a better fit between the user and the item. After investigating several techniques used to capture data and obtain a proper fit, the following classification is proposed in this study: a) direct methods: manual + technological and b) indirect methods: manual + technological.

2.5.3.1 Direct methods

Direct methods are used for capturing the data of the user's limb without intermediaries and different levels of technology can be used.

a) Manual

Direct-manual methods are performed by taking measurements on the limb or body area without using an automatic process, namely, technological devices that can capture physical information such as 3D scanner or software. Examples of direct-manual procedures are impressions, trace patterns or taking measurements. The reason for using them can be related to the technological resources available to the manufacturer or with the ease and efficiency of capturing data by a person.

The benefits of utilising direct-manual methods are the low cost of production because sometimes, the equipment used is not specialised, also, the training of manufacturers is minor in comparison with technological methods. In some cases, an advantage is a short delivery time because the process has less precision, such as some hand and wrist orthoses.

The disadvantages are the lack of accuracy in the parts and this can cause an incomplete personalised device; for example, some hand prostheses require only key user dimensions for being scaled and adapted to them. Another downside is that this method could be considered invasive for the patient, some products such as teeth corrector braces, hand and ankle-foot orthoses, hand prosthesis and masks for radiation follow a direct-manual process for being personalised. The information obtained from the manual method could be temporal and if, at a later stage the same information is needed, the process should be repeated.

b) Technological

Direct-technological methods are performed utilising special equipment to collect information directly from the person's limb. This method is used by companies that decide to invest in technology in order to obtain more accurate information from a part of the body. Technology such as 3D scanning and pin-based contact digitizer machine are used to gather data.

3D scanners can be used in short-range distances (less than 1 metre) or in mid- and long-range distances [61]. The scanning of limbs is usually conducted close to the object (short distance) and for this range there are technologies such as laser triangulation 3D scanners and structured light 3D scanners. Laser triangulation scanners use a laser line or a laser point to scan a part, they point out an object and the laser light is reflected and captured by a sensor, as shown in Figure 2.1.

After this, the system computes the distance between the object and the scanner via trigonometric triangulation.

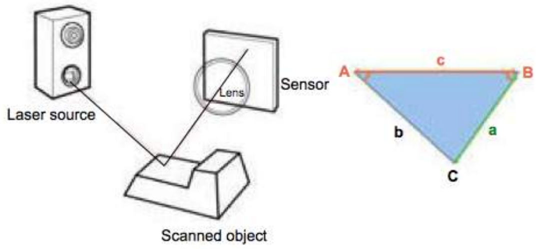

Figure 2.1 - Laser triangulation 3D scanners [61]

Meanwhile, in structured light 3D scanners, shown in Figure 2.2, a series of linear patterns are projected onto a part, the edges of the projected lines are examined and there is a calculation of the distance between the scanner and the surface of the part through trigonometric triangulation.

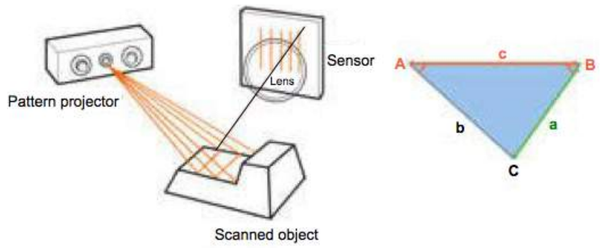

Figure 2.2 - Structured light 3D scanners [61]

As for benefits, direct-technological methods can capture more detail and deliver more information and analysis to the user than manual methods; this is relevant because additional data can be useful in a further stage, for example, in the production of 3D printed clothing, the user is scanned, therefore, all body measurements are saved and can be used later for building other garments. People who handle the equipment have a level of expertise. The method is less invasive than the manual one because sometimes the data is captured without being in contact with the area of the body and if so, the capture of information is conducted under automatic already established parameters and this can avoid inconsistencies of manual processes. Sometimes, the shape of the final device can be modified in order to achieve a more appealing design to the user.

As disadvantages, because of the high level of personalisation, the production time and cost is generally higher than the manual methods. Also, this method needs more expensive less common machines to manufacture the bespoke parts.
The difference on how manual and technological methods capture data is exemplified in the following images. Figure 2.3 shows how, in a manual process, an ankle-foot orthosis obtains a user's negative impression, later, a positive model is created and it will be used for shaping the orthosis or the prosthetic socket.

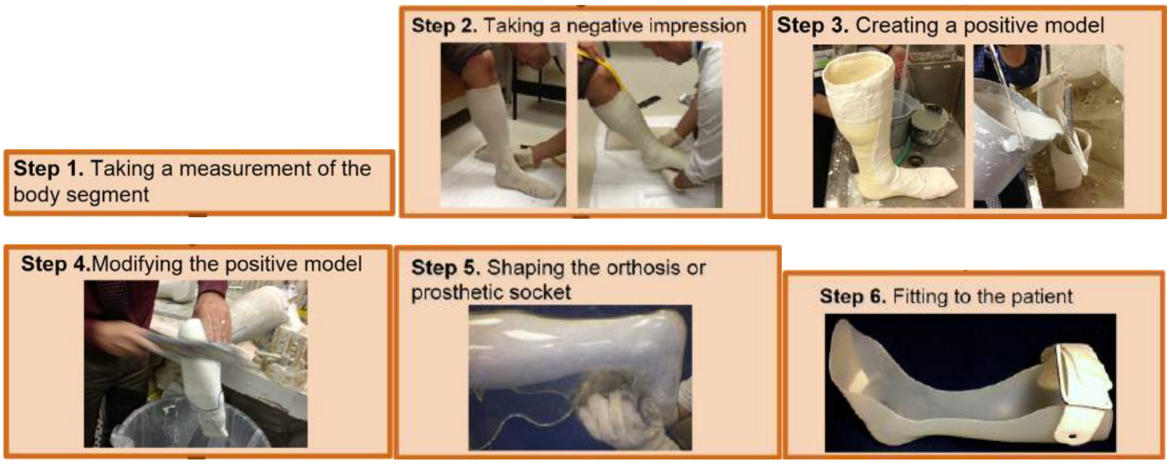

Figure 2.3 - Manual process for producing an ankle-foot orthosis [62]

On the other hand, in a technological method, the collection of data for producing an ankle-foot orthosis is achieved through the use of a 3D scanner. In this process the leg is scanned and the obtained data is modified in a CAD program, the resulting .stl file is printed and fitted to the user. Figure 2.4 illustrates the process.

Figure 2.4 - Additive manufacturing process using a 3D scanner [62].

Illustration of Step 5 "Production in 3D printing" was omitted in the original source

The use of a direct method in the study will be convenient whether the selected assistive device should wrap or immobilise the user's limb.

2.5.3.2 Indirect methods

Indirect methods capture data from an external device that contains the user's information rather than directly from the part of the user.

a) Manual

It is possible to gather information with a manual device as a first step and then capture and translate this data using technology. For example, in the production of rigid and semi-rigid foot orthoses, the first step is an impression of a foot into a foam box and later on, this data is collected by a 3D scanner to be modified in a software and then 3D printed.

One of the advantages of using indirect-manual methods is that the process can be cheaper because a manual tool is used and there will be lower production costs and lower training time for staff. Also, the process is less invasive than the direct method.

The downside of this process could be the lack of accuracy, caused by the manufacturer or by the supportive device. Also, the manual device provides less information than technological equipment.

b) Technological

Indirect methods are classified as technological when the manufacturer is trusting an external technological device to collect data, this device delivers the information automatically, with the aim to avoid a human error. A soft foot-orthosis can be produced using this method utilising a pin-based contact digitizer machine. The advantages of the indirect-technological method are the presence of a specialised device to obtain measurements, which has been created and tested for the application, and, in many cases, it is an upgraded version. Also, the physical device can be supported by specialised software; this can help to shorten the production time. Data and the analysis provided by the device are better than the information provided by a manual method. Staff who operate the technological device should have a high level of expertise in order to interpret the resulting information and provide an accurate feedback.

As disadvantages, it requires professional training for manufacturers in order to use the product and provide maintenance to the equipment. Also, there is an initial investment on research and finance in the device.

The production of foot orthoses (FO) illustrates the difference between both methods, indirect-manual and technological. In the indirect-manual process, a semi-rigid and rigid FO can be built through the imprinting of the user's foot into a foam box in order to obtain a negative impression of their plantar surface; after this, a 3D scanner is used to capture this imprint, Figure 2.5 illustrates this process.

Figure 2.5 - Foam impression box and 3D scanning [62]

On the other hand, in an indirect-technological method, soft FOs utilise a pin-based contact digitizer machine, shown in Figure 2.6, to measure the plantar surface profile and the height of the contact pins are calculated and translated by an Orthoses and Prostheses (O&P) computer-aided design (CAD) program into the profile of an insole. After this, a 3-axis computer numerical control (CNC) carving machine uses the profile to produce the orthosis in ethylene-vinyl acetate (EVA).

a) **b)** **c)**

Figure 2.6 - Foot plantar surface profile measurement device (a), O&P CAD software (b) and CNC machine (c) [62]

The decision about using a direct or indirect method for this study will depend on which will be the selected assistive device, and, once defined, how easy it is to capture the data of the limb when it is in the position of using the device. If the position of the limb is easy to capture, the direct method can be applied; otherwise, the indirect procedure will be used. About the manual or technological type, the resources will be defined according to their availability, efficiency and speed for gathering the data. As long as it is convenient, an optimum approach is the direct-technological procedure because working straight over the limb might be faster than using an intermediary and beside this, technological resources can also lead to faster results intending to avoid human errors.

2.6 Additive manufacturing

AM is one method of achieving personalisation and will be described here. AM started in the 1980s with the patent of Charles Hull in 1986 and the development of his first machine in 1988 [63]. AM is defined as the process where “a model, initially generated using a three-dimensional computer aided design (3D CAD) system, can be fabricated directly without the need for process planning” [64]. There are several AM processes, they differ in: materials used, production time, post-processes, and mechanical properties can be varied depending on the material used. This wide range of techniques produces several parts that can be applied in many fields. The AM technologies that will be explained in this investigation are shown in Table 2.3:

AM processes				
Stereolithography (SLA)	Jetting Systems	Z-Printing	Fused Deposition Modelling (FDM)	Laser Sintering (LS)

Table 2.3 - AM processes

2.6.1 AM workflow process

In general, this process starts with the creation of a 3D CAD and ends with the delivery of the physical part [64]. The workflow is mentioned in Figure 2.7.

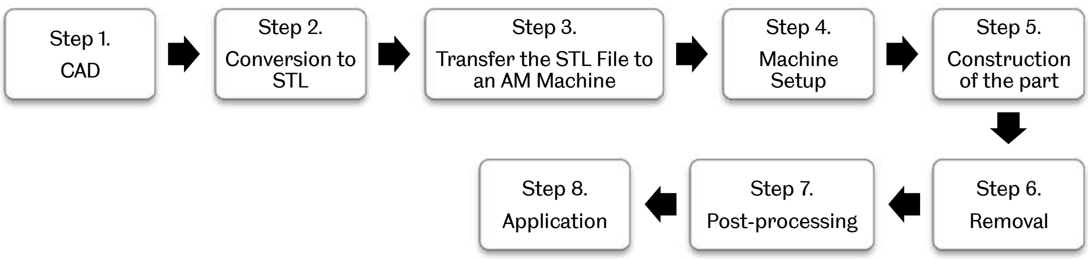

Figure 2.7 - Basic AM process

As a first step, a CAD (Computer Aided Design) is created using a modelling software, resulting in a 3D solid or a surface; as a second step, the file is converted to STL (Standard Tessellation Language), this depicts an external closed surface. In step 3, the STL file is transferred to an AM machine and there may be some adjustments such as modification of size or relative position for its production; the orientation of the part and the quantity of the generated supports are associated with the building time where taller builds will take more time than the shorter ones [64]. In step 4, the machine setup is conducted and parameters such as process time, layer thickness, materials, structures for supporting the parts and accessories such as nozzles are considered and modified [65]; in the case of some processes like laser sintering, parameters are considered such as part bed temperature, the power of the laser and layer thickness [66]. In step 5, the construction of the part can occur almost without supervision but aspects can be considered such as lack of material, power, software or hardware problems. In step 6, the final part is removed from the machine and it is prepared for post-processing. During step 7 some extra material, powder or supports can be removed from the parts; also, finishing can be applied such as manual polishing, sandpapering, polishing tubs, drying, baking ovens or coatings. The type of post-processing will depend of the final application of the part and the machine; some processes develop brittle components that will need a coating. In step 8, some parts may require treatment in order to be used, such as priming, painting or to be assembled in another mechanism.

Besides the acknowledgement of the AM process, it is important to consider the maintenance of the machine, the materials used and adequate workplace conditions such as moisture, excessive light and contaminants. Variations in these 8 steps are system-dependent but a watertight CAD model is crucial to obtain a quality product via AM and any personalisation approach must consider this.

2.6.2 Advantages

AM has been considered a disruptive technology because it creates physical parts with unique features. Some benefits are connected, meaning that one advantage can trigger another. These are:

1. Lack of tooling

- AM can produce parts from zero adding layers of material and this allows the production of positive models, therefore, it is possible to eliminate steps such as the development of moulds. Lack of tooling leads to the increased production speed, production of single parts, cost reduction but, also, it allows more design freedom, production of assemblies, personalisation and optimisation, these last 4 benefits will be described with more detail in separate points.

- Lack of tooling allows benefits in terms of production time because mould design and manufacturing are not necessary; also, the final cost of a single part is cheaper and therefore, it is more affordable to achieve personalisation and the part can have more iterations of design. There could be a production of more parts, providing service to more clients. Printing all the parts required within a period of time without delaying its delivery, for example, printing parts of prosthesis for a child who grows rapidly.
- Easy production of one single part. Manufacturing only one part has the following benefits: it is possible to perform changes on design without investing high economic resources; saving money in staff in charge of moving parts in the inventory; saving space for inventory; sell on request, avoiding financial losses. Also, it is possible to provide service to clients that require only small batches. The parts of an assembly can be easily replaceable.
- Reduction of costs. The reduction of costs may bring new opportunities to a company because those savings can be invested in innovations, research equipment, materials, or in their portfolio of products. Also, reduction of costs may represent selling cheaper products than the competency and as a consequence obtaining more clients.

2. Design freedom

- AM creates parts through the deposition of layers of materials, this deposition can be manipulated in three directions, x, y and z, this allows the development of more creative and freer shapes. Also, companies have developed software with specialised options to facilitate modelling free forms such as Rhinoceros (Rhino 3D), Autodesk Alias, Autodesk Maya, Autodesk 3DS Max. Another resource used for creating organic shapes is 3D scanners, which have evolved in accuracy, speed and capacity to capture data.
- Parts can be organic and complex; this would not be cost-effective using other manufacturing methods such as moulding, machining, extrusion, etc. Figure 2.8 and Figure 2.9 show examples obtained through AM.

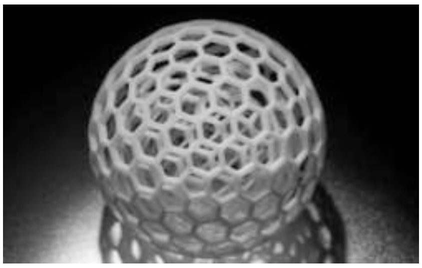

Figure 2.8 - Multiple series of spheres [67]

Figure 2.9 - Architect's model [68]

- Creation of texture. The freedom of shape can allow the creation of different textures on the products' surface.

3. Production of assemblies

- AM can produce joined parts, they are modelled leaving the required space between them in order to avoid undesired bonds, for example, complex interlocked moving parts result in a reduction of manufactured pieces as seen in Figure 2.10.

Figure 2.10 - "Tie-down clamp, with moving parts, made as a single integrated moving component" [63]

- A smaller number of parts allow reduction in cost, assembly time, space in warehouse, possibility to produce complex assemblies, avoid possible human errors during assembly, a single final part in one material facilitates recycling; also there are performance benefits in the product such as prevention of leak and dust inside, improvement in fluid flow and airflow because of the geometry [69], high strength to weight ratio, heat transfer and energy absorption [70].

4. Personalisation

Personalisation of parts is possible because AM has the following characteristics:

- Facilitate production of curves, organic and complex shapes, that are similar to the shape of the body, this allows manufacture of devices or products that are in direct contact with the body. Examples of personalised devices are hearing aids, handles, prostheses for legs, arms, teeth, skulls, hips and jaw; orthoses, dental and foot impressions, among others. They can be printed in small sizes in batches [69].
- Biomaterials can be used in 3D printing and this enables the creation of devices used inside the body avoiding risks for their implantation.
- 3D scanning is complimentary to AM and it could be used as a first step in order to capture data from a limb or the entire body enabling the opportunity to produce different designs based on the user's shape.
- Development of specialised design software that facilitates the creation of personalised parts such as consumer products, skulls, jaws, ears, etc. For example, Polygonica software that is utilised in the medical industry.
- Mass-individualisation is possible because a series of equal products can be slightly modified in order to obtain different and unique versions but within the same design rules [69].

Personalisation can be seen in the medical industry such as the design shown in Figure 2.11, a customised wrist splint achieved by AM.

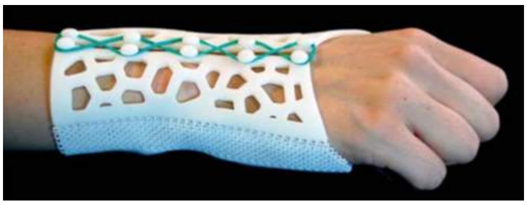

Figure 2.11 - Wrist splint [71]

5. Optimisation

- The creation of a complex geometry allows optimisation in weight, strength, airflow, heat transfer, material, number of parts, etc. [69]. Optimisation brings economic savings, for example, in cars or planes where the use of lighter parts represents fuel savings. Also, it allows a better efficiency of energy in equipment such as wheelchairs or bikes, savings in material and less fatigue in people who carry optimised parts.

6. Supply chain issues

- The benefit of producing AM parts is that the final product will be built in the same location, this diminishes the carbon footprint and the replacement of parts is faster.
- Just-in-time production because all the parts of one product can be produced in the same batch.
- Easier supply on demand of spare parts including actualisation of pieces. It is not necessary to consider stock of spare parts from external suppliers, nor tooling for each piece [69].

2.6.3 Limitations

AM presents limitations in comparison with other conventional manufacturing processes; these are:

- Expensive materials and limited options, also there is a restriction in knowledge about long-term material properties [69].
- Issues in mechanical properties. AM parts can also suffer from strength problems due to the fragile bonding between each layer, causing fractures when the part is submitted to force [69].
- Parts can have problems such as accuracy, geometric tolerances, repeatability in properties and surface finishing such as the stair - stepping effect [69]. The precision obtained in parts could be better using some other manufacturing methods; for example, the CNC process is used to produce final products and generally uses hard materials providing, as a result, homogeneous and high accuracy parts, and some parts built through AM may present voids or anisotropy [64].
- In cases of assemblies, the correct distance between the parts in the 3D model should be considered, otherwise, the parts may be clogged or may not have the freedom to move in the required direction. If one of the parts has a problem during printing, the entire assembly is damaged and it would be necessary to print them again. If the parts of the assembly are requested in different colours, the use of an appropriate printer would be necessary.

- Issues in AM systems should be considered, related to machine cost, build speed, build volume (capacity and limitations of print size) and machine automation because there are set-up tasks and post-processing activities that should be executed by staff [69].
- Current 3D CAD modelling software can export in a suitable format for AM, but it is necessary to consider the limitations of each program as it is not always possible to create models that are as complex as AM can produce [69].
- Training concerning the different AM technologies, materials, design for AM, machine set up, building parameters and orientation of parts and post-processing should be provided to staff in charge of 3D printed production [69].
- It is not clear who is the owner of the intellectual property of products when people who do not have a printer submit their work or files into 3D printing services [69]. Companies should respect the intellectual property of the designer and both parties should sign a contract before producing.
- People who use their own printed parts may become responsible if their product failed because, despite the involvement of several stakeholders as system manufacturer, material supplier and software producer, the designers are responsible for their own ideas [69].
- As .stl files and printing services are accessible for all, already created models should be approved by the company before being uploaded and available in its gallery. Also, people who use their own printers or models must access to the internet for printing them and these .stl files should be approved or not by a system in order to prevent printing questionable models [69].

2.6.4 Examples of AM applications

The use of this technology has grown as the process and materials have been investigated and improved. AM has been used to develop many products belonging to different areas such as healthcare, aerospace, automotive, fashion, textiles and consumer products. Parts such as mass-customised products, prototypes, replacements and end-user parts [72] have been produced.

According to the Wohlers Report, the main areas that utilise this technology are: Industrial/business machines, consumer products/electronics, motor vehicles, aerospace, medical/dental, academic institutions, government/military, architecture and "others" such as the industry of oil and gas, non-consumer sporting goods, marine products and various other products [73]. Some of the areas that generate most revenues will be described.

2.6.4.1 Medical/dental

AM is used in this sector because many of its applications require a personalised shape for a specific condition of a user. Some AM processes can use biocompatible materials; this allows the development and integration of devices into the human body or its use near the skin for a prolonged time. Other products include the 3D printing of cells, blood vessels, bandages, bones, ears, jaw bones, exoskeletons, windpipes, tissues [67], cranial, hip, knee and spinal implants [73]. Hearing aids are another example of medical parts using AM, its creation and personalisation is possible since the shape of the ear can be captured using a 3D laser scanner and its complex organic geometry can be built, it is also possible to produce several hearing aids at the same time. Different models are shown in Figure 2.12.

Figure 2.12 - Customised hearing aids [63]

2.6.4.2 Automotive and aerospace industry

AM in these sectors is often used for manufacture of prototypes and for optimisation.

An application of this area is the redesign of an aircraft part, as illustrated in Figure 2.13; in this case, the AM process was used because the optimisation is feasible, it allows having a part with the same external form and strength as a regular part but lighter, this causes a reduction of the material used resulting in fuel economy.

AM also allows use of the same material of many automotive and aerospace components: metals; this allows the same mechanical properties of the part to be maintained.

However, these industries have limitations; the size of their parts is usually big and restricted by the machine. Also, automotive and aerospace areas require the production of parts with a high level of accuracy because they have to comply with safety certifications.

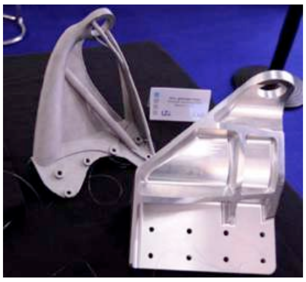

Figure 2.13 - 3D printed optimised aircraft part and original machined part (Boeing and Hamburg University of Technology) [74]

2.6.4.3 Consumer products

The freedom in shapes permits the creation of a broad range of products. This has propelled the extension of the use of the AM in consumer products. Complex geometry like Joris Laarman's bone chair and Freedom of Creation's stools shown in Figure 2.14. Also, a bespoke geometry can be achieved leading to personalisation of products according to the requirements of the user.

Figure 2.14 - Bone chair and Monarch stool [74]

2.6.4.4 Fashion, textiles and jewellery

AM is also used to produce textiles, clothes and jewellery. One aspect to consider is the bonding of the elements in garments in order to produce a wearable item. The scanning process can be used to create bespoke clothes.

In jewellery, AM can be used in one phase of the production process or to achieve the final product, that is to say, a final part can be 3D printed in wax and this will be used to obtain a mould where the final material will be poured; but also, precious metal printing allows high-end direct jewellery.

Some applications of this category are shown in Figure 2.15. These were created using AM because they require a high level of complexity, detail, personalisation and assembly.

Figure 2.15 - “Hydroshift” top “Singapore International 3D Printing Competition 2013”. “Orchid-Spirit” dual-function bracelet. Ti-6Al-4V (Ti=Titanium, Al=Aluminium, V=Vanadium) and SLM (selective laser melting) Machine-Anodised treatment [75]

2.6.5 Processes

Although several materials can be used in AM including metals, polymers, ceramic, concrete, glass fibre and carbon fibre, this research will focus only on polymers because it is possible to produce cost-effective and high quality prototypes or end-user parts with acceptable detail, also a range of technologies, affordable 3D printers and different types of preformed processible polymers [76] have been developed. Some of the main processes that use polymers will be explained in this section.

2.6.5.1 Stereolithography

Stereolithography (SLA) was the first AM technique patented in 1984 [77]. In this process, a portion of a liquid resin is cured through the action of an ultraviolet (UV) laser as shown in Figure 2.16, the part needs support for overhangs; after the first layer is completed, the platform drops by one layer height and then another layer is scanned. Once the part is finished, it is removed from the platform and it goes directly to post-processing inside a UV or thermal oven.

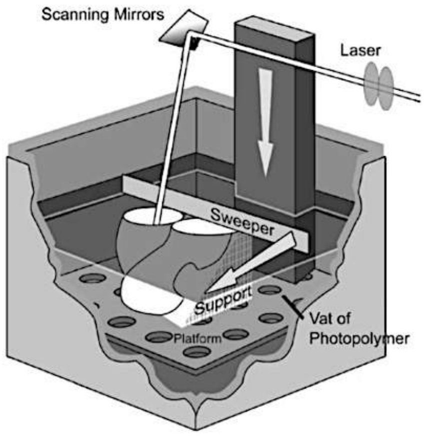

Figure 2.16 - Stereolithography process [78]

Its greatest advantage over other processes lies in its accuracy of 0.1%, even for bigger models the drop of accuracy does not exceed 0.5% [79]; this technique can achieve the best accuracy and resolution, as details of 20 μm in size [80]. Besides this, it is considered an easy to do process that, once started, does not require the attention of the operator and that helps to reduce the cycle time for product development since it does not require advanced experience to operate [81]. Its disadvantages are the shrinkage of the model after being processed, this can result in the deformation of the part [81]; another limitation is the reduced quantity of available resins, the usage of only one resin during the process [80] and the low thermal and mechanical properties of its materials [82].

More than 40 resins can be used in the SLA. Initially, the materials for SLA had enough strength but they were brittle. Now, many of them have the appropriate conditions required by the market; some are flexible, others have mechanical properties similar to thermoplastics; some applications include the development of parts such as personalised hearing aid shells, which are suitable to be in long-term contact with the skin. Another application is the production of electrical connectors, currently batches of up to 16,000 can be made using Stereolithography [78].

2.6.5.2 Jetting systems

The principle of this approach is to use inkjet technology, one of these systems is PolyJet printing, which uses several printing heads to simultaneously deposit an acrylate-based photopolymer [78] as illustrated in Figure 2.17.

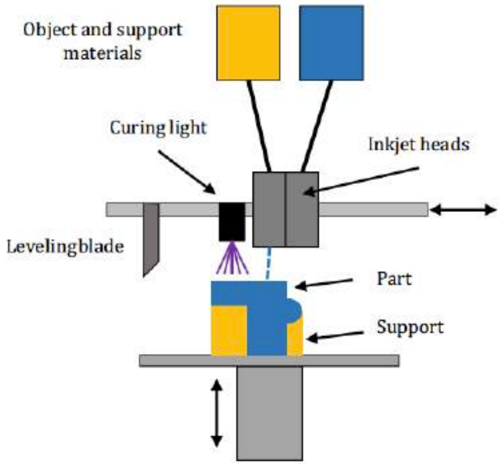

Figure 2.17 - PolyJet process [76]

This technique can produce smooth surfaces, complex shapes in a variety of colours and different materials with particular properties due to its multiple printing heads. A final treatment is not required as the layer thickness is under 20μm [76]. When the final part is ready, the supports are removed manually, with water jet or with sodium hydroxide solution [83].

PolyJet technology can produce a smooth and good quality surface, complex shapes and a variety of colours [84]. As mentioned above the layer thickness using PolyJet can be up to 16μm, this is one of its advantages and, as a result, it produces parts with high resolution, but compared with some other processes the parts made using this process are considerably weaker [85]. Other limitations are the high cost of materials and 3D printers, the parts are usually not recycled, issues in removing supports and slow production in large parts [86].

This technology is used to create rapid prototypes with a high quality resolution, medical models, manufacturing tooling and communication models [87] [88], as shown in Figure 2.18.

Figure 2.18 - Medical training models [87] [87] [88]

2.6.5.3 Z- Printing

In the process of Z- Printing, a binder material is spread into a selected area of a powder layer. The binder is applied through a nozzle, which joins the powder particles producing the final shape. The remaining material can be recycled to manufacture other parts. Figure 2.19 illustrates this technology created at the Massachusetts Institute of Technology (MIT) in 1993.

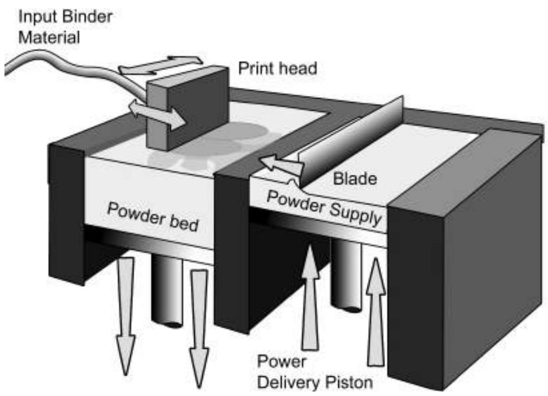

Figure 2.19 - Z- Printing process [78]

The main advantages are that it allows the use of cheaper materials that reduces the costs, accelerates the process and allows more iterations with different designs. Also, the machines are easy to use and coloured parts can be produced. The limitations are weakness and low mechanical properties [86].

The Z-printing process is most often used for concept or visualisation models [86].

2.6.5.4 Fused deposition modeling

The inventor of the fused deposition modeling (FDM) technology is Scott Crump and Stratasys commercialised it in 1991. In this process the material is extruded through a nozzle or a fine print head completing one layer by one layer until the part is constructed; a heated chamber can be used to decrease the thermal distortion related to the cooling process. Figure 2.20 illustrates this technology.

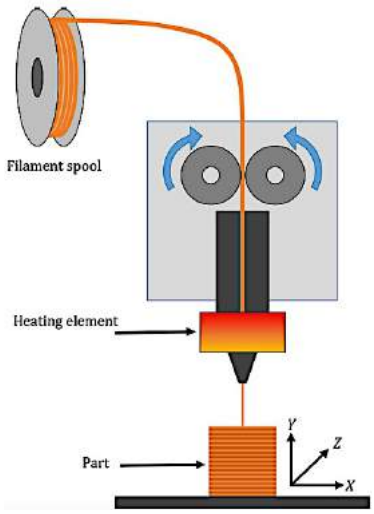

Figure 2.20 - Fused deposition modelling [76]

The benefits are the creation of complex parts and internal features; also, it can produce customised parts using high-performance materials with properties such as strength, durability, heat and chemical resistancy [89]; for these parts chemical post-processing is not necessary, nor a cure process, and the machine has a lower price than other technologies [85]; cheap and quick desktop machines have been created and this facilitates access to this technology. As disadvantages, this process can produce parts with greater anisotropy than LS and SLA processes; also, a low surface quality due to the resolution on the z-axis, which may require a finishing process [85] and there are limitations in material density and production speed [64].

FDM has been used in a wide range of fields: aerospace manufacturing, automobile prototyping, industrial, medical, architecture models and UAV (unmanned aerospace vehicle) component manufacturing. It is also used in functional prototypes, concept models, detailed parts, high heat pieces and end-use parts [89]. One specific application is the production of pill tubes [78]. Some examples are shown in Figure 2.21.

Figure 2.21 - A concept model, a functional prototype and manufacturing tool produced through fused deposition modelling [89]

2.6.5.5 Laser sintering

Laser sintering creates complex and organic parts with high mechanical properties and stability in properties [86], these characteristics make them a good and reliable technology for producing personalised parts, therefore it will be used for this investigation.

In laser sintering (LS) a laser scans a powder bed to melt selected areas, the process is repeated layer by layer until the shape is finished; the powder around the part acts as a support and can be recycled. The technology is shown in Figure 2.22.

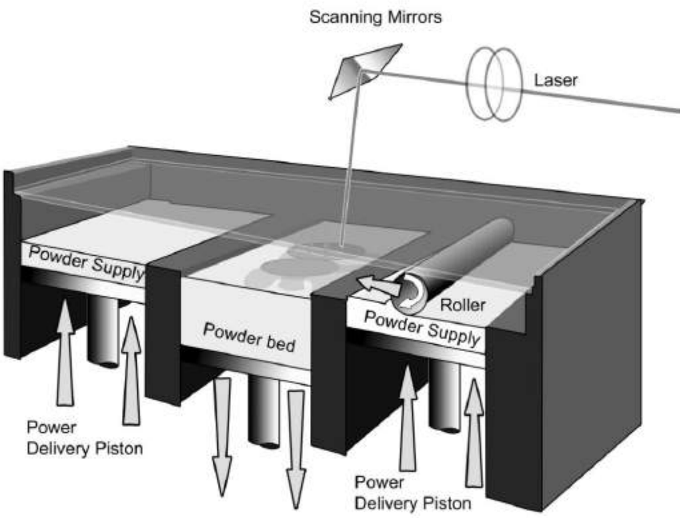

Figure 2.22 - Laser sintering process [78]

Pre-heating helps to reduce the temperature needed for the sintering process and decreases the gradients of heat between the melted area and the non-sintered zone. The melt temperature allows the union of the particles resulting in strong mechanical properties.

The advantages are the possibility of part customisation, recycling of the unused powder [85], support structures are not necessary for building plastic parts, assemblies can be produced in a single batch, fewer post-processing activities and better surface finish [86]. The limitations are the risk of shrinkage and deformation of the part as a consequence of the sintering and cooling stages; agglomeration of the powder, tearing, cracks due to stress, bent layers, lack of cohesion and problems in the surface such as porosity and non uniformity [90].

Applications of this technology include: "models for design testing, patterns for investment casting... injection moulding, rapid tooling for electrical discharge machining electrodes, polymer moulding, sand casting moulds, zirconia moulds for titanium castings and biomedical applications" [90].

2.7 Summary

In the second chapter, five core topics of the investigation were introduced: diseases, classification of activities, assistive devices, personalisation and Additive Manufacturing.

The description of each disease helps to understand their consequences and how they affect the performance of the activities. This knowledge, in conjunction with defining a set of activities core to daily living becomes a basis to assess the assistive devices that support them. Some of these assistive devices are in direct contact with the body, therefore, a better fit between them could be beneficial and this adjustment can be achieved through personalisation.

In this chapter personalisation methods were shown, these can employ manual or technological methods for creating the personalised assistive device and can hence be used within this research. Also, AM can support the production of personalised products aided by tools such as 3D scanners and CAD and post-processing software.

The following chapter will provide a review of the relevant literature based on the topics relevant to this PhD.

3 LITERATURE REVIEW

This chapter will present a review of key literature in the following relevant areas: assistive devices, personalisation, AM and methodologies. The review of literature will provide a view of the current state of research in these areas and it will help define the scope and aim of this research. Likewise, it will be used to gather tools and data relevant to this study.

3.1 Assistive devices

3.1.1 Assistive Technology

As mentioned before, the term “assistive devices” relates to Assistive Technology (AT) [54].

AT is the “technology designed to be utilised in an assistive technology device (assistive product) and in assistive technology services” [91], but it is also used for creating modifications in the environment, services and processes with the aim of offering more adequate access and use to people with disabilities.

AT involves the action of several parties, it is a complex and multidisciplinary field composed of a diversity of academic and practical disciplines, and, together, they contribute to the creation and the correct implementation of AT. Considering the definitions of the Assistive Technology Act of 2004 (ATA2004), the International Classification of Functioning, Disability and Health (ICF) framework and the American Medical Association (AMA) terminology, Elsaesser and Bauer [92] mention a classification for AT professions, which will be used to identify the disciplines involved in the field. AT professions are classified as:

- Health professions: These professions are in charge of evaluating body functions and, based on this, define the impairment and the level of function that an adequate device may provide. The evaluations are conducted using established procedures, for example, vision tests, hearing tests, among others. Health professionals may comprise doctors, nurses, ophthalmologists, audiologists, physical and occupational therapists.

- Health-related professions: These professionals evaluate the limitations that the user may have during the execution of activities and the restrictions in their participation. The evaluations are conducted following standards, for example, standardised tests for learning or evaluations of performances in a work environment. Examples of health- related professions are allied health professionals, special education teachers, AT specialists and vocational rehab counsellors.
- Product and technology professions: These professions are involved with research, development, commercialisation, marketing and distribution of Assistive Technology devices. Professionals may comprise scientists who conduct research, engineers, manufacturers, brokers, distributors and suppliers.
- Resource professions: These professions are related to environmental factors, they encompass public and private services, for example provision of benefits and programmes; systems, such as administrative control and monitoring; and policies, for example, regulations of the systems that control the services. Examples of resource professionals are employers, organisations and government that distribute goods and services to people with disabilities.

Based on the previous information and using the Higher Education Classification of Subjects (HECoS) coding system [93], it is suggested that the disciplines shown in Figure 3.1 are involved in the Assistive Technology field.

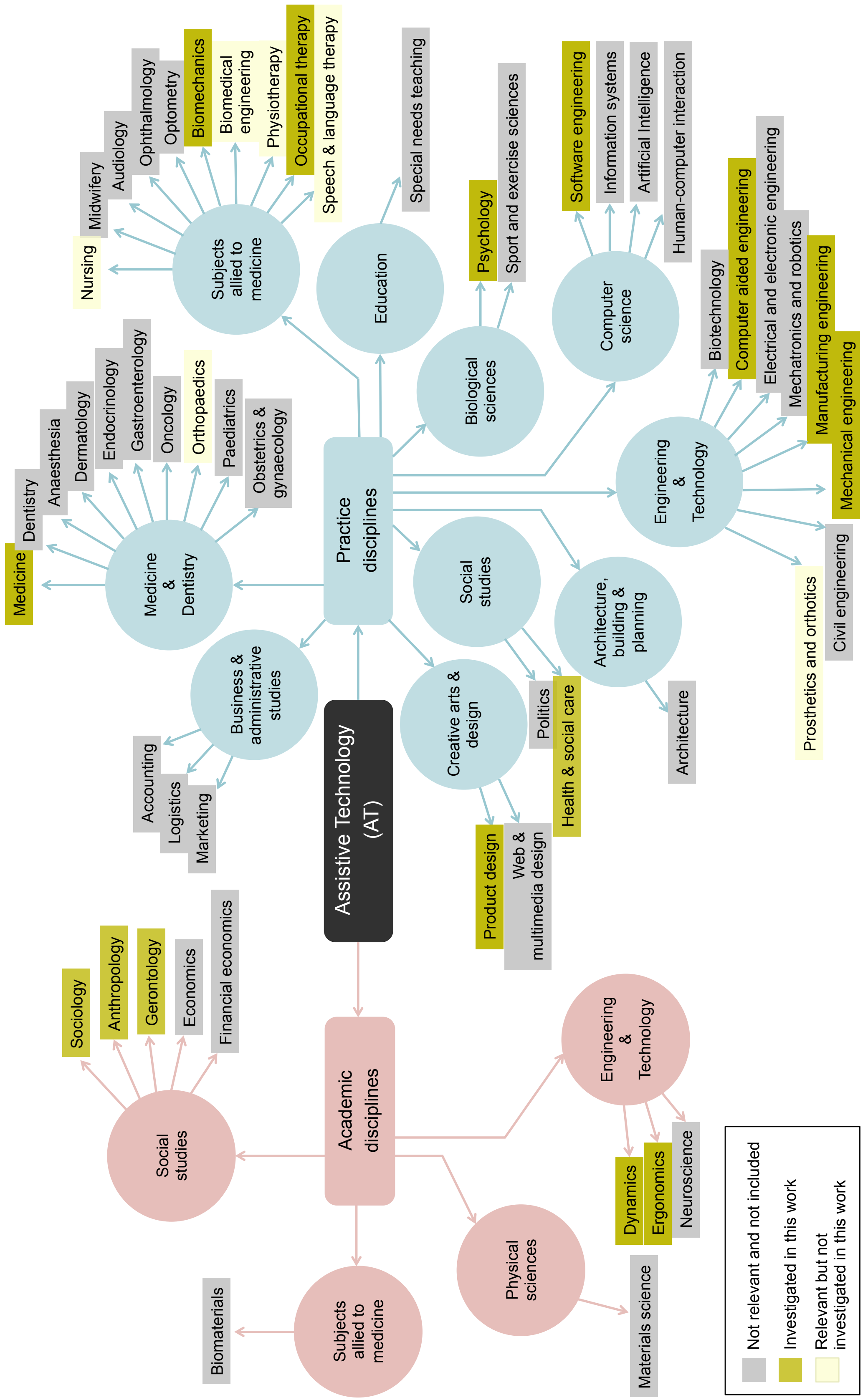

Figure 3.1 - Multidisciplinary fields of Assistive Technology (AT)

Not all the previous fields of study are considered in this research; Figure 3.1 illustrates through different colours the following classifications: grey depicts disciplines not applicable in the investigation and therefore not considered, green highlights those which are investigated in this study, and cream shows the disciplines relevant to the study but not included. This classification is explained as follows:

Grey: Among the disciplines not relevant to the research and not included are, from social studies, politics because the assistive devices produced in the project do not need to meet any government regulation since they won't be a commercial device, and also, it is not necessary to gain the support of any government financial entity for production, commercialisation or distribution. Also, for commercialisation reasons, economics and financial economics from social studies, and accounting, logistics and marketing from business and administrative studies are excluded. Special needs teaching from the education area is not involved because it teaches students with learning, emotional or physical difficulties and this is not the scope of the investigation. From biological sciences, sports and exercise sciences are also excluded because the focus of the study is open to a broad range of assistive devices rather than a product specifically from a sports context. From creative arts and design, web and multimedia design won't be required because a display interface is not necessary to show information to users. From computer science, information systems is not considered because it is not necessary for processing and application of data; artificial intelligence is also excluded because the research is focused on assistive devices that involve a more manual interaction rather than equipment or products characterised by an intelligent system; and human-computer interaction is not incorporated either because during the study or tests there is no interaction between the user and a technological interface. Material science, from physical sciences, and biomaterials from subjects allied to medicine are not included because the study does not involve nanomaterials, electronic, magnetic, optical or biocompatible materials. There are other specific disciplines that, due to the nature and aims of this study, do not fit into it either, they are: architecture; from subjects allied to medicine, midwifery, audiology, ophthalmology and optometry; from medicine and dentistry, disciplines such as anaesthesia, dentistry, dermatology, endocrinology, gastroenterology, oncology, paediatrics and obstetrics and gynaecology; and from engineering and technology, disciplines such as neuroscience, biotechnology, electrical and electronic engineering, mechatronics and robotics and civil engineering.

Green: The disciplines applicable to this study are, for social studies, sociology and anthropology because social behaviour, society, social interaction and culture influence users' perception of assistive devices towards preferences; also gerontology and health and social care are included because the investigation is focused on people aged 65 years and over, and on the assistance and support they may receive. From biological sciences, psychology participates in the study since perceptions and preferences on devices are connected to this subject. From creative arts and design, product design is involved because although no new products are created in the study, there will be a redesign of them. From medicine and dentistry, general medicine is included because it is necessary to describe illnesses that could affect the elderly population, their characteristics and symptoms. From subjects allied to medicine, occupational therapy is included indirectly, as participants that help to analyse and identify the case study device may have this background; also, biomechanics has an implicit participation because the different versions of the chosen assistive device should allow the same activities and movements to be performed as the standard commercial product. From computer science, software engineering is considered in the study because it will be necessary to use design and 3D printing software to create the alternative versions of the assistive devices. From engineering and technology, ergonomics and dynamics are included because, during the investigation, the new versions of the selected assistive device should be created based on the physical user's characteristics in order to achieve comfort, also, the new versions should perform their original function and allow the required movements to be conducted; computer aided engineering, manufacturing engineering and mechanical engineering are involved because production of different versions of an assistive device should be conducted utilising CAD software and an Additive Manufacturing technology.

Cream: There are other disciplines that are relevant to the study but not included, for example, from the medicine and dentistry area, orthopaedics may be useful since it is a potential branch of knowledge that could be related to the design and development of assistive devices, as it is the case of biomedical engineering from subjects allied to medicine. Also from this last branch, there are three other disciplines: nursing, physiotherapy, and speech and language therapy which are in constant contact with assistive devices and their users. From engineering and technology, prosthetics and orthotics are relevant because they are in charge of the design, development and fit of these types of products which are well-known devices. None of the previous disciplines are involved in the investigation because there is more limited access to these types of areas.

After revision of the disciplines, it is shown that the focus of the investigation is on the social, design and process areas of the Assistive Technology.

3.1.2 Characteristics of assistive devices

Marcia Scherer in her book “Living in the state of stuck: how technology impacts the lives of people with disabilities” discussed that there are many features of mainstream products that remain relevant for users of assistive devices, such as: lightweight, portable, easy to use, compatible with other products, cost-effective, safe, reliable, durable and attractive [94]. Although it is not possible to determine which of these characteristics this research will focus on at this stage, they can be seen as a starting group, and with the aid of other studies it will be decided which ones to take into account as well as deciding if there are important characteristics not mentioned in this group.

A study by Jacobson at Aalto University in Helsinki [48] focused on the perception of young adults with physical disabilities on the design process of assistive devices. A series of interviews were conducted, and amongst the findings it is highlighted that participants that used wheel chairs preferred them to be small and light but when it came down to other assistive devices different characteristics were mentioned. The previous study provides the insight that the desired characteristics for an assistive device will vary greatly from one type to another. Likewise, the same can be said about the different diseases and also the differences in users, a study done with 103 stroke patients analysed the following aspects [95]: use and utility of the devices, social context, consequences of use and cultural perceptions about the use of devices. The type of devices that were talked about more were mobility ones despite being third place for the number of patients that were prescribed one, the first two places were dressing and seating devices which received more positive comments compared with mobility devices. These two studies together prove how complex it can be to define a set of desired characteristics for an assistive device since the disease, the user and the device itself affect the requirements, thus it can be concluded that some level of personalisation may be preferable because it allows all variables to be taken into consideration, it is also clear that personal interviews can be a valuable tool to find out the desirable characteristics for each user.

3.1.2.1 Size

Size is an important characteristic that affects the performance of assistive devices. In a study conducted by Lewis and Narayan, two tools were designed for male and female subjects based on ergonomic principles. Their goal was to compare the stresses exerted on the handle between the designed tools and the standard ones. As expected, with the ergonomic ones they had a better result, but another important finding was about size as they did not need to customise the tools for each subject and only three sizes were needed to satisfy all their male and female subjects [96]. This is a very important finding if working with handheld devices and personalisation since it suggests that personalisation may not require the size of each device to be tailored to each person.

3.1.2.2 Aesthetics

When talking about assistive devices, most of the time, the focus is on their performance and not on their aesthetics although on the initial group of characteristics it was mentioned that attractiveness was important and a study done in Norway by Ravneberg concluded the same. Interviews were conducted on 11 subjects and it was found that aesthetics can be as important as performance since the device is seen by the users almost like a part of themselves and that it represents their personality and identity, similar to clothing [97]. These ideas are usually ignored when it comes to assistive devices but analysing the markets for bicycles, glasses and many other products shows the aesthetics of the product is important for both the producer and the consumer; therefore, it should not be a surprise that it is the same situation with assistive devices, even more so since the daily usage of an assistive product can be higher than, for example, the daily usage of a car or bicycle.

3.1.2.3 Social stigma

Another aspect related to aesthetics, especially when it comes to the elderly population, is social stigma as it was found in a study of 201 elderly people conducted in Germany whose goal was to find out why they stopped using assistive devices, and, in the particular case of the cane, the main reason was because it was seen as a mark of old age [98].

3.1.2.4 Design problems

Besides social stigma, the previous study also found that another main reason for the disuse of assistive devices was because they were difficult to use which points towards the design process and faults within it, this is discussed in more detail in the next study.

In Australia at Queensland University of Technology, 210 questionnaires were completed by elderly people and then 27 interviews took place, the main goal was to identify if both the disuse and the ineffectiveness of an assistive device were due to a change in the abilities of the user or if the problem was the design; the study concluded that it was the latter and the key aspects to consider when designing a device were: blending, reliability, personalisation, practicality and affordability [99].

3.1.2.5 Blending

Once again, aesthetics is seen as important since blending, which refers to the integration of the device with the environment, was mentioned. Furthermore, many investigations have been made that researched the psychosocial aspects and their impact in the users, there is even a scale PIADS (Psychosocial Impact of Assistive Devices Scale), blending is one of the aspects analysed. The elderly sometimes want to avoid attention and in most cases do not want to showcase their disabilities, some of them think that usage of an assistive device is proof that their physical abilities are diminishing and this is something they do not want to admit. They also feel that if it is obvious that they are disabled in any way they are more prone to be assaulted, abused or discriminated against. It is for this reason that they want their devices to blend in as much as possible.

3.1.2.6 Reliability

Reliability is important not only because it relates to the proper functioning of the device and thus an improvement in the quality of life of the user and their capabilities, but also because of safety reasons. The devices found to be more unreliable were the cane and the rollator which are both key devices that allow mobility that can cause falls and injuries if they do not function properly. Other investigators have found that the most unreliable devices are those related to reaching and gripping objects.

3.1.2.7 Personalisation

Another aspect mentioned was personalisation, which has been discussed widely before in this document. The previous study describes two kinds, one focused more on the appearance, for example a cane with different prints to make it look better, and the other one focusing on improving the performance of the devices. Device usage is quite common in the elderly and it has been studied extensively, the ability to personalise products improves device usage by enhancing ownership and reduces abandonment since a personalised device performs better and is better suited to the user.

3.1.2.8 Practicality

When using an assistive device practicality takes an important role, after all the device is supposed to improve the capabilities of the user and to make things easier. Still, there are some scenarios when assistive devices have been considered impractical, especially when they fail to adapt to different environments, for example trying to use a rollator on an uneven floor or in a place that does not have ramps, trying to open a door when using a rollator can be very difficult, the same can be said of using public transportation, several elders describe the rollators as being cumbersome. The previous study also indicated that, for the elderly, practicality comes before aesthetics.

3.1.2.9 Affordability

The economic aspect was also mentioned. Although affordability is an important issue to consider there is also the matter of uncertainty; some of the elders expressed that, even though they could afford the assistive device, sometimes they did not buy it because they were not sure if it would work properly and if it was really necessary.

3.1.2.10 Disuse of assistive devices

Another study that discussed the disuse of assistive devices is the one conducted by the University of Florida and the University at Buffalo in which interviews were conducted with 1,056 subjects. The levels of use and satisfaction found were high, around 84% for both metrics, but after a close look at the assistive devices that were not in use or considered unsatisfactory it was found that the majority were mobility devices with canes and walkers at the top of the list with the main reason being a poor fit between user and device [100]. These findings reinforce those discussed in the previous paragraph, that mobility devices are the ones that created more concern among the elderly population. This can lead to the conclusion that these kinds of devices need improvement and could benefit from being personalised. The same team conducted another study with 157 elderly people with the goal of doing a comparison between the use of and the need for assistive devices. Interviews were carried out focused mainly on how many devices were owned by each subject and what devices they did not have but thought they needed. Once again, mobility devices were the highlight since they were mentioned as the most needed type of devices that the subjects did not have. Also discussed in the same study were complaints about the devices owned and, again, the ones related to mobility came in first place [47].

The two previous paragraphs highlight the user's perception that the design process for assistive devices is not optimal. This is also found in a study done by Southampton University in which 204 subjects participated: patients that have suffered a stroke, relatives, carers and health professionals. Interviews and focus groups were conducted to find out about the experiences, strengths, weaknesses, barriers and facilitators they had encountered in the use of assistive devices. A common comment on this study was that the participants felt that although assistive devices had the potential to impact and improve their lives such potential was currently not achieved, and one of the main reasons for this according to them was the design of the devices [101].

3.2 Personalisation

3.2.1 Application of personalisation in products

Nowadays, the conventional manufacturing of the products is focused on mass production, but originally, before the Industrial Revolution, their fabrication was hand-made [102] and the products could be personalised and fulfil special requirements for the consumer (Heskett, 1980; Weightman and McDonagh, 2003) [102]. Using the mass production system limited the final options for the market because one product was released to cover the needs of the whole population (Jencks and Silver, 1972) [102], in that time, these authors came up with the idea of designing products according to individual demands. In 1980, Toffler created the new concept: “prosumers”, where the user was involved in two roles, as a consumer and as a producer [102]. Subsequently, the products were created considering the consumer indirectly through the collection of insights of a target group; although better results were achieved, these solutions were still not satisfactory for everyone since there are always fringe consumers that have very specific needs. For this reason, organisations sought to accomplish the interests and insights of the consumers by involving them in the product development process through means of personalisation [103]. Product personalisation is to create or modify the aesthetic or function of a product to increase consumers' satisfaction [103].

A study was conducted to determine if appearance personalisation had an effect on emotional attachment and, therefore, in the use of a product. 149 subjects completed questionnaires focused on personalised bicycle supports and they also participated in the personalisation process. The time and effort spent created a greater bond between device and user since the former is seen as an expression of the person's identity and it also reinforces the sense of ownership [102]. These findings are in accordance with some of the findings of the previous section, specifically the need to integrate aesthetics into the design of assistive devices and that their disuse is a common occurrence in the elderly population.

More successful examples of personalisation can be found in the review made by Yu-an Jin et al. who compared conventional orthoses and prostheses with custom ones made with AM. Their conclusion was that the custom ones provided more comfort because they had a better fit but at the same time they also had adequate strength compared with their conventional counterparts [62].

Another study, conducted in the University of Loughborough by Salles and Gyi, manufactured insoles for running shoes and in order to evaluate their performance 38 runners were recruited to test them. AM together with 3D foot scans were used to create 19 insoles, the other half were standard insoles, the participants did not know which kind of insole they received but all were asked to use it for three months. The insoles were evaluated in two aspects: biomechanical which was based on data obtained directly while the participants trained, and discomfort which was based on the participants' opinion. In terms of biomechanics, the personalised insoles performed better, thus reducing the risk of injury, while in the discomfort evaluation both insoles were rated poorly for the section under the arch of the foot but the personalised ones were considered better in overall fit and on the heel area [104].

In 2018, in Korea, a personalised assistive device was designed for a 19 year old man who suffered from a brain injury and as a result had limited use of his right arm and hand, his left hand and arm were not affected and thus were used to create a 3D model which was then recreated with AM. In order to evaluate the device, the Jebsen-Taylor Hand Function Test was used. All the activities were performed faster with the use of the personalised device and the feedback from the user was also positive in terms of fit, easiness of use, comfort as well as enhancement of functional movement of the arm [105].

These examples illustrate that personalisation can provide several advantages to the end users and that personalised products can perform better than standard ones. Also, it can be pointed out that AM is the technology utilised in several of these examples precisely because this technique can manufacture single products and adapt them to users according to their needs. This characteristic is essential for the development of assistive devices because these types of products are usually in direct contact with a part of the body; besides the individuality and adaptation of the parts produced with AM, this could achieve the fabrication of organic parts which is very convenient for the development of an assistive device.

Bespoke assistive devices, as well as many products from other segments, for example, sneakers, bikes, etc., have the goal of developing a better fit or connection with the user, resulting in an increment of functionality and a major interest based on the consumer's insights. The benefits obtained by personalised products are several, as it was mentioned before, they can have these characteristics: a better fit adapted to the specific condition of the person and enhancement of performance in activities giving better results. Despite this, the manufacturing of bespoke devices is not common; the main reasons could be related to the following aspects:

1. Price. They have a higher price than the regular products, because there is a need for investment in research, design, materials or additional tools in the process in order to obtain a particular item, for this reason people do an evaluation between cost and benefits of a bespoke device; for example, in the first case mentioned of personalisation, the bespoke shoes for cycling, their price (£1370) is due to the advantage that they provide to the user in terms of

improvement in the discipline, in an Olympic game all the cyclists' equipment is selected to improve performance, therefore, the acquisition of this product is justified; besides this, there is a budget determined for each participant, thereby, buying custom shoes is feasible.

2. Delivery time. A bespoke solution will often take longer to produce because additional resources are implemented to it; planning and creating a new design takes longer since it is a different concept as well as other tools that have to be considered, for example, research, materials, process and testing.

3. Sometimes a standard or adjustable device could already provide a temporary or partial solution; for this reason, a person with an impairment may adapt him or herself to the device, instead of searching for a better solution.

4. The number of manufacturers of bespoke devices is limited. A company should justify the production of personalised products since it is not always convenient for the business due to the investment in resources such as research, training, expertise in the company and technology.

3.2.2 Assistive devices and personalisation

Assistive devices and personalisation have a very close relationship; assistive products may be created in standard sizes to support the needs of people who have the same physical condition, but they cannot cover an entire user group because some of them could present different and particular conditions due to the progression of their impairment, thus, an assistive device should be adapted to their specific requirements through personalisation. In order to develop a personalised product, the design of the assistive devices should consider the participation of their users during the process; some frameworks have been developed to support it as user-centred (de Jonge et al., 2007) [106] or user-centred assistive product design (Poulson and Richardson, 1998) [107]. The idea of the user-centred approaches was suggested during the 1980s; In 1984, Papanek [108] advised the involvement of disabled people in the design process and in 1982, Zola [109] recommended that users with impairments provide recommendations to designers for generating a more creative outcome.

The idea of user involvement is supported by Pape et al. (2002). They stated that the success of an assistive device [110] is also achieved by reviewing the meaning that the users give to the products, as well as considering people's expectations and social costs. This standpoint supports the need to consider the user in the design process; they recommended this type of interaction to promote creativity and a deeper understanding of the impairment and which specific requirements people may have.

Susanne Jacobson's research [48] focused on finding how people experience the design of assistive products in their daily use, she focused on both standard products and personalised ones and wanted to find out if personalisation had an effect on the stigma of using such products. To this effect, she interviewed 11 health professionals and five users of assistive devices. This study, just as some mentioned previously, concluded that assistive devices that are personalised are not only better in a physical way but also in an emotional one. This is because people with physical impairments consider that some of the standard assistive devices may stand out and cause a negative perception from others. It was also concluded that creating a tailored product based on users' needs strengthens product attachment and, consequently, prevents abandonment. Another aspect drawn from Jacobson's research is that personalised assistive devices may positively change the perception of users and non-users related to assistive products; some of her participants showed changes of perception about the appearance of people with impairments due to the use of personalised assistive products.

It is clear that the user's involvement provides a potentially significant benefit to the likelihood of satisfaction with a product; this will, therefore, be a key aspect of the work conducted in this thesis.

3.2.3 Fit between user and assistive device

An adequate fit between user and assistive device is achieved through a suitable 3D shape; however, there are other elements to consider that will contribute to a comfortable fit.

Besides geometry, pressure and load management needs to be examined in assistive devices or products because it has been demonstrated that their excess and wrong distribution can contribute to health issues. Peak pressures in handheld tools have been related to discomfort, pain, musculoskeletal conditions and injuries, for example carpal tunnel syndrome and tendonitis [111]. Aldien et al. [111] studied pressure peaks and resulting contact forces of hand-held tools and their relation to different sized handles and push forces. 10 adults pushed and gripped different sizes of cylindrical handles (30, 40 and 48 mm) wrapped with a pressure-sensing mat; it was found that high grip and high push forces produce peak pressures that achieve and surpass the discomfort threshold. Also, when grip and push forces are applied at a moderate level using a 48 mm handle, the peak pressures surpass the suggested pressure values, affecting the efficiency in work. The push force produced a contact force on proximal phalanges and the palm and the grip developed forces on the fingers' surface. This work demonstrated that, besides a suitable handle in work tools, as they must be comfortable for workers, it is necessary to consider the magnitudes of the peak pressures and what factors influence them.

Pressure management also has an impact on skin and it can cause negative effects such as ulcers on different parts of the body due to pressure and duration on the skin's surface [112]. Assistive devices exist to alleviate or prevent them, for example, special mattresses used by people with spinal cord injuries, cushions for wheelchairs, removable cast walkers, among others. In all of them, pressure and load distribution must be analysed in order to achieve an adequate solution for their users. Chun-Ting Li et al. [113] were aware of the lack of investigation into the effect of sitting assistive devices used on reclining wheelchairs; they analysed human-wheelchair interface pressure using four different versions of reclining wheelchair and in some of these scenarios a sitting assistive device was included. 16 people participated in the study and the interface pressure was measured during five seconds in these four positions: 1) back reclined mode, 2) the lumbar support with back reclined mode (utilising one cushion on the back), 3) the femur upward with back reclined mode (using one cushion under the femur) and 4) the lumbar support with femur upward with back reclined mode (using one cushion on the back and another under the femur). The results indicated that position 4) caused the lower stress load on the ischial zone, also, in none of the positions was the back area impacted by the stress load. This study shows the relevance of analysing the pressure loads that could affect different areas of the body during the use of assistive devices with the aim of providing the highest possible comfort and achieving effectiveness and connection with the user.

An adequate pressure management is also used on foot orthoses. Ulcers can also appear on feet and an effective treatment can be provided by contact casting. Mueller et al. [114] investigated the recurrence of a neuropathic ulcer in people who stopped using a casting after their ulcer was healed; the objective of the study was to obtain plantar pressure measurements and utilise spiral x-ray computed tomography (SXCT) in order to find a solution for people with this type of problem. They worked with a patient diagnosed with type 1 diabetes mellitus, peripheral neuropathy and who suffered from a recurrent ulcer located in the plantar area. Plantar pressure measurements and SXCT were conducted and the results showed that the patient had a deformation in a bone in the same location as the highest pressure zone. This information is valuable because it can be used to design more adequate orthoses considering each special case.

Distribution of loads and pressure has also been analysed in crutch handles. Sala et al. [115] investigated the differences in load distribution, pressures, and areas of the hand where weight is supported, the analysis was made comparing two different types of crutch handles, 1) cylindrical and 2) wide in order to detect if one of them had a higher impact on the carpal tunnel area. Two groups participated in the study, the first was composed of thirty volunteers without mobility injuries and the second group had six crutch users. In order to collect the information, the palm was divided into six regions: distal ulnar, middle and radial, and in proximal ulnar, middle and radial, and an F-Scan system was used to measure vertical forces. At the end of the study it was concluded that the weight-bearing load distribution was similar in both handles, however, the wide handle allows the loads to be spread over a greater area compared to the cylindrical one, where the load and pressure were more focalised.

Prostheses are other assistive device where load and pressure distribution should be analysed to contribute to a comfortable fit and a suitable performance. An example is leg prosthesis, where the consideration of these factors is key. Goh et al. [116] centred one of its works on this, they incorporated finite element analysis (FEA) into a CAD of a socket design in order to obtain a better evaluation of this device in relation to the limb, and thus, achieving a better fit. They developed software that automatically converted the geometry of the stump in mesh and then materials, load and boundary conditions are applied, after this, the resulting pressure was compared with values obtained from a real case of a person with an amputation. The results showed that the pressure distribution obtained from the FEA is similar to those values coming from the real scenario, therefore it is a reliable tool. This CAD-FEA system is relevant because it could be useful for prosthetists to evaluate their prosthesis designs before conducting a first fitting with a patient and, in this way, they could achieve a better fit in the first appointment.

The previous examples in literature illustrated the relevance of developing assistive devices considering pressure and load distribution and their role to contribute to a comfortable fit. Although they are not explicit topics in this investigation, participants will consider them and they will influence in the selection of their preferable option.

In a more general scenario, a proper fit could also be influenced by inherent properties of the device such as material and also, by the user's characteristics such as skin sensitivity, motor skills, body part position during use and additional supports for the assistive device. All aspects mentioned previously are shown in Figure 3.2.

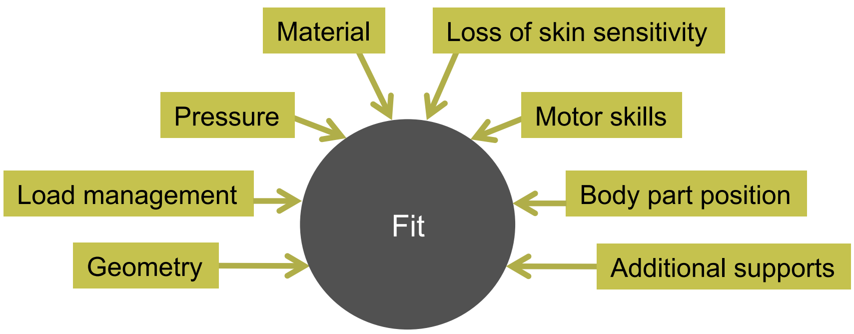

Figure 3.2 - Chart depicting influences on fit

These aspects might influence on fit in different ways; the properties of a material could allow the adaptation of a device to a specific user's needs, for example, some of them could be heated or cooled in order to obtain a particular form, other materials are elastic which suffer deformation during use taking the shape of the supported limb but returning to the original form when the applied force is removed. Another factor that influences fit is the loss of skin sensitivity, this is relevant because if the user suffered a lack of sensation there is not an adequate reception of stimuli and it is not possible for the user to realise if there is a suitable adjustment. An adequate level of motor skills allows the user to be able to manipulate or have more control over devices improving the fit. The position of the body part over the device and during its use may vary among individuals, therefore, it is necessary to assure or provide appropriate training, a correct position will lead to a more favourable fit. According to particular characteristics, the user may need additional supports to improve the fit of the assistive device, for example, utilising braces on splints to reinforce the attachment.

From all the previous aspects, only the influence of geometry will be considered, taking the advantages provided by the AM process such as a way of capturing physical information, and transferring this data to a design, modifying it and producing a final part, this allows work with support on geometries and facilitates the production of several personalised versions of the selected assistive device which is one of the objectives of this investigation. Personalised geometries will be captured through a proposed methodology, but this specific process could also have an influence on the final result, therefore, precision is required to obtain a suitable shape and achieve the best possible fit.

3.3 Additive manufacturing

3.3.1 AM and personalisation

A benefit of using AM in order to produce personalised products is the ability of this technology to create complex and organic forms. This is a vital feature used to personalise devices because most of them are created to be used with the hands, wrists, arms, legs, feet, or other parts of the body with unique shapes depending of several factors such as age, complexion, and their use will be determined by the reliable interaction between body and device. Besides the capacity to create complex forms, AM has the following advantages when personalising a product:

- Faster production times [117].
- A more comfortable experience for the user when a body part is involved since there is no need for plaster castings to obtain the data required because it is done with 3D scanners [117].
- Lower product price due to lowered production costs. This is possible because of the ability of AM to produce on demand thus reducing or eliminating stock and reducing space and infrastructure required, ability to

produce in different locations, streamlined process that requires less production management as well as less production equipment [117] [118].

One example of AM being used to produce an assistive device was made in 2019 by Schwartz et al. Different pillboxes were created and offered to 14 participants. The designs were either completely new or modified versions of existing products, and the participants' routines and needs were considered as well, for example those that were only required to take two pills a day had a pillbox with two compartments. Two methods were used to evaluate the devices: Quest 2.0, which focuses on satisfaction, and the Adherence to Refills and Medications Scale (ARMS) focused on medication adherence. Both methods yielded positive results, the pillboxes made with AM increased both the satisfaction of the users and improved their medication adherence [119].

Personalised solutions produced via AM can be created to improve the condition of the lives of the population with impairments. An example can be obtained from the equipment used in the Rio 2016 Paralympic Games such as a customised prosthetic leg for cycling shown in Figure 3.1. The prosthesis encompasses the zone of the leg below the knee and it was customised to the limb to ensure a better fit. The previous prosthesis used by the cyclist was hand-made using carbon fibre, however, the new one was produced in 3D-printed polycarbonate because the former one utilised a plaster cast and the printing technology offers the advantage of expediting this process through the scanning of the limb, another benefit can be seen in the production time. While the process of the hand-made carbon fibre prosthesis takes approximately 10 weeks, the new one has a production time of 5 days. The new part was reduced in weight and price, costing one quarter of the former one.

Figure 3.3 - 3D-printed sports prosthesis [120]

Using AM, the personalisation of a device can be achieved at a minor cost and with a freer shape. In this manner, a solution suitable for one particular person with an impairment can be developed; an example of this is the creation of splints designed specifically for a single user with special requirements, taking advantage of the AM and the possibility of manufacturing several parts during different stages of the disease.

3.4 Design methodologies

Design methodologies have been formulated to establish guidelines to design products and systems in a repeatable and systematic way, optimising the design process. Some of the objectives of a methodology are improving the criteria of the design selection, the design process, the performance of the design and offers a scientific base for obtaining design solutions [121]. There are different design methodologies that are focused in several aspects such as cost, environment, user requirements, technology and competition; important methodologies are design for manufacture (DFM), design for assembly (DFA), design for quality (DFQ), design for disassembly and recyclability (DFDR), design for life cycle (DFLC), design for environment (DFE) and design for maintainability (DFMt) [121].

It can be noted that none of these design approaches achieve the objective of the research focused on the development of an assistive device for a particular group of individuals. Therefore, this research focuses on design approaches where the user is the main focus of the entire process, these can be useful because the final product has to accomplish special needs; some of these methodologies are "user-centred", "participatory", "universal design" and "inclusive design".

In "user-centred design", the developer analyses users in order to gather information from them and turn it into design requirements; at a later stage, the designer uses these requirements to develop a product design and evaluate it [122].

On the other hand, in "participatory design", the user participates in the complete design process taking part in the conception of the product; he/she plays the role of a "partner" and the design is not created only considering his/her input but designer and user collaborate together. Participatory design can be divided into three phases, plus phase 0; in phase 0, "project definition", resources, money, staff, goals and start/end dates of the project are identified; phase 1, "exploration", is related to understanding the user's environment and routines; phase 2, "discovery" involves the collaboration of users and designers where the goal is established together, also, users express their ideas to help and strengthen the project and in the last phase 3, "prototypes of technology", the idea turns into a physical device, which is tested and improved several times. One of the projects where participatory design was applied was "Sisom". This is an application for a tablet where young patients with cancer annotate their symptoms before having an appointment with the doctor and, in this way, enhance the communication [122].

The type of interaction required in this study is not the participatory design approach because the goal is already established and the prototype will not have iterations.

"Universal design" promotes the creation of products that can be used by all without modification and products designed for disabled people that can be favourable and utilised by others [123]. The design process may be guided by the Seven Principles of Universal Design, achieving these principles may lead to the implementation of this design approach. The seven principles are: "equitable use", which means that the design is helpful and marketable for a variety of people; "flexibility in use", "simple and intuitive use", "perceptible information", the design transmits correct information to the user despite the environment and the user's abilities; "tolerance for error", the design reduces danger on users; "low physical effort" and "size and space for approach and use" [124]. Universal design is applied when it is desirable to create products and environments that can be utilised by the broadest variety of people possible. In this study, personalisation achieved through AM would be implemented, for this reason, the Universal Design approach is discarded.

"Inclusive design" encompasses the development of products for diverse consumers [125]; one of its definitions is: "the design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible on a global basis…" [126]. It is in this definition when is found its difference compared to the universal design approach because "reasonably possible" implies the possibility of not considering people with disabilities if it is too expensive or difficult their incorporation into the design of a product or service. A model for the inclusive design approach was proposed by the University of Cambridge, it encompasses four phases: "explore", which is related to the identification of needs; "create" that involves generation of ideas; "evaluation" of design concepts and "manage" where there is a revision of the progress and the next activities [127]. In the case of this investigation, the use of personalisation is contradictory to the need of impacting the diverse consumers that "inclusive design" focuses on.

After reviewing these four design approaches and taking into account that the goal of the investigation is to develop a personalised assistive device for an elderly user with impairments and specific requirements, "user-centred design" (UCD) has been chosen as the design approach.

One successful example of the application of UCD can be found in a study done in Wales by Dorrington et al. [128] who wanted to determine if UCD could be applied successfully in a medical engineering environment because there had not been many attempts to apply the methodology in the field and because most of the work in the field requires prescription and tailoring of equipment for an individual. A total of ten participants with different impairments were contacted, all of them used electromyography (EMG) switches which are devices that convert electromyographic signals, that are present on the skin near muscle activity, into a signal that can then be sent to activate an assistive device. The application of UCD in this case yielded information that would not be acquired other wise. The methodology enabled the researchers to determine the specific needs of each individual but also common factors between the ten participants. Besides problems with current switches, UCD was also helpful in identifying aspects that could be improved when designing new switches from scratch.

Another example of the application of UCD can be found in the study conducted by Santos et al. The goal was to design an assistive device to support feeding for a single patient with Parkinson's disease that affects people differently, thus a device designed for one patient cannot be used by another. It is this difference in requirements that led to the use of UCD. Among the results, four main aspects of the design process improved greatly due to the use of UCD: communication between multidisciplinary teams, clearer identification of the design demands from the perspective of the user, reduction of development time and improved solutions with better functionality, and more innovative [129].

3.4.1 User-centred design methodology

The tools of UCD have been utilised to create assistive devices [130]. These types of devices are developed to improve or maintain the functional capabilities of disabled people who may have different cognitive and physical conditions and special requirements [130]; this leads to the design of assistive devices for unique scenarios and the process may be focused on specific users. For these cases, the

UCD methodology can be utilised because it considers the users in the design process in order to match the product with their needs [131] having, as a result, an increase in the product usability [131].

Four steps are recognised for UCD, they are [132]:

1. Understand and specify the context of use.
2. Specify user and organisational requirements.
3. Produce designs and prototypes.
4. Carry out user-based assessments.

For steps 1 and 2 it is essential to gather information from stakeholders. There are different alternatives for gathering information in qualitative research, such as observations, textual or visual analysis (example, books or videos) and interviews (either individual or in group questionnaires) [133]. In healthcare research, the methods most used are interviews and focus groups.

A focus group is used to better comprehend the thoughts of people concerning a situation. They were introduced during World War II as a result of looking for an alternative method of interviews where interviewers offered limited answers to participants. As a consequence, the role of the interviewer was less dominant, allowing participants the freedom to put emphasis on the subjects they considered appropriate as well as to explain and express comments and attitudes [134].

The focus group will be useful because the answers of some members of the group could trigger beliefs or opinions of other participants, exchanging experiences or viewpoints and generating more information, therefore, the results would be more beneficial [135]. Also, the technique could produce a deeper conversation and critical responses than conducting interviews [136].

Focus groups succeed if participants feel comfortable and free to disclose personal thoughts. This feeling is perceived when they are with similar people: "subjects tended to disclose more about themselves to people who resembled them in various ways than to people who differ from them", Jourard, 1964 [134]. For this reason it is important to bring together participants who have similar characteristics in the same focus group and emphasise this in the introduction. This technique will be used because an understanding is required about the opinions, experiences and insights of people (users) in regard of assistive devices [135].

Some directives to conduct a successful focus group are, developing a question guide considering different aspects such as behaviour, physical experiences, opinions, knowledge, feelings and background/demography of the participants. Other directives are deciding if the focus group will be conducted face-to-face, via conference call or internet call, determining an adequate number of participants per session, the participants must always feel secure and comfortable, manage interactions between participants, step in if hostilities have developed or if a particular participant is doing most of the talking, and determining how the data will be collected, via video, audio, transcripts, etc. [137].

For collecting personal information based on physical needs it is useful to conduct separate face-to-face appointments or individual interviews. This provides privacy to participants' personal preferences and abilities without external influence. These can be used to compliment focus groups within the design process. Key considerations of individual interviews are, during the session, the creation of a comfortable environment for the participant, also, the interviewer must avoid mentioning "yes", "no", personal opinions, leading questions and manage a correct body language. Another aspect to take into account is the intensive time required to conduct the interview, transcribe it and analyse it as well as all the steps that are required in its process such as the identification of stakeholders and the information needed from the session, the approval by the concerning ethical committee, developing the interview protocol, translation, collect and analyse data and communicate results [138].

3.5 Summary

Based on the studies mentioned in this section it can be concluded that when designing an assistive device, aesthetics can be important but the key focus is on characteristics that impact fit and performance. Performance features will vary depending on the user, device and illness, therefore, personalisation and user involvement will also have an impact in the design process; this could be helpful because in a previous study, design process was mentioned as a reason for the disuse and under performance of the devices, especially those related to mobility which were mentioned in the studies as requiring improvement. Another common factor mentioned among the studies was the use of interviews and focus groups with users, and sometimes with relatives and carers, to determine their needs as well as to identify problems with their assistive devices.

Most of these studies applied/used one or more of the following: personalisation, AM and the use of interviews and focus groups. The relationship between these three factors and how they complement each other becomes apparent and even obvious. AM is a tool that has the potential to produce personalised solutions but in order to provide better performance and acceptance among the users it is relevant to understand and analyse the needs and feedback from users and the best way to do so is via interviews and focus groups. To further complement these three factors there exists UCD that considers the input of the users but at the same time provides a methodology to design and assess devices.

Many assistive devices have been manufactured using mass-customisation, which allows inexpensive and accessible products for people; however, the available options do not satisfy the requirements of all population leaving unmet needs. For this reason, companies have started to produce items by means of personalisation. Personalised products provide a better fit with the user, they are fabricated based on special requirements and individual forms when it is necessary, as a consequence, consumers obtain an improvement in their functionality and receive a unique and specialised expertise from the company; however, there are some limitations that do not allow the fast implementation of the personalisation, which, from the standpoint of the user, could represent a higher cost in the product and additional time because of a longer product development process.

Personalisation is related to assistive devices because many of the solutions provided for an illness have to be adapted to the user due to the variety of manifestations of the impairment and the unique body or limb shape. It is for this reason that mass customisation tends to provide partial or incomplete solutions to the user's problem. The creation of a personalised product can be expensive, however, AM may have the potential to be used because one of its advantages is producing individual parts cheaper than other fabrication methods. AM is a process that offers this feature because of its freedom in design, as well as the scan technology that can be combined with it to obtain a 3D CAD model that represents unique information about the user.

There have been studies where standard devices have been compared with personalised versions and as a result, users can be either like or dislike the tailored product. However, other types of results and conclusions can be withdrawn if a third option is provided in a test, that is to say, a version between a personalised and a standard model would allow to know or compare to what extent a personalised or standard option is preferred.

Also, identification of important aspects in an assistive device would be useful for this study, because variations of each one can be created and participants in tests can choose from several options achieving a more suitable match.

In addition, exploring unique properties of AM in the design of products may have the possibility to provide advantages for the user such as application of texture, changes in shapes and sizes.

Direct methods with technological resources have been utilised for capturing personalisation data through the use of a 3D scanner; other ways to gather this data can be explored.

This section has identified the key considerations needed when attempting to personalise a device, which will be carried through into the methodology for this work. In the following section, there will be a plan to define the assistive device utilising the possibilities of personalisation of the AM to develop a bespoke device that provides support for the particular needs of a user.

4 SHORTLISTING OF POTENTIAL CASE STUDY DEVICES

In order to assess the value of personalisation using AM for assistive devices, an example device needs to be selected. Rather than choosing any device as a case study, a programme of work is proposed to select a device with the maximum posible impact. This workflow is based on accomplishing three objectives (see Figure 4.1):

1. Definition of research basis.
2. Shortlisting assistive devices.
3. Selecting the assistive device.

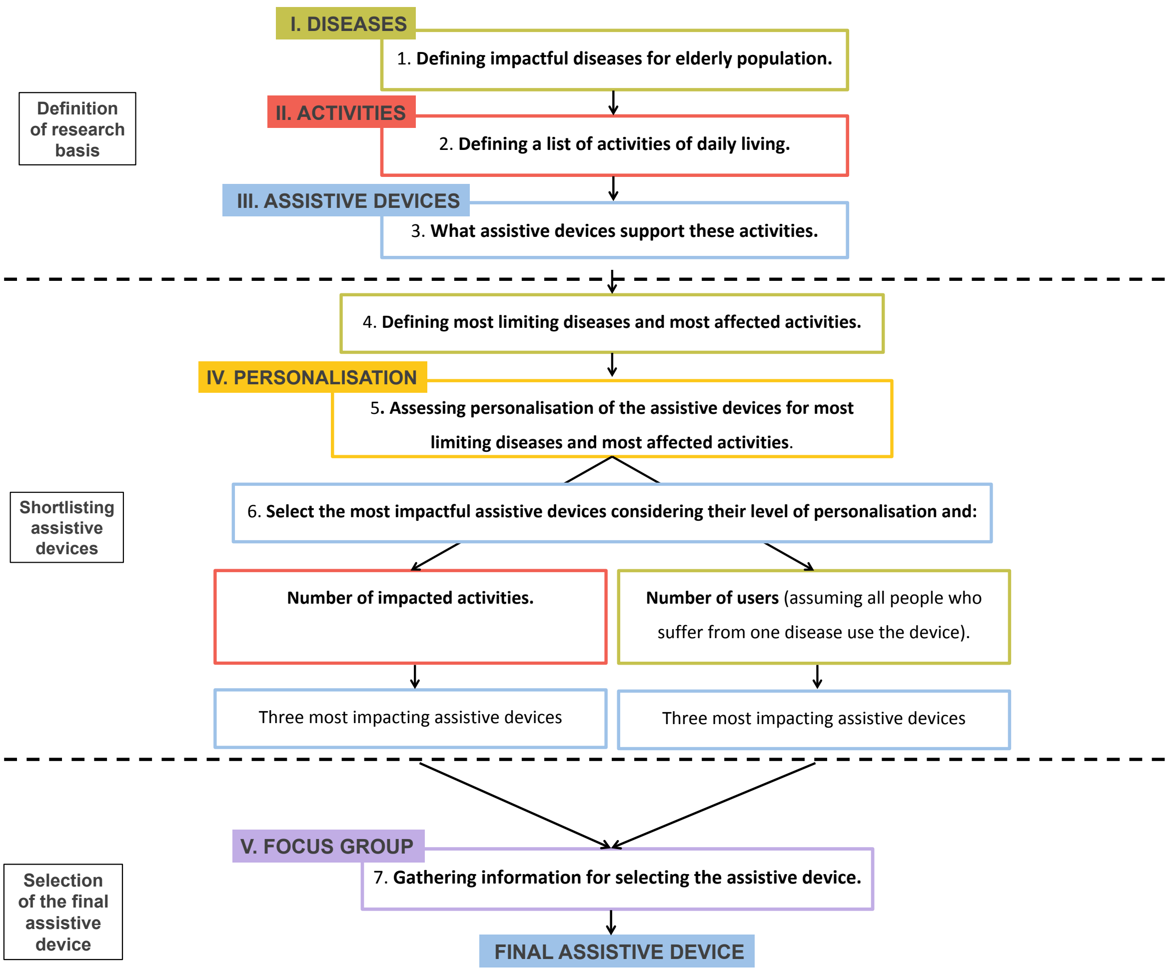

Figure 4.1 - Flowchart for selecting the assistive device

Besides the aspects mentioned in this device selection process, there are other important factors that are related to the evaluation of a suitable assistive device. Some of them are implicit in the study but others are not. These aspects are:

Avoiding devices or activities with high intra-subject variability. The requirement or the user condition may change within a short period, from one day to another or maybe several times per day, this means that the potential device should have a high intra-subject variability, however, creating a personalised product that must adjust to all scenarios could be difficult and not cost-effective.

Including devices or activities with high inter-subject variability. A relevant criterion is the high inter-subject variability because devices that are used differently from one individual to another may have a high and positive impact if they are personalised.

Big impact on small groups. It could also be possible to generate a high positive impact when personalisation of devices is aimed at small groups or a particular case; due to an uncommon situation, condition or illness, the user may require a very different device that does not exist in the market and a novel solution could provide them a high level of satisfaction.

Small impact on large groups. If a large population use a device manufacturers could have already produced several versions of it to cover the demand, therefore, a variety of solutions of the device may already exist and the impact of having the personalised version could be lower than the benefit of having a personalised device of a novel solution. However, the developed methodology considering a large population also has the objective to provide a broader applicability, be used for other scenarios scaling it down to smaller samples or markets.

Gross body and fine motor movements. Examine the assistive devices that support gross body movements versus those that help fine motor skills and identify if one group provides a higher impact than the other.

The aim of Chapter 4 is to execute the first two steps of the flowchart: 1. “Definition of research basis”, and 2. “Shortlisting assistive devices”.

4.1 Research basis

Given that many assistive devices are used by the elderly population the first step is to establish what the major diseases affecting the elderly population are. This in conjunction with daily activities and available assistive devices will help to establish a list of assistive devices. This list can then be shortlisted according to their potential to be personalised and their potential impact. This shortlist will then be used with potential users in a focus group to establish a final device.

According to the flowchart, the research basis involved three steps:

1. Defining impacting diseases for the elderly population.
2. Defining a list of activities of daily living.
3. What assistive devices support these activities.

4.1.1 Defining impactful diseases for the elderly population

The elderly population is significantly affected by diseases, as mentioned in Chapter 2, the most common after general ageing reducing mobility and strength is hearing loss (6.4 million), the numbers are noted in Table 4.1.

		Population in the UK (million)	Age
	Ageing	11.4	65+
Diseases	Arthritis	4.74	65+
	Osteoporosis	2.41	65+
	Dementia	0.77	65+
	Parkinson's disease	0.12	60+
	Urinary incontinence	3.2	65+
	CVD	2.94	65+
	Sight loss	1.44	65+
	Hearing loss	6.4	65+

Table 4.1 - Number of cases per disease in the UK including sight and hearing loss

***No data was available for tactile impairment, anosmia and ageusia.**

Ageing [3], arthritis [5] [6], osteoporosis [9], dementia [11], Parkinson's disease [17], urinary incontinence [20], CVD [25], sight loss [33], hearing loss [3]

However, many of these illnesses hinder the execution of daily activities, thus, affecting individuals' quality of life. See Chapter 2 "Background information" for further details on the diseases and their symptoms.

The most prevalent symptoms resulting from the 11 diseases (Table 4.1, tactile impairment, anosmia, ageusia) and from the ageing process are, in first place, "balance problems", followed by "decreased range of motion" and then "presence of pain", "sleep disturbances" and "reduction of communication skills"; all of these symptoms are present in one or more diseases. Table 4.2 shows the relation of each symptom to the diseases and Table 4.3 summarises the information. This information with explanations is found in Appendix A.

Diseases	Symptoms																		
	Swelling	Stiffness	Pain	Decreased range of motion	Loss of height over time	A stooped posture	An unexpected bone fracture	Tremors	Painful muscle cramps	Spasms	Balance problems	Cognitive dysfunction	Depression	Sleep disturbances	Bladder dysfunction	Gradual loss of memory	Reduction of communication skills	Difficulty with thinking and reasoning	Disorientation
Arthritis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Osteoporosis	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No
Dementia	No	Yes	No	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Parkinson's	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
Urinary incontinence	No	No	No	No	No	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	No
Heart disease and strokes (CD)	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ageing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No	Yes	No	No
Visual impairment	No	No	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	No
Hearing impairment	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	Yes
Tactile impairment	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No
Anosmia	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Ageusia	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No

Diseases	Symptoms																		
	Visual hallucinations	Indigestion	Heartburn	Nausea and vomiting	Fatigue	Breath problems	Palpitations	Hearing loss	Visual impairment	Poor visual acuity	Poor contrast sensitivity	Poor depth perception	Visual field loss	Unable to know where the noise is coming from	Hearing a buzzing or whistling in the ears	Lack of sensation of external stimuli	Problems with odours identification	Decreased appetite	Problems with flavours identification
Arthritis	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
Osteoporosis	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Dementia	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Parkinson's	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
Urinary incontinence	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Heart disease and strokes (CD)	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No	No	Yes	No	Yes
Ageing	No	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Visual impairment	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Hearing impairment	No	No	No	No	Yes	No	No	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No
Tactile impairment	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
Anosmia	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
Ageusia	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes

Table 4.2 - Symptoms per disease

	Symptoms	Number of diseases with this symptom
1	Swelling	3
2	Stiffness	5
3	Pain	6
4	Decreased range of motion	7
5	Loss of height over time	4
6	A stooped posture	4
7	A bone fracture	3
8	Tremors	3
9	Painful muscle cramps	3
10	Spasms	2
11	Balance problems	10
12	Cognitive dysfunction	5
13	Depression	4
14	Sleep disturbances	6
15	Bladder dysfunction	5
16	Gradual loss of memory	2
17	Reduction of communication skills	6
18	Difficulty with thinking and reasoning	2
19	Disorientation	4
20	Visual hallucinations	2
21	Indigestion	1
22	Heartburn	1
23	Nausea and vomiting	1
24	Fatigue	3
25	Breath problems	3
26	Palpitations	1
27	Hearing loss	2
28	Visual impairment	3
29	Poor visual acuity	3
30	Poor contrast sensitivity	2
31	Poor depth perception	3
32	Visual field loss	3
33	Unable to know where the noise is coming	2
34	Hearing a buzzing or whistling in the ears	2
35	Lack of sensation of external stimuli	2
36	Problems with odours identification	4
37	Decreased appetite	4
38	Problems with flavours identification	4

Table 4.3 - Summary of number of diseases per symptom

4.1.2 Defining a list of activities of daily living

The first step to understand how the previous 11 diseases and ageing affect activities is to elaborate a list about what activities are impacted by these diseases. After reviewing information [2] [139] [140] [141] [142] [143] [144] [145] [146] [147] [148] [149], and including only activities that might involve assistive devices, the result was:

1. Gripping and holding items.
2. Eating

3. Preparing a meal
4. Dressing
5. Showering
6. Toileting
7. Moving about the living quarters
8. Moving outside the house
9. Exercising
10. Communicating
11. Socialising
12. Sleeping
13. Handwriting
14. Safekeeping
15. Housekeeping or doing work around the garden

These 15 activities were compared with an already established standard of activities, the Barthel Index [150] (for ADLs) and the Lawton Scale [151] (for IADLs), and combine them into a final list. As a result of this comparison the final list is composed of 17 activities because “gripping and holding items” was removed and 3 IADLs [152] were added:

1. Managing finances
2. Ability to use the phone
3. Taking medications

Table 4.4 shows the two standards. From the ten activities of the Barthel Index, four were not considered because #2 “moving from wheelchair to bed and returning” and #7 “ascending and descending stairs” are included in “moving about the living quarters” and #9 “controlling bowels” and #10 “controlling bladder” are under “toileting”. From the eight activities of the Lawton Scale, #2 “shopping” is under “moving outside the house” and #5 “laundry” is under “housekeeping or doing work around the garden”.

	ADL/ IADL	Is it included in the new list with this name?
Barthel ADL	**1. Feeding.** The patient can feed himself a meal from a tray or table when someone puts the food within his reach. He must put on an assistive device if this is needed, cut up the food, use salt and pepper, spread butter, etc.	Yes
	2. Moving from wheelchair to bed and returning. Patient can safely approach the bed in his wheelchair, lock brakes, lift footrests, move safely to bed, lie down, come to a sitting position on the side of the bed, change the position of the wheelchair, if necessary, to transfer back into it safely, and return to the wheelchair.	No
	3. Doing personal toilet. Patient can wash hands and face, comb hair, clean teeth, and shave. He may use any kind of razor but must put in blade or plug in razor without help as well as get it from drawer or cabinet. Female patients must put on own makeup, if used, but need not braid or style hair.	Yes
	4. Getting on and off toilet. Patient is able to get on and off toilet, fasten and unfasten clothes, prevent soiling of clothes, and use toilet paper without help. He may use a wall bar or other stable object for support if needed. If it is necessary to use a bed pan instead of a toilet, he must be able to place it on a chair, empty it, and clean it.	Yes
	5. Bathing self. Patient may use a bath tub, a shower, or take a complete sponge bath. He must be able to do all the steps involved in whichever method is employed without another person being present.	Yes
	6. Walking on level surface. Patient can walk at least 50 yards (45 metres) without help or supervision. He may wear braces or prostheses and use crutches, canes, or a walkerette but not a rolling walker. He must be able to lock and unlock braces if used, assume the standing position and sit down, get the necessary mechanical aides into position for use, and dispose of them when he sits. (Putting on and taking off braces is scored under dressing.)	Yes
	7. Ascending and descending stairs. Patient is able to go up and down a flight of stairs safely without help or supervision. He may and should use handrails, canes, or crutches when needed. He must be able to carry canes or crutches as he ascends or descends stairs.	No
	8. Dressing. Patient is able to put on and remove and fasten all clothing, and tie shoe laces (unless it is necessary to use adaptations for this). The activity includes putting on and removing and fastening corset or braces when these are prescribed. Such special clothing as suspenders, loafer shoes, dresses that open down the front may be used when necessary.	Yes
	9. Controlling bowels. Patient is able to control his bowels and have no accidents. He can use a suppository or take an enema when necessary (as for spinal cord injury patients who have had bowel training).	No
	10. Controlling bladder. Patient is able to control his bladder day and night. Spinal cord injury patients who wear an external device and leg bag must put them on independently, clean and empty bag, and stay dry day and night.	No
Lawton IADL	**1. Ability to use telephone.** Operates telephone on own initiative (looks up and dials numbers, etc.). Dials a few well-known numbers. Answer telephone.	Yes
	2. Shopping. Takes care of all shopping needs independently.	No
	3. Food Preparation. Plans, prepares and serves adequate meals independently. Maintain adequate diet.	Yes
	4. Housekeeping. Maintains house alone or with occasional assistance (e.g., "heavy work-domestic help").	Yes
	5. Laundry. Does personal laundry completely.	No
	6. Mode of Transporation. Travels independently on public transportation or drives own car.	Yes
	7. Responsibility for own medications. Is responsible for taking medication in correct dosages at correct time.	Yes
	8. Ability to handle finances. Manages financial matters independently (budgets, writes cheques, pays rent, bills, goes to bank), collects and keeps track of income.	Yes

Table 4.4 - Comparison between ADL - IADL standard and activities in new list

The 17 activities can be grouped into the following categories; these are shown in Table 4.5:

CATEGORIES	ACTIVITIES
1. Personal care: These activities are related to hygiene and personal grooming.	• Dressing • Showering • Toileting

2. Feeding: These activities correspond to the processes of preparing and ingesting food and meals.	• Eating • Preparing a meal
3. Mobility: These activities are related to the physical health of the people and they require a certain physical fitness in order to be done.	• Moving about the living quarters • Moving outside the house • Exercising • Housekeeping or doing work around the garden
4. Communication: These activities are related to different kinds of communication such as verbal or written, as well as communication through electronic devices such as telephone.	• Communicating • Handwriting • Socialising • Ability to use the telephone
5. Healthcare: This category focuses on taking care and maintaining the physical health of a person.	• Sleeping • Safekeeping • Taking medications
6. Others	• Managing finances

Table 4.5 - Categories and activities

16 out of 17 activities are under the same group except "managing finances", which includes aspects such as mobility and communication but many other actions such as calculating budgets and making payments, therefore, it is better to classify it as "others".

This final list of 17 activities will be considered throughout the study.

4.1.3 What assistive devices support these activities

This section will discuss existing assistive devices that support the 17 activities pre-established in section 4.1.2. Also, products that may support, diminish or alleviate symptoms that are present in several diseases and activities will be described.

4.1.3.1 Assistive devices to alleviate or support symptoms caused by several diseases

There are assistive devices that can be used to mitigate symptoms present in several diseases. Products such as heat and cold pads and splints are used to relieve muscles, joints and limbs.

Pads and wraps are created to reduce inflammation in joints and improve mobility; some of them can surround limbs providing different temperatures according to users' needs, such as the products shown in Figure 4.2. They can adapt their form to some parts of the body such as wrists, elbows, knees and ankles.

Figure 4.2 - Thermophore arthritis pads [153] and hot & cold joint relief wraps [154]

Some of these pads and wraps could have limitations requiring more pressure to have better contact with the body; also, they could heat up fast causing problems for people with sensitive skin.

Other products created for bringing relief, stabilisation and alignment to fingers and hands are splints. These can be preforms with straps to place the arm for resting and to heal spasms.

These devices are favourable solutions as they fix the forearm, wrist and fingers, however, it is important to consider the situation of the patient. A person who suffers from a high level of spasms and deformation, for example, due to arthritis, could need a product focused on blocking specific areas of the hand, otherwise, the devices would not be able to improve the condition, as shown in Figure 4.3.

Figure 4.3 - Dynamic hand in splints [155]

Other products are focused on solving conditions in the feet, such as foot drop, through a design with a flexible strap and a plastic inlay into the shoe that provides dynamic support during walking. Other devices help contractures using a special support, alignment and a proper adjustment of toe; some of these products have a dynamic flex action of the sole foot shoe that allows less pressure on the heel, such as the orthosis shown in Figure 4.4.

Figure 4.4 - Sole foot shoe of orthosis RCAI (Restorative Care of America Incorporated) MPO 2000 Active® [156]

Other products provide straightening and relief to overlapping toes and hammer toe through a shape that protects the toe. There are other devices that align other conditions such as hallux valgus and tailor bunion using straps to attach to the toes and the heel.

Most of the products in this group are adaptable to the user; however, they do not cover the entire population because there could be cases of people with advanced levels of diseases.

4.1.3.2 Dressing

For this activity many products have been developed to cover specific actions such as reaching items, taking clothes off and putting clothes on, putting on and taking off shoes and others that improve mobility.

Extensions for reaching objects, shown in Figure 4.5, are manipulated by a handle that should be squeezed; these products may have limitations to reach objects in short distances due to their fixed length, and the user requires enough mobility and finger strength to squeeze the trigger and to rotate the wrist. If the design of the handle is not comfortable for the users, it could be modified through personalisation in order to give a better grip.

Figure 4.5 - Extensions for reaching objects [157] [158]

“Dressing” also requires products for taking the clothes off and on. Some devices have hooks at one end but they are limited to reach certain types of clothing, preferably with belt loops; also, their handles could have an ergonomic design but their performance will depend of the user’s strength and mobility; examples for dressing are shown in Figure 4.6.

Figure 4.6 - Products for dressing [158] [159]

Other products that support precision of fingers are aids to fasten buttons, zips and belts. Also, there are solutions for putting on and taking off shoes that consist of a rigid and lightweight stick with a handle that closes and opens a pincer at one end which helps to hold the heel part of the shoe and enables the user to put it on. A limitation could be the shape of the handle since it is not functional for people with low strength and mobility problems in fingers and wrists.

4.1.3.3 Showering

The existing products for this activity focus on grabbing, opening/closing taps and washing.

Grab rails offer support for accessing and leaving the shower or bathtub, they can be located at any place or height according to the user’s needs and have a proper diameter for an easy handgrip, are rigid and sold in different lengths. However, people could require an extra support to grab them due to restricted mobility in wrists and fingers.

There are also extensions for products used for washing, these are useful to avoid additional efforts in users, for example, extensions for back brushes or hair and toe washers. However, their use could be restricted for people with a limitation in movement and they may require an additional support for gripping and handling them. Extensions for opening and closing taps facilitate this task but if the user does not have enough strength in the hand or mobility in hands, wrists and fingers is limited, the product may not be functional.

Showering should be performed carefully because of the possible danger around it. If people are not able to take a shower by themselves, the help of a carer is essential to achieve the activity safely.

4.1.3.4 Toileting

The products for this activity cover the actions of sitting down, standing up, flushing, opening and closing taps, personal care and self-wipe.

Grab rails support people with problems to sit down and stand up from the toilet; as mentioned before, they come in different shapes and lengths according to the user's needs, also, they are robust and can be fixed in any place on the wall. If it is necessary, the creation of a special surface (texture) could be developed to provide a better grip.

Products for self-cleaning have a long reach and a rounded design to avoid discomfort, they are illustrated in Figure 4.7. However, some of them are used with both hands because the tissue has to be wrapped around the angled clamp while a button is pressed and people with only one functioning hand may struggle with the product.

Figure 4.7 – Self-wipe toileting hygiene aid [160]

In case of gripping problems, the handles of toileting products such as self-wipe aids and flush handles can be personalised according to the user's needs.

Toileting is one of the activities that require significant care when people cannot perform it, because it is related to other relevant aspects in the human life such as basic needs, hygiene and impact on social acceptance.

4.1.3.5 Eating

Products for "eating" help to manage and handle food and drink, improving the use of cutlery, the transfer of food from plate to mouth and drinking liquids from a glass. Most of them bring support to the handling of devices through the modification of its grip with different shapes and sizes according to the user's needs. This provides better control. There have also been good solutions created for people with tremors, limited coordination or weakness in upper limbs, such as spoons that restrict spillage of food with a lid cover.

The modification of the handles could also provide a solution in devices that support other activities; however, it is important to consider particular cases of mobility problems and personalisation in handles or additional straps should be evaluated.

4.1.3.6 Preparing a meal

The products designed for preparing a meal, help with reaching items and managing accessories for cooking.

The devices for reaching items (in this case food, ingredients) were already mentioned in the "dressing" section; they are flexible because they can be used in more than one activity.

There are accessories that support utensils for cooking; many of them focus on providing an extension between the user and the item such as handles for cutlery, can opener and lid opener, shown in Figure 4.8. They facilitate this action considering design and proper materials, some of them are made of plastic because it allows proper friction between the accessory and the user.

Figure 4.8 - Lid opener [161]

Products such as cutlery have an adaptation of its handle that results in a better support.

Other types of products, such as gloves, protect the user from different dangers inside the kitchen. Their materials have an important role for their performance; the fabric can be flame retardant, which allows cooking in a safer way, or flexible steel mesh. Both materials provide a good solution for preparing food, also, a flexible steel mesh have an adequate use because it fits into a hand with freedom of movement and this is an important aspect for cutting food.

“Preparing a meal” involves many actions, some of them come with a particular risk such as cutting and heating food, this has propelled the development of products such as the metal glove, slicing helpers, cheese graters shown in Figure 4.9.

Figure 4.9 - Metal glove [162], slicing help [163], cheese grater [164]

4.1.3.7 Moving about the living quarters

These devices were created to support people with walking impairments; such as sticks with a moulded handle that distributes the pressure of the whole hand with adjustable heights. Other products are belts with handles that provide support to a fragile person who walks assisted by a carer, moulded splints that align wrists and distribute the weight through a walker and custom-moulded foot brace.

4.1.3.8 Moving outside the house

These products support the actions of moving, reaching items, tracking and maintaining independence. Devices developed for moving were already covered in the previous activity “moving about the living quarters” and the devices for reaching items were mentioned in “dressing”. The products for maintaining independence were created to help people to be more active within a society; some of them provide a better grip and leverage in accessories, such as handles for keys; or other solutions bring a better support and balance for people with stability problems, such as a car transfer aid. These products can be personalised depending of the user’s needs; for example, a sole to track people was created and this could be bespoke, this also applies to the handles of the devices or splints.

Devices utilised in this activity can create an ethical conflict, for example, the use of soles to track individuals could affect their right to privacy.

4.1.3.9 Exercising

These products are auxiliaries in holding equipment for doing exercise. They help to support items in a safe way. Some of them hold devices with a strap that covers the hand and are secured onto the wrist, this allows using the force of the hand with a weak handgrip. Other products assist people with a resistant looped strap attached to the wrist, allowing the use of the forearm strength. These types of products, shown in Figure 4.10 allow people who cannot hold things properly to perform and complete activities.

Figure 4.10 - Aids for holding items [165] [166]

4.1.3.10 Housekeeping or doing work around the garden

These products have been created for reaching items such as accessories for cleaning or working the garden. These were mentioned in “dressing”.

These devices support the handling in order to complete functions. There are products with robust handles that allow a better grip, ideal for people who suffer from arthritis or have mobility problems in their hands. The handles have been designed to avoid the bending of the user’s wrist, such as equipment for cultivating and shearing grass, shown in Figure 4.11.

Figure 4.11 - Cultivating equipment [167] and grass scissors [168]

4.1.3.11 Communicating

These devices were designed to help people to speak more clearly (speech), understand what other people say (hearing), improve eyesight and be able to follow a conversation.

Many of these devices present amplified features of the product, for example, phones with a greater size of keys in order to allow a better visualisation for people with sight problems, or amplifiers of sound in hearing aids. This can be useful for people who are losing their senses, however, there could be users with special needs, for example, an adequate shape of a hearing aid according to the size of their ears.

4.1.3.12 Socialising

For this activity, the products allow and propel communication between people. An example is a technological device that is used to interchange messages, pictures, reminders, music, videos and calendar appointments; it is shown in Figure 4.12. The limitations of this product are related to the training that the user needs, their capacity of learning, memorisation to access it and access to the Internet.

Figure 4.12 - The GrandCare Systems [169]

4.1.3.13 Handwriting

Some of these products provide an extension to the object used to write, in this way, the user has a better handling and control of their movements and stress on the wrist is reduced; these devices can be used by people who suffer from mobility problems. Other devices have a better support at the bottom; this allows more stability to people who suffer from Parkinson's disease. Also, products such as templates have been created for people with visual impairments in order to limit the space for signing.

4.1.3.14 Ability to use the telephone

These products provide support for making or answering telephone calls to people with limited functional skills and strength in hands. Some of them give a solution for people with mobility problems in wrists, fingers and hands.

Other products, such as telephones, may provide a solution for people who suffer from arthritis, dexterity problems, memory problems and visual impairments by having bigger buttons and allowing the user to press them without high accuracy, buttons with images to help dial phone numbers in a single click and flashing lights that indicate when a phone call is incoming.

The design of these solutions can be generic and simple but effective; however, there could be some special cases where these devices should be adapted depending on the individual's needs.

4.1.3.15 Sleeping

The products for "sleeping" have been developed to give better comfort during the night and uninterrupted sleep, for this reason, devices such as "stop snoring" mouthpiece, shown in Figure 4.13 and urinals can be included.

Figure 4.13 - "Stop snoring" mouthpiece [170]

These products may have a standard and ergonomic shape for women and men. The ergonomic shape of the "stop snoring" can be adapted to the user's mouth because it is made from an expanded rubber that can be heated up and moulded into the mouth. In this case, the material of the device helps to solve the problem.

4.1.3.16 Safekeeping

For this activity, products such as gloves have been created, examples are shown in Figure 4.14; they are helpful for people with visual and tactile impairment. The materials, flame retardant and cut resistant are efficient for the activities. The size of these products is relevant because some of them are used to execute precise activities and the device should be adapted to the user.

Figure 4.14 - Flame retardant oven mitt [171]. Cut resistant glove [162]

There are also alarms for hot surfaces, fire detection or toxic gases.

4.1.3.17 Taking medications

These devices support taking syrup or pills through the creation of cutlery that has cushioned and robust handles, it allows a better grip and control. Some of the devices support through the use of a plastic and adaptable strap, others help to open products and others decrease the leakage of syrup because of a lid cover. There could be adaptation of the handle according to individual cases.

There are not many devices that provide support to grab pills; these devices could be useful for people who suffer from mobility problems in fingers, wrists and hands. Existing products help specific actions such as an applicator of eye drops, a pill puncher and a tablet splitter, shown in Figure 4.15; however, these products may require an adaptation in some cases depending on the user's condition.

Figure 4.15 - Applicator of eye drops [172]. Pill puncher [173]. Tablet splitter [174]

4.1.3.18 Managing finances

Products developed for "writing" and "diminishing symptoms of illnesses", can also be used to support activities related to finances; since actions such as writing cheques and going to the bank are carried out.

There are devices for writing with different shapes that allow better control. This can be helpful but some of them could be personalised if required.

Managing finances also requires carrying out actions as going to the bank, keeping track of income and managing budgets; for this, the use of products to improve walking or transportation is necessary, for example, the use of a stick with a personalised handle or straps for transporting.

Many of the devices mentioned in this chapter are triggered or manipulated using arms and hands; in fact, the movements of upper limbs are involved in many of the activities mentioned, even for disabilities of the lower limbs the hand plays an important part. For example, in order to move in a wheelchair you will need to put your hands around the wheels or if you are going to use a cane the grip will be an important factor to consider, for these reasons, handheld devices are relevant in this study.

The previous assistive devices have been created to support the 17 established activities and the 11 diseases and ageing. This information will be used in the next section, where a shortlist of the most impactful assistive devices will be obtained.

4.2 Shortlisting assistive devices

After establishing a list of diseases, a list of activities of daily living and existing supporting products, the following steps will be conducted to shortlist the assistive devices:

1. Defining most limiting diseases and most affected activities.
2. Assessing the potential for personalisation of the assistive devices for most limiting diseases and most affected activities.
3. Select the most appropriate assistive devices for greatest potential impact.

4.2.1 Defining most limiting diseases and most affected activities.

The 17 activities have been analysed with respect to each disease identified in sections 2.1 and 2.2. This comparison allows knowing what the impact of the diseases is on the activities. For example, having arthritis causes inflammation and pain in joints, bones and muscles, therefore, this has an impact on activities that involve movements in limbs such as dressing, showering, toileting, taking medications, eating, among others.

Table 4.6 shows an excerpt of this comparison and Table 4.7 gives a summary of the information, both help to identify which diseases affect more activities and vice versa, and which activities are the most affected by diseases. This information will be considered to decide what kind of product will be selected in order to ensure the greatest possible impact. More detailed information about diseases vs. activities is found in Appendix B.

DISEASES		Personal Care		
	ACTIVITIES	**Dressing (ADL).** Involves: 1. Put on all kind of clothing from underwear, pants, socks, blouses, sweaters, t-shirts. 2. Being able to button shirt and to use zippers. 3. Being able to put on any kind of shoes and socks [2].	**Showering (ADL) [2].** Involves: 1. Coordinate hands and arms to wash the whole body. 2. Grab shampoo and soap. 3. Get in and out of the shower. 4. Operate the taps and regulate the temperature of the water.	**Toileting (ADL) [2].** Involves: 1. Being able to sit on the toilet and stand up from it. 2. Being able to do self cleaning after.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms stiffnes and pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		√ There is a difficulty because of the inflammation of joints in knees, hips, wrists, fingers and toes, this can limit the activity of dressing [279] [139].	Inflammation and pain in joints in upper and lower limbs inhibits the movements which are required to carry out showering such as pain in knees, toes, hips, wrists and fingers [279] [139].	The arthritis can cause inflammation in knees, hips, wrists and fingers. This makes the action of toileting difficult [279] [139].
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8].		√ There can be problems for people who have suffered a fracture because it can cause fragility in bones and lack of mobility and stability [203] [209] limiting actions of dressing.	The problems with showering are related more to the possibility of a fall than the activity itself. The elderly population is prone to suffer falls when they are taking a shower [313]. If the person has osteoporosis the possibility of suffering a fracture is greatly increased [139] [309].	The problems with toileting are related more to the fear of a fall than the activity itself. The elderly population is prone to suffer falls when they are toileting [313]. People lose muscular strength as they grow older [28] thus activities like sitting down or standing up in the toilet can be difficult and can lead to falls and fractures [139].

Table 4.6 - (Excerpt). Diseases and how they impact on the activities

DISEASES		Personal Care			Feeding		Mobility				Communication				Healthcare			Others
	ACTIVITIES	Dressing (ADL).	Showering (ADL).	Toileting (ADL).	Eating (ADL).	Preparing a meal (IADL).	Moving about the living quarters (ADL).	Moving outside the house (IADL).	Exercising (ADL).	Housekeeping or doing work around the garden (IADL).	Communicating (IADL).	Handwriting (ADL).	Socialising.	Ability to use the telephone (IADL).	Sleeping (ADL).	Safekeeping (IADL).	Taking medications (IADL).	Managing finances (IADL).
Arthritis		√	√	√	√	√	√	√	√	√	X	√	√	√	√	X	√	√
Osteoporosis		√	√	√	√	√	√	√	√	√	X	√	√	√	X	X	√	√
Dementia		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Parkinson's		√	√	√	√	√	√	√	√	√	√	√	X	√	√	X	√	√
Urinary incontinence		X	√	√	X	X	√	√	√	X	X	X	√	X	√	X	X	√
Heart disease and strokes (Cardiovascular diseases)		√	√	√	√	√	√	√	√	√	√	√	√	√	√	X	√	√
AGEING a) Ageing		√	√	√	√	√	√	√	√	√	√	√	X	√	√	√	√	√
b) Visual impairment		√	√	√	√	√	√	√	√	√	√	√	X	√	X	√	√	√
c) Hearing impairment		X	√	√	X	√	√	√	√	√	√	X	√	√	X	√	X	√
d) Tactile impairment		X	√	√	X	√	√	√	X	√	X	√	X	√	X	√	√	√
e) Anosmia (the loss of the sense of smell)		X	X	X	√	√	X	X	X	√	X	X	√	X	X	√	√	X
f) Ageusia (taste impairment)		X	X	X	√	√	X	X	X	X	X	X	√	X	X	√	√	X

"√" states that the disease affects the activity and "X" indicates that it does not.

Table 4.7 - Diseases and activities impacted

For more details on Table 4.7, see Appendix B.

Table 4.8 and Table 4.9 indicate the results. Table 4.8 shows the number of activities affected by each disease:

Different diseases	Number of activities affected by disease
Arthritis	15
Osteoporosis	14
Dementia	17
Parkinson's disease	15
Urinary incontinence	8
Heart disease and strokes (CD)	16
Ageing	16
Visual impairment	15
Hearing impairment	12
Tactile impairment	11
Anosmia	6
Ageusia	5

Table 4.8 - Number of activities affected by disease

As it can be seen, dementia affects all the activities; followed by ageing and cardiovascular disease affecting 16 activities each, and in joint third place are arthritis, Parkinson's disease and visual impairment, impacting on 15 activities each.

The diseases that affect fewer activities are ageusia (taste impairment) limiting six activities, followed by anosmia (the loss of the sense of smell) causing limitations in five activities; the main reason is because these are impairments that block specific zones of the body affecting only activities related to feeding, housekeeping or doing work around the garden, socialising and safekeeping.

This analysis is important because in this way it is feasible to observe which diseases impose more limitations on the daily living of the elderly population.

From the activities standpoint, "preparing a meal" is the most affected since 11 out of 12 diseases can cause limitations in its performance. In second place are "showering", "toileting", "taking medications", "moving about the living quarters", "moving outside the house", "housekeeping or work around the garden", "managing finances", and in third place are "eating", "exercising" and "ability to use the phone". The least affected are "communication" and "sleeping". Table 4.9 shows this information:

Activities	Number of diseases that affect an activity
Dressing	7
Showering	10
Toileting	10
Taking medications	10
Eating	9
Preparing a meal	11
Moving about the living quarters	10
Moving outside the house	10
Exercising	9
Housekeeping or doing work around the garden	10
Communicating	6
Handwriting	8
Socialising	8
Ability to use the telephone	9
Managing finances	10
Safekeeping	7
Sleeping	6

Table 4.9 - Number of diseases that affect an activity

4.2.2 Assessing personalisation of the assistive devices for the most limiting diseases and most affected actitivites.

After identifyng the most limiting diseases and most affected actitivities it is necessary to evaluate the level of personalision of the assistive devices that support them.

Three questions have been formulated to assess the importance of a product being personalised. They focused on three factors: user, product and process.

User

- Could a personalised device generate better results for users than the existing solutions?

There are useful standard options available on the market but the user should find a positive difference on a personalised product, either functional or emotional.

Process

- Does AM exhibit advantages over traditional processes?

Evaluate the advantages of utilising AM for producing a personalised shape rather than using other technologies.

Product

- Will the personalised solution have an improvement in the number of parts and in material use compared to existing solutions?

Assessing the advantages of the product being produced in different materials or if their components can be reduced without reducing its performance.

Each question is evaluated with 1, 2 or 3 points, 3 being the most optimal value. These questions were applied to 38 assistive devices that support the most impacting diseases and the most affected activities previously identified. Table 4.10 shows these devices, the scores and the total points per device. The assistive devices used per activity and diseases are shown in Appendix C.

Assistive device	User	Process	Product	Total. Level of personalisation
Shoe dressing	2	3	2	7
Reacher	2	3	2	7
Buttonhook	2	3	2	7
Zipper aid	2	2	1	5
Belt aid	1	1	1	3
Relief pads	2	1	1	4
Splint and strap for arms, hands	3	3	3	9
Splint and strap for legs and feet	3	3	3	9
Rail	2	2	3	7
Washer	2	2	2	6
Extensions for personal care products	2	2	2	6
Tap turner	2	2	2	6
Self wipe	2	2	2	6
Notifier	1	1	2	4
Adapted cutlery	2	3	3	8
Jar or can opener	2	2	1	5
Walking stick	2	3	3	8
Walking belt	2	2	2	6
Walker hand splint	3	3	3	9
Double key turner	2	2	2	6
Exercise aid	2	2	3	7
Ergonomic pen with extra support	3	3	1	7
Telephone aid	2	2	2	6
Type aid	2	2	2	6
Talking alarm clock	1	1	1	3
GPS sole	3	3	2	8
Stop-snoring mouthpiece	3	1	1	5
Gloves	2	1	1	4
Plastic signature guide	1	1	1	3

Table 4.10 - Level of personalisation per product

Having the value of personalisation of each product, they will be compared with a) the number of activities affected, and b) their number of users (assuming all people who suffer from a disease use the device). The results will be useful to define the most impactful assistive devices.

4.2.3 Select the most impactful assistive devices

The comparison between the personalisation level and the number of activities impacted per device are indicated in Table 4.11, the highest five scores are shown in green: splints and straps for arms, relief pads, splints and straps for legs, walker hand splints and walking sticks. The number of activities impacted per device can be found in Table of Appendix D.

Assistive devices	Personalisation	Number of activities impacted
Shoe dressing	7	1
Reacher	7	4
Buttonhook	7	1
Zipper aid	5	1
Belt aid	3	2
Relief pads	4	14
Splint and strap for arms, hands	9	13
Splint and strap for legs and feet	9	10
Rail	7	3
Washer	6	1
Extensions for personal care products	6	1
Tap turner	6	4
Self wipe	6	1
Notifier	4	4
Adapted cutlery	8	3
Jar or can opener	5	3
Walking stick	8	5
Walking belt	6	5
Walker hand splint	9	5
Double key turner	6	1
Exercise aid/different purposes	7	6
Ergonomic pen with extra support	7	2
Telephone aid	6	2
Type aid	6	4
Talking alarm clock	3	3
GPS sole	8	3
Stop-snoring mouthpiece	5	1
Glove	4	2
Plastic signature guide	3	2

Table 4.11 - The green colour indicates the top five devices when comparing their level of personalisation with the number of activities impacted

On the other hand, from the comparison between the level of personalisation of the assistive devices and the affected population, these five products obtained the highest scores: rails, walker hand splints, walking sticks, walking belts and telephone aids. These values are indicated in Table 4.12. The population affected by the diseases was obtained from Table 4.1 and the diseases supported by each device can be found also in Table of Appendix E.

Assistive devices	Personalisation	Population (million)
Shoe dressing	7	10.21
Reacher	7	10.21
Buttonhook	7	10.21
Zipper aid	5	10.21
Belt aid	3	10.21
Relief pads	4	10.21
Splint and strap for arms, hands	9	10.21
Splint and strap for legs and feet	9	10.21
Rail	7	22.02
Washer	6	10.21
Extensions for personal care products	6	10.21
Tap turner	6	8.57
Self wipe	6	10.21
Notifier	4	5.15
Adapted cutlery	8	10.21
Jar or can opener	5	7.68
Walking stick	8	18.82
Walking belt	6	18.82
Walker hand splint	9	18.82
Double key turner	6	7.68
Exercise aid/different purposes	7	4.74
Ergonomic pen with extra support	7	10.21
Telephone aid	6	18.82
Type aid	6	10.09
Talking alarm clock	3	3.71
GPS sole	8	3.71
Stop-snoring mouthpiece	5	2.94
Gloves	4	1.44
Plastic signature guide	3	1.44

Table 4.12 - The green colour indicates the top five devices when comparing their level of personalisation with the people impacted

The graphic representation of these values is shown in Figure 4.16 and Figure 4.17. The assistive devices selected were those affecting more activities, most population and able to personalise.

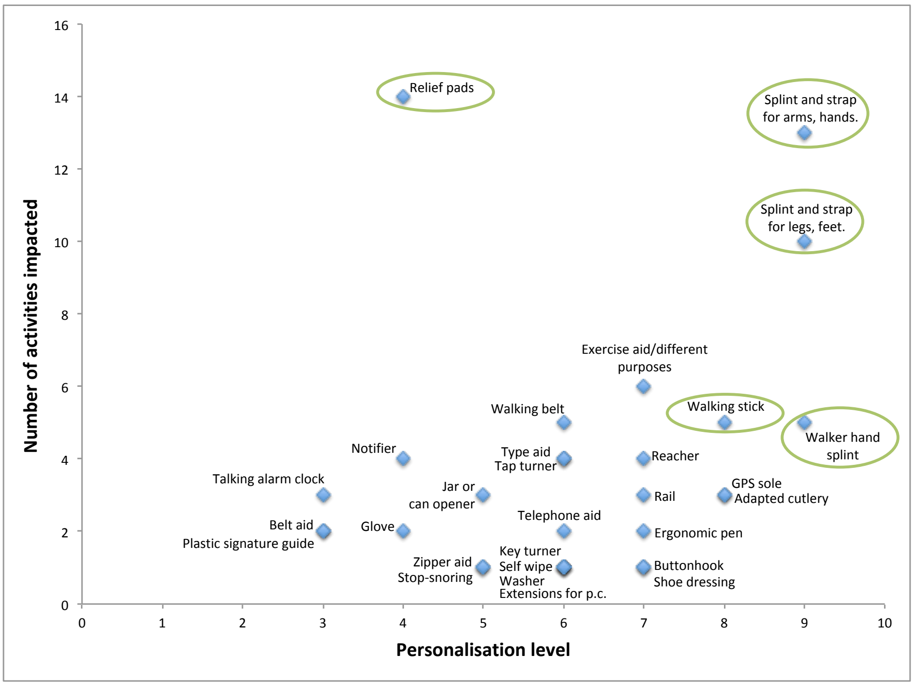

Figure 4.16 - The oval indicates the top five devices comparing their level of personalisation with the number of activities impacted

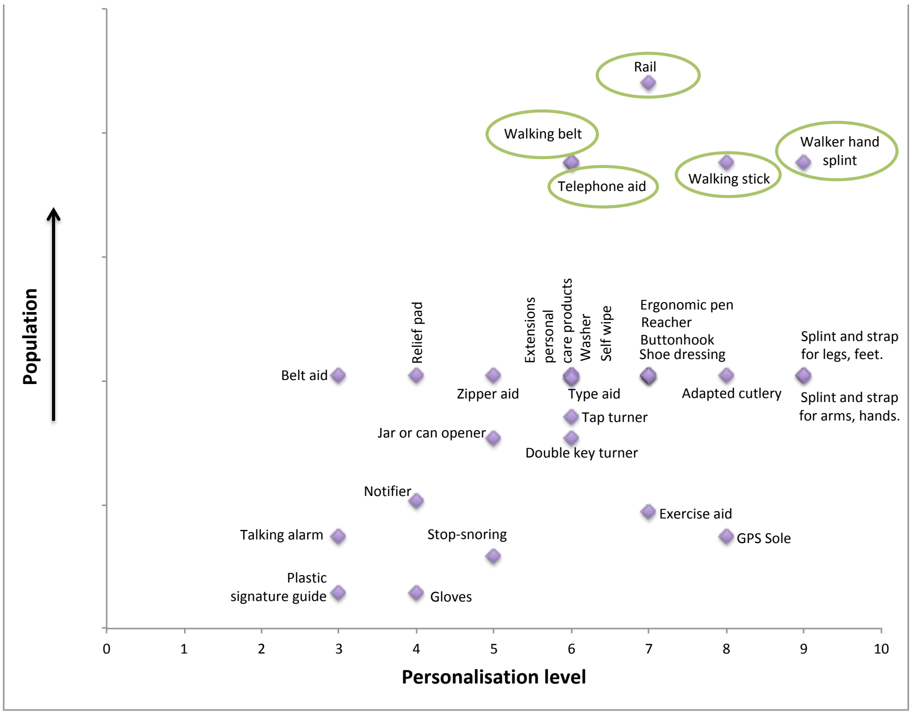

Figure 4.17 - The oval indicates the top five devices comparing their level of personalisation with the people impacted

The top five devices per graph are shown in Table 4.13; from each one, the three highest ranked products (highlighted in table) were selected to go through the next stage. These shortlisted items were chosen considering the ones that had the maximum scores in level of personalisation and activities affected and in level of personalisation and population impacted.

Personalisation vs. activities impacted	Personalisation vs. population impacted
1) Splints and straps for arms	1) Rail
2) Relief pads	2) Walker hand splint
3) Splints and straps for legs	3) Walking stick
4) Walker hand splint	4) Walking belt/Telephone aid
5) Walking stick	

Table 4.13 - 6 shortlisted assistive devices

After this pre-selection, the next step was to choose the final assistive device; the process and details are shown in the following chapter.

5 SELECTION OF FINAL CASE STUDY DEVICE

As discussed in section 3.4.1, user involvement through focus groups is a good way of helping to achieve a successful result; they were used in this study to identify the most suitable device for further investigation.

5.1 Objective

The objective of the focus groups is to obtain relevant data and information about the preselected devices to determine which one has a higher impact amongst the elderly population as well as being the one that could benefit the most from personalisation.

5.2 Participants

Krueger et al. recommend conducting three or four focus group sessions, unless there are limitations in resources such as time, financial resources or too few volunteers. Also, they suggest that for most non-commercial topics the size of each session is between 5 to 8 participants, however, factors such as high complexity of the topic and high participants' level of experience or expertise allows for fewer people to be invited [134]. On the other hand, Kitzinger considers an ideal size of focus group to be between four and eight people [136].

Despite the suggestions about the quantity of sessions, the number of focus groups to conduct depends on data saturation being reached. This concept represents the point where no new data is obtained from the information collected in qualitative tests, therefore, it can be applied to focus groups.

There are not many studies that justify their size samples in focus groups, neither if data saturation was achieved. However, some investigators have explored this field in order to present a deeper analysis based on empirical research. Hennink et al. [175] analysed ten focus groups with the aim of proposing a method that clarifies when data saturation can be reached and what parameters can be considered to determine in advance the number of focus groups to conduct.

Their method consisted of two approaches, 1) code saturation that allows knowing all concepts related to the concerned topic, and 2) meaning saturation that involves the significances, dimensions and nuances of each previous code generated. The code saturation is achieved when no new code is registered and the meaning saturation when no new significances per concept arise.

In the first step, code saturation, the codes are generated from each focus group session and then categorised as inductive, propelled by participants, or deductive, generated from the discussion guide; also, the codes can be divided in concrete which are explicit concepts or conceptual, related to perceptions or feelings; in a final classification, codes can also be low or high prevalence, that represents how many focus groups the code appears in. In that study, all codes were present, on average, in seven focus groups, therefore high-prevalence codes were those that appeared in more than seven sessions and low-prevalence codes in less than seven. During the assessment of the second step, meaning saturation, a selection of codes are traced in each focus group to know any aspect, dimensions or nuances about each one and saturation is reached once there is no new information to add. As a conclusion in this particular study, code saturation was obtained with four focus groups reaching 94% of the appearance of the codes and in the third session 97% of the high-prevalence codes was reached.

Despite their clear results, the authors mentioned that data saturation is not achieved by a definitive number of focus groups, rather, they provided six parameters and each one proposed a range of sessions, the final number of focus groups will be determined by the nature of each study and considering an average of the values given to each parameter; these parameters are 1) study purpose, where the identification of issues will need a small sample to achieve saturation, for example four focus groups, and more groups will be required by studies that need a deeper understanding of these issues; 2) type of codes, if the study is searching concrete codes the sample size will be small, but if conceptual codes are needed the sample will be bigger; 3) group stratification, if the session is not divided into subgroups, three to six sessions will be required, otherwise, more groups will be needed; 4) group per strata, two sessions per strata are recommended; it was demonstrated that conducting more than two sessions per stratum provides little benefit; 5) type of saturation, investigations that prefer code saturation require smaller samples (four focus groups) than those seeking meaning saturation (more than five); and 6) degrees of saturation, studies that seek 80% saturation will require few sessions (two to three), meanwhile studies searching for 90% saturation will conduct between four to five groups. Although saturation is not achieved until the analysis of information is conducted, the resulting figure will help to justify in advance the number of focus groups in a project.

For this investigation, two focus group sessions were planned due to availability of volunteers plus an additional trial session, all comprised of a minimum of four participants. Ethics approval was required from the University of Sheffield for conducting the focus group. This document is shown in Appendix F.

As the objective of the focus groups was to collect information and opinions about the six shortlisted assistive devices, people who have had experience with these types of products were required, therefore, non professional carers of the elderly population and professionals who had investigated or worked with assistive devices were recruited.

Focus group session one was composed of non-professional carers because:

- Bringing together people with this profile garners information about their experience and knowledge acquired whilst for caring for their close relatives, and they could be aware of the users' deep perceptions.
- The participants could know the evolution of an illness in several people and this can result in knowledge of several assistive devices (used for the several stages of the disease) or modifications in the same product.

The second session was composed of professionals who have been involved in the development of assistive devices in order to:

- Obtain technical data and additional facts based on their professional experience in assistive devices.
- Obtaining information about the implications and advices about working with the assistive devices.

Both types of participants may be more likely to be in touch with several elderly people who suffer from different impairments and use different types of devices, therefore, they may know more assistive devices and provide more information than a person who may only know the device that he/she is using. However, users of the selected assistive device aged 65 years old and over were called in a further stage for individual interviews.

5.3 Recruitment

Professionals related to the use of assistive devices were contacted through the Centre for Assistive Technology and Connected Healthcare (CATCH) at the University of Sheffield. For non-professional carers, the volunteer lists for staff and students of the University of Sheffield's database were used. They were also asked to help identify potential elderly participants for the next stage.

All of them received an invitation via email that included overall information about the focus group and a "participant information sheet" with details of the project. These documents are shown in Appendix G and Appendix H respectively. The participants indicated any doubts about the project or their interest in participation by sending an email to the main researcher (Karla Huerta) to kehuertalucio1@sheffield.ac.uk. It was important during the recruitment process that the moderator provided each participant with personalised communication and attention, making clear why their experiences and insights are significant for the investigation. A reminder was sent days before conducting the session to further highlight its importance [134].

5.4 Moderator

In the focus group, the researcher plays the position of moderator and a second researcher could be an observer of the process [176].

The moderator should speak slowly and clearly to the audience, allow the participants time to think and respond, prevent interruptions and introduce each topic to the audience before asking the questions [176]. It is important to encourage negative and positive opinions and not to express personal thoughts about the topics [177], as well as controlling body language in order to avoid the disclosure of a position [134]. Techniques for moderators are useful such as "five second pause" where people are requested to mention additional comments related to previous opinions, or the "probe" that asks participants details or a broader description of their given answer [177].

5.5 Dynamic focus group sessions

The key points of the two sessions were:

1. Welcome and introduction by researcher.
2. Delivery of one copy of the participant information sheet to each participant.

3. Delivery of two copies of the consent form to each participant. One for them to keep and another to sign and return to the researcher. This document is found in Appendix I.
4. Researcher explained the objective of the research, the objectives of the focus group, the profile of the involved participants, dynamic and technical points.
5. Researcher asked the participants two questions related to the challenges and accidents of the elderly population.
6. Researcher showed the six shortlisted assistive devices and participants interacted with each one.
7. Then, participants orally answered two further questions about which assistive device was the most used by the elderly population and what would they change about each device.
8. After this, the moderator provided one form to each participant where they ranked the previous six assistive devices regarding which would have more benefits if it were personalised and why. This complete form is shown in Appendix J.
9. Participants returned the document and then, they answered orally which product they considered could be improved more if it were personalised and why.
10. End of the session. The researcher thanked the participants for attending.

The detailed session can be found in Appendix K.

5.6 Analysing data

Data analysis also includes planning the focus group. The steps are [134]:

1. Defining who will coordinate the analysis. In this case, the researcher will conduct the analysis because he/she has been completely involved in the investigation and he/she knows details such as research purpose, participant selection and elaboration of questions for the focus group.
2. Development of questions thinking on analysis. Planning the questions/dynamic of the focus group in order to obtain the required answers. For example, when the moderator directs a question to the whole group, some participants respond faster than others and they influence them, therefore, when it is required, it may be necessary to change the dynamic and ask people to write down their answers on a form and then share them.
3. Anticipation of discussion. Review and conduct a test focus group to foresee situations.

4. Use strategies for capturing information. The techniques used were memory, field notes, handouts, camcorder and voice recorder.
5. Reflection of the information after finishing the focus group, including review notes and highlights.
6. Collect and organise the material obtained from the session such as rating sheets per group and storing videos and audios on a computer.
7. Full transcript of the sessions, using videos, audios, forms completed by participants and notes made by the moderator. Anonymised transcripts can be found in Appendix L.
8. Coding process. Read the transcript and select a question, then classify the answer with a label, select a second response and if it is similar to the first one assign the same label, if not give it another code; proceed with all answers until finished. After reviewing and coding all the answers, a report will be generated.

Before conducting the sessions, it was important to carry out a test focus group where it was possible to detect unexpected situations in advance and to review how the session worked.

5.7 Test focus group

A preliminary session was conducted following the established dynamic in section 5.5. The most important information is mentioned in the following points:

5.7.1 Objectives

This session had several objectives:

- Be aware of possible behaviour of participants: understanding of questions, interaction with the assistive devices and partners, and completion of documents.
- Estimating times for each part of the session.
- Knowing unforeseen situations and improving them for the following sessions.
- Revision of the layout.
- Revision of the recording equipment functioning and quality of the result.

5.7.2 General information

- The session was conducted on Monday 16th October 2017.
- Time: 10:00 am – 11:00 am

- Venue: 64 Garden Street. Faculty Of Engineering. Meeting Room D16. 1st Floor.
- Refreshments were provided.

5.7.3 Layout and participants

- The number of participants was five. Staff and students from the University of Sheffield were recruited through an email sent to the volunteers list of the same university and an invitation was also sent to the Human Interactions Group from the University of Sheffield.
- Usage of videotape and audio recorder. The set up is shown in Figure 5.1.
- Windows were opened to provide better lighting.
- Food and drinks were placed on a visible table and easy to reach.
- The assistive devices were located on a separate table in order to avoid possible distractions for the participants during the first two questions.

Figure 5.1 - Camcorder located at front, audio recorder placed at the centre of the table and set up of the participants

5.7.4 Moderator

For all the sessions, the main researcher conducted the focus groups. Her place was in the centre and at the end of the table, facing to the camcorder.

5.7.5 Conclusions

This preliminary session focused on:

5.7.5.1 Behaviour of participants

- During the session, people participated with enthusiasm and took their time to complete the given form mentioned in #8 of section 5.5. They also showed interest in the interaction with assistive devices, shown in Figure 5.2, they talked to each other about the products and this enriched the session more.

Figure 5.2 - Interaction of participants with the assistive devices

- One participant, who started to walk using the leg splint, encouraged the others to interact by giving them more confidence. The actual usage of devices was encouraged in the following two sessions of the focus group.

5.7.5.2 Estimated times for each session

This preliminary session helped to measure the times in each question as well as time allowed for the interaction with the devices:

- Participants interacted with the assistive devices longer than expected (approximately fifteen minutes).
- Participants took around ten minutes to complete the last form and they wrote a complete explanation of each question.

5.7.5.3 Unforeseen situations

- This test session allowed the researcher to be more aware of some situations, for example, review that all participants have access to the room, prepare the room at least 40 minutes prior to start the session as some participants may arrive early, check the battery of the camcorder and audio recorder and turn them on before starting the session.
- The test session also helped to establish a checklist of all the elements that should be ready for each session, including forms, participant information sheet, consent forms, pens, assistive devices, 3D printed parts, refreshments, audio recorder, camcorder and tripod.

5.7.5.4 Revision of the layout

- This layout worked in a favourable way because all of the participants were around a table and they were able to see each other and also had a clear view of each assistive device.
- The room had ample space if they wanted to interact with the products and that space also allowed the camcorder to be placed in the correct position to record a wide shot.
- The room had adequate light.

5.7.5.5 Revision of the recording equipment

- The use of a camcorder was so useful because the whole session could be watched again in order to make notes. It also provides a complete and general outlook of how the focus group was managed and it helps to identify comments about particular devices when they were not mentioned in the session, only pointed out.
- Audio recorder was also useful because it was placed in the centre of the table and it could record the sound more clearly than the camcorder; also, when the assistive devices were shown, conversations between participants or even whispers could be captured.

5.7.5.6 Changes in focus group 1 and focus group 2

Almost all the elements of this trial were kept for the next official sessions, the only changes were:

- Time and venue. The official sessions were conducted at a different hour, according to the participants' availability, and using another room within the University of Sheffield that did not require special access.
- The estimated time per each section of the session, trying not to exceed one hour.
- Writing down essential data in a notebook because, although the session was recorded, this is useful and practical in order to identify key concepts.

5.8 Focus group 1

After conducting the test session, focus group 1 was carried out. The procedure was identical to 5.7 with the exception of the changes mentioned in 5.7.5.6. Details of this focus group are mentioned in Appendix M.

5.8.1 Layout and participants

For focus group 1:

- Although four participants agreed to attend, one was unavailable at short notice. The focus group, therefore, proceeded with three members.
- A videotape and audio recorder were used. The videotape was placed in the corner of the room, the audio recorder was located in the centre of the table, the room's curtains were lowered to provide privacy and comfort to the people, and the participants were located randomly in the seats.
- The set up of the focus group is shown in Figure 5.3. Figure 5.4 shows the interaction with the assistive devices.

Figure 5.3 - Camcorder located in a corner, audio recorder placed in the centre of the table

Figure 5.4 - Participants interacting with the assistive devices

5.9 Focus group 2

The procedure for focus group 2 was the same mentioned in 5.7 with the exception of the aspects mentioned in 5.7.5.6. Details of focus group 2 are also mentioned in Appendix M.

5.9.1 Layout and participants

For focus group 2:

- Although five participants agreed to attend, one was unavailable at short notice. The focus group, therefore, proceeded with four members.
- The camcorder was placed in the corner of the room and the audio recorder in the centre of the table. Also, the room had enough natural light.
- A picture of the session is depicted in Figure 5.5 and Figure 5.6 shows the participants interacting with the devices.

Figure 5.5 - Camcorder located in a corner, audio recorder placed in the centre of the table

Figure 5.6 - Interaction with the devices and completing forms

5.10 Results

Participants from the first group talked more about the devices they had been in contact with, while, in the second session, there were more comments on other products and the technical aspects of the assistive devices and their consequences on users. These types of answers are expected due to participants' research backgrounds.

The information obtained from the focus group sessions encompasses perceptions, facts and opinions about:

1. The most challenging activities for the elderly population.
2. Activities or situations where the elderly population are more prone to suffer accidents.
3. Most used shortlisted assistive device by the elderly population.
4. Changes or improvements on shortlisted assistive devices.
5. Which shortlisted assistive device would benefit most from personalisation?

5.10.1 The most challenging activities for the elderly population

5.10.1.1 Data from focus group sessions

From the discussion of both sessions, the results were:

- **Qualitatively**

All the participants in the first focus group (non-professional carers) related the most challenging activities with some assistive devices that support them. Also, two out of three participants stated "actions" rather than activities; the most mentioned was getting up (from a chair, bed or toilet). This answer can be linked to activities such as toileting or moving about the living quarters (both activities include "getting up" as actions). Also, P1 mentioned getting in and out of the bath (bathing) and getting up from the toilet (toileting).

In session #2, P2 suggested relating the most challenging activities and the most commonly provided devices, and one of them: "must be the walking stick", this could be related (mainly) to the activity of moving about the living quarters or moving outside the house. On the other hand, P3 mentioned as the most challenging activities: eating, drinking, bathing, dressing. Also, P3 cited that according to the "Inclusive Design Toolkit" [178] from the University of Cambridge, the biggest problem was in locomotion and getting about.

- **Quantitatively**

The number of citations of the most challenging activities varied per session, the results are shown in Table 5.1:

Session #1 – Non professional carers		
	ACTION	**ACTIVITY**
P 1	Getting in and out of the bath Getting up from the toilet (person should grab a rail at the side of the toilet)	Bathing Toileting
P 2	Getting up from a chair or a sofa	Moving about the living quarters
P 3	Getting up from a chair or a sofa	Moving about the living quarters
Session #2 – Professionals involved in the development of assistive devices		
P1	No answer	
P2	Mentioned walking stick as one of the most provided devices	Moving about the living quarters Moving outside the house
P3	Locomotion, getting about	Eating, drinking, bathing, dressing Moving about the living quarters Moving outside the house
P4	No answer	

Table 5.1 - Answers about the most challenging activities

These results are summarised in Table 5.2:

ACTIVITY	Total mentions
Moving about the living quarters	4
Moving outside the house	2
Bathing	2
Toileting	1
Eating	1
Drinking	1
Dressing	1

Table 5.2 - Number of times mentioned of most challenging activities

- **Analysis**

In general, participants in session #2 better identified what was an activity and also justified their answers, making references to external resources; meanwhile, in session #1, the most challenging activities were identified based on participants' experience, making reference, in all the cases, to their relatives. The most challenging activity was identified as "*moving about the living quarters*".

From the six preselected assistive devices, problems of locomotion or getting around could be solved or supported with splints for legs, walker hand splints or walking sticks; therefore, at this point, these three products are among the top ones for the investigation.

5.10.1.2 External resources

In the second session, the "Inclusive Design Toolkit" [178] from the University of Cambridge was mentioned because they have investigated the loss of capabilities in people, mentioned locomotion and getting about as challenging activities. The Inclusive Design Toolkit establishes that the understanding of the user capabilities and their impact in the products and services is relevant to developing inclusive design products. They mentioned that the user capabilities could be separated into five main categories for product interaction: vision, hearing, thinking, reach and dexterity and mobility. From these five categories, mobility represents the capability most lost among adults aged 16 years and over, this includes, moving around, climbing steps and balance. The comparison of people with a capability loss among these five categories is shown in Figure 5.7 obtained from the website of Inclusive Design Toolkit:

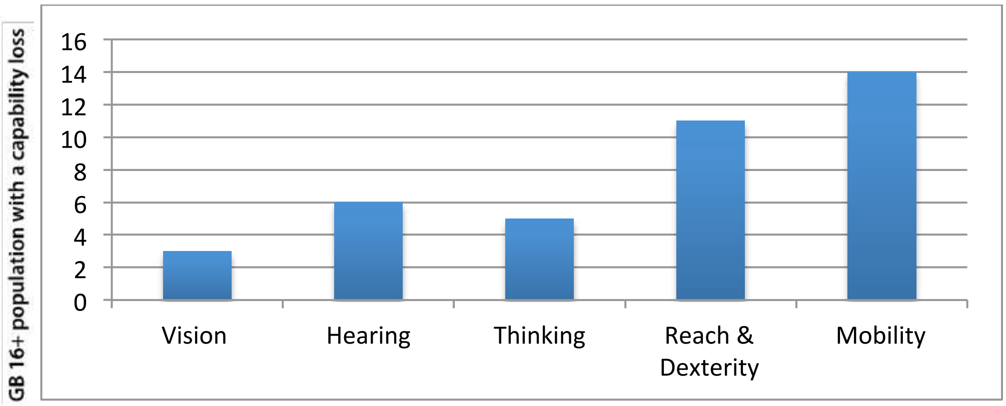

Figure 5.7 - % of people aged 16 years and over with a capability loss [178]

It was calculated based on 43.3 million adults in Great Britain who live in private homes in 1997 [179]

There are other resources that support mobility as one of the most impacted activities. The Department for Work & Pensions, issues its document "Family Resources Survey 2016/17" [180] where it collects information from a sample of people (19,000 households) living in private accommodation in the UK regarding income, housing tenure, caring needs, disabilities, education, childcare, among others. In this document, it is established that 22% of people suffer from a disability (2016/17), that represents 13.9 million people in the UK. The percentage of people is represented in Figure 5.8, having the highest value "state pension age adults".

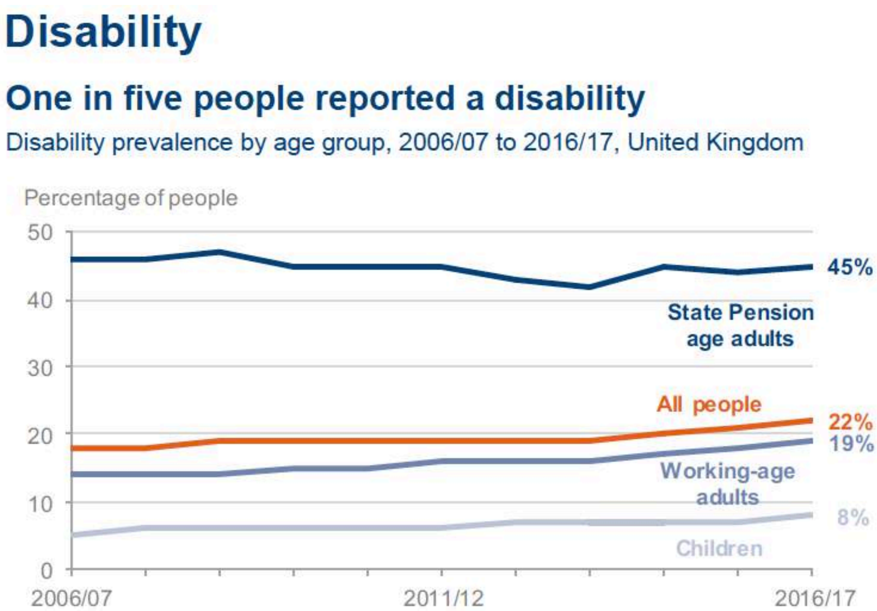

Figure 5.8 - Comparison of groups of people who suffer from a disability [180]

This document establishes that mobility is the disability with the highest percentage of cases among the people interviewed in the UK, reporting at 51% in 2016/17. Figure 5.9 contains the information of several disabilities including mobility.

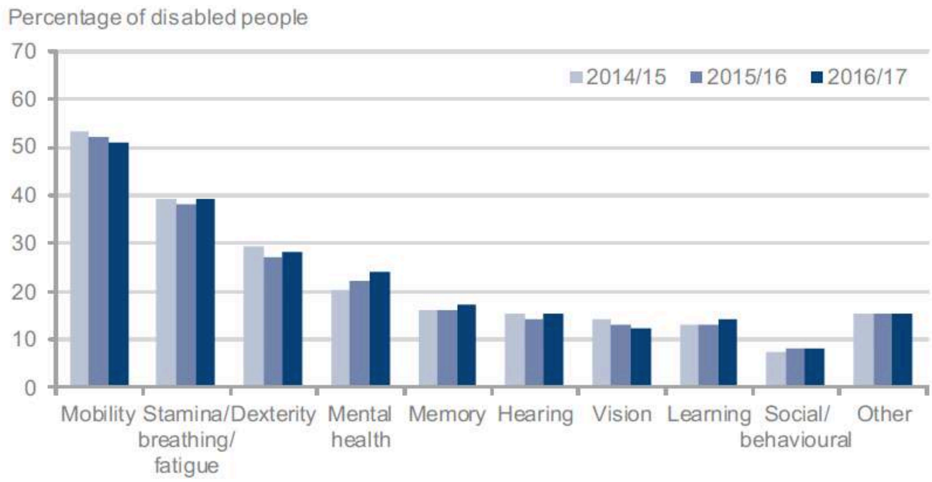

Figure 5.9 - Percentage of disabled people from 2014 to 2017 [180]

Also, if each disability is divided into three age groups (working-age adults, state pension age adults and children), the "state pension age adults" group has a major percentage of disability in mobility, as shown in Figure 5.10.

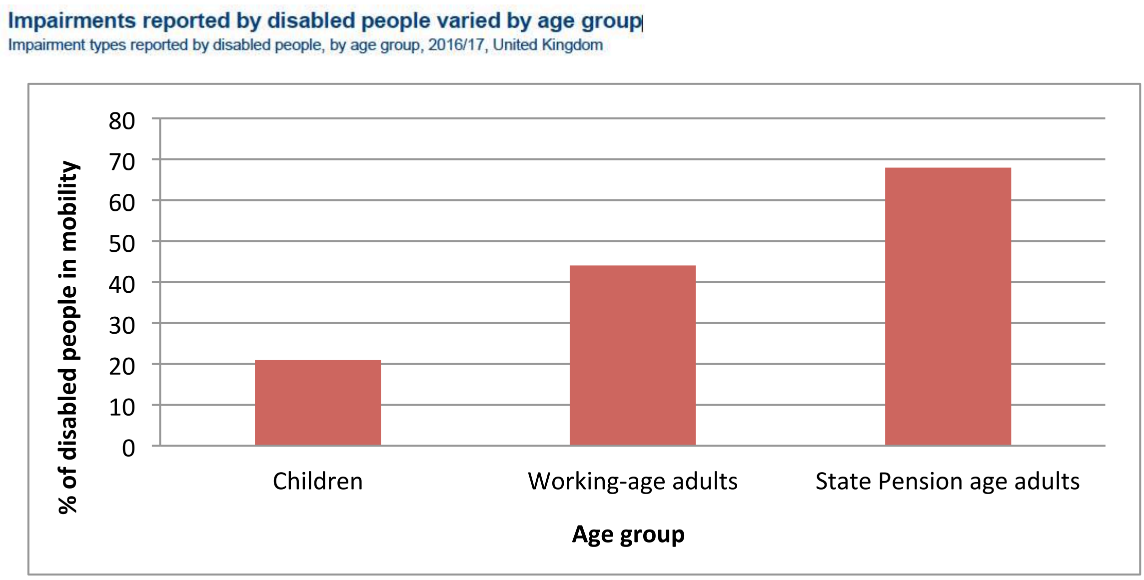

Figure 5.10 - % of disabled people in mobility per age group: Children (21%), Working-age adults (44%) and state pension age adults (68%)

Mobility has the highest % of cases among others diseases. The total is more than 100% since one person could state more than one disease. 2016/17. UK [180]

5.10.2 Activities or situations where the elderly population are more prone to suffering accidents

5.10.2.1 Data from focus group sessions

About the situations/activities that can cause accidents in the elderly population, the data obtained was:

- **Qualitatively**

The answers for the situations and/or activities more involved in the elderly's accidents were, from the first session, slipping, and, as a result of this question, another participant mentioned problems with putting the feet up because people who cannot go out due to an impairment usually spend a lot of time in their house and do not lift their feet when walking as much as they did it.

P3 mentioned slipping as well, and falling, but this is as a consequence of visual impairments, dizziness, and also because some people are not used to performing activities such as dancing, jumping, (usually) they are only around the house.

These actions, slipping, not putting the feet up and falling are associated with moving around the living quarters and moving outside the house; "exercising" could be discarded because of the impairments, the elderly people may prefer only walking.

Also, two other participants commented: dropping things as a consequence of gripping problems, non-movable limbs or not bending the fingers properly, due to arthritis for example.

In the second session, there were answers such as falling. There is a study from the University of Birmingham stating people are more prone to fall if they do not look where they are going. In fact, another study was mentioned by a participant, citing the list of reasons why people prefer moving from their home to care homes and falls was the number one.

Also during the focus group, bathing was mentioned, problems in feeding, memory failure because it affects how older people carry out their activities, sensory impairments (sight and hearing) could affect falls.

- **Quantitatively**

The situations/activities that could cause accidents in the elderly population are presented in Table 5.3:

	ACTION	ACTIVITY
Session #1 – Non-professional carers		
P1	Not putting the feet up Dropping things	Moving about the living quarters Moving outside the house Drinking/Eating
P2	Slipping Dropping things	Moving about the living quarters Moving outside the house Drinking /Eating
P3	Slipping Falling	Moving about the living quarters Moving outside the house
Session #2 – Professionals involved in the development of assistive devices		
P1	Memory failure Sensory impairments (sight and hearing) affect ability in balance and walking	The activity was not specified Moving about the living quarters Moving outside the house
P2	Memory failure	The activity was not specified
P3	Falling Locomotion	Moving about the living quarters Moving outside the house Eating (nutrition) Bathing Dressing
P4	Falling	Moving about the living quarters Moving outside the house

Table 5.3 - Activities related to accidents in the elderly population

Table 5.4 summarises these results:

ACTIVITY	Total mentions
Moving about the living quarters	5
Moving outside the house	5
Drinking/Eating	2
Eating (Nutrition)	1
Bathing	1
Dressing	1

Table 5.4 - Number of times mentioned activities related to accidents in the elderly population

- **Analysis**

An activity itself implicates many actions, and in this topic (situations or activities that involve accidents), the incident is caused by specific actions instead of an activity, for example, in session #2 it was mentioned that a fall, which can be found under "walking", could be caused by many factors such as: problems with legs, not putting the feet up, dizziness, sensory impairments such as hearing and vision, this is why the conversation was more focused on situations than activities, in the end, the most mentioned activity was "moving".

5.10.2.2 External resources

About the situations or activities that can cause accidents among elderly people falls were mentioned, this information can be supported by the Policy Studies Institute (PSI), a research centre at the University of Westminster; it is focused on environmental and sustainability matters, and in its book "Elderly People: Choice, Participation and Satisfaction" [181] mentioned reasons why people move into residential care; the top five were: fall/fracture, acute illness, deterioration in their health and their ability to look after themselves, pressure of their carer and loneliness.

The data was collected reviewing 103 residents, interviewing an elderly person, an informal carer and a head of the residential home, and in most of the situations the answers coincided, having the highest percentages (26%) falls/fractures and the deterioration in physical/mental health. These percentages are shown in Table 5.5.

	%
Fall/fracture	26
Deterioration in physical/mental health	26
Pressure on informal carer	20
Acute illness	14
Loneliness	14
Base: all elderly people in residential care	((103))

Table 5.5 - Reasons for moving into residential care [181]

5.10.3 Most used shortlisted assistive device by the elderly population

5.10.3.1 Data from focus group sessions

From the six shortlisted assistive devices, each participant considered which was the most used by the elderly population; results are shown in Table 5.6.

Session #1 – Non-professional carers	
	MOST USED ASSISTIVE DEVICE
P1	Walking stick
P2	Walking stick and grab rail
P3	Walking stick
Session #2 – Professionals involved in the development of assistive devices	
P1	Walking stick
P2	Walking stick
P3	Walking stick
P4	Not answered

Table 5.6 - Most used assistive device from focus group sessions

Most of the participants agreed that the walking stick was the most used device; although P4 did not answer, this participant did not show disagreement when the rest of the group mentioned their answer.

5.10.3.2 External resources

The opinions about the most used assistive device can be supported by the University of Wales, which, in 1998, published a paper related to the ownership and use of assistive devices among the elderly population [182]; in this study, 1405 participants aged 65 years and over were asked about which assistive devices they used and the walking stick was the second most mentioned (24%), only behind the non-slip bath mat (50%). The complete list of devices is shown in Table 5.7.

	No. (and %) of subjects, by age	
Device	**<75 years**	**>75 years**
Walking stick	192 (24%)	227 (39%)
Two sticks	21 (3%)	20 (3%)
Walking frame	13 (2%)	38 (6%)
Wheelchair	16 (2%)	34 (6%)
Crutches	6 (<1%)	6 (<1%)
Lavatory rail	73 (9%)	100 (17%)
Raised lavatory seat	26 (3%)	47 (8%)
Commode	49 (6%)	85 (15%)
Bathroom rail	141 (18%)	191 (32%)
Non-slip bath mat	424 (53%)	342 (57%)
Bath seat	45 (6%)	81 (14%)
Bath board	61 (8%)	98 (17%)
Stair rail	106 (13%)	99 (17%)
Bed hoist	4 (<1%)	7 (1%)

Table 5.7 - Possession (%) of assistive devices by age [182]

5.10.4 Suggested changes or improvements on shortlisted assistive devices

The modifications suggested by the participants were aesthetics and functional.

5.10.4.1 Grab rail

The changes mentioned by the first group for the grab rail were the lack of variety in colours, having rougher textures that allow a better and more confident grip and the preference in utilising other materials such as metal instead of plastic because there could be a better psychological perception of support and a better perception of hygiene. The second group also highlighted that the grab rail should come in a broad range of colours and textures and also have a change in its surface that allows things to be placed on it. Besides this, the four participants of the second session agreed about the idea of adapting the grab rail as an inherent part of the bathroom that represents another element in the space, this with the purpose of it blending in with the environment as a natural accessory. This is important because some people are reluctant to use it as they have a negative perception about it.

5.10.4.2 Relief wrap

The observations regarding the relief wrap were, in the first group, concern about the durability of the Velcro and in the second group it was mentioned that this device had a non-intuitive design and this could weaken a joint during usage; also, as all of the presented assistive devices were bought without a medical prescription, their use should be only temporary.

5.10.4.3 Splint for wrist

The durability of the Velcro was also pointed out in the splint for wrist by the first group, this is because the splint had several strips that were made to ensure its position in the hand and they should provide confidence; on the other hand, the second group indicated the repetitive colours in a range of beige and brown for splints or for assistive devices in general; besides this, they pointed out the low quality of the item and the risks on its design as some of its parts could cut users, other areas could pressure them or the splint could be too tight and cause problems in people with bad circulation.

5.10.4.4 Splint for leg

For the splint for leg (robust version), both groups agreed that it was difficult to walk with it; also, the splint lacks texture at the bottom and there is not enough friction in case the user wants to take some steps which could be unsafe. In the case of the light version of this splint, a participant mentioned that the sole seemed to be too wide to put it inside of a shoe, and if the foot came out of place in the splint, the foot could be damaged by the risen edges of the sole.

5.10.4.5 Walker hand splint

In the case of the walker hand splint, both groups mentioned that there could be a problem if, during its use, the person wants to conduct an additional action with their hands, this creates a dangerous situation because the user has their hands attached to the device. The second group also indicated that people with cognitive problems could find it difficult to put on as it has a non-intuitive design and there are several strips to secure. They also stated the difficulty for the user if they do not have the proper muscle to grab the walker when walking; there is another issue regarding closing or adapting the curve of the splint to the walker since the part that should be adapted is made of stiff metal. There could also be circulation problems if people fasten the tabs too tight and danger if users fasten the tabs too loose.

5.10.4.6 Walking stick

For walking sticks, participants of the first session mentioned the wear issue on tips in the Ergonomic and Fischer models; the second group noticed problems on both grips and difficulty in the use of the mechanism for changing the height. Their suggestions were portability but having stability, variety in textures, stand by themselves and the ability to change the handle over time as the user's physical condition changes.

The comments of session 1 are shown in Table 5.8, and Table 5.9 includes the answers from session 2.

	Session #1		
Device	**P1**	**P2**	**P3**
Rail	How it is fixed on to the wall. Variety of colours. Made of metal due to psychological perception of support.	A rougher surface.	Variety of colours. Made of metal for hygienic purposes.
Relief wrap	Durability of Velcro.	The relief wrap could come close to the hair and some hairs could stick to it.	Not answered.
Splint for wrist	Durability of Velcro.	Durability of Velcro.	Not answered.

Splint for leg. Robust model	Seems difficult to walk.	It does not seem comfortable for walking.	Lack of corrugation on the bottom creates friction and walk.
Splint for leg. Light model	Not answered.	Seems wider for putting it inside a shoe. Foot may be moved and damaged by the edges of the splint.	Not answered.
Walker hand splint	Not answered.	The hands are not free if user wants to do an additional action with hands.	Not answered.
Walking stick. Ergonomic	Not answered.	Durability of the tip.	Durability of the tip.
Walking stick. Fischer	Not answered.	Durability of the tip.	Durability of the tip.

Table 5.8 - Suggested changes or improvements on shortlisted assistive devices. Session 1

Device	P1	P2	P3	P4
Rail	Coordinate it with the bathroom. Adapt a grab rail in a house that could be hidden if it is not required by the dwellers.	Make it a standard fitting in bathrooms.	More colours, textures, ability to place things on it. Make it part of somebody's life story. Coordinate it with the bathroom as another element of the line.	Coordinate it with the bathroom, otherwise it stands out. If it were created as a part of the bathroom, the user would want to have it and use it.
Relief wrap	It should only be for temporary	Due to its non-intuitive design it	It has a non-intuitive design.	It should only be for temporary use

	use as it is non-prescribed.	could weaken a joint during use.		because it is non-prescribed.
Splint for wrist	Top edges could cut users, other parts put pressure on them. It could be too tight for people with bad circulation.	Not answered.	So risky to put it on. Low quality item. Horrid colour (beige and brown tones) is consistent in assistive devices.	So risky to put it on. No variety in colours (only beige tones).
Splint for leg. Robust model	Not useful for walking, only for being static and maybe for standing up.	Not useful for walking, only for being static and maybe for standing up.	Not answered.	Not answered.
Splint for leg. Light model	Not answered.	Not answered.	Not answered.	Not answered.
Walker hand splint	Difficulty for people with cognitive problems to use. Users should attach the splint to the walker and then fasten the hand. Circulation problems if people do the tabs too tight. Unsafe if they do them too loose.	It is hard to close the curve of the splint to the walker, would it be necessary to mention the diameter of the walker to the splint fabricator in order to have the same dimension.	Did not agree with the splint design.	The person could not have the proper muscle to grab it. It is not useful if you want to grab other things.

Walking stick. Ergonomic	The grip, obtain the needed walking stick height. Portable but steady enough.	Height. Ability to change the handle over time as user's condition changes. Rehabilitate through it.	The grip. Difficulty to change height. Different textures.	It cannot stand by itself and falls down, and it is difficult for the user to lift it up.
Walking stick. Fischer	The grip, obtain the needed walking stick height. Portable but steady enough.	Height. Ability to change the handle over time as user's condition changes. Rehabilitate through it.	The grip. Difficulty to change height. Different textures.	It cannot stand by itself and falls down, and it is difficult for the user to lift it up.

Table 5.9 - Suggested changes or improvements on shortlisted assistive devices. Session 2

5.10.5 Which shortlisted assistive device would benefited most from personalisation?

Table 5.10 shows how the participants ranked the six shortlisted assistive devices about which of them would benefit the most from personalisation, 1 being the most benefit and 6 the least. Therefore, the lowest score would indicate the greatest potential benefit of personalisation.

	Session #1			Session #2				
Device	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**	**P4**	**Total**
Rail	2	2	2	2	5	2	2	17
Relief wrap	4	5	5	Not sure	4	3	3	24
Splint for wrist	3	4	6	Not sure	2	3	3	21
Splint for leg	6	6	4	Not sure	1	3	3	23
Walker hand splint	5	3	3	6	6	3	3	29
Walking stick	1	1	1	1	3	1	1	9

Table 5.10 - Results. Shortlisted assistive device that would benefit most from personalisation

According to the results, the lower sum was obtained by the walking stick which means the highest score, it was ranked in first place by 6 participants; then, in second place was the rail, followed by the splint for wrist, the splint for leg, the relief pad and in the last place, the walker hand splint. The walking stick is an assistive device related to one of the most challenging activities for elderly mentioned before, which is walking.

5.11 Conclusion

After collecting the information and perceptions from the participants of the focus groups, the outcomes were:

- The most challenging activity by the elderly population was identified as “moving about the living quarters” with four mentions, followed by “moving outside the house” and “bathing” mentioned twice, and in third place, “toileting”, “eating”, “drinking” and “dressing” mentioned once. From the six shortlisted devices, the top activity could be supported with splint for legs, walking hand splints and walking sticks.
- The activities where the elderly population are more prone to suffer accidents were indicated as “moving about the living quarters” and “moving outside the house” in first place with five mentions, in second place “drinking” and “eating” with two mentions and in third place “eating” (nutrition), “bathing” and

"dressing". Also, splint for legs, walking hand splints and walking sticks are used to improve or support these activities.

- Six out of seven participants voted for the walking stick as the most used device used by the elderly population. In second place was the grab rail with only one mention.
- The most voted assistive device that would have more benefits (advantages such as better fit, better performance, achieving a more intuitive design) if it were personalised was the walking stick. The three participants of the first focus group selected it because of its frequency of use indoors and outdoors and three out of four participants from the second session voted for it because of its potential for avoiding serious injuries and its usage by many people for a long time.

The most voted challenging activities and where most accidents could occur are related with three assistive devices: the splint for legs, walker hand splint and walking stick; besides this, the walking stick was considered as the most used and the one that would benefited the most from personalisation. Based on a collation of all the information discussed in the previous sections, the walking stick was a consistently highly rated device, and was therefore chosen as the case study device for the remainder of this work.

6 PREPARATION FOR USER TRIALS

Having selected walking sticks as the most appropriate case study device, the next steps were to begin the user-involvement stage of the process.

The full testing process involved three individual sessions with participants, as shown in Figure 6.1. The purpose and structure of each session will be discussed at the appropriate point in this thesis, but a brief summary is included here.

Session 1: User testing of a variety of different samples, to identify specific user preferences.

Session 2: Capturing user geometries in order to personalise examples of the user's preferred example from Session 1.

Session 3: Present the user with personalised and non-personalised options to analyse and obtain their preferences.

In advance of Session 1, the following activities were required:

- Consider which specific part of the walking stick is most appropriate for investigation.
- Define and specify which aspects of this part will be investigated in the first stage of user involvement.
- Manufacture of samples.

These activities will be discussed in this chapter.

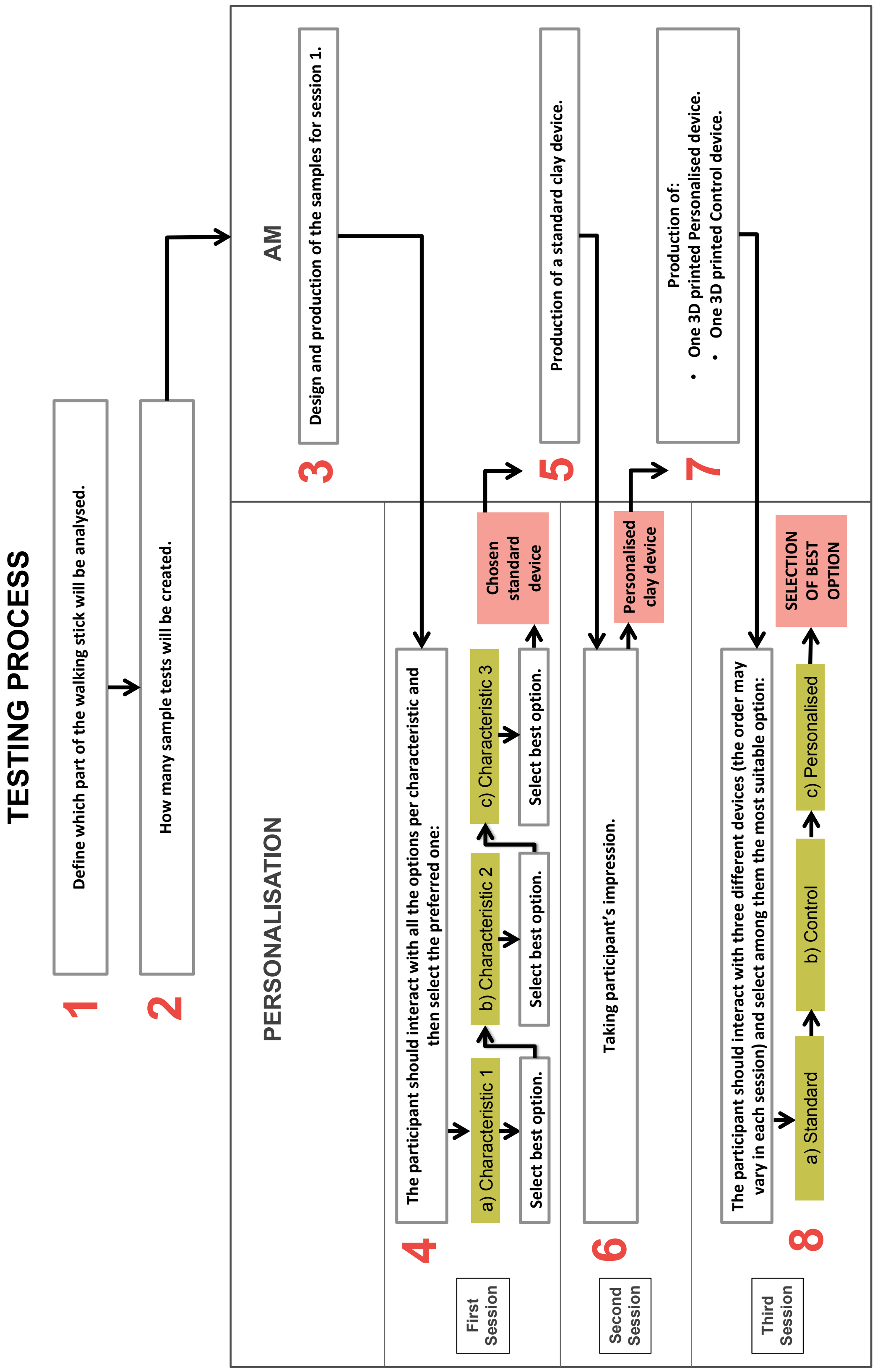

Figure 6.1 - Diagram of testing process

6.1 Analysis of walking stick components

The main parts of a walking stick are shaft, handle and support; these three components and their different types will be analysed in the following sections.

6.1.1 Shaft

The shaft is the element of the walking stick that joins the handle and the support and its fixing is key to provide the user stability and confidence to use it. In its simplest shape this is a single, fixed and non-adjustable height piece but over time it has had variations such as adjustable versions, foldable and more particular models such as walking stick with seats, which are shown in Table 6.1.

Non-adjustable	Adjustable	Folding sticks	Walking sticks with a seat
This type of stick has a set height that cannot be modified.	These are canes that can have their height adjusted for different users or the same patient who requires changes over time.	Lightweight, with a fixed and an adjustable height.	These are used for people who need to rest due to their condition. They should be light because they are used by elderly people who sometimes do not have enough strength to manage them; also, its folding and unfolding should be easy and intuitive to do.
			

Table 6.1 - Different types of shafts.

Images: Non-adjustable from [183], adjustable [184], folding sticks [185] and walking stick with a seat [186]

All of these options have been created considering the different positions or situations where a user needs a walking stick, combining postures such as standing up, walking [187] or seated, even providing flexibility inside the same posture, for example, regarding walking or standing up, the user could have different heights over a short period of time due to changes in their physical condition, therefore, he/she would need a walking stick that provides comfort in height at any stage. Another situation is in traveling and transportation, in this case, a foldable walking stick has been developed in order to facilitate the user's commute.

6.1.2 Handle

The handle is the part in direct contact with the user and allows the manipulation of the walking stick; its physical features should coincide to the user's requirements. Existing variations are shown in Table 6.2.

<table>
<tr><th>"Rounded and simple"
Crook style [188]</th><th colspan="3">"Straight"
Crutch, Derby [188] and Offset [189] styles</th></tr>
<tr><td>It has a slight continuous curve that improves balance and decreases fatigue [190]; however, its support area can be less comfortable and thinner in comparison to anatomical models. When it is not used it is possible to hold it over the arm due to its shape.</td><td colspan="3">These models consist of a right angle handle that directly supports the weight of the user. The Derby style has a slight hook that can be used to holding it over the arm. The offset model helps people with wrist problems and with a weak grip since the body's weight and pressure is distributed over the shaft giving balance and support [189].</td></tr>
<tr><td>
Crook</td><td>
Crutch</td><td>
Derby</td><td>
Offset</td></tr>
<tr><th colspan="4">"Anatomical"
Fischer, Relax, Ergonomic and Escort styles [188].</th></tr>
<tr><td colspan="4">The pressure of these orthopaedic models is extended over a wider area of the user's palm and it provides support and more comfort on painful hands. The Fischer handle was created by the Austrian Dr Fischer and it may help people who suffered from arthritis and rheumatism [188]; the Ergonomic also helps people with the previous conditions but it was designed for smaller hands [188]; in the Relax model, the thumb and the index finger lay over the handle and the rest of the hand is held over it, this helps with the support and decreases the</td></tr>
</table>

<table>
<tr><td colspan="2">stress on the hand [191]; meanwhile the Escort model provides a firm grip and has an ending in the handle that prevents the hand from slipping [188].
   
Fischer Ergonomic Relax Escort</td></tr>
<tr><th>“Spherical”
Knobstick and Pistol grip styles [188].</th><th>“Spherical”
Staff and Thumbstick [188].</th></tr>
<tr><td>These models have a rounded and spherical handle, they look like one single piece but the palm of the pistol grip is more horizontal.
 
Knobstick Pistol grip</td><td>Both have a vertical shape. The staff is usually used for hiking and it may have a wrist strap. The thumbstick has a “V” shape in its upper part and the thumb is placed there, the rest of the fingers surround the stick.
 
Staff Thumbstick</td></tr>
<tr><th colspan="2">“Decorative”
Cap stick and Character styles [188].</th></tr>
<tr><td colspan="2">Both handles have a different characteristic from the previous models as they follow a particular shape; the cap stick is usually used for decoration and the character type utilises shapes of animals and birds as a grip.
 
Cap stick Character</td></tr>
</table>

Table 6.2 - Different types of handles.

Handle images [188], except offset handle image [189]

6.1.3 Support

The support (or base) is a relevant part of a walking stick because it can help the user to avoid or trigger a fall; since it has direct contact with the walking surface its material and components should not have adherence problems on regular, irregular and slippery surfaces. Variations of supports are shown in Table 6.3:

Simple support	Tripod	Three base support	Four base support	Five support system base
The simple support has a regular rubber tip that could provide restrictions to the user, this occurs because the shaft should be held vertically against the floor, but users tend to create an outer angle during their walking and when the tip is in contact with the floor there is an angle and this may cause slippery problems [192].	The tripod has more points of contact with the floor than the simple support; it allows more stability, balance and applying more pressure on the device [187].	This type of support provides better stability to the user than a conventional single base. Also, having a three base support allows the walking stick to stand up on its own [193].	With four support points, this base has a larger contact area than a regular single tip; also, it is non-slippery and provides additional stability on different surfaces. Because of the arrangement of its base, the walking stick can stand up on its own [194].	It provides more stability during locomotion, it has a central support plus four additional; all of them are used when the cane is 90° in comparison to the floor (vertical position) and when the user is walking, the angle of the stick related to the floor changes using the central support plus the other two [187].
				

Table 6.3 - Different types of walking sticks supports. Images from [187]

6.1.4 Part to be redesigned

As mentioned previously, the three main parts of the walking stick are the shaft, the handle and the support. Each of them has its own particular function; the shaft should offer stability and resting and at the same time it is convenient, its adaptation to the user through achieving different height options, this may allow advantages such as a correct posture, support and a better perception of the user related to safety. The second component, the handle, allows the manipulation of the walking stick where an anatomical version results in a suitable option because its surface tends to imitate the shape of the user's hand and also because its grip has a wider surface than other models, this allows the body's weight to be spread over the entire hand rather than being concentrated on only some areas. The third part, the support, permits an adequate base and adhesion to the ground that results in a higher level of stability.

From these three parts, the component to be focused on will be the handle because it has more possibilities of being personalised as every user has a different hand, and this discrepancy increases when a person suffers from a condition that leads to a physical change. The other elements such as shaft and support are less sensible to be personalised. The shaft already has variations that aim to satisfy the user's height and the support can be chosen regarding the type of ground and activity that will be performed by the user but this type of adaptation does not need to meet the shape of the body, therefore, the part that will most benefit from being personalised to a user's limb is the handle.

After selecting the handle as the component that will be focused on, it is necessary to define which of its characteristics will be chosen to produce variations, this is explained in the following section.

6.2 Factors to vary

After reviewing the information obtained in Chapter 2 and 3, shape, size and texture were defined as common aspects of products which can be personalised beyond a simple aesthetic change. These were the main aspects chosen to include in these trials.

6.2.1 Shape

During the manipulation of the handle, the user's hand tends to adapt to the surface and a better grip is achieved if there is an adequate match between both.

This match is obtained through the most favourable shape for the user; therefore, offering variations in shape increases the possibility of finding the most suitable version.

As shown in Table 6.2, most of the handles follow organic shapes, beside this, the adaptation of the handle to the user or adding extra features to achieve a better grip could result in a more organic look in the handle, which is feasible to be produced through AM because of the characteristics of its parts mentioned previously.

Shape should be very intuitive and it should help to know how the device is put on and how it is used, otherwise, its usage could be limited for people with or without cognitive problems. There were some comments in the focus group sessions about the difficulty of putting on some devices for hands and these led to thinking about ergonomics and the ease of interaction with the new handle. An intuitive walking stick handle would involve:

How to start to use the device. It is necessary to be clear about how the handle can be gripped. For this reason, the handle should be ergonomic, in this way its form will imitate the shape of the hand and would be easy to identify how the hand is placed.

How to use the product. A walking stick is a well-known device by many people, therefore, it is expected to be easy to use; however, in this investigation, the intention is to create a special handle for one participant, therefore, that unique shape should be very well understood by them. It is intended to demonstrate if this characteristic could be achieved through indications in the shape such as marks or indentations that show the users how grab it while they are walking. An intuitive characteristic in a handle is important because it can help the user to obtain an intrinsic “feedback” from the product while they are using it, and this will allow them to know if it is being used correctly, increasing their confidence.

6.2.2 Size

Besides the shape, size is also an important factor because although the user is gripping the most suitable shape for their hand, not having the right size makes it difficult to achieve a correct adaptation.

Loughborough University conducted an evaluation with ten participants about their opinions of 3D printed personalised product designs considering the "product value" and the "experimental value" [195]; both are components of the value that is perceived when a product is designed by an end-user. "Product value" is related to the experiences provided by the use of the product and "experimental value" with the interaction process between the user and product when it is personalised.

Within the "experimental value" participants were asked about which design attributes they considered in a product personalisation process and "changing sizes" was answered by four participants; also, they mentioned what co-design activities had conducted during the product personalisation process and "alter shapes, sizes and forms" obtained the first place with ten mentions.

This study shows that modification in size and shapes in personalised products are relevant for end-users.

Nowadays, size modification in virtual designs is possible through CAD software where scale commands permit parts to be increased or decreased proportionally in three axes or only in one axis. These CAD programmes are compatible with AM.

On the other hand, size and shape are factors that influence grip [196], which is a property that wants to be improved for a better manipulation of the handle. Also, it is important to mention that the coefficient of friction that optimises the grip increases with the area of contact [196].

6.2.3 Texture

The incorporation of texture in a walking stick is important for two reasons; the handle manipulates the walking stick, therefore, it is necessary to have a secure attachment between the user and the product; the second reason is because AM has the capability of printing personalised features in small scales, therefore, the production of texture in parts is feasible without an expensive financial investment.

Besides the physical effects of texture such as its influence in friction and traction, the incorporation of textures as tactile elements gives the user a psychological experience related to products; for example, manufacturers of beers or soft drinks produce matt surfaces in their containers and this could lead to men having a more rough or masculine perception of these drinks [197]. Another example is skin care brands that could present their products in a soft-touch packaging and this can cause a better perception to the user about its properties of caring for and improving the skin's softness [197]. This effect is also important in terms of this study because it can increase the sense of safety in the user when he/she holds the handle.

An investigation conducted at the University of Twente proved that surface texture could change perceptions about products [197]. It utilised AM to produce two different containers of ice cream, one with a smooth surface and the other one with sharp texture, both shown in Figure 6.2. The results indicated that the texture influences the taste, enhancing sweetness for the smooth container and enhancing intensity of the flavour in the sharp cup.

Figure 6.2 - Cup with sharp texture surface (left) and smooth texture surface (right) [197]

Texture is also involved in achieving a better grip, changing materials or texture can improve friction and, as a consequence, obtaining a better grip [196]. During the gripping of objects, normal force is used, but it is affected by the increment of age. That is to say, in elderly people, this has as the result that they should apply a higher normal force than younger people (excluding children); this is due to the properties in their skin and the development stage of their brain and receptors, that implies a change in friction of their fingers, a decrement in the ability to detect the properties of friction on a surface of contact (due to the reduction of the hydration of skin) and a deterioration of the receptors of their fingers [196].

It was found that texture could modify people's perception of a product. Also, to achieve a better grip it is necessary to improve the coefficient of friction of the surface, even more so in products used for the elderly population, considering materials, texture and a wider area of contact. Having a good grip is key to avoiding falls that may be frequent as explained in a previous chapter, and can help elderly people who may have decreased grip strength due to the loss of muscular mass and loss of skin sensitivity and hydration.

After defining the three factors that could have an impact on user preferences, the next step is to create variations of each one, in this way, several versions of shapes of handles, sizes and textures will be 3D printed for session 1. This has the intention of offering a range of options to the participant and, therefore, creates a more suitable match. The different versions of shapes, sizes and textures are shown in the following section.

6.3 Test samples variations

6.3.1 Shape

The previous section 6.1.2 shows several types of handle shapes available on the market, from these options were chosen models that include representative characteristics from others. It was also considered within the scope of this investigation, that it should be a functional shape that could be used to provide support to the elderly population.

As a result, five types were selected: “Crook”, “Crutch”, “Pistol”, “Fischer” and “Ergonomic”.

“Crook” style is different from other types because it has a thin and continuous curve. The “Crutch” model includes characteristics from the Derby and the Offset models. The third option is “Pistol” that is very similar to the knobstick, but it was selected because its contact area is flatter than the knobstick and this could exert less pressure on the user’s palm. From the anatomical group, “Fischer” and “Ergonomic” models were chosen because the first one was the most different type among the Ergonomic, Relax and Escort as the ending area of the palm is wider and points out upwards; the ”Ergonomic” model was selected because its curves are more pronounced than the Relax and Escort and this can help to better situate the palm over it. The Relax model resembles the “Crook” and the Escort to the “Crutch” handle.

The rest of the handles in section 6.1.2, “Staff”, “Thumbstick”, “Cap” and “Character” were discarded from this test as their surface is less suitable for leaning on.

Figure 6.3 shows the designs of the five shapes. Dimensioned drawings of each model can be found in Appendix N.

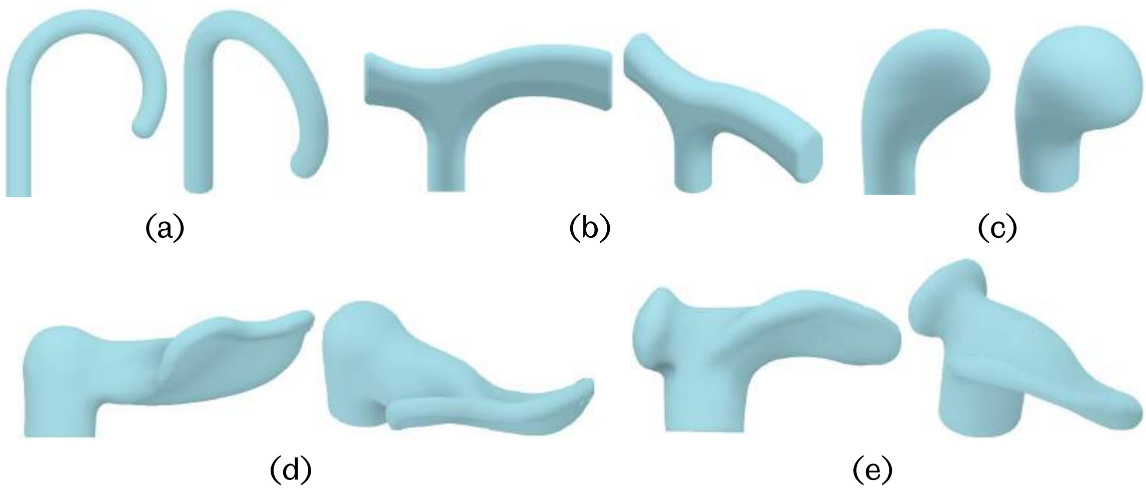

Figure 6.3 - Top. Crook (a). Crutch (b). Pistol grip (c). Fischer (d). Ergonomic (e)

6.3.2 Size

During the test, each participant will interact with different sizes of each of the established shapes. As mentioned previously, according to a study conducted by Lewis and Narayan [96], where standard tools were compared to personalised versions, three different sizes were needed to satisfy all the participants, this is useful as it demonstrated a reasonable number of samples to present in a test. Based on this, a common standard size will be used per model and this will be modified to obtain a smaller and a bigger version.

For the design of the smaller and bigger sizes, it is necessary to establish which are the anthropometric dimensions that are involved during the interaction of the handle and identify the ranges of measurements.

The parts of the body that interact with a walking stick handle are: palm, fingers and wrist, therefore, the anthropometric dimensions required for the design are those related to these areas.

Also, it is important to know how the hand is positioned over the handle in the different models to confirm that the correct dimensions have been considered. These are shown in the following Table 6.4.

Type of walking stick	Sizes available in market	Position of the hand
 Crook	Variations in dimensions were found but there was no classification in sizes for the crook cane.	 [198]
 Crutch	Variations in dimensions were found but there was no classification in sizes for the crutch cane.	 [199]
 Pistol grip	Variations in dimensions were found but there was no classification in sizes for the pistol grip cane.	 [200]
 Fischer	Smaller and larger sizes were not found, only a standard type.	 [201]
 Ergonomic	Smaller and larger sizes were not found, only a standard type.	 [202]

Table 6.4 - Sizes available in market and positions of the hand for handles

After reviewing the position of the hands over the handle and considering the information in the “Older Adultdata” handbook [203], the anthropometric dimensions that will be used are the hand breadth (#100) illustrated in Figure 6.4.

Figure 6.4 - Hand breadth dimension (identified as #100 in Older Adultdata handbook) [203]

Also, the finger grip diameter dimension (#105), shown in Figure 6.5 will be considered as a reference of the upper limit in which a person can hold a handle.

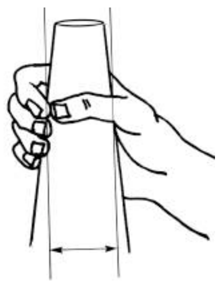

Figure 6.5 - Finger grip diameter dimension (identified as #105 in Older Adultdata handbook) [203]

The range of values for the #100 "hand breadth" dimension was obtained from "Older Adultdata" handbook; the range of values for the dimension #105 "finger grip diameter" was calculated considering the data from "Older Adultdata" handbook. This information can be found in Table 6.5.

Adultdata			OLDER Adultdata					
Dimensions	Country	Anthropometric dimensions	Dimensions	Country	Age	Anthropometric dimensions	Estimated data in the UK for Older adults	
		Female 5th%ile – Male 95th%ile				Female 5th%ile – Male 95th%ile		
HAND BREADTH	UK	70.5 – 95.1	HAND BREADTH	**UK**	**65-80**	**65 – 90 mm**	**Minimum** value of 70.5 mm (in ADULTDATA) decreases to **65.0** Factor = 0.9219 **Maximum** value of 95.1 mm (in ADULTDATA) decreases to **90.0** Factor = 0.9463	HAND
							Now, having the factors for the minimum and maximum value, I calculated:	
FINGER GRIP DIAMETER	UK	32.1 – 45.8 ø	FINGER GRIP DIAMETER	**UK**	**65-80**	**29.6 – 43.34 mm ø**	**Minimum** value of 32.1 mm (in ADULTDATA) * Factor 0.9219 = decreases to **29.6** **Maximum** value of 45.8 mm (in ADULTDATA) * Factor = 0.9463 = decreases to **43.34**	GRIP
		DATA OBTAINED FROM THE HANDBOOK				DATA OBTAINED FROM THE HANDBOOK	**CALCULATIONS**	

Table 6.5 - Values calculated for "finger grip diameter" in the older population (identified as #105 in Older Adultdata handbook) [203]

Per each type of handle, the anthropometric dimensions that were considered are shown in the third column of Table 6.6. The original information is provided in groups of female and male population, each one has a range that encompasses the dimensions from 5th %ile until 95th %ile, in order to include all the population possible the range of values is considered from female 5th %ile to male 95th %ile.

Walking stick	Identification # in the "Older Adultdata" handbook	Anthropometric dimensions mm. UK. Female 5th %ile – Male 95th %ile
 Crook	# 100 (hand breadth) # 105 (finger diameter)	65 – 90 29.6 – 43.34 ø
 Crutch	# 100 (hand breadth)	65 – 90
 Pistol grip	# 100 (hand breadth)	65 – 90
 Fischer	# 100 (hand breadth) # 105 (finger diameter)	65 – 90 29.6 – 43.34 ø
 Ergonomic	# 100 (hand breadth) # 105 (finger diameter)	65 – 90 29.6 – 43.34 ø

Table 6.6 - Anthropometric dimensions considered for scaling the handles

The regular size was obtained from current average models available on the market, therefore, there were no modifications in dimensions for these versions; for the smaller size of the crook handle the minimum length of 65 mm of dimension #100 was considered and for the larger handles the size was 90 mm, after this, the same conversion factor was used to scale the other four models. Dimension #105 was only used as a reference as it is bigger than the diameter needed for grabbing the handles.

6.3.3 Texture

The textures were selected in order to create a range from smoother to rougher; in this way, the participant can interact with one of each type during the session.

Six types of textures were developed: raw, that was the original finish of the material; smooth, which was the sanded part; medium, a combination of a smooth and rough texture; circles, with little half balls; bump, with bigger half spheres and closer among them, and cracked texture, with little fissures. Figure 6.6 illustrates the created digital textures. The fifth image, a plain texture, was used to produce the raw and the smooth versions.

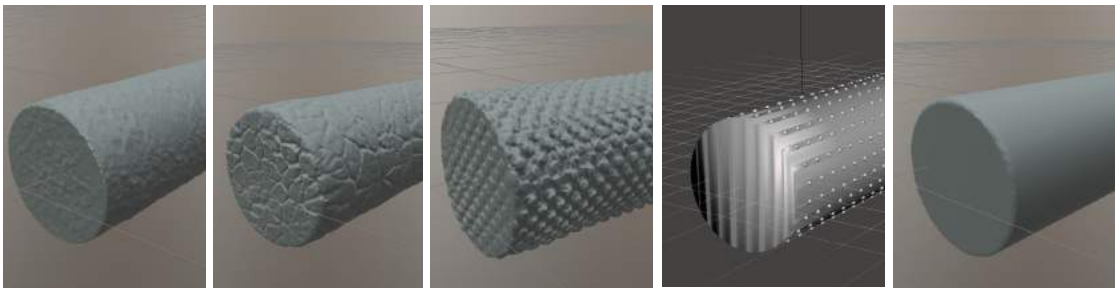

Figure 6.6 - Medium, cracked, bump, circles and a plain digital part used for raw and smooth textures

6.3.4 Shaft for supporting the handle

In order to allow users to interact fully with the walking stick handles, they must be connected to a shaft before testing; therefore, it was necessary to obtain an independent stick. For this reason, a commercial Fischer walking stick was purchased and its handle was removed, in this way, its adjustable shaft was ready to use with the 3D printed handles. The commercial Fischer walking stick shown in Figure 6.7 was acquired:

Figure 6.7 - Commercial Fischer walking stick

6.4 Design and manufacture of samples

The variations of shapes, sizes and textures were already shown in section 6.3. Most of them were designed using 3D CAD software, their design and manufacture will be detailed in the following sections.

6.4.1 Shapes and sizes

The first step was to create the different shapes of handles; there were two different routes for it; some models such as the crook, the crutch and the pistol grip were developed from scratch using Autodesk Inventor 3D CAD software, meanwhile, the Fischer and the ergonomic models were bought, scanned and enhanced in Meshmixer software where their surface was smoothed but without loosing its features.

After the creation of the 3D CAD models it was necessary to add them to a virtual stem, which was going to be used as a connector with the real walking stick in the sessions. In the case of the models that were created virtually from the beginning, this stem was added at the end of its modelling, but the Fischer and the ergonomic versions were opened in Fusion 360, converted into a surface, exported as .iges format and opened in Autodesk Inventor in order to add the stem.

After creating these base models, all of them were modified in Autodesk Inventor in order to obtain a smaller and larger size, then the texture was ready to be applied.

6.4.2 Texture

There were four textures created digitally: “medium”, “circles”, “bump” and “cracked”. For the “circles” texture Meshmixer software was used and for medium, bump and cracked, 3DCoat software. The raw and the smooth textures were obtained after their production via AM; the raw was the natural finish of the part and the smooth type was achieved after it was sanded.

After applying the digital texture the parts were ready to be 3D printed utilising laser sintering technology.

6.4.3 Laser sintering technology

Laser sintering was used in this research because its produced parts have a high quality and high resolution with a competitive price and it can produce parts throughout the entire build volume without the need for any sacrificial support structures.

As it was explained in section 6.3, the production of parts for the first session included: five standard handles in regular size produced in six different textures = 30 handles; the same type of handle printed in different textures allows the participant to interact at the end of the session with their preferred combined choice. Additionally to this quantity, five standard handles in small size and five in large size were printed as well as six cylinders in each texture. The six textures were printed in a single cylinder and shown to the participant before the handle with the applied texture in order to avoid influencing their perception. In total, 46 parts were used in the first sessions for all the participants.

All the parts in this investigation were printed in batches around of eight handles using the EOS Formiga P100 laser sintering machine that is located in the Advanced Polymer Sintering Laboratory at The University of Sheffield. Figure 6.8 shows the equipment and its inner build chamber.

Figure 6.8 - EOS Formiga P100 laser sintering machine and the inner build chamber

After their production (around 28 hours per this batch) and cooling (28 hours), the parts were removed and cleaned with compressed air using the Euroblast machine from Guyson. Equipment and parts are shown in Figure 6.9.

Figure 6.9 - From left to right, parts extracted, Euroblast machine and its inner chamber

Figure 6.10 shows different shapes of handles, sizes and the final application of textures.

Figure 6.10 - Five types of standard handles (crutch, crook, pistol grip, Fischer and ergonomic) in three different sizes and six cylinders with several textures

Following this production, these parts were used for the testing described in the following sections.

7 INFLUENCE OF PERSONALISATION ON USER PERCEPTION

7.1 Overall approach

In order to establish whether there was any perceived benefit to the use of a personalised handle, three different sessions were conducted. These had two overall objectives:

1. Identify each participant's preferred size, shape and texture.
2. Identify whether personalisation of their preferred choice influences the user's perception of the handle.

In order to achieve these two objectives, each session was focused on different outcomes:

a) Session #1: In this session the participants chose and discussed their preferred option among several alternatives of shapes, sizes and textures.
b) Session #2: This session involved obtaining a physical impression of the participant's hand grip, which was later converted by scanning and laser sintering into a personalised handle. During this session a benchmark 'personalised' handle was created from the researcher's hand grip. This was to identify whether any perceived differences were due to personalisation or simply a change to the overall geometry.
c) Session #3: Interaction and evaluation with the personalised, control and standard handle.

7.1.1 Participants and number of sessions

Prior to these tests, a second approval was obtained from the Ethics Committee of the University of Sheffield, this letter is shown in Appendix O.

The tests were conducted with the aim of finding the preferences and perceptions of users in relation to several options and characteristics of walking stick handles. Because of their purpose, they are considered as perception studies and qualitative research.

To determine the number of subjects in perception studies, several publications were searched [103] [197] [204] [205] [206] [207] [208] [209] [210] and their sample sizes varied from 3 to 176 subjects. It is relevant to mention that none of these papers provided an explanation of their proposed figures. This issue is also pointed out in “Sample size for qualitative research” [211], where it is established that qualitative researchers do not usually justify sample sizes in their research.

According to the document "Qualitative Research Part II: Participants, Analysis, and Quality Assurance" [212], in qualitative tests, the sample sizes are not always predetermined, that is, the number of participants will depend on the number of users or answers that can provide all the information required in the study. The sample size will be enough when interviews, tests or focus groups do not provide any new information, this point is called data saturation. This concept is also mentioned in “The Royal College of Surgeons in Ireland Sample size handbook” [213].

Despite the existence of the data saturation concept, according to a revision by Greg et al. [214], there have been many journals that have used this criterion but did not provide a description of how the saturation level was determined and they did not mention guidelines for calculating sample sizes for interviews. Furthermore, Greg et al. conducted another revision in social and behavioural science literature reviewing 24 research methods books and seven databases without obtaining clear results about how to obtain the data saturation. Therefore, Greg et al. documented with a study when data saturation could be achieved. In their investigation, 60 in-depth interviews were conducted with African women. The results indicated that basic elements arose in the first six interviews and data saturation was achieved within the first twelve interviews.

However, other researchers suggested different figures; J. M. Morse [215] mentioned that semi-structured interviews that provide little information per interview question would need a large number of subjects, minimum 30, maximum 60; for phenomenological studies, and when a person is interviewed many times, the quantity suggested could be six to ten subjects, and for grounded theory when it is necessary to conduct two or three unstructured interviews per participant, the range suggested is from 20 to 30 subjects. These values can vary depending on research factors such as the scope of the study, the nature of the topic, the quality of data, the study design and the use of shadowed data, which is people talking about the experiences of others.

The existing information does not suggest an exact number of participants in qualitative studies, therefore, it is necessary to consider the characteristics of the current investigation to propose a number. This study will attempt to obtain information from participants through in-depth structured interviews and every subject will be interviewed twice; with these features of the study and according to the previous suggestions, the minimum number of subjects for the interviews will be six with a maximum of 12. This range was selected because it has been demonstrated that with six participants it is possible to reach basic elements of the information and with 12 data saturation could occur [214]. Moreover, Morse suggested the range of six to ten participants in phenomenological studies with many interviews. The range from 20 to 30 was not selected because the study is not a grounded theory, which is the type of study where the first step is data collection rather than researching and developing a hypothesis [216].

Considering the previous recommendations, nine participants were recruited using similar methods to the previous focus groups, and each of them attended all three sessions, the recruitment email can be found in Appendix P. These sessions took place either at the CATCH (Centre for Assistive Technology and Connected Healthcare) Home Lab of The University of Sheffield, or at the participant's home or other convenient place.

The participants were people aged 65 years and over who used a walking stick due to any physical condition or illness, but who did not have a severe mobility problem.

Conducting the sessions at the Home Lab was appropriate for the study because this is a space that simulates a real home environment where volunteers can test different technologies. It allows the researcher to explore deeper into a user's situation, collaborate together in the design process in order to create a solution. The Home Lab has several areas such as living room, kitchen and bedroom, with a suitable space that allows different activities to be conducted using a variety of available technologies such as "Pepper Robot", "MiRo Robot", "Tobii Pro 2 eye tracking glasses", a camera observer system, among others. Figure 7.1 shows the Home Lab layout.

Figure 7.1 - CATCH Home Lab. The University of Sheffield [217]

7.1.2 Technical details

1. Date and hour.

These were set in accordance with the availability of each participant.

2. Duration of each session.

Between 30 – 45 minutes.

3. Additional equipment.

For each session with one participant, notes, an audio recorder and a camcorder were used in order to record details.

4. Identification.

Each member was identified in the investigation as Participant #1, Participant #2, etc.

7.2 Conducting session 1

7.2.1 Layout

Figure 7.2 shows which are the required elements for the session, such as 3D printed parts, furniture in the room, recording equipment, refreshments, paperwork, material for printing hand shapes and how they were located:

Figure 7.2 - Session #1 conducted at the CATCH Home Lab, University of Sheffield

7.2.2 Dynamic

In session #1, the preferences of a standard design were tested. The essential points of this session were:

1. Welcome and introduction by researcher.
2. Delivery of one copy of the participant information sheet to the participant. Document found in Appendix Q.
3. Delivery of 2 copies of the consent form to the participant. One for the participant to keep and another to sign and return to the researcher. This document is shown in Appendix R.

4. Researcher explained the objective of the research, the objectives of the first session, the profile of the involved participants and technical points of the session.
5. Participants answered an oral questionnaire in order to identify their opinion about desirable characteristics in a walking stick and the best aspects and performance of their current device. This document is found in Appendix S.
6. Researcher showed five different shapes of walking sticks and the participant interacted with each one, made comments and chose the most liked.
7. Then, the chosen shape was shown in three different sizes and the participant interacted with each one, made comments and selected the most liked.
8. After this, the researcher showed six different textures applied on cylinders and the participant interacted with them, made comments and chose the most liked.
9. Researcher showed the shape with the texture chosen connected to a commercial stick and the participant interacted one more time to assure their selection.
10. Researcher thanked the participant and gave a reminder about the second follow-up meeting where the handprint will be obtained.

The details of the dynamic of session #1 can be found in Appendix T and transcripts in Appendix U.

7.2.3 Results of session #1

Participants in session #1 demonstrated a variety of thoughts and perceptions related to what they expected and preferred in a walking stick. P1 highlighted the stability of their current walking stick but also, the discomfort of its handle, therefore, P1 wished for a handle that better distributed the pressure over the palm with a smooth, polished or padded finish; among all the options their selection was a medium ergonomic handle with smooth texture. P2 mentioned that their current handle did not add pressure points over the hand and arm but sometimes their hand slipped; they preferred a handle made to fit with an anti-slip surface rather than standard and at the end of the session they found the medium Fischer handle with a cracked texture more suitable. P3 got tired of holding their handle at the end of the day so they wished for a better fit for their hand, injured due to arthritis; their preferred and most comfortable handle was a medium ergonomic style with medium texture. P4 mentioned that they had proper control over their current walking stick handle but despite this, they found its surface too smooth; therefore, they were looking for some special features in a handle such as separations for the fingers in order to obtain a firmer grip. After interacting with all the options, P4 chose a medium Fischer handle with medium texture. P5 found that their current walking stick could support their weight while leaning on it also, the participant could hold it over their arm and carry on; however, the handle did not provide the right grip so that was a desirable characteristic. After comparing all the options, they found the medium Fischer handle with cracked texture to be the best combination of features in a handle. The current handle of P6 was the best aspect of their walking stick as it has a wider surface than other models as the crook style, however, they had an inclination for rougher texture, this was shown in their final selection which was a medium Fischer handle with a bumpy texture. P7 stated no issues with their current walking pole handle, as they preferred a handle that keeps a straight position in their wrists; also, a firm material for a handle was mentioned as desirable; after comparing all the options, a medium Fischer handle with smoother texture was chosen. P8 highlighted good aspects in their current wooden handle as it was better than others made from metal and it was handy; however, their crook handle was not flexible and did not fit properly, therefore, a better grip was preferred with a little flexibility to provide comfort, and not with a totally smooth finish because it can cause a slip; at the end of the session, a medium Fischer style with cracked texture was selected. P9 found their current Fischer handle to be the best option among other models available on the market, however, it caused their fingers to ache after walking long distances, therefore, a material that better distributes the pressure points was desirable. Also, they showed a preference for rougher surfaces rather than smooth, so, in the end, their selection was a medium Fischer model with a bumpy texture.

Results and comments from participants related to session #1 can be found in Appendix V.

As a summary, the preferences of the nine participants regarding type, texture and size are shown in detail in Table 7.1.

Participant (P)	Date	Type	Texture	Size
P #1	Friday, 22nd February	Ergonomic	Smooth	Regular/Medium
P #2	Wednesday, 27th February	Fischer	Cracked	Regular/Medium
P #3	Tuesday, 5th March	Ergonomic	Medium	Regular/Medium
P #4	Wednesday, 6th March	Fischer	Medium	Regular/Medium
P #5	Friday, 8th March	Fischer	Cracked	Regular/Medium
P #6	Monday, 11th March	Fischer	Bump	Regular/Medium
P #7	Wednesday, 13th March	Fischer	Smooth	Regular/Medium
P #8	Friday, 15th March	Fischer	Cracked	Regular/Medium
P #9	Tuesday, 20th March	Fischer	Bump	Regular/Medium

Table 7.1 - Preferences in type, texture and size of the handles

These results inform which handles will be printed for session #3 per each participant. Table 7.2 displayed these options:

	SMOOTHER						MEDIUM						CRACKED						BUMP					
	Ergonomic			Fischer			Ergonomic			Fischer			Ergonomic			Fischer			Ergonomic			Fischer		
	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised	Standard	Control	Personalised
P #1		1	2																					
P #2																	3	4						
P #3								5	6															
P #4											7	8												
P #5																	3	9						
P #6																							10	11
P #7					12	13																		
P #8																	3	14						
P #9																							10	15

Already produced.

Table 7.2 - Handles printed per participant

After this, the next step is to conduct session #2.

7.3 Conducting session #2

Taking each participant's preferred shape and size from session #1, session #2 was aimed towards the production of a personalised version of this option. The complete production of this handle involves two different phases: the hand printing process and 3D printing production; each phase has several steps. These are shown in Figure 7.3:

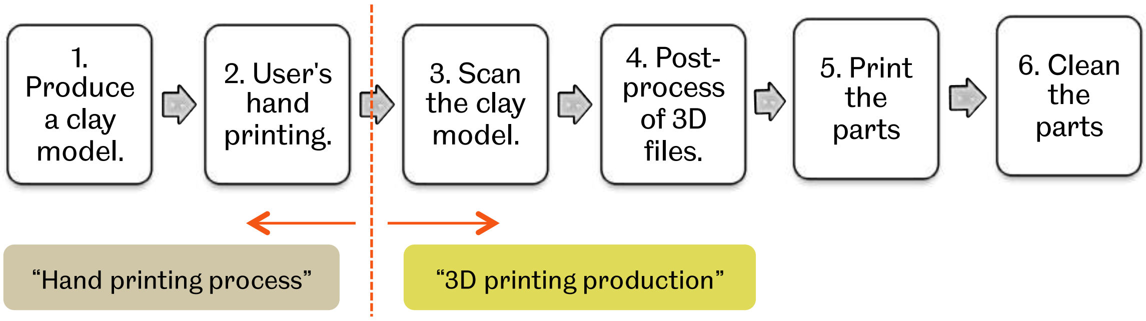

Figure 7.3 - Phases and steps of production of personalised 3D printed handles

Before conducting session #2, it is necessary to accomplish step #1 of the hand printing process, which is the production of a clay model.

7.3.1 Step #1. Production of a clay model

In session #2, participants should be able to print their hand while they are gripping a handle, for this reason, it is necessary to produce a handle in a malleable material.

The creation of the clay model implies the fabrication of a) a silicone rubber mould which takes a 3D printed handle as a positive model to create the cavities, and b) the production of a handle in clay, which is obtained after pouring a pre-heated clay. Both processes are shown in Figure 7.4:

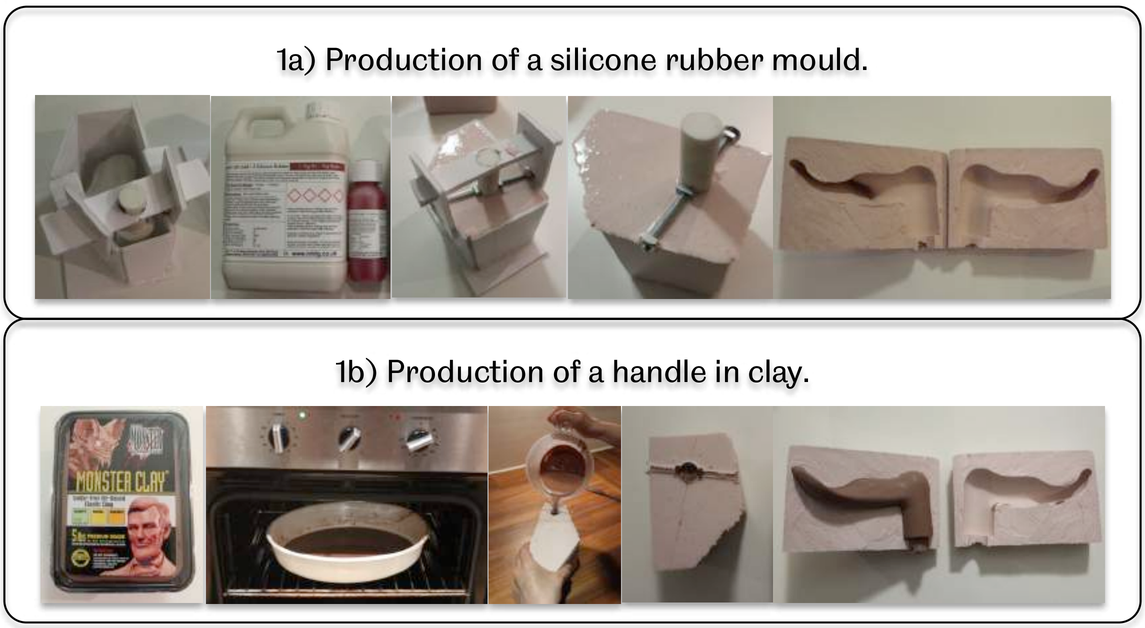

Figure 7.4 - Step 1. Production of a clay model

After producing the clay handle, session #2 was ready to be conducted and with it, step #2: user's hand printing. Full details of this step can be found in Appendix W.

7.3.2 Step #2. User's hand printing

As described in Appendix W, during session #2, the pre-formed clay model was connected to the commercial walking stick, after this, it was warmed up in water until it was slightly flexible. Later, each participant was told to, if possible, stand up (all of them could do it) and grip the handle as strongly as they could in the position of usage, until they felt their hand grip had been printed. After this, each participant determined whether the final clay handle had achieved a suitable shape for them, if not, polymer clay was added in specific areas where participants indicated there was material missing, this with the aim of achieving a better match between the handle and their hand, thus improving the grip. User's handprint is illustrated in Figure 7.5:

Figure 7.5 - Step 2. User's handprint

Besides the participant's personalised handle, a benchmark handle was created following the same process but using the researcher's hand grip. This was to allow differentiation between a preference for inclusion of a 'grip' feature and a preference for inclusion of a personalised grip feature.

7.3.3 Steps #3 to #6. 3D printing production of the handle

After the creation of the personalised clay handle, steps #3 to #6 of the production of personalised 3D printed handles were executed; they are highlighted in green in Figure 7.6.

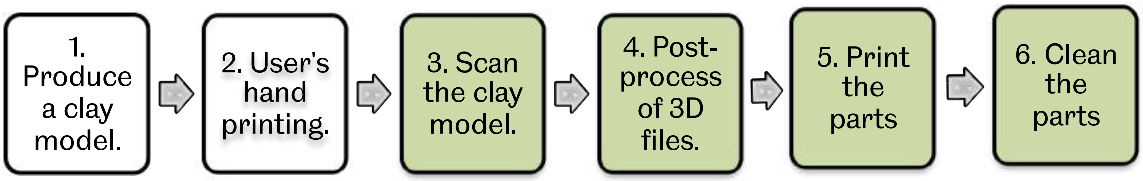

Figure 7.6 - Steps #3-#6. Production of personalised 3D printed handles

These handles were also produced using the EOS Formiga P100 laser sintering machine. Details of the six steps can be found in Appendix W.

As a result, nine personalised handles and six control (benchmark) handles based on the researcher's hand grip were built. The quantity of control handles is six because some of them were used in more than one session; the Fisher model with cracked texture was used in three sessions, the Fischer with bumpy texture in two sessions, and in each of the other four sessions, a different control handle was used. These numbers are shown in the previous Table 7.2.

The creation of the personalised 3D printed handles allowed to conduct the round of sessions #3.

7.4 Conducting session #3

7.4.1 Layout

The layout was similar to the one used in session #1 but only three different handles were shown to each participant. Figure 7.7 shows the layout of the CATCH Home Lab:

Figure 7.7 - Session #3 conducted at the CATCH Home Lab, University of Sheffield

7.4.2 Dynamic

In session #3, the participants discussed their perceptions of the 'standard', benchmark and personalised versions of the option they selected during session #1.

The key activities of this session were:

1. Welcome by researcher.
2. Researcher explained the objective of this session and technical points.
3. Researcher showed three different handles attached to the same stick and the participant interacted with each of them (in a pre-established, randomised, order).
4. After the interaction with the three handles, the researcher asked about the participant's preferences, reasons, assigned scores to each model, likes and dislikes.
5. Researcher asked about rating factors that could influence the selection of handles.
6. Researcher asked about assigning a score to each factor per handle.
7. Ranking of the participant's current walking stick and comparison with the other three 3D printed handles.
8. Researcher thanked the participant for attending the three sessions.

The detailed description of the dynamic of session #3 can be found in Appendix X and its transcript in Appendix Y.

7.4.3 Results of session #3

Session #3 was planned to show every participant three different 3D printed handles (standard, control and personalised) and to determine, based on their opinion and perceptions, which was their preferred model. Their preferences are shown in Table 7.3.

P	Type of handle	Texture	First place	Second place	Third place
1	Ergonomic	Smoother	Personalised	Standard	Control
2	Fischer	Cracked	Standard	Personalised	Control
3	Ergonomic	Medium	Standard	Control	Personalised
4	Fischer	Medium	Standard	Personalised	Control
5	Fischer	Cracked	Standard	Control	Personalised
6	Fischer	Bump	Standard	Control	Personalised
7	Fischer	Smoother	Standard	Personalised	Control
8	Fischer	Cracked	Personalised	Control	Standard
9	Fischer	Bump	Personalised	Control	Standard

Table 7.3 - Preferences about the 3D printed handles per participant

From the nine sessions, six participants selected the standard handle as their preferred option and the other three subjects chose their personalised handle. In none of the cases was the control handle selected as first option but it reached second place five different times.

In total, there were four different orders of ranking: “personalised handle (in first place), standard and then control”; “standard (first place), personalised and control”; “standard, control and personalised” and “personalised, control and standard”.

7.5 Individual results

7.5.1 Participant #1

Participant #1 selected the ergonomic handle in the medium size with smoother texture from session #1.

Currently, P1 uses a non-adjustable wooden crook handle, which was provided by the NHS. This walking stick is shown in Figure 7.8:

Figure 7.8 - Current walking stick of P1

They mentioned that their hand became painful after a short time using the current handle but they found that it was more comfortable when they use a glove. In session #1, they had stated their preference for padded, polished or smooth surfaces in handles and pressure more evenly distributed on a handle but allowing a firm grip.

7.5.1.1 Preferred handle from session #3

P1 was presented with the handles in this order: standard, control and personalised and the personalised one was chosen as their favourite.

Their reasons for choosing this model were:

1) Good palm rest.
2) Ability to locate the index finger specifically, meaning they could grip the handle firmly.

They selected the personalised model as soon as they interacted with it.

7.5.1.2 Scores and ranking

The participant assigned 90 to the personalised model, 10 to the control type and 60 to the standard handle. Table 7.4 shows the ranking and scores provided:

	1st place	2nd place	3rd place
	Personalised	Standard	Control
Score	90	60	10

Table 7.4 - Scores and rankings of the three 3D printed handles. P1

When testing the control handle the participant instantly disliked it because it was not so easy to grip.

7.5.1.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The participant identified the personalised handle as the most comfortable for the hand because, despite its palm did not cover as well, it had a most adequate shape around the knob that was useful for wrapping their finger around.

The participant felt the palm on the standard handle was slightly better than on the personalised one, but around the knob was not smooth and this did not allow them to place the index finger comfortably.

The participant mentioned that the surface of the control handle was not bad; the situation was that if they placed their hand according to the shape, they could not put the index finger around the knob comfortably.

1.2 By size

The standard model had a bigger surface than the personalised and it covered the participant's whole palm, this is because the personalised handle was squeezed during printing and it became smaller. Despite this, the personalised type had other advantages, mentioned previously, that were more important for the user.

2. Ease of maintaining grip during use

Among the three options, the participant could grip the personalised model better.

The control type could not be held properly.

3. Enough support for the hand and fingers

The palm of the personalised model was firm for resting on; however, the standard model also had a very firm palm and the participant liked it more but the personalised type provided a better comfort for the hand.

If the participant gripped the knob of the control handle, they did not obtain the proper support on the palm for the hand.

7.5.1.4 Importance of factors

The participant considered that most of the factors mentioned were very relevant; six out of eight aspects were scored with 10, only “intuitive shape” obtained 9 and “appealing to the user” was the lowest one with 2.

After assigning the values of the factors per model, it can be seen that the personalised handle obtained the best values, while the control type the lowest ones with a range from 1 to 3, therefore, these numbers coincided with the general ranking. The values are shown in Table 7.5:

	Participant importance rating	**FIRST OPTION** Standard	**SECOND OPTION** Control	**THIRD OPTION** Personalised
1. Comfort on hand	10	6	1	9
2. Comfort on wrist	10	7	2	9
3. Intuitive shape	9	7	3	10
4. Ease of maintaining grip	10	7	2	10
5. Support on hand/fingers	10	7	3	10

6. Stability in static posture	10	7	2	10
7. Stability in movement	10	7	2	10
8. Appealing to the user	2	7	2	9

Table 7.5 - Importance of each factor and the score per handle. P1

In every category, the personalised handle was scored higher than the standard option, which was again scored higher than the control type.

In order to form an overall assessment, the handles have been evaluated by combining the importance with rating as shown in Table 7.6:

	FIRST OPTION Standard	**SECOND OPTION** Control	**THIRD OPTION** Personalised
1. Comfort on hand	60	10	90
2. Comfort on wrist	70	20	90
3. Intuitive shape. How do you grip it?	63	27	90
4. Ease of maintaining grip while it is used	70	20	100
5. Enough support for the hand and fingers	70	30	100
6. Stability of the user in static posture	70	20	100
7. Stability of the user during movement	70	20	100
8. Appealing to the user	14	4	18

Table 7.6 - Overall assessment of factors. P1

After obtaining the total overall, it can be seen that the participant had a very clear preference in every aspect for the personalised handle; inclusively, this tendency was demonstrated with values of 100 in some categories. In the next section, the comparison of this preferred option with their current handle will be shown.

7.5.1.5 Comparison with current handle

The participant mentioned that the personalised handle could provide a higher level of comfort than the current walking stick handle. With the current one, a wooden crook handle, they have experienced that after using it for a moment, the hand becomes painful, and there is pain in the wrist due to the angle of the handle. Because of this, they have expressed before that they would prefer a surface in a handle that could distribute pressure more evenly on their palm and, at the same time, provides a firm grip, and the personalised handle fits better to their hand size giving a better hold.

Comparing to the other three handles, the participant scored the current one with 0 (zero) mainly because of the stress that it causes on wrist and palm.

7.5.2 Participant #2

In session #1, Participant #2 selected the Fischer handle in a medium size with cracked texture as their preferred option. They also showed interest in a handle made to fit instead of a standard device.

Participant #2 currently uses two adjustable elbow crutches with ergonomic handles, the model is shown in Figure 7.9; prior to the elbow crutches, a walking stick was used.

Figure 7.9 - Elbow crutches of P2

7.5.2.1 Preferred handle from session #3

The interaction with the 3D printed handles followed this sequence: control, personalised and standard one; this last model was the preferred option.

The most outstanding characteristics for being selected were:

1) A better fit for the palm.
2) The hand sat better.
3) There were no pressure points in the hand when gripping.

They were convinced that the standard handle was the best option since they grabbed it and they did not change their mind at any point during the session.

7.5.2.2 Scores and ranking

Participant #2 assigned 90 to the preferred handle and 50 to the other two models. Table 7.7 shows the scores and ranking:

	1st place	2nd place	3rd place
	Standard	Control/Personalised	Not applicable
Score	90	50/50	Not applicable

Table 7.7 - Scores and rankings of the three 3D printed handles. P2

Unlike the other eight participants, P2 was not comfortable in assigning numerical values to any of the three models because none of them fit well in an overall way. In a second attempt, the standard and the personalised options were scored but not the control one, because the participant preferred to define it as not suitable. In a third attempt, the control handle was scored with 50.

The participant perceived the personalised and control options as not good enough and it was not possible to qualify their features and differentiate them; thus, both were scored with the same value.

7.5.2.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The control type had a bit in the top surface and it was not comfortable for the user's hand. The indentations made for placing the fingers when it is gripped were found to be useless.

In the personalised model, the user's palm did not sit around the handle, its upper surface was lumpy and not so smooth to wrap the hand; also, the top surface was too sharp and it had a particular angle too sharp, too narrow and too bulky.

1.2 By size

The standard handle was comfortable for the hand in one position but in another position caused discomfort; this was caused by its size. The participant's hand fitted fine on the overall surface and it was comfortable, however, the handle was short in length for the hand, this meant that the index finger was closer to the stem and was uncomfortable for the participant affecting the grabbing. Figure 7.10 (left side) shows how the palm sits on the handle and how the index finger is pressed; the right image illustrates how the user needed to grip it to walk with it.

Figure 7.10 - Left image. How the hand fits on the handle. Right image. How the handle is gripped for walking

The control type was also short in length and this caused strain in the hand while it grabbed the handle, this could affect tendons, ligaments and the arm. However, this model was closer to the standard one in terms of suitability.

The personalised type was not comfortable as its neck was too narrow.

2. Intuitive shape

The control model had indentations for placing the fingers but they were useless for the participant.

3. Ease of maintaining grip during use

Among the three options, the participant could grip the standard handle better.

The personalised and control handles could not be held properly.

4. Enough support for the hand and fingers

The ending part of the personalised handle's palm did not have a soft and curved shape to provide support and rest to the palm, and the participant did not find the purpose for that specific area.

7.5.2.4 Importance of factors

The participant showed a high interest in eight out of the nine aspects since they were ranked with 10. Before scoring them, the participant mentioned these factors could not be measurable because the assigned value could not provide a meaning since the situation or origin of the problem for each participant was different.

Also, they were not comfortable scoring each aspect in the personalised and control handles because they found them unsuitable. Despite this, they assigned the scores shown in Table 7.8:

	Participant importance rating	**FIRST OPTION** Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	10	7.5	7.5	9
2. Comfort on wrist	10	7.5	7.5	9
3. Intuitive shape	10	7.5	7.5	9
4. Ease of maintaining grip	8	7.5	7.5	9
5. Support on hand/fingers	10	7.5	7.5	9
6. Stability in static posture	10	7.5	7.5	9
7. Stability in movement	10	7.5	7.5	9
8. Appealing to the user	10	7.5	7.5	10
9. Psychological confidence to use it	10	7.5	7.5	10

Table 7.8 - Importance of each factor and the score per handle. P2

The participant scored the standard model better in every aspect; the control and the personalised handle obtained the same value in all the categories.

The importance factor and each qualification were combined in order to obtain a total evaluation of the handles; the results are displayed in Table 7.9:

	FIRST OPTION Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	75	75	90
2. Comfort on wrist	75	75	90
3. Intuitive shape. How do you grip it?	75	75	90
4. Ease of maintaining grip while it is used	60	60	72
5. Enough support for the hand and fingers	75	75	90
6. Stability of the user in static posture	75	75	90
7. Stability of the user during movement	75	75	90
8. Appealing to the user	75	75	100
9. Psychological confidence to use it	75	75	100

Table 7.9 - Overall assessment of factors. P2

After the total assessment, the standard option reached the maximum value in two categories. The participant had mentioned the aesthetics was important because they like to show in a certain way that the walking stick is an important part of their life, and aspect #9 was added by them because it was relevant.

The control and the personalised handles continued in second place as the general ranking, being clear the preference for the standard option.

7.5.2.5 Comparison with current handle

The preferred option (standard handle) cannot provide a higher level of comfort than their current commercial handles as the participant needs to use elbow crutches and their handles are different. Despite the current handles of the crutches providing more comfort, they cannot be compared with a walking stick handle as they were created for different purposes; the position of the hand, how it rests over the surface, is different and it is influenced by the wrist and arm that came from a different position when elbow crutches are used.

Ranking and assigning a score to the current walking stick handle was not possible for them, because currently they use a pair of elbow crutches and they mentioned it was not possible to remember how the walking stick handle fitted to their hand.

However, the participant was able to judge the handles of the current elbow crutches. They preferred them since they are ergonomic, more comfortable and suit better than the other three 3D printed handles and scored them with 100. As can be seen in Figure 7.11, their hand sits accordingly over the shape of the crutch's handle and there is enough space for grabbing it comfortably, contrary to the standard handle.

Figure 7.11 - Different views of the handles of the current elbow crutches

7.5.3 Participant #3

Participant #3 chose the option of an ergonomic handle, in a medium size with the medium texture from session #1, that is to say, a mix of smooth and rough surfaces. Also, P3 was interested in a handle that could fit the hand because it was incapacitated due to arthritis.

P3 owns a foldable crutch walking stick with a wooden handle shown in Figure 7.12.

Figure 7.12 - Crutch walking stick

7.5.3.1 Preferred handle from session #3

The handles were introduced in this order: personalised, standard and control. After the interaction with all of them, the standard option was selected.

The reasons for selecting it were:

1) Best support for the palm.
2) Best support for the hand.

After the first round of interactions, the participant perceived the three handles in the same way as all of them had good support. In the second trials, they discarded the control type since they did not like it as much as the other two; after this, the personalised handle was tried again and rejected because it was a “little bit short”, defining the standard model as the best.

7.5.3.2 Scores and ranking

Before assigning the qualifications, Participant #3 mentioned that none of the three handles was a bad option. Table 7.10 details the scores and ranking of the three types:

	1st place	2nd place	3rd place
	Standard	Control	Personalised
Score	90	70	60

Table 7.10 - Scores and rankings of the three 3D printed handles. P3

At the beginning, the control handle had been the least liked option but during the ranking it was moved to the second place; for this reason, the control and the personalised handles were tried again, and even though, it was difficult to determine the ranking by the participant, the control handle was defined as the second preferred option.

7.5.3.3 Detailed discussion of preferences

In general, the participant mentioned that all the models were good despite their disadvantages.

1. Comfort on hand

1.1 By shape

The control handle was not very well rounded around the knob, therefore, the index finger was not comfortable whilst gripping.

2. Comfort on wrist

The standard handle provided more support on the wrist than the other models.

3. Ease of maintaining grip while it is used

With the control handle, the participant felt a more closed gap between the thumb and the index finger when gripping; its surface was fine for them when they grabbed it but it did not have as good a grip as the standard type.

4. Enough support for the hand and fingers

The personalised handle did not provide so much support for the participant's hand as it was short in the rest area close to the wrist; however, the handle was a good representation of the participant's hand.

Among the three models, the standard type had the best support for the palm, but, as a downside, the participant stated that none of the three models had a support between the thumb and the index finger and there was a gap between them. This disadvantage is shown in Figure 7.13:

Figure 7.13 - Participant gripping the handle and showing the lack of support in the top of the knob area

7.5.3.4 Important factors

Participant #3 scored the importance factors and the three handles. Table 7.11 shows these qualifications. The given values to the ratings and to the handles were high; there is no value below 7.

	Participant importance rating	FIRST OPTION Personalised	SECOND OPTION Standard	THIRD OPTION Control
1. Comfort on hand	9	7	9	8
2. Comfort on wrist	8	9	10	9
3. Intuitive shape	9	8	10	8
4. Ease of maintaining grip	10	7	10	9
5. Support on hand/fingers	9	7	9	8
6. Stability in static posture	9	8	10	9
7. Stability in movement	10	7	9	8
8. Appealing to the user	8	8	10	8
9. Material	9	8	8	8

Table 7.11 - Importance of each factor and the score per handle. P3

On average, the values assigned to the preferred handle (standard) were higher than the other two models and the control model obtained the second place, therefore, considering the average, the positions were the same as in the previous ranking.

The total overall shown in Table 7.12 also shows that there are no very noticeable differences among the personalised and the control handles.

	FIRST OPTION Personalised	SECOND OPTION Standard	THIRD OPTION Control
1. Comfort on hand	63	81	72
2. Comfort on wrist	72	80	72
3. Intuitive shape. How do you grip it?	72	90	72
4. Ease of maintaining grip while it is used	70	100	90
5. Enough support for the hand and fingers	63	81	72
6. Stability of the user in static posture	72	90	81
7. Stability of the user during movement	70	90	80
8. Appealing to the user	64	80	64
9. Material	72	72	72

Table 7.12 - Overall assessment of factors. P3

The qualifications of the three handles reflect the participant's opinion that, despite the disadvantages of each model, they were all good.

7.5.3.5 Comparison with current handle

The participant considered that their current handle provided them less comfort compared to the standard model; they mentioned that the standard type could assist them more than their crutch walking stick because it gave them more support for the palm and wrist.

They scored their current handle with 30 because there is no support for the palm when gripping and there is no structure around the thumb and the index finger.

Their hand grip did not have a complete adaptation to the surface of their current handle, this can be seen in Figure 7.14:

Figure 7.14 - Participant holding their current walking stick with crutch handle

This handle, evaluated with a score of 30, is the less favourable option among the available models. Although the personalised type was not chosen, it will be an improvement for them, because it obtained a 60, but if the participant uses a standard handle, the level of comfort will rise from 30 to 90.

7.5.4 Participant #4

In session #1, Participant #4 selected the Fischer handle, in medium size with medium texture (mix of smooth and rough), stating that, that type of surface was the ideal for them. P4 was interested in a handle with a rougher surface than their current one and with raised areas to improve the grip.

P4 currently uses one adjustable walking pole instead of a walking stick; the model and how it is gripped is shown in Figure 7.15. In the past, they used walking sticks but these options stopped being reliable for them. They prefer the pole stick because they like the straight line from the handle to the tip, and they feel more in control of it. They use it mostly for going outside.

Figure 7.15 - Current walking pole of P4

7.5.4.1 Preferred handle from session #3

The handles were shown to the participant following this sequence: standard, personalised and control. They selected the standard model as the best one.

The reasons for making this choice were:

1) The handle did not grip the hand too much and it provided flexibility to grab it.
2) The handle gave support to the participant and at the same time did not allow loss of control.

The differences between the standard and the personalised handles were difficult to find, therefore, a second trial was conducted defining the standard model as the best one.

7.5.4.2 Scores and ranking

The scores and ranking of the handles given by Participant #4 are shown in Table 7.13:

	1st place	2nd place	3rd place
	Standard	Personalised	Control
Score	75	55	45

Table 7.13 - Scores and rankings of the three 3D printed handles. P4

The participant made two rounds of trials following the same order before ranking them.

7.5.4.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

In the three handles, the palm enclosed the participant's hand, but in the standard model only in a minor way and this was the main reason why this handle was the most comfortable for the user.

2. Intuitive shape

The control handle had indentations for the fingers but these were too small for the participant.

3. Ease of maintaining grip while it is used

The grip of the standard model did not wrap the participant's hand too much and this provided them more flexibility because they were not restricted about how they grabbed the handle, and at the same time they felt more in control over it.

The personalised handle enclosed the hand more; this, for some people, could be better, they may feel safer and that could be an advantage, but this was not the case for this participant.

The control type wrapped the user's hand more than the other two models.

4. Enough support for the hand and fingers

The best support was provided by the standard handle.

7.5.4.4 Importance of factors

For the participant, comfort and intuitive shape were really important; these aspects were ranked with 10. The participant did not lean so much on the walking stick, therefore, the other factors were ranked between 6 and 7.5. “Appealing to the user” was one of the factors with the lowest score.

On average, the values for the standard option were the highest, followed by the personalised and then the control handle as the first general ranking. Table 7.14 shows these scores.

	Participant importance rating of the factor	**FIRST OPTION** Standard	**SECOND OPTION** Personalised	**THIRD OPTION** Control
1. Comfort on hand	10	10	6	5
2. Comfort on wrist	10	8	4	4
3. Intuitive shape	10	10	5	5
4. Ease of maintaining grip	7.5	8	4	4
5. Support in hand/fingers	6	7	4	4
6. Stability in static posture	7	6	3	3
7. Stability in movement	7.5	8	4	4
8. Appealing to the user	6	8	4	3

Table 7.14 - Importance of each factor and the score per handle. P4

The values of the personalised and control handles were similar and this is reflected as well in the previous general rating, where the control type obtained 45 and the personalised 55.

The overall assessment of the handles in Table 7.15 shows the preference for the standard option.

	FIRST OPTION Standard	SECOND OPTION Personalised	THIRD OPTION Control
1. Comfort on hand	100	60	50
2. Comfort on wrist	80	40	40
3. Intuitive shape. How do you grip it?	100	50	50
4. Ease of maintaining grip while it is used	60	30	30
5. Enough support for the hand and fingers	42	24	24
6. Stability of the user in static posture	42	21	21
7. Stability of the user during movement	60	30	30
8. Appealing to the user	48	24	18

Table 7.15 - Overall assessment of factors. P4

Despite the three models being similar in shape, the participant perceived physical features that determined their score in the last factor "appealing to the user", mentioning that the standard type had a more "graceful" shape and the other two looked more manipulated, this is the reason why the standard handle obtained a particular score of 8, the personalised a 4 and the control a 3 in the "appealing" aspect.

7.5.4.5 Comparison with current handle

Currently, the participant's pole stick is more useful than the standard handle because they do not need to lean on the device; therefore, the pole stick meets its function. Probably, in the future they will find the standard option more useful if they need to lean on a walking stick.

Also, their fingers are able to hold their current walking pole solidly.

At the moment they assigned 70 to the walking pole because it should be held by wrapping all the fingers around it, and, at some point, this could tire them.

7.5.5 Participant #5

Participant #5 chose a Fischer handle in a medium size with a cracked textured as the most suitable option in session #1. They mentioned a better grip as a desirable characteristic in a handle.

P5 uses a non-adjustable wooden crook walking stick; this device is shown in Figure 7.16.

Figure 7.16 - Crook walking stick of P5

7.5.5.1 Preferred handle from session #3

Participant #5 interacted with the models in this order: personalised, control and standard; after this, the standard handle was selected as the preferred one.

The selection was made based on:

1) The handle provided more safety.
2) The participant could held it more firmly than the other two models, especially in the inner palm found more support.
3) It had an adequate size.

The choice was between the standard and the control handles since the personalised model was discarded during the first interaction.

7.5.5.2 Scores and ranking

The scores and the ranking made by Participant #5 are shown in Table 7.16:

	1st place	2nd place	3rd place
	Standard	Control	Personalised
Score	100	90	50

Table 7.16 - Scores and rankings of the three 3D printed handles. P5

Despite the difference in score between the standard and the control models, the participant did not hesitate in defining which was the preferred one.

7.5.5.3 Detailed discussion of preferences

Participant #5 based their preferences on the grip.

1. Ease of maintaining grip during use

The standard handle provided the best grip among the other options. The participant did not mention anything wrong about this model.

The control type had a good grip and, as a disadvantage, the participant stated that there was nothing that they did not like, but when the handle was compared with the standard, this last one was the best.

The personalised model was "quite nice" for the participant but when it was compared with the other two types, those were superior and more suitable for them as the personalised handle did not provide as good and firm a grip as the other two options.

7.5.5.4 Importance of factors

Participant #5 ranked "appealing to the user" as the least important factor. Among the three handle options, the standard model obtained the best values, followed by the control and then the personalised; these positions are the same in the general ranking. All the values are displayed in Table 7.17:

	Participant importance rating	**FIRST OPTION** Personalised	**SECOND OPTION** Control	**THIRD OPTION** Standard
1. Comfort on hand	10	8	9	10

2. Comfort on wrist	9.5	8	9	10
3. Intuitive shape	9	8	9	10
4. Ease of maintaining grip	8	8	9	10
5. Support in hand/fingers	9	8	9	10
6. Stability in static posture	10	8	10	10
7. Stability in movement	8	8	9	10
8. Appealing to the user	7	8	10	10

Table 7.17 - Importance of each factor and the score per handle. P5

The values assigned to all of the factors per handle were so similar among them, for example, the personalised type obtained 8 in all the factors, the control handle was scored mostly with 9 and all the fields of the standard model obtained 10.

However, the difference between the values changed when they were assessed overall. Table 7.18 presents the results:

	FIRST OPTION Personalised	**SECOND OPTION** Control	**THIRD OPTION** Standard
1. Comfort on hand	80	90	100
2. Comfort on wrist	76	85.5	95
3. Intuitive shape. How do you grip it?	72	81	90
4. Ease of maintaining grip while it is used	64	72	80
5. Enough support for the hand and fingers	72	81	90
6. Stability of the user in static posture	80	100	100
7. Stability of the user during movement	64	72	80
8. Appealing to the user	56	70	70

Table 7.18 - Overall assessment of factors. P5

In the overall total, the difference among the three handles is similar from one to another, unlike the general ranking in Table 7.16 where the least liked handle (personalised) obtained 50, the control 90 and the standard 100.

7.5.5.5 Comparison with current handle

The participant considered that their current handle had disadvantages compared to the standard model because as they stated since the first session, a desirable characteristic in a handle was a better grip, which was found in the standard type. Also, the standard model provided them more comfort and support. However, they found that they could hold the crook model on their arm and have freedom in their hands which was useful.

Because of the downside mentioned, the current handle was scored with 20; this value shows that any of the three 3D printed versions are better than the current style.

7.5.6 Participant #6

In session #1, Participant #6 selected a Fischer handle in a medium size with bumpy texture because they prefer rough surfaces in walking stick handles.

P6 currently utilises an adjustable Fischer walking stick shown in Figure 7.17. They find its wide handle useful because, prior to this, they used a crutch walking stick but it caused a lot of pain on their inner palm when gripping.

Figure 7.17 - Current walking stick of P6

7.5.6.1 Preferred handle from session #3

Participant #6 interacted with the handles in this order: control, standard and personalised. From these options, the standard type was selected as the preferred one.

The reasons for choosing it as the most suitable handle were:

1) The physical contact with its surface was pleasant for the participant.
2) It provided more safety to the hand during gripping.

3) The handle was comfortable.
4) It has a right shape.
5) The bumps of the texture were more raised and closer together.

The standard and control options were revised again before naming the best handle. Once the standard handle was chosen as number 1, it was inspected one more time to confirm the choice. According to the participant, the standard handle was “really similar” to their hand as if it was made to fit.

7.5.6.2 Scores and ranking

Table 7.19 displays the scores and positions assigned to every handle:

	1st place	2nd place	3rd place
	Standard	Control	Personalised
Score	85	70	20

Table 7.19 - Scores and rankings of the three 3D printed handles. P6

Before scoring them, the participant interacted again with every handle.

7.5.6.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The control handle was very comfortable for the participant; their hand fitted “nicely” around it. However, the curve of the end part of the grip was a little different from the user’s inner palm.

The shape of the standard handle was the most comfortable among the other models.

For the participant, the personalised model was not “ergonomic enough”. Also, the end part on the grip (area closer to the wrist) was obsolete as it had additional material and it should have a better fit around the palm.

1.2 By size

The control and the personalised handles had a narrow neck.

2. Ease of maintaining grip while it is used

In the standard model, the end part of the handle should follow the user's palm more, like enclosing the hand in order to avoid the palm slipping. This situation occurs with the current walking stick with sweat but the application of texture could help to avoid slips.

3. Enough support for the hand and fingers

The participant felt secure walking using the standard and the control handles but not with the personalised one.

The personalised model had one of the areas of the handle (left part) downwards that caused an inclination and this negatively impacted the support. The participant mentioned that this side should point upwards.

7.5.6.4 Importance of factors

Almost all the factors were very important for the participant as six out of eight scored 10; the least important was the "appealing to the user" aspect.

There was a preference for the standard model as it obtained the maximum score in all the aspects; in second place, the control handle was scored mostly with 8 and the lowest scores were given to the personalised model. These values are shown in Table 7.20:

	Participant importance rating	**FIRST OPTION** Control	**SECOND OPTION** Standard	**THIRD OPTION** Personalised
1. Comfort on hand	10	8	10	3
2. Comfort on wrist	10	8	10	3
3. Intuitive shape	10	8	10	3
4. Ease of maintaining grip	10	8	10	2

5. Support on hand/fingers	10	7.5	10	2
6. Stability in static posture	6.5	8	10	7
7. Stability in movement	10	8	10	2
8. Appealing to the user	5	10	10	10

Table 7.20 - Importance of each factor and the score per handle. P6

The overall assessment of each handle is shown in Table 7.21:

	FIRST OPTION Control	**SECOND OPTION** Standard	**THIRD OPTION** Personalised
1. Comfort on hand	80	100	30
2. Comfort on wrist	80	100	30
3. Intuitive shape. How do you grip it?	80	100	30
4. Ease of maintaining grip while it is used	80	100	20
5. Enough support for the hand and fingers	75	100	20
6. Stability of the user in static posture	52	65	45.5
7. Stability of the user during movement	80	100	20
8. Appealing to the user	50	50	50

Table 7.21 - Overall assessment of factors. P6

The overall results showed that the highest values were obtained by the standard model, followed by the control handle and then the personalised option. The same ranking and similar scores were given in the first assessment (Table 7.19). However, in that former ranking, the standard handle obtained 85 and then in Table 7.20, it was scored with 10 in every single factor.

7.5.6.5 Comparison with current handle

The current handle is the same model as the selected choice, the only difference is the material and the texture applied. With these differences they preferred the 3D printed option because this type of surface creates a rougher feel for them and a stronger contact. For this reason, they ranked their current device with 80, that is 5 points below the standard option.

7.5.7 Participant #7

In session #1, Participant #7 had selected a Fischer handle in a medium size with a smoother texture.

Currently, P7 owns an adjustable pole stick because it was suggested by a physiotherapist and a friend who uses it. They like its handle, the comfort of the grip since the shape is more natural for them and it keeps the wrists straight rather than bent. However, they stated that if the weather was hot, the material of their current handle could be sweaty. They also showed a preference for firm materials, but not hard. Figure 7.18 shows the current walking pole and how it is gripped.

Figure 7.18 - Walking pole of P7

7.5.7.1 Preferred handle from session #3

The handles were shown to the participant following this sequence: personalised, standard and control. The standard option was selected as the best type.

The reasons for choosing this option were:

1) Compared to the other handles, the neck area was more substantial.
2) The end part of the palm was not too long and did not interfere with the user's wrist during use.

Among the three options, only the standard model was considered as the best handle.

7.5.7.2 Scores and ranking

The scores and ranking provided by Participant #7 are shown in Table 7.22:

	1st place	2nd place	3rd place
	Standard	Personalised	Control
Score	80	60	5

Table 7.22 - Scores and rankings of the three 3D printed handles. P7

The participant interacted again with the personalised and the standard handles for reviewing the given score.

7.5.7.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The personalised handle could have been more comfortable if the palm had been lower. The bottom area of the handgrip where the fingers are placed was comfortable. The contact between the user's inner palm and the upper surface of the handle was fine and there was a comfortable area for the bottom part of the thumb, which has been affected by arthritis.

The standard model was more comfortable at the end part of the handle and it did not hit against the wrist. However, the area for resting the bottom part of thumb was less comfortable than the personalised but it was fine.

The control model was not as comfortable as the other two models.

1.2 By size

The neck of the personalised model was thin.

The standard handle was substantial around the neck and it helped not gripping it so hard.

2. Comfort on wrist

The personalised model had additional material at the end of the resting area and it pressed the wrist when walking.

3. Intuitive shape

The personalised model had indentations for the fingers, but, when gripping, the participant had to move their fingers around the grooves in order to fit them because this did not happen naturally. The grooves were fine for the participant because they define where to place the fingers; the downside was that this did not provide freedom to move them and it could tire the hand.

The standard model did not have grooves in the bottom area; therefore, the fingers had more freedom to move.

4. Enough support for the hand and fingers

In the control model, the left side of the handgrip was supportive for the user's palm, but the right area was not.

7.5.7.4 Importance of factors

Participant #7 showed a high importance in six factors as they were all ranked with 10. The standard handle received the best scores, followed by the personalised and then the control. This ranking was the same as established previously (Table 7.22). Now, Table 7.23 displays all the values:

	Participant importance rating	**FIRST OPTION** Personalised	**SECOND OPTION** Standard	**THIRD OPTION** Control
1. Comfort on hand	10	6	8	4
2. Comfort on wrist	10	2	8	4
3. Intuitive shape	10	7	8	7
4. Ease of maintaining grip	7	5	6	4
5. Support on hand/fingers	10	7	6	5
6. Stability in static posture	10	6	6	5

7. Stability in movement	10	5	6	4
8. Appealing to the user	8	4	5	2

Table 7.23 - Importance of each factor and the score per handle. P7

In the overall total, shown in Table 7.24, the discrepancy among the average of the three models is similar. However, in the previous general ranking (Table 7.22), the standard option obtained 80, the personalised 60 and the control 5; in that scenario, the gap between the personalised and the control handles was bigger than when these handles were scored on individual factors.

	FIRST OPTION Personalised	**SECOND OPTION** Standard	**THIRD OPTION** Control
1. Comfort on hand	60	80	40
2. Comfort on wrist	20	80	40
3. Intuitive shape. How do you grip it?	70	80	70
4. Ease of maintaining grip while it is used	35	42	28
5. Enough support for the hand and fingers	70	60	50
6. Stability of the user in static posture	60	60	50
7. Stability of the user during movement	50	60	40
8. Appealing to the user	32	40	16

Table 7.24 - Overall assessment of factors. P7

7.5.7.5 Comparison with current handle

The participant considered that the current walking pole is more comfortable that any of the 3D printed options because when they hold the pole, they did not twist their hand, wrist and arm. They provided a 90 to their current device because if they use it for a long time, around half an hour, they can start to feel an ache in their shoulder.

It was clear that their current device was better than the other options.

7.5.8 Participant #8

In the first session, Participant #8 selected a Fischer model in a medium size with cracked textured and they showed interest in a more comfortable handle that allows them to lean on it.

P8 owns a non-adjustable wooden crook walking stick. It is easy to manage for them and it is attractive; however, its handle is inflexible, does not fit them because of its shape and, after using it for a while, it hurts the area of the palm below the thumb. This shape can be appreciated in Figure 7.19.

Figure 7.19 - Crook walking stick of P8

7.5.8.1 Preferred handle from session #3

Participant #8 interacted with the handles following this sequence: standard, control and personalised. In this case, the selected handle was the personalised.

The motives for this choice were:

1) The user's hand fitted better in this handle.
2) It provided a lot of support in the lower area of the user's inner palm.
3) The handle had an indentation underneath the palm that allowed a better fit of the finger and the user felt well supported.
4) The participant perceived its texture not as rough as the standard model.

7.5.8.2 Scores and ranking

Participant #8 assigned the scores and ranking shown in Table 7.25:

	1st place	2nd place	3rd place
	Personalised	Control	Standard
Score	90	80	60

Table 7.25 - Scores and rankings of the three 3D printed handles. P8

According to the participant, the best handle was between the personalised and the control type and this was reflected in the values assigned to them.

7.5.8.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The standard handle had a good shape, however, in the bottom area it did not have an indentation for one of the participant's fingers. Also, its texture was too rough.

The control handle was a little more comfortable than the standard one.

The personalised handle was the most comfortable and it had an indentation underneath so one of the fingers fitted better and the participant felt well supported.

2. Ease of maintaining grip while it is used

The participant's hand fitted better in the personalised handle, followed by the control model.

3. Enough support for the hand and fingers

The personalised handle provided a lot of support for the palm. The standard model also provided a good support.

4. Appealing to the user

The personalised model had an elongation of material that caused a longer length; this remaining area was too visible for the participant and they considered that people could identify a disability.

7.5.8.4 Importance of factors

The values assigned to the importance of the factor varied from 5 to 10.

Despite this, the average value per model was similar, the personalised option kept the first position, followed by the control and then the standard model. All the values are shown in Table 7.26:

	Participant importance rating	FIRST OPTION Standard	SECOND OPTION Control	THIRD OPTION Personalised
1. Comfort on hand	9	8	8	10
2. Comfort on wrist	6	7	7	7
3. Intuitive shape	7	6	6	9
4. Ease of maintaining grip	9	5	6	7
5. Support on hand/fingers	10	8	8	10
6. Stability in static posture	5	9	9	9
7. Stability in movement	9	9	9	9
8. Appealing to the user	8	8	9	6

Table 7.26 - Importance of each factor and the score per handle. P8

The overall assessment is shown in Table 7.27. The only value of 100 was obtained by the personalised model in "enough support for the hand and fingers" aspect, it coincided with the feature that determined that this model was the preferred choice.

	FIRST OPTION Standard	SECOND OPTION Control	THIRD OPTION Personalised
1. Comfort on hand	72	72	90
2. Comfort on wrist	42	42	42
3. Intuitive shape. How do you grip it?	42	42	63

4. Ease of maintaining grip while it is used	45	54	63
5. Enough support for the hand and fingers	80	80	100
6. Stability of the user in static posture	45	45	45
7. Stability of the user during movement	81	81	81
8. Appealing to the user	64	72	48

Table 7.27 - Overall assessment of factors. P8

7.5.8.5 Comparison with current handle

The participant mentioned that the personalised model could provide more comfort than their current walking stick because it was customised to their hand, it did not hurt their palm and there was enough space for placing the hand, unlike the crook handle. It also provided good support because of the contact area and it was less likely that their hand could slip.

Their current walking stick was scored with 20 because it has a reduced surface to grab it with comfort.

7.5.9 Participant #9

In session #1, Participant #9 selected a Fischer handle in a medium size with bumpy texture.

P9 owns four different devices. They try to reduce the pain in the wrist and hand when using the walking stick and usually, they change model in order to find the most suitable. But the adjustable Fischer walking stick shown in Figure 7.20 has the best handle that they have found.

Figure 7.20 - Fischer walking stick of P9

7.5.9.1 Preferred handle from session #3

The handles were shown to Participant #9 in this order: control, personalised and standard. After the interaction with each one, the personalised handle was considered as the best option.

The reasons for this selection were:

1) The personalised handle had a better grip than the other two models.
2) This handle has been moulded for the participant's hand shape and it was suitable for their grip in the way they use the walking stick.
3) The grip was firm.
4) The participant did not struggle to hold the handle.
5) It was possible to have a relaxed grip due to the material added around the handle's neck.

7.5.9.2 Scores and ranking

Table 7.28 displays the scores and ranking assigned to the three handles, these values are:

	1st place	2nd place	3rd place
	Personalised	Control	Standard
Score	92	72	55

Table 7.28 - Scores and rankings of the three 3D printed handles. P9

7.5.9.3 Detailed discussion of preferences

1. Comfort on hand

1.1 By shape

The personalised handle was moulded to the participant's hand.

The shape of the palm of the control handle did not provide the fullness that the participant's hand needed.

1.2 By size

The personalised model had a bigger and more comfortable neck.

The standard handle was fine for the participant, it was functional when first using it, but after a while the hands could start to feel tired because the model is a little thin.

2. Comfort on wrist

In the personalised model, the end part of the handgrip was high and this additional material could hit against the wrist during the movement. If the handle was made with a softer surface perhaps that situation would not be a problem.

3. Ease of maintaining grip while it is used

The grip of the control model was good but the personalised grip was the best among the three options, it provided a relaxed grip during use. On the other hand, the participant needed to squeeze the standard handle in order to have a full grip, this can cause strain on the palms or on points of the hand.

4. Enough support for the hand and fingers

The best support was provided by the personalised model, followed by the control and then, the standard type.

7.5.9.4 Importance of factors

The importance factors were ranked in a range from 5 to 10, the lowest being the “appealing to the user” aspect.

According to the average scores, the personalised handle was the best, followed by the control, and then the standard model. These positions coincided with the general ranking (Table 7.28). The assigned values are shown in Table 7.29:

	Participant importance rating	**FIRST OPTION** Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	10	6	8	5
2. Comfort on wrist	10	8	8	7

3. Intuitive shape	8	8	10	5
4. Ease of maintaining grip	8	8	10	5
5. Support on hand/fingers	7	8	10	5
6. Stability in static posture	9	5	5	5
7. Stability in movement	10	8	10	7
8. Appealing to the user	5	6	6	7

Table 7.29 - Importance of each factor and the score per handle. P9

There are a variety of values per handle, for example, the personalised model obtained scores from 5 to 10 but despite it being the best handle it did not win in all the categories.

The overall total is shown in Table 7.30, it also shows a variety of values from 30 to 100.

	FIRST OPTION Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	60	80	50
2. Comfort on wrist	80	80	70
3. Intuitive shape. How do you grip it?	64	80	40
4. Ease of maintaining grip while it is used	64	80	40
5. Enough support for the hand and fingers	56	70	35
6. Stability of the user in static posture	45	45	45
7. Stability of the user during movement	80	100	70
8. Appealing to the user	30	30	35

Table 7.30 - Overall assessment of factors. P9

7.5.9.5 Comparison with current handle

The participant considered that the personalised model could provide more comfort than their current Fischer walking stick because, like the standard handle, it has a thin handgrip and it should be squeezed when it is gripped by P9.

The score they provided to the current handle was the same as the standard model, 55.

After considering the outcomes of the three sessions, the next chapter will discuss this data and the effects of several factors key in the investigation.

8 DISCUSSION

This section will tie together the findings from throughout this work and attempt to draw conclusions based around the need for, and process to achieve, personalisation.

8.1 Effect of shape

Table 8.1 summarises the results obtained in session #1 regarding the preferences of shape (type).

Participant	Shape
P1	Ergonomic
P2	Fischer
P3	Ergonomic
P4	Fischer
P5	Fischer
P6	Fischer
P7	Fischer
P8	Fischer
P9	Fischer

Table 8.1 - Preferences in shape of handles. Session #1

These results indicated the participants' preference for an anatomical handle, since all of them chose either the ergonomic or the Fischer type, but seven out of nine had an inclination for the Fischer.

From the five shapes (ergonomic, Fischer, crook, crutch and pistol) there were three styles considered as the least liked: pistol, crook and crutch. Eight participants agreed that the pistol model was not suitable for them, the disadvantages mentioned were: the user had all the pressure in the centre of the inner palm, the hand could slip easily, the wrist was bent during use, it was unsafe, it did not provide support, it was not possible lean on it, the participant had to hold on to it and it affected the grip, it was uncomfortable and it was too small. Eight participants did not like the crook handle and it was considered uncomfortable, too narrow causing pain and pressure in the inner palm and did not have a shape that was similar to the participant's hand, it was unsafe, people cannot lean on it and its curve was too tight for the user's hand. The second least liked model was the crook style since seven participants commented on downsides such as it being uncomfortable, there was pressure during use, it was not possible to lean on it and it was not very stable.

Participants that selected the ergonomic handle found that its shape matched their hand better than the other models, also, the medium size in this ergonomic model was the best for them as it had the curves and the entire form in the right position for the users.

Besides this, the two participants (P1 and P3) felt a more comfortable position for their wrist in the ergonomic handle. One of them also mentioned that their arm was comfortable on it. Pressure more evenly distributed on the hand and a firmer grip were characteristics sought in a handle by P1 and P3. However, improvements in grip also were mentioned by other participants who chose the Fischer model, therefore, a firmer or better grip is not an exclusive characteristic provided by the ergonomic handle.

Participants who chose the ergonomic model stated that its size had been a determinant factor for choosing it and, according to its dimensions, it is smaller than the Fischer handle. Figure 8.1 shows D1 and D2 for the ergonomic handle (left) D1: 112.26 mm and D2: 57.44 mm vs. dimensions of the Fischer (right) D1: 132.75 mm and D2: 74.81 mm. Although not measured in this work, this may potentially be due to those participants having smaller hands. This could be a consequence of their physical complexion, ageing or due to an impairment.

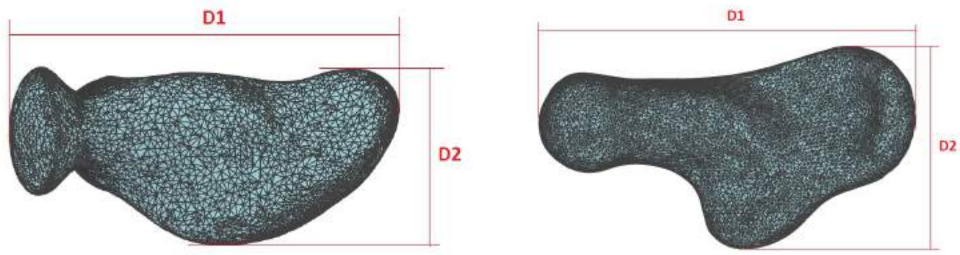

Figure 8.1 - Dimensions of standard ergonomic handle (left) and standard Fischer handle (right)

Based on the results of the nine participants, the decision of the preference in shape is related to the comfort provided by an anatomical form because it matches the user's hand shape.

8.2 Effect of size

The preferences in sizes from session #1 are shown in Table 8.2.

Participant	Shape
P1	Regular/Medium
P2	Regular/Medium
P3	Regular/Medium
P4	Regular/Medium
P5	Regular/Medium
P6	Regular/Medium
P7	Regular/Medium
P8	Regular/Medium
P9	Regular/Medium

Table 8.2 - Preferences in size of handles. Session #1

The regular size of the anatomical handles was the most suitable for all the participants; only one participant felt comfortable using the big size, mentioning that pressure could be spread properly over the hand but in the end, the medium size was more suitable.

Participants in this study had different sized hands, despite this, all of them chose the standard size as the most comfortable. The variation or gaps between sizes should be smaller than the current ones, since participants discarded the other two sizes because they felt the bigger size was too big and the smaller size was too small which had a negative impact on fit.

8.3 Effect of texture

Table 8.3 summarises the results obtained in session #1 regarding the shape (type) preferences.

Participant	Shape
P1	Smoother
P2	Cracked
P3	Medium
P4	Medium

P5	Cracked
P6	Bump
P7	Smoother
P8	Cracked
P9	Bump

Table 8.3 - Preferences in texture of handles. Session #1

Rougher textures are relevant in this study, since seven out of nine participants demonstrated an inclination for them while only two people selected the smoother finish. P1 found that none of the rougher textures were suitable and also, since the beginning of the session they had stated their preference for a smooth surface in a handle. The other participant, P7, selected the smoother version because it was more comfortable than the other types but they also found the raw, medium and cracked versions suitable. Between these two participants, there were no similarities in opinions about the other options of textures, as one liked only smoother types and the other participant approved of rougher types.

Results and comments from participants related to session #1 can be found in Appendix V.

None of the participants selected the raw texture, most of them defined it as "too smooth". The "circles" texture was also rejected because it was too prickly for most of the participants.

There is no a clear inclination among the chosen rougher textures since the cracked texture was chosen three times, medium and bumpy twice; but there were comments by four participants for selecting them as "the right amount of roughness" and anti-slip. The variety in chosen textures indicates that providing a broad range of options to the users could better satisfy their particular needs. Table 8.4 shows a summary of the preferences in size, type (shape) and texture considering the nine participants from session #1.

Shape	Ergonomic Fischer	2 7
Size	Regular/Medium	9
Texture	Smoother Cracked Bump Medium	2 3 2 2

Table 8.4 - Summary of preferences in session #1

8.4 Perceived benefit of anatomical handle over current stick handle

The current handle of each participant was incorporated in the third session with the aim of knowing its position in relation to the other three 3D printed handles, which were anatomical. The results will show if there is a benefit for the user if they change from their current walking stick to an anatomical handle.

From the nine participants, only two of them preferred their current handle and the reasons were, P2 actually uses two crutches with anatomical handles, therefore, they are more convenient according to their needs. The other participant, P7, chose their current handle as they use walking stick poles which are more suitable for them, they do not need to lean over the device and also, they preferred their wrists to be straight rather than bent.

The preferences of all the participants can be seen in Table 8.6. During session #3, the participants were asked to assign a score out of 100 to the three types and to their current walking stick handle; these values and the differences among the four models are shown in Table 8.5 and are visually represented in Image 8.2:

P	Standard	Control	Personalised	Current WS
1	60	10	90	0
2	90	50	50	-
3	90	70	60	30
4	75	45	55	70
5	100	90	50	20
6	85	70	20	80
7	80	5	60	90
8	60	80	90	20
9	55	72	92	55
Average	77.222	54.668	63	45.625

Table 8.5 - Scores given by participants to every handle

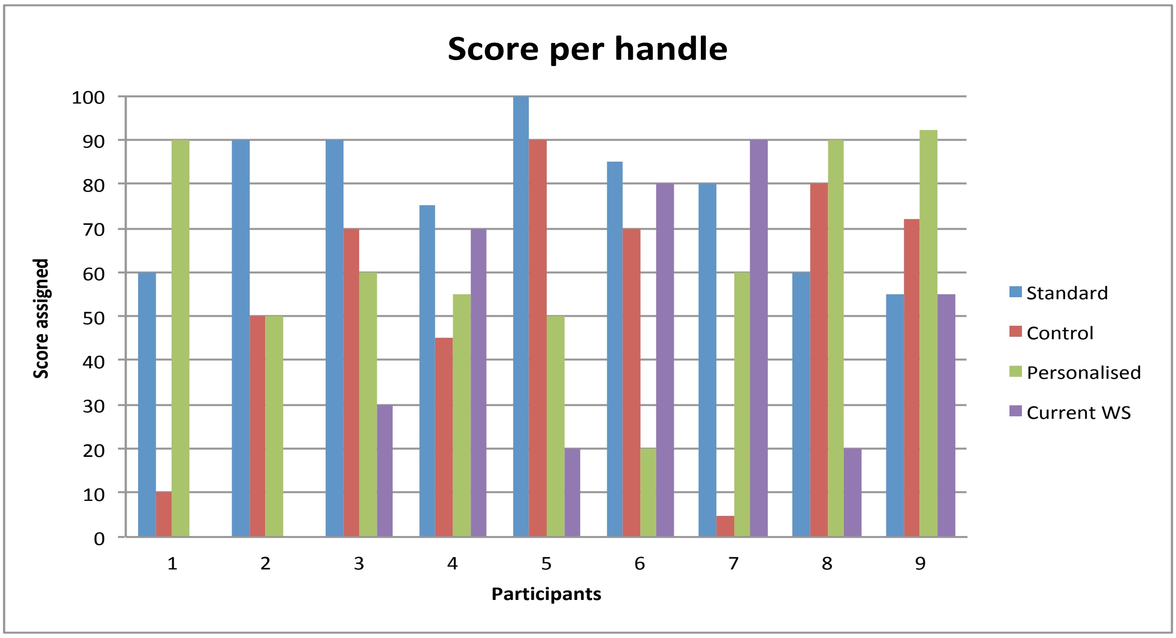

Figure 8.2 - Scores given by participants to every handle

Table 8.5 shows the difference in average among the four models. The standard handle obtained the first place with an average score of 77.22 out of 100; this can also be seen in Figure 8.2 where the blue bar of the standard model is located above the other bars of the three models. Meanwhile, the average score of the personalised handle was 63, being the second place, the control handle obtained 54.67 and the current walking stick had a score of 43.65, being the least preferred option among the four models. Figure 8.2 shows that there are no bars for the current handles in P1 and P2, as P1 ranked it with zero and the value given by P2 was not comparable with the other models as the current handle was for crutches.

Being in last place does not mean the current handle is not useful because, despite its average lower score, two participants selected it as the second best option. The other five people found their current walking stick handle was the least liked option. This information is represented in the following Table 8.6:

P	1st place		2nd place		3rd place		4th place	
1	Pers.*	90	Standard	60	Control	10	Current ws.*	0
2	Standard	90	Control/ Pers.	50/ 50				
3	Standard	90	Control	70	Pers.	60	Current ws.	30
4	Standard	75	Current ws.	70	Pers.	55	Control	45
5	Standard	100	Control	90	Pers.	50	Current ws.	20
6	Standard	85	Current ws.	80	Control	70	Pers.	20
7	Current ws.	90	Standard	80	Pers.	60	Control	5
8	Pers.	90	Control	80	Standard	60	Current ws.	20
9	Pers.	92	Control	72	Current ws. Standard	55 / 55		

Table 8.6 - Ranking of 4 handles. *Pers.= Personalised. *Ws.= Walking stick

Participant #1 found the personalised handle to be a better option. They scored it with 90 and their current one with 0; therefore, its usage should be an improvement for them. Despite not being number 1, the standard and the control models, also show an increase in usage and comfort in comparison with the current stick.

Participant #2 chose the standard walking stick but it did not present an improvement over the current handles of their walking aid (which were scored with 100). Nowadays, P2 uses two elbow crutches (previously a walking stick was used), therefore, their two current handles cannot be compared directly with a walking stick handle as they are from a different walking aid and are used in a different position.

For Participant #3, there will be an improvement with the use of any of the 3D printed models (anatomical models), rather than their current crook handle, since the shape is ergonomic and these adapt better to their current needs.

For Participant #4, it is more useful to utilise a walking pole because they do not currently need to lean on it, but, despite this and in case they require it, they found the standard Fischer walking stick a good choice.

From the four handles, the current walking stick is the least suitable for Participant #5; if they obtain a personalised model there will be an improvement but if they buy a standard Fischer model the enhancement will be higher.

Participant #6 selected the standard model, which is the same type as their current device. However, the standard model was ranked higher than the current device, this shows that a texture could support to a walking stick user.

As Participant #7 stated in session #1, they found their current handle comfortable and after the test it continued to be the best device for them. Because of their current different support needs, some of the participants still find their current handles comfortable; this is the case of participants 2, 4 and 7 who preferred to use the handles of elbow crutches or walking poles. These types of handles provide a different gripping direction for their hand, wrist and arm.

Participant #8 had stated that they desired a better grip that provided them more comfort because their current walking stick hurts their hand after using it for a while. In the Fischer model they found a wider surface that gave them a comfortable grip and the personalised type had a particular shape that was better for them. Therefore, in their case, there is an improvement from 20 (current) to 90 (personalised). Even if their new walking stick were a standard model (scored with 60) it would also bring them relief.

For Participant #9, their current stick handle was the least preferred option alongside the standard version. This is because both had the same shape and size, thus they had the same issues such as they were a little bit small for their hand and they had to hold it tightly causing strain in their hand.

After reviewing the nine cases, a relevant improvement occurred where the participants had either a crook or a crutch model as a current handle. There were four cases where the improvement would be significant if they change to the selected most liked option, either Fischer or an Ergonomic type. Table 8.7 shows the value of the highest score given to the preferred option (thicker border) versus the value that represents the participant's current walking stick (dotted border).

Participant	Standard	Control	Personalised	Current walking stick
1	60	10	90	0 - Crook
3	90	70	60	30 - Crutch
5	100	90	50	20 - Crook
8	60	80	90	20 - Crook

Table 8.7 - Scores given by the participants to the three 3D printed handles and to their current walking stick

In the previous four cases, changing to the anatomical chosen shape could bring a greater improvement to the participants. All of them had stated the desire for a more comfortable handle since the beginning.

8.5 Effect of personalisation

Table 8.8 shows the final preferences of the nine participants in session #3 considering the standard, personalised and control models.

P	First place	Second place	Third place
1	Personalised	Standard	Control
2	Standard	Personalised	Control
3	Standard	Control	Personalised
4	Standard	Personalised	Control
5	Standard	Control	Personalised
6	Standard	Control	Personalised
7	Standard	Personalised	Control
8	Personalised	Control	Standard
9	Personalised	Control	Standard

Table 8.8 - Preferences about the 3D printed handles per participant among standard, personalised and control versions

According to the results of session #3, the walking stick users tend to choose the standard handle (6 out of 9 participants); however, there were three cases where the personalised handle was chosen, each of these models had specific modifications to their palm. In none of the cases was the control model the preferred option.

As mentioned previously, three participants selected the personalised model for different reasons. Figure 8.3 shows the indentation close to the knob in the personalised handle and how the participant could grip it with comfort.

Figure 8.3 - Participant #1 gripping the personalised handle

In the case of P8, there was also an indentation created for the thumb that results in a better grip, this is shown in Figure 8.4:

Figure 8.4 - Interaction of P8 with the personalised handle

During the hand printing, P9 requested to wrap additional material around the neck of the handle to produce a more substantial grab. Figure 8.5 shows the interaction with the handle.

Figure 8.5 - Interaction of P9 with the personalised handle

The specific features in these handles allowed a more comfortable grip to be created.

Each participant had their own criterion to make the selection of their handle. The reasons for their preferences varied; P1 selected the handle because, in general, it was the most comfortable option, the surface fit into their palm but also, due to the personalisation, the handle had an indentation below the knob which makes it easier to hold. P2 chose their handle because it fit well in their palm and there were no pressure points; on the downside, the length and the stem were a little short for them but the shape was considered more important than the size. P3 selected their handle because it provided a better support for their hand than the other two options. The control was another reason for selecting the handle, P4 referred to it while they chose their preferred one: “It feels like it gives me support without loosing control”. Feeling safe during its use was also mentioned as one of the motives of selection by P5, the safety feeling was highlighted during the session because the participant felt a firmer grip with a specific handle in comparison with the others. Similar to other participants, P6 chose their handle for its comfort and safety. The selection made by P7 was based on the right fit of the handle, it was not too big and the section of the neck fitted better. Fit and support were also highlighted by P8 as well as an indentation for the thumb that made the contact better. P9 identified as decisive factors: firm grip, comfort, the shape offers fullness between the hand and the handle.

The reasons of their choices can be summarised in:

1. Adequate shape that generates a better adjustment/fit of the hand.
2. Better grip.
3. Comfort.
4. Better support for the hand.
5. Having control.
6. Sense of security.
7. The curves and indents fit to the participant’s hands.

On the other hand, several downsides were mentioned in relation to personalised handles. There were participants that expressed discrepancies between the personalised handle and their hand in width, length, planar, sharp and bulky top surface, which reduces the proper resting and support of the hand. Size (shorter or bigger) and the lack of support in the inner low palm also were considered for discarding. Also, the shape of the handle was a consideration for one of the participants, who rejected two models because they enclosed the hand a lot and it was difficult to relax, in this way, the discrepancy in shape also causes it not to have as firm a grip as is expected. In other cases, according to the participant's perception, the neck of the handle was too narrow, the handle itself was not ergonomic, did not provide confidence and it had indentations that were not comfortable, also, it had extra material at the end of the handle where the inner palm rested and the support close to the stem was down and the hand could slip down. Another participant found one of the edges of the handle not quite supportive enough and, overall, the shape was the least comfortable and there was a lack of material around the neck. Also in the same case, there was an excess of material at the end of the handle that pressed the wrist. Besides this, the grooves on the bottom side of the handle do not allow the fingers to move anywhere else. Another reason for discarding was the excess material; even if it does not bother the participant it was big enough to be more visible and noticeable by other people so they could identify a disability in its user. In another participant, there was additional material at the end of the palm of the handle that could produce pressure on the wrist during movement.

It is relevant to review the disadvantages of the personalised handles in order to find if there is any consistency. Table 8.9 summarised them:

	Length								
Reduced neck	Short length	Big length	Narrow	Planar surface	The palm encloses much	Shape	Indentations	Excess of material at the end of the palm	Not supportive one of the edges
	3	1							
3	**4**		**1**	**1**	**1**	**3**	**2**	**4**	**1**

Table 8.9 - Frequency of disadvantages

According to the summary, there are two common disadvantages. One of them, that is repeated on four occasions is the "excess of material at the end of the handle", this is a characteristic that can be reviewed and eliminated in further cases of personalisation. The other most common situation, with four mentions, was not having the proper length; in the case of Participant #4, the big length could be produced as a consequence of an excessive squeezing during the hand printing. In the case of Participant #2, the excess material at the end of the handle was removed because it had a big elongation. The second most mentioned factors were having a thin neck and discrepancies in shape between the hand and the handle. The slimming of the neck could be caused by a strong grip during the printing of the hand. The third most mentioned factor was the indentations, that, in the two cases in which it was mentioned, was a disadvantage rather than an advantage.

Considering these factors, it could be possible to conduct walking handle personalisation, towards the making of better results.

8.6 Dimensional analysis of personalised handles

The reasons of the selection of a specific handle vary per participant, but a physical analysis of the changes of the personalised handles could help to determine if there is a relation between the modification suffered and its selection as the best handle. This analysis will be conducted in this section.

The nine personalised handles will be compared with the standard model in order to know what deformation each one suffered. The results will determine whether there is a relation between the grade of deformation of the personalised handle and its selection as the best; specifically, whether the personalised model was chosen as number #1 when it suffered a different level of deformation.

8.6.1 Methods

To analyse the differences between the personalised handle and its original shape (the standard version), two methods are used:

a) Comparison utilising Geomagic Control X software.
b) Comparison through dimensions.

8.6.1.1 Comparison - Geomagic Control X software

A comparison was made between each personalised model and the standard one; the differences can be seen through a scale of colours that represents values from -10 mm (or lower) to +10 mm (or higher). The results are shown in Figure 8.6:

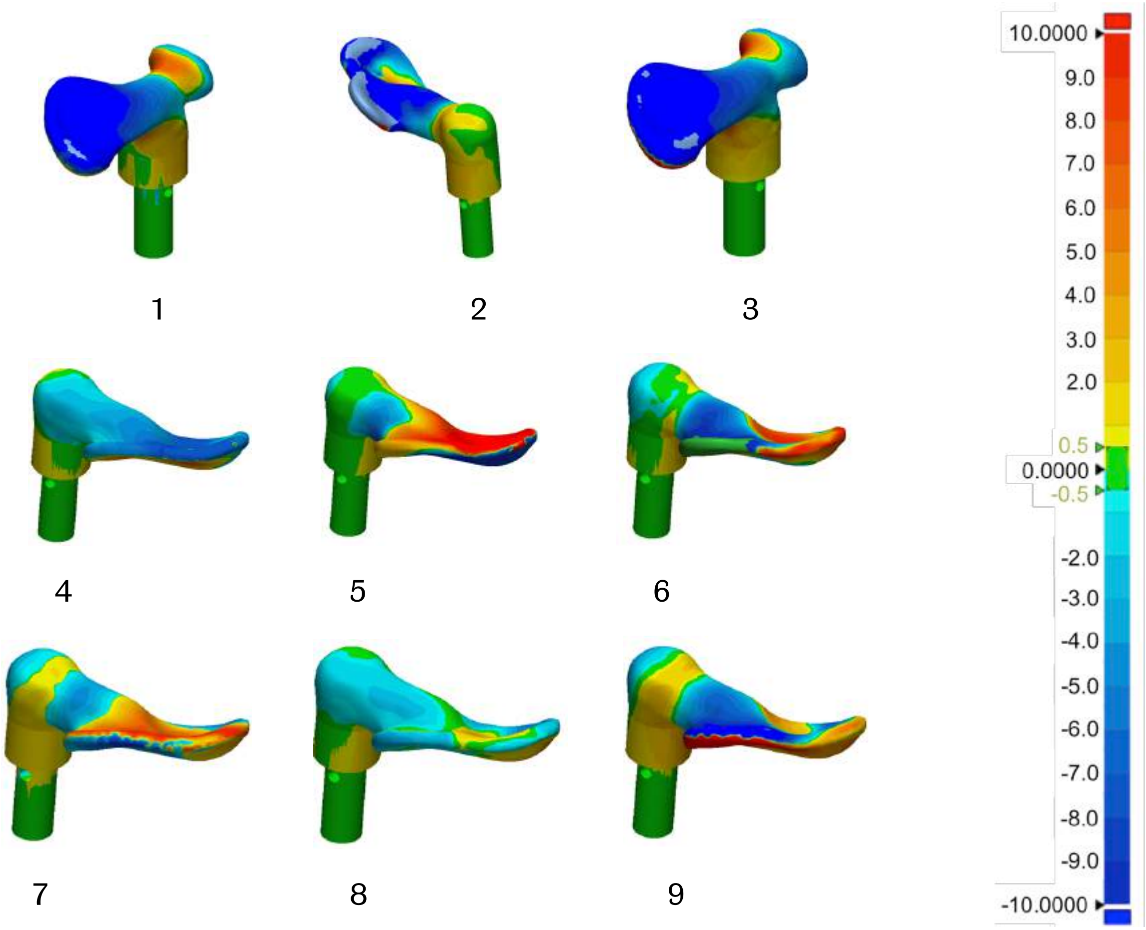

Figure 8.6 - Nine personalised models compared to the standard handle

The green area indicates the differences of both models in a range from -.5 mm to +.5 mm (in other words, minimal variation); the warm colours (yellow, orange and red) display an accumulation of material of the personalised handle in comparison to the standard one; and the cold colours (light, medium and dark blue) denotes a reduction of material.

These representations in colour show that there are two personalised handles that show the lowest differences related to the standard model; these are handles #4 and #8 as the colour of their surface is mostly in light blue. Quantitatively, this can be demonstrated with the standard deviations of the handles, these values are shown in the Table 8.10, along with other results such as the minimum and maximum deviation value, the average of the deviations and the percentage of the handle inside and outside the tolerance ± .5 mm.

Comparison	Min. deviation value	Max. deviation value	Average of deviation values	Std. Dev.	In Tol. (%)	Out Tol. (%)
Pair 1	-16.95	18.00	1.14	7.72	11.9517	88.0483
Pair 2	-32.87	35.61	2.13	8.00	17.3751	82.6249
Pair 3	-23.49	28.15	2.28	11.41	8.7785	91.2215
Pair 4	-8.33	8.77	0.09	3.25	20.4634	79.5366
Pair 5	-10.75	29.20	3.11	7.72	18.4901	81.5099
Pair 6	-29.24	27.24	3.40	8.80	14.137	85.863
Pair 7	-11.05	18.73	1.98	5.36	3.631	96.369
Pair 8	-5.02	12.40	1.03	2.56	24.3394	75.6606
Pair 9	-33.67	33.49	2.43	8.13	9.5609	90.4391

Table 8.10 - The standard deviations are shown in the fifth column; also, minimum, maximum and average of the deviations and % of the part inside and outside the tolerances

According to the values of the standard deviation, the personalised handles closest in geometry to the original handle are #8, followed by #4 and then #7 (shown in a thicker border). From these three handles, only #8 was selected as a preferred one.

This information demonstrates that there is no relation between the overall difference of the personalised and standard models and the user's preference.

However, a deformation in a particular zone of a handle could affect the decision of the selection. This will be analysed in the following section through dimensions.

8.6.1.2 Comparison - Dimensions

For this type of comparison, the dimensions for each type of handle will be defined. For the ergonomic model they are shown in Figure 8.7. Table 8.11 summarises the values of these dimensions for the Participants #1 and #3 (the two participants who selected this model in session #1) and Table 8.12 contains the differences of the dimensions of the personalised handle regarding the standard version.

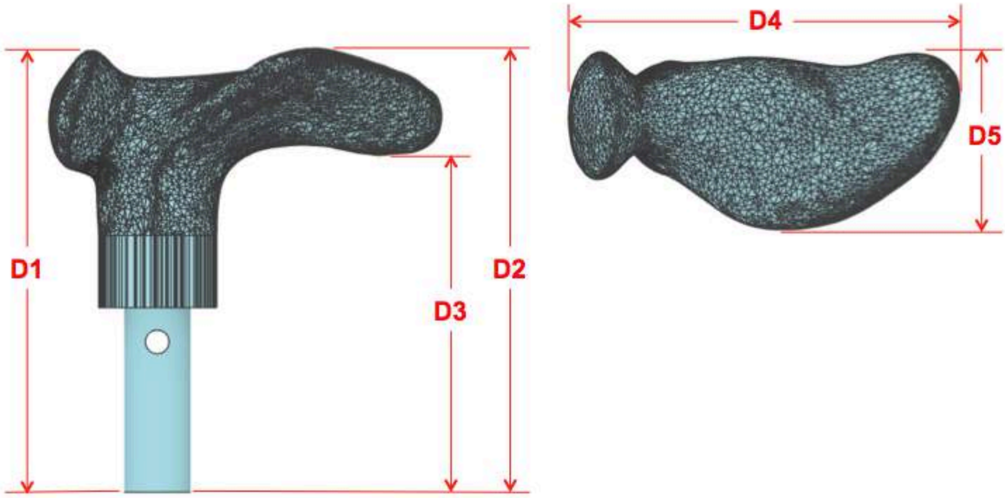

Figure 8.7 - Dimensions selected for the ergonomic handle

	D1 Height - knob	D2 Height - palm	D3 Height - bottom	D4 Length	D5 Width
Ergonomic	129.33	130	98.62	112.26	57.44
P1	130	116.1	81.56	112.18	52.31
P3	130	109.52	70.85	112.76	53.79

Table 8.11 - Dimensions (mm) of standard ergonomic handle, personalised model #1 and #3.

	D1 Height - knob	D2 Height - palm	D3 Height - bottom	D4 Length	D5 Width
Ergonomic	129.33	130	98.62	112.26	57.44
P1	0.67	-13.9	-17.06	-0.08	-5.13
P3	0.67	-20.48	-27.77	0.5	-3.65

Table 8.12 - Differences in mm of personalised models in relation to the standard handle

The two personalised models, #1 and #3, did not have a significant change in length (D4). In width (D5), model #1 is 5.13 mm smaller than the standard and model #3 is 3.65 mm smaller, which could have influenced the comments of Participant #1: "(the personalised model) doesn't cover as well", and Participant #3 mentioned: "short on the wrist side".

In relation to the heights, D1 had a little variation of .67 mm bigger in both cases; however, D2 had a downfall of 13.9 mm in P1 and 20.48 mm in P3 also, in D3 there was a decrement of 17.06 mm in P1 and 27.77 mm in P3. The differences in D1, D2 and D3 in comparison to the original were caused by excessive pressure exerted vertically during the hand printing process. Figure 8.8 shows this difference in heights for both cases:

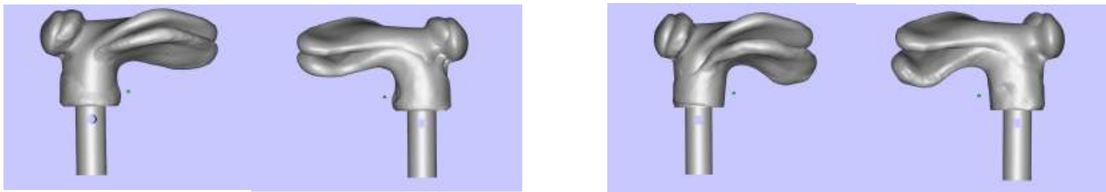

Figure 8.8 - Comparison of the personalised handle with the standard model. Left - Participant #1. Right - Participant #3

The personalised model #3, which had the major differences in height in the palm area (D2 and D3) was not selected as a preferred one by the participant.

For the Fischer model, the dimensions selected are shown in Figure 8.9 and the results and differences in models are described in Table 8.13 and Table 8.14:

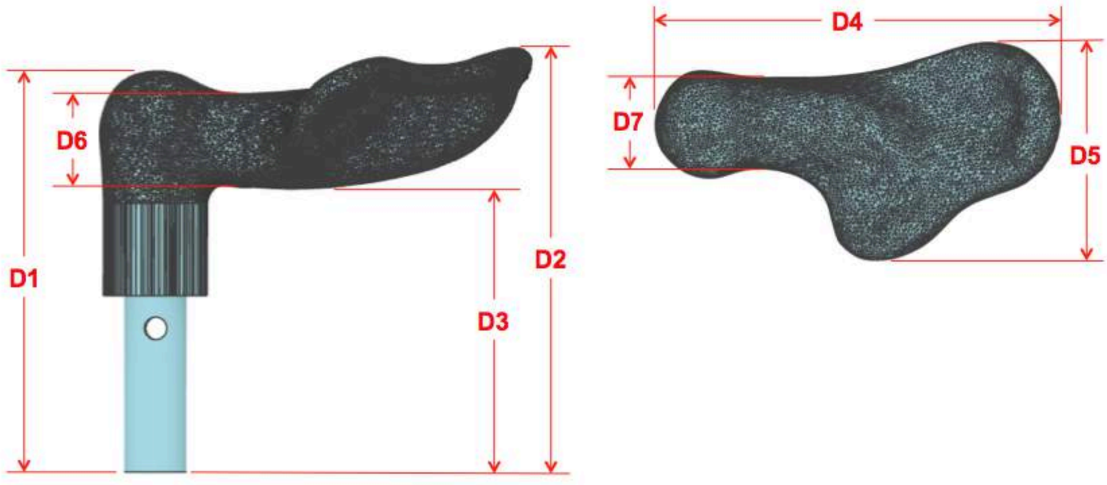

Figure 8.9 - Dimensions selected for the Fischer handle

	D1 Height - knob	D2 Height - palm	D3 Height - bottom	D4 Length	D5 Width	D6 Neck - side	D7 Neck - top
Fischer	122.77	130	86.7	132.75	74.81	28.01	29.91
P2	122.59	113.37	79.16	139.82	59.65	26.42	25.07
P4	122.59	122.52	82.16	130	70.25	27.41	28.83
P5	122.59	156.99	89.15	125.95	80.39	27	27
P6	122.59	154.33	79.94	142.21	80.75	27.46	30.06
P7	122.59	147.01	82.67	140.62	67.24	27.69	25.17
P8	122.59	130.55	83.5	134.77	71.83	29.63	29.72
P9	122.59	135.79	77.84	135.58	79.99	30.26	29.74

Table 8.13 - Dimensions (mm) of the standard Fischer model and personalised models, #2, #4, #5, #6, #7, #8 and #9

	D1 Height - knob	D2 Height - palm	D3 Height - bottom	D4 Length	D5 Width	D6 Neck - side	D7 Neck - top
Fischer	122.77	130	86.7	132.75	74.81	28.01	29.91
P2	-0.18	-16.63	-7.54	7.07	-15.16	-1.59	-4.84
P4	-0.18	-7.48	-4.54	-2.75	-4.56	-0.6	-1.08
P5	-0.18	26.99	2.45	-6.8	5.58	-1.01	-2.91
P6	-0.18	24.33	-6.76	9.46	5.94	-0.55	0.15
P7	-0.18	17.01	-4.03	7.87	-7.57	-0.32	-4.74
P8	-0.18	0.55	-3.2	2.02	-2.98	1.62	-0.19
P9	-0.18	5.79	-8.86	2.83	5.18	2.25	-0.17

Table 8.14 - Differences in mm of the personalised Fischer related to the standard one

Analysing Table 8.14 in D4, there were variations in the deviations in length from -6.8 mm to 9.46 mm, the two selected personalised models (#8 and #9) obtained the lowest positive values; that means they were closer and bigger than the standard type dimension. In width (D5), the highest difference was obtained by P2 with a reduction of 15.16 mm and this was the only participant that stated specifically that the handle was too narrow. In D2, the handle of P2 had a decrement of 16.63 mm and the participant had mentioned that the surface of the personalised handle was "too moulded" and that it was not possible to fit the hand on its surface. Higher than the value of P2, are P5, P6 and P7 who had the highest deviations in D2. P6 and P7 had mentioned that one of the disadvantages of the personalised handle was the additional material and this is reflected in the value of deviation. D3 did not influence the selection because P9 obtained the highest difference and this participant chose the personalised handle. In D6 and D7, the two participants that selected the personalised handle (P8 and P9) had the highest increment in neck.

8.6.2 Conclusion

For this study, the results of the comparisons with Geomagic Control X provided a general statement about the deformations between the two handles and visually showed their changes; however, the information obtained using the second method indicated the key parts of a handle that could influence its selection as the best.

In the Fischer model, dimensions such as overall length (D4) and overall height in palm (D2) influenced the decision; in D4 and D2 according to the results, the highest differences (in increment and reduction of material) belong to personalised models that were not chosen as the preferred ones. It was the same in the ergonomic handle for D2, but ergonomic models did not show a significant variation in D4.

In the Fischer model, the five handles that were not chosen had the highest differences (in increment and reduction of material) in the overall width (D5), stating that a variation in this dimension affects the selection of the ergonomic handle, but high variations in D5 did not.

In the Fischer model, the increment of material in the neck (D6, D7) also provided favourable results.

It can be seen that there was a decrease in six out of seven cases (considering the Fischer model) in D3 (height of the bottom of the handle) but this dimension did not affect the selection. But in the ergonomic handles, the model with the biggest decline in D3 was rejected.

Therefore, in Fischer models, the overall height in palm (D2), overall length (D4), overall width (D5) and neck (D6, D7) were the most influential measurements in ergonomic handles (D2) and (D3) influenced in its selection.

These influential dimensions are related to the participant's choices, for example, the personalised handle of P2 was rejected by the participant since the curves of the handle had flattened, thus, the height decreased. Also the width and neck were not suitable for them. P6 and P7 stated that they did not choose their personalised option because it was too long for their hand and it hit against their wrist, they also mentioned the neck was too narrow for them.

This represents that during the hand printing, an excessive vertical pressure over the handle must be avoided because it can cause a diminution or an increment in height of the overall handle (D2) (D3); also, high variations in (D4) and (D5) should be avoided and reductions around the neck, the latter caused by an excessive force applied during the gripping.

8.7 Most significant considerations relating to handle preference

The scores of the factors given by every participant are shown from highest to lowest importance in Table 8.15:

Factor	P1	P2	P3	P4	P5	P6	P7	P8	P9	Average
1. Comfort on hand	10	10	9	10	10	10	10	9	10	9.78
7. Stability in movement	10	10	10	7.5	8	10	10	9	10	9.39
2. Comfort on wrist	10	10	8	10	9.5	10	10	6	10	9.28
3. Intuitive shape	9	10	9	10	9	10	10	7	8	9.11
5. Support on hand/fingers	10	10	9	6	9	10	10	10	7	9
4. Ease of maintaining grip	10	8	10	7.5	8	10	7	9	8	8.61
6. Stability in static posture	10	10	9	7	10	6.5	10	5	9	8.5
8. Appealing to the user	2	10	8	6	7	5	8	8	5	6.56
9.Psychological confidence to use it	-	10	-	-	-	-	-	-	-	-
10. Material	-	-	9	-	-	-	-	-	-	-

Table 8.15 - Importance rating of each factor

On average, “comfort on hand” (1.) was the most important factor for the participants, followed by “stability of the user during movement” (7.) and then “comfort on wrist” (2.). “Appealing to the user” (8). was the least preferred aspect.

During the session, and before the researcher mentioned the list of factors, “comfort on hand” had been stated by eight of the participants as one reason for scoring a handle; “stability of the user during movement” or only “stability” was not mentioned; and “comfort on wrist” was mentioned three times. This means that comfort is a characteristic that users consider a handle must have, and aesthetics, which coincides with literature. It establishes that aesthetics is a desirable characteristic when it is possible, but function is still more important. Although participants did not mention functionality, this is another characteristic that a handle must have.

8.8 Additional considerations

8.8.1 Manufacturing

To understand differences of walking stick handles related to their manufacturing, the following three categories are proposed:

a) Simple standard. This category includes walking stick handles that are already available on the market and have non-ergonomic shapes, such as crook, crutch and pistol grip styles.

b) Ergonomic standard. It comprises already commercialised anatomical walking stick handles such as the Ergonomic and Fischer.

c) Produced with AM. These handles are created via AM and they can have a standard shape or be modified until they achieve personalised features.

Each classification will be analysed under the following aspects:

8.8.1.1 Range of options

a) Simple, and b) ergonomic standard

Simple and ergonomic commercial handles, such as crook, crutch, pistol grip ergonomic and Fischer, can be found in different options, these are shown in Table 8.16:

	Crook	Crutch	Pistol grip	Ergonomic	Fischer
Sizes	Variety of sizes	Variety of sizes	Variety of sizes	One size	One size
Handle used by right or left-handers	Model can be used by both hands	Model can be used by both hands	Model can be used by both hands	Right hand grip Left hand grip	Right hand grip Left hand grip

Materials	Wood Metal covered with foam/plastic Rubber	Wood Plastic Aluminum alloy with sponge cover	Wood Acrylic	Wood Plastic	Wood Acrylic Plastic Rubber
Textures	Smooth-wood Smooth-plastic Foam	Polished wood Polished plastic Sponge	Polished wood Polished acrylic	Smooth-wood Polished plastic	Soft-touch coating on wood/ plastic Polished/cracked plastic

Table 8.16 - Choices of crook, crutch, pistol grip, ergonomic and Fischer handles*.

***Description of walking sticks on websites does not provide the dimensions of the handle**

c) Produced with AM

The choices of handles produced with AM are shown in Table 8.17:

	Handle produced with AM
Sizes	A 3D printed handle can be manufactured in a broad range of sizes. The maximum dimensions of the part depend of the capacity of the machine, for example, the LS machine EOS P100 can print a part up to 200 mm x 250 mm x 330 mm.
Handle used by right or left-handers	A handle can be produced for right or left-handers.
Materials	In plastics, EOS LS machines can print in polyamides (PA), polystyrenes (PS), thermoplastic elastomers (TPE) and polyaryletherketones (PAEK). AM technology can use: metals, plastics and composite materials.
Textures	A variety of textures can be created in a 3D printed part; its surface can be modified until the desired finish is obtained. This modification can occur before or after printing. Examples are, but not limited to raw material, smooth, semi-rough, cracked and bumped.

Table 8.17 - Choices for a 3D printed part

For simple standard handles, a big variation in shapes is not found for crook, crutch and pistol grip, but these handles can be acquired in different sizes; in the case of the crook style, it is produced in different diameters.

There were no options for variations in shape in ergonomic and Fischer handles, only, as they are anatomical models, they were found in two versions, for right and for left-handers. The only modification option for these types of walking sticks was on the appearance of the shaft.

For handles produced via AM, it is possible to create a variety of complex, organic and adapted shapes and modifications in size, shape and in the creation of continuous or different textures over the same handle.

8.8.1.2 Variation in price

a) Simple, and b) ergonomic standard

Table 8.18 shows some examples of prices of the “Simple” and “Ergonomic” commercial models, such as crook, crutch, pistol grip, ergonomic and Fischer. The price of the crook style can vary around £6.00 to £50.00 depending on the material, shaft and base; also, the addition of elements such as crystal could increase the price. The price of a crutch model can be around £3.90 to £35.94, or more, depending on the material of the handle, shaft and base. Prices for the pistol grip are around £13.59 to £55.95, but more expensive models can be found according to its material. Prices for ergonomic models varied around £8.75 to £48.00 but special and more expensive models were found with prices of £90.00 for the pistol grip, £60.00 (standard) and £87.50 (personalised) for the ergonomic one. For the Fischer walking stick special models were found at £68.99, even though a regular range of prices were between £4.38 and £34.99. In this search, it can be seen that the pistol grip had less options available on the market compared to the other four models and the cheapest version found of the pistol (price - £13.59) was the most expensive among the four models.

	Crook	Crutch	Pistol Grip	Ergonomic	Fischer
1	£5.34 [218]	£3.90 [219]	£13.59 [220]	£8.75 [221]	£4.38 [222]
2	£8.09 [223]	£6.99 [224]	£23.95 [225]	£9.42 [226]	£10.79 [227]
3	£11.27 [228]	£11.27 [229]	£36.99 [230]	£10.74 [231]	£11.94 [232]
4	£17.99 [233]	£12.99 [234]	£43.99 [235]	£12.11 [236]	£14.10 [237]
5	£21.35 [238]	£19.99 [239]	£44.99 [240]	£12.49 [241]	£20.99 [242]
6	£23.99 [243]	£23.99 [244]	£47.84 [245]	£14.60 [202]	£24.99 [246]
7	£29.99 [247]	£27.06 [248]	£48.00 [249]	£18.47 [250]	£26.99 [251]
8	£31.99 [252]	£27.49 [253]	£52.99 [254]	£22.99 [255]	£32.99 [256]
9	£42.99 [257]	£28.99 [258]	£55.95 [259]	£24.99 [260]	£34.99 [261]
10	£49.99 [262]	£35.94 [263]	£90.00 [264]	£48.00 [265]	£43.99 [266]

Table 8.18 - Examples of ten walking sticks per type

Commercial models, such as crook, crutch, pistol grip, ergonomic and Fischer can be acquired directly in store or through company websites; they usually have delivery times between one to five working days. One of the pistol grip models stated that for handmade walking sticks the delivery was approximately four weeks. It was found that one standard ergonomic walking stick took up to ten days for delivery and ergonomic personalised walking sticks (pattern applied over the shaft) between seven and ten working days. But generally, the commercial walking stick can be acquired within five working days, in a range of £4.00 to £50.00.

c) Produced with AM

For a handle produced with AM, the relative price is calculated considering factors such as the AM technology, the material cost, size of the part, company profit, among others.

Table 8.19 indicates differences in price of the same 3D printed part, but using different suppliers, in this way, an average market price can be obtained. The parameters used were laser sintering as the technology method and the material is nylon-12 powder, which is acquired as PA 2200, it is a polyamide with properties such as ductile, impact resistant, strong [267], low water absorption and deformation temperature up to 83.5 °C [268].

Considering these characteristics, the price for one personalised handle with dimensions of X: 63.1 mm, Y: 133.0 mm and Z: 130.3 mm and a volume of 144.10 cm^3 was calculated.

Company	Technology	Material	Price	Lead time (working days)
ProtoLabs [269]	SLS	PA12 White	£142.23	-
3D Hubs [270]	SLS	Nylon 12	£70.00	6 days
RICOH [271]	SLS	PA 6	£96.00	5 days
Materialise [272]	SLS	PA12	£58.86	5 days
LAVA (China) [268]	SLS	PA12	£64.65 (production) £81.43 (with delivery)	7 days
Craftcloud (Belgium) [273]	SLS	Nylon	£70.39 (Production) £79.01 (with delivery)	6-7 days
Ogle [274]	SLS	PA2200	£91.17	-
Sculpteo [275]	SLS	Nylon PA12 100-120 µm	£86.25 £123.23	7 days 2 days
3D Print UK [276]	SLS	PA 2200 Nylon	£80.59 £161.18	7-12 days 2-4 days
Xometry (Germany) [277]	SLS	PA12 White	£70.96 (production) £125.05 (with delivery)	10 days

Table 8.19 - Prices of a personalised 3D printed handle given by different suppliers

Considering the longest lead-time, which is, on average, seven working days, the price of one personalised 3D printed part would be around £76.00.

Despite the higher price of one personalised handle vs. a commercial one, there are studies that prove that the cost of one 3D printed part can be lower than a part produced using a conventional method when there is a production of thousands. Hopkinson and Dickens [278] made a cost analysis to compare one part produced with layer manufacturing processes vs. a part produced with injection moulding. The layer manufacturing methods used were stereolithography (SLA), fused deposition modelling (FDM) and laser sintering (LS) and they considered that these machines were going to be producing during one year and with a simultaneous production of several parts.

From the four processes, the cost (in euros) per one part of 35 mm in length was, SLA, €5.25 (£4.70); FDM €4.47 (£4.00); LS €2.20 (£1.97) and using injection moulding €0.23 (£0.21) plus €27,360 (£24,489.42) of tool cost.

From the three 3D printed techniques, LS provided the part with the lowest individual cost and this, compared to the injection moulding allows cheaper parts to be produced until a volume of approximately 14,000 parts is achieved, considering that LS is able to print several parts simultaneously; for this study 1056 nylon parts were printed on an EOSP360 machine, therefore, the size of the part also influences the price, since smaller parts allow a higher simultaneous production.

8.8.2 Personalisation method

For this study, a personalisation method that involves manual and technological resources was used. The steps followed are shown in Figure 8.10:

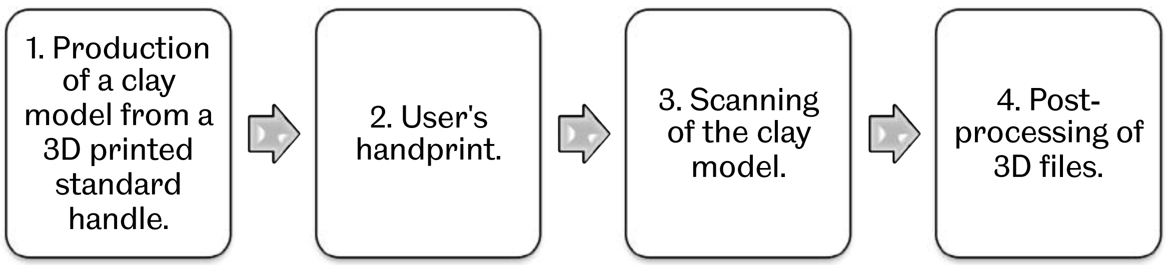

Figure 8.10 - Previous steps of the 3D printed production of personalised handles

Technological resources such as scanning and post-processing of 3D files were possible since the production of the handles was via AM, therefore, it allowed to work directly with already compatible tools such as scanning or already available software for fast modification or enhancement of digital files. Manual resources were used because it was necessary to capture the user's grip which means that their hand should be in the position of use, therefore, its capture gripping a real handle was the most accurate way of obtaining that printing.

The entire process resulted in the printing of the user's grip; however, the main limitation was the excessive change resulting in an accumulation or reduction of material in some areas. There were two handles in clay that suffered a notable deformation while hand gripping was taken, caused by the pressure applied. The hand printing of P7 was taken twice because the first handle in clay was torn during the gripping. On the other hand, the personalised handle of P2 showed a visible variation when it was compared to the original version (standard model) because a high pressure was applied.

Besides the personalisation process used in this research, other methods exist for achieving or capturing personalisation, such as:

a) Physical impressions of the required part on materials.

b) Capturing the form using moulds.

c) Manual adaptation of the material to a user's limb.

d) Scanning the user's limb directly.

e) Scanning the place that has the impression of the user's limb.

These five methods may differ in aspects such as simplicity, speed, cost and accuracy. The simplest process among them are generally a) taking a physical impression of the part directly in a material, there are usually two elements for conducting it, the part and the material that will collect the form, for example, the impression of teeth on alginate; after this, the c) manual adaptation of material to a user's limb for example to adapt a sheet of warmed plastic to a limb in order to produce a splint, then d), b) and e) since this step is usually conducted after another personalisation process. Speed is related to the simplicity of the process, therefore, the positions are the same than the previous, from the fastest to the slowest the positions are a), c), d), b) and e). Cost can be related to the material used in each process but, generally, using technological resources will increase the price as in the case of d) and e) where scanning is used, but e) will be more expensive than d) because of the additional step needed which is the first impression to be scanned. Commonly, accuracy is related to cost, thus, the most expensive procedures will result in the most accurate, but sometimes cost-effective processes are still accurate, for example, the impression of teeth using alginate, which should be well conducted with accurate results in order to obtain exact physical models.

There are some personalisation processes that require the implementation of more than one of the previous methods, for example, for the present study, a) physical impression on a clay handle and e) scanning the clay handle where necessary but, prior to this, it was necessary to create a mould, not for capturing the form of a printed part but for producing the clay handle that would be used in a).

Each of these steps adds more production time to a regular 3D printed handle, this is shown in Table 8.20:

Activity	Time	Total additional time
1. Production of a clay model from a 3D printed standard handle. This involves: - Production of a silicone rubber mould. - Production of the clay handle.	25 hours 2.5 hours	~ 36 hours.
2. User's handprint.	30 minutes	
3. Scanning of the clay model	4 hours	
4. Post-processing of 3D files.	4 hours	

Table 8.20 - Total additional time due to personalisation activities

These four steps also add costs to the production of one 3D printed handle. They are displayed in the following Table 8.21:

Activity	Material used	Total price	Used per one model
1. Production of a clay model.	1. PVC foam board to make the containers. Size A1.	£3.60	£0.50
	2. Glue gun	£5.00	£5.00
	3. Glue sticks	£5.00	£0.83
	4. Polycraft GP3481-F silicone rubber 1.1k	£42.50	£21.25
	5. Three thick rubber bands (90 x 6mm)	£2.49	£0.50
	6. 125g of Monster Clay 5lbs (2.26796k).	£27.95	£1.54
2. User's handprint.	1. One flask 1l	£6.00	£6.00
	2. Fimo Soft Clay (57g)	£2.60	£1.30
3. Scanning of the clay model.	1. 3D Systems Sense (1st Gen) 3D Scanner	~ £385.00	–
4. Post-processing of 3D files.	1. Meshmixer software.	Free	–
	2. Fusion 360 Autodesk software.	Educational license	–
	3. Inventor Autodesk software.	Educational license	–
	4. 3DCoat software.	Free – 30 Trial £359.60 – Permanent professional license	–
	5. Magics software.	Advanced Polymer Sintering Laboratory	–

Table 8.21 - Prices of materials used

The previous factors increase the price of one personalised handle, they are shown in Table 8.22:

Material/Equipment	Amount
1. PVC foam board	£0.50
2. Glue gun	£5.00
3. Glue sticks	£0.83
4. Polycraft GP3481-F silicone rubber 1.1k	£21.25
5. Three thick rubber bands	£0.50
6. Monster Clay	£1.54
7. One flask 1l	£6.00
8. Fimo Soft Clay	£1.30
3D printed handle	£76.00
TOTAL	~ £112.92

Table 8.22 - Relative final price of one personalised handle

The relative final price of a personalised handle is around ~£112.92, compared to ~£50.00 of the standard handles (price of one of the most expensive models), this represents an increment of 2.26 times. Related to lead time, besides the seven working days, 36 hours will be added; the result is nine working days.

Handles produced through AM have a higher cost and lead time than the simple and ergonomic commercial models; also, there is a higher effort in acquiring a personalised model because face-to-face sessions are necessary to choose a handle as a base and for printing the hand. However, the number of choices in sizes, materials, textures and personalisation are superior.

8.8.2.1 Positive factors in the personalisation process

The following steps are considered as favourable for the personalisation process:

- Obtaining the handprint while the participant is gripping a handle. This is a reliable way to capture the gripping because a reproduction of the preferred handle is used.
- Obtaining the handgrip in a handle that is connected to a commercial shaft. After the handprint, this connection helps the participant to walk and review the comfort they feel with the printing made.
- Possibility of adding clay (white colour) to improve the user's support.
- Production of a silicone rubber mould. This material is easy to prepare, solid but also flexible enough to cut in two halves and split it without suffering

deformation, this allows the material to be poured into one single container and takes only one cut to de-mould the part instead of planning and making a more elaborate mould. It also captures details of the 3D printed handle.

8.8.2.2 Negative factors in the personalisation process

Some of the steps did not contribute to achieving the most optimal result:

- A significant modification between the original handle (standard) and the personalised one could have been produced due to the pressure applied during the hand printing as the participants may lean on it.
- A participant mentioned that the preferred option (the standard handle) fitted their palm ok but it was short in length, which could have been corrected in a personalisation process, in this way the participant could have obtained the advantages of the standard in terms of shape but adapted to the length of his hand. With this specification and restriction in design, personalisation can be achieved. This leads to thinking that the personalisation process in walking stick handles could work better with guidelines or limits.
- Structure of the clay model. Even though the clay model was easy for the participants to modify, the lack of guidance in its deformation was relevant. In some hand printings, there were areas of the handle were the deformation was excessive, and this brought as a result: reductions on neck, flatter curves, and an additional elongation in handle length.

8.8.2.3 Proposed solution in the personalisation process

The handle should have a strong inner structure that establishes limits in deformations concerning width, length, neck and curves. It is more suitable that this structure connects directly with the commercial shaft in order to avoid movement in the handle during the trial. However, the surface of the handle should continue be malleable; for this reason, the use of clay is still considered.

The solution is to create a smaller 3D printed handle and place it in the centre of the silicone mould, after this, the heated Monster Clay will be poured into the mould, therefore, the resulting part will have the 3D printed part as a core and the outer in clay.

8.8.3 Justification for personalisation

Personalisation will be conducted where an ergonomic standard handle does not completely satisfy the user after interaction with it. This dissatisfaction can occur due to a special requirement of the person.

However, personalisation concerning sizes may be considered as well as the increment of the range of textures. A variation on the application of textures can be useful for a user if various textures are applied within the same handle, achieving a personalisation on the pattern.

9 CONCLUSIONS, LIMITATIONS, CONTRIBUTION TO KNOWLEDGE AND FURTHER WORK

This study was focused on evaluating the potential of additive manufacturing for personalised assistive devices. Findings are described in the following sections.

9.1 Conclusions

9.1.1 Area of most potential benefit

It was found that handheld devices have the potential to benefit a high number of people who suffer from diseases and activities since upper limbs are used to conduct many of them; even, activities that mainly use lower limbs such as walking sticks or walkers, utilise upper limbs to be completed. Also, handheld assistive devices are benefited through personalisation as they are in direct contact to the user and a better match between them and the user improves their function.

9.1.2 Shape, size and texture

Variations of the selected assistive device provided the user the possibility of being aware what they need finding a more suitable match between them and the product. A range of options in shape, size and texture allowed participants to compare and conclude their preferences towards the two anatomical types and application of rougher textures.

9.1.3 Personalisation process

Personalisation process should be conducted considering aspects such as but not limited to, the part that is required to be printed and in what position will be used, required quality that is linked to the function product, delivery time and resources available such as material and equipment. Technological and manual resources can be both used in a same process as they can complement each other when there is a lack of one of the previous aspects. Also, it is essential to avoid possible additional deformations during the printing through the use of guidance or restrictions in the process and evaluate the level of detail required in the printing of the product, for example, in the case of a walking stick handle, it was mentioned that grooves were not always favourable for the user as it was difficult to find indentations for fingers and they could limit the freedom of reposition them.

Also, it is important to consider AM in a personalisation process because besides its ability to produce organic and complex parts, it is compatible with 3D scanning which enables to capture data from limbs or impressions of parts.

AM also is related to the use of software, where it is possible to clean and prepare digital files for printing, and also, some of them have developed galleries of textures, which can be applied into digital models and offer a variety in patterns.

9.1.4 User's perception and preferences concerning personalised and non-personalised handles

There was no consistent preference regarding the personalised handles, users tended to perceive a better shape and comfort in non-personalised versions. Due to the personalisation process, the overall shape of the handle may suffer a modification and this may not be attractive for users who could prefer an overall comfort rather than specific features adapted to them (with additional no needed modifications in other areas).

A change to an ergonomic non-personalised handle may bring an improvement, especially for crook and crutch handle users.

9.1.5 Potential benefits and/or disadvantages of personalising

In this study, no inclination for personalised walking stick handles was shown, but it may be worth applying and evaluating personalisation in other types of assistive technology devices.

For some people, personalisation in handles is not so beneficial because depending of their disease, the condition of their hands could vary from day to day and it is not linked to a single shape, hence personalisation for one scenario can cause the loss of freedom in other situations.

9.2 Limitations

The limitations of the study are found in the following aspects:

9.2.1 Data saturation in focus group

Considering the six recommended parameters for data saturation mentioned in section 5.2, a suggested sample size for this investigation would be around four focus groups reaching around 80% of saturation. Although only two sessions were conducted, data saturation is verified until the analysis of the collected data.

The codes in this study for seeking saturation are: assistive devices supporting challenging activities, getting up, getting out, toileting, bathing, moving about the living quarters, moving outside the house, eating, drinking, dressing, inability to lift the feet, dropping things, slipping, falling, memory failure, sensory impairments, walking stick, grab rail, device fixed on the wall, variety of colours, different materials, rougher surface, durability of materials, difficult to use, comfort, coordination of device with other areas of the house, proper adaptation of device in the house, ability to place things on the device, unsafe device, design problems, not useful device, adaptability of device, rehabilitation through device and splint for leg.

As a result, the total number of codes identified in the study was 34; from these, 19 (56% of the codes) were reached in the first focus group and 15 (44%) during the second session. The limitation with conducting two focus groups is that it is not clear whether more codes will appear in a following third session, therefore, it is restricted to demonstrate that data saturation was achieved with two sessions.

In this study, a prior focus group was conducted as a trial session, and there, some of the codes appeared for the first time, this provides the researcher with a more clear idea about what type of information or topics may arise in the official sessions. On the other hand, a higher number of focus groups could have provided more information about different topics and the achievement of data saturation, but the availability of participants was limited, perhaps because one of the groups with the required profile (carers) may spend part or most of their time helping their relatives.

9.2.2 Personalisation factor

One of the influential factors in the device selection process was the level of personalisation in each product. To obtain this level, three questions were asked per product, involving aspects where personalisation could influence: user, product itself and process; however, there is a limitation in this assessment because the values obtained per aspect (user, product and process) were provided based on the researcher's criterion. There were products where the assignation of points (from 1-lowest score to 3-highest) was clearer than in other cases. For example, the benefit for a user of a personalised product version was clear for a splint and it obtained the maximum value (3), for a plastic signature guide, the need for personalisation is lower and it obtained 1, but for adapted cutlery the need for personalisation could be high for some users but for others it could be less relevant and in the case of this study, the assigned value was 2 but it was given considering the researcher's subjectivity.

Although, it could be necessary to develop guidance that establishes more parameters for obtaining an absolute scoring, as a result of the evaluation conducted, a suitable device was selected for this study.

9.2.3 Wider professional knowledge

There were some points during the study where the involvement of more specialists could have been beneficial. One of these phases was during the initial device selection, that involved the analysis of impactful diseases, activities and level of personalisation in products, and after the selection of shortlisted devices, two focus group sessions were conducted. It was shown the benefits and the type of information provided by the focus group composed of specialists in the development of assistive devices. One of their attendees was an occupational therapist who provided a valuable output, but this participation was taken under the dynamic of this specific session and the type of questions were different to those that could have been asked in a focus group conducted with only occupational therapists. Therefore, the involvement of medical specialists or occupational therapists from the beginning of this phase can provide a general outlook about assistive devices and the collected data can also help to select the device.

If the availability of specialists or occupational therapists is limited in this stage, their contribution could be possible via other methods, not necessarily participating in focus group sessions, but for example, responding to a short electronic survey.

The hand printing process is another phase of the study where the presence of a specialist could have enriched the outcomes. In this case, an occupational therapist could have advised on a correct fit between the participant and the handle and, after the session, it could be relevant to obtain from the therapist the reasoning behind their advice and recommendations for next printings. Their experience and knowledge could bring unknown concepts and information to the study.

9.2.4 Pros and cons of the control handle

The control handle was created using the researcher's handprint and it was shown in each session alongside the personalised and standard handles; it provided control for the texture and size parameters as they remained equal in the three samples. Other similarities are, the control handle was based on the researcher's right hand and all participants tested this right-handed version; the material of the clay handle, where the print was taken, was the same used for the researcher and all participants. However, the applied pressure was uneven among the researchers and participants, as some of them applied pressure for longer or stronger. Also, there was less control concerning the shape parameter as each handle varied in this aspect.

It could be thought that the shape of the control handle could not represent exactly the same for each participant because of differences in their hands. Although there is a possibility that the researcher's hand was very similar to the hand of one participant and thus influencing the preference towards the control handle, this possibility is small; even in the case that this happened, both the participant and the researcher would grab the handle in different ways and apply pressure on different points, making it even more unlikely that the researcher's handle would end up being a good fit for any of the participants.

9.2.5 Device selection process

One of the limitations of the investigation in the early stages was to define the procedure for the selection of the final case study device. As it was mentioned, this was composed of seven steps considering key aspects as factors that influenced the final choice. Although there was a justification for each of the seven steps, there could be other criteria or important factors. These aspects were mentioned at the beginning of chapter 4; their impact in this study is explained in the following paragraphs:

Avoiding devices or activities with high intra-subject variability. This criterion did not have an impact in the study because there was no participant who needed to use the same device in several ways; due to the users' requirements they only utilised it in its original shape. If someone needed a device that could be adapted to different situations, instead of producing a handle that changes its shape during the day, several handles could be produced where each one supports different scenarios.

Including devices or activities with high inter-subject variability. Among participants, they wanted to use the device to conduct similar activities, therefore, the variability in this aspect is low; however, variability in shape is high as everyone needed a different option regarding form due to their hand's unique characteristics.

Impact on small and large groups. At the beginning of this study it was thought that creating a device for a large part of the elderly population would result in a bigger impact due to the number of people that would benefit from the device that was going to be designed. After finishing the study it was found that some people preferred the standard version of the assistive device and that those that chose the personalised one scored it between 90 and 95, and gave the standard one a value between 50 to 60. Therefore, due to the ranges of difference, it can be concluded that the impact of personalisation was not as high as expected. For smaller groups with more specific or extreme problems, personalisation might be able to have a greater impact since it is expected that the standard device would fail to satisfy the needs of this niche group. Therefore, the argument that there is a bigger impact in a small group rather than in a bigger population should be analysed in further studies.

Gross body and fine motor movements. During the analysis of the information collected from the focus group, figures and percentages of lost capabilities in people were obtained; in one study, “mobility” was mentioned as the most frequently lost, in second place was “reach and dexterity” and in another study, “mobility” was also the most affected ability and “dexterity” was in third place. If gross body movements could be related to mobility and fine motor skills related to “reach and dexterity”, it could be shown that AT devices that support gross body movements could have a higher impact on elderly people than those that support fine motor skills, but this should be demonstrated in additional investigations.

9.3 Contribution to knowledge

The main contributions of this study can be separated into those relating to the assistive device selection process, the personalisation process and, to an extent, the findings related to the benefits of personalisation in certain areas. These areas are discussed here.

9.3.1 Device selection

The methodology followed in the assistive device selection had the objective to find the most suitable device for the elderly population considering the most limiting diseases, the most affected activities and the level of personalisation. However, this approach could easily be adapted to other areas in which the identification of a suitable case study device would be appropriate. Figure 9.1 shows the flowchart of the main steps used in this investigation for the device selection process, the red arrows (horizontal shafts) represent suggested points to be included for other studies.

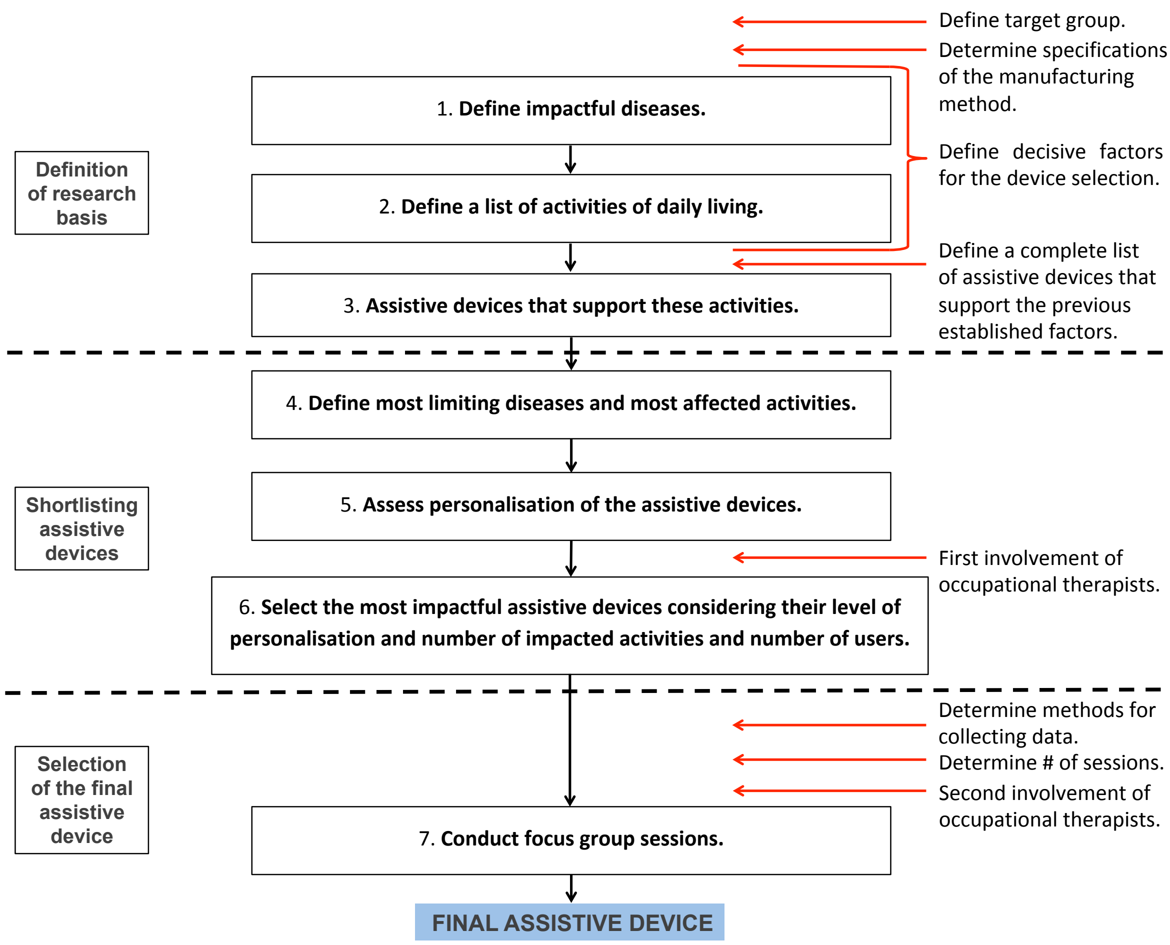

Figure 9.1 - Flowchart for selecting the assistive device including recommendations for further studies

When using this approach, the following specific points are suggested for consideration:

- Before planning the device selection process, the characteristics of the target group and any special requirements they have should be defined.
- Based on the characteristics of the target group, it is suggested to define what factors will be decisive for the device selection. For example, for this study, the target group was the elderly population, but as the illnesses that

they suffered from were not specified, several possible diseases where considered as parameters. Also, it was expected that all of the target group wanted to conduct independent activities, this is why two standards of activities of daily living were explored. However, if the target group was a group of children between 1 to 3 years old, it is not expected they should conduct all independent activities, therefore, the parameter of activities should be modified.

- Define details of other stages of the investigation such as a complete list of assistive devices that support the selected illnesses, activities or the defined factors; also determine the adequate methods for collecting data and the specifications on the manufacturing method.
- Involvement of occupational therapists who can provide their expertise and suggestions for the final device selection. It is recommended to include them after the definition of research basis and before shortlisting the assistive devices because, in this way, researchers could gain knowledge not only about key facts of the study prior to meeting the specialists but also about the existing assistive devices and will acquire their own criteria about which ones could be a possible solution. The interaction with the occupational therapists will help to share knowledge and confirm the most suitable options. Also, they can be included in focus group sessions.
- Determine an appropriate number of focus group sessions to achieve the required data saturation and, where necessary, conduct sessions classifying the participants per stratums (see section 5.2 for more information about data saturation and factors to consider).

9.3.2 Personalisation process

The personalisation process encompasses everything from the fabrication of the clay model to the 3D printing of the handles. Figure 9.2 shows a flowchart that contains some steps and questions that can help the researcher with the selection of the personalisation process.

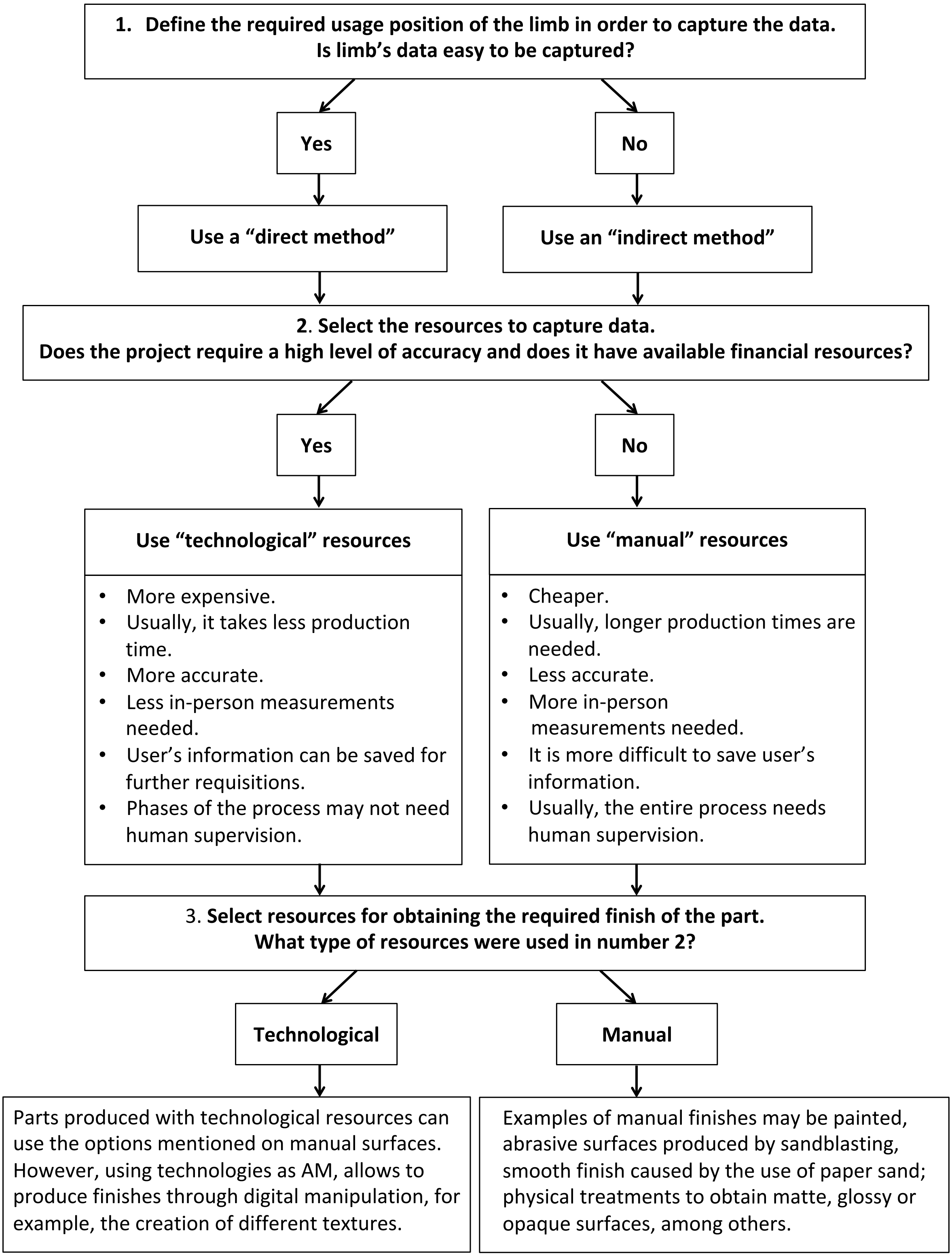

Figure 9.2 - Flowchart for selecting the personalisation process

There were several lessons learned in the personalisation process used in this study and as a consequence, these practice guides are recommended:

- Depending on the selected device and how easy it is to capture data in its position of usage, the method for obtaining the personalised information may vary; in this study, an indirect method was used because the hand was printed on clay and then the clay model was scanned; however, if the selected device was an orthosis for the leg, a more convenient option could have been to use a direct method, capturing the data directly on the limb without utilising an intermediary.
- It is important to consider the advantages of technological resources; when it is appropriate, the use of 3D scanning is recommended since this technology is compatible with 3D printing and accurate data could be captured. Also, technological methods can save the user's information for a further stage.
- Despite the advantages that the technological method provides, manual resources are also relevant, the capturing of data may require an expert to conduct a manual examination of the user's limb in order to achieve a more suitable fit between it and the product.
- It is suggested that an occupational therapist should be present in each personalisation session to advise how the process can be improved.
- If a printing is conducted, it is important to establish limits during the capture of data, this will avoid excessive deformation in the final model.
- If a model is required to capture a printing, investigate a material with a suitable malleability or, also, the printing can be achieved utilising a model with the required malleable material in the outer but with a non-malleable core to set a limit regarding extra deformations. In case the model requires the production of a cost-effective and reusable mould, the use of silicone rubber is recommended.
- During the post-process of 3D files, it is worth exploring technological resources such as software that optimises the creation of features in models. For example, software that includes modules for generating textures.
- The study also suggests that there could be several ways of producing assistive devices and each one will be chosen depending on the suitability it provides to the user. One of them is the personalised option; this works for a person that does not find a solution in existing or standard products and AM may be suitable for their manufacturing. The second option is the standard device that might work for some people who could even adapt it to themselves without struggling. The third means offers the user a range of

already designed options, where one of them might be the most suitable. If several versions of the same product are produced, each one could cover a broader population since it would be suitable for more than one individual. An example of this was observed in this study on the different types of shapes, sizes and textures that were offered to the participants, where one version of shape and texture, was preferred by more than one participant. The benefit of producing a higher volume of parts is that conventional and cheaper manufacturing methods could be used.

9.3.3 Benefits of personalisation

Whilst the results presented here are based on a relatively small number of people, some interesting findings have been uncovered which may provide some assistance in:

- In the study, 9 out of 9 participants found the ergonomic and Fischer models (both anatomic) more comfortable and, therefore, they were preferred over the other non-ergonomic versions (crook, crutch and pistol); this indicates that the basic or fundamental shape of a device has a big impact on the decisions of users. Their underlying shapes, including their width, natural forms, edges and curves are more similar to the user's hand in a position of gripping.
- It was mentioned by all current users of non-ergonomic handles that changing to the chosen anatomic model provided a big improvement since their current handles were scored from 0 to 30 and the chosen anatomic versions between 90 to 100. This is a positive indication towards the shape of the ergonomic handle.
- It might be expected that personalised versions of products provide more benefits than the standard option since they could solve specific conditions; however, the study shows that there was an inclination towards the preference of the standard version, this could indicate that the fundamental shape of a product has a high relevance for the user and, therefore, its design should be considered as a priority aspect.
- These findings might have relevance in several industries for example, but not limited to medical, consumer products, non-consumer sporting goods; more specific in devices such as handles of diverse products (cutlery, scissors, knitting accessories, taps, telephone, accessories for cooking, etc.), but also in prostheses, orthoses, soles, splints, among others.

9.4 Further work

This study has shown results of the involvement of AM towards the production of personalised assistive devices, for complementing and supporting this area of research, the following tasks have been identified:

1. Improving the device selection process could provide guidance for other investigations or projects to find the most impactful device in a well-defined scenario and considering its most relevant variables. In this specific study for example, the most valuable factors were diseases, activities and level of personalisation.

   Providing a clearer guidance in the assessment of personalisation of devices could be applied in further investigations as a standardised method.

   It is still recommended to use qualitative methods such as focus groups and surveys and increment the number of sessions to extract vast information about perceptions, experience, opinions but also on technical aspects of assistive devices; this type and amount of information could be difficult to obtain using other approaches.
2. Including experts during the personalisation process promotes the awareness of key concepts or user's measurements that need to be considered to capture an adequate shape. Besides this, experts can guide or provide suggestions about how to conduct the personalisation process.

   As a result, there could be the possibility of improving a current personalisation technique, adding or removing steps to the process. The expert could share limitations of the current methods to the researcher and together they may find a solution or a better approach. Also, it is relevant to share potential materials, software and hardware available on the market that can contribute to a more suitable result.
3. Conducting further tests that involve different types of standard handles will indicate if the tendency towards the preference for ergonomic models (ergonomic and Fischer) continues. This phase of the study, could also be replicated in other investigations where the selected assistive device is other than a walking stick.

   Also, it is relevant to conduct additional comparisons among the three different versions (personalised, standard and control) of the selected walking stick handle. This will strengthen, or not, the preference for the standard ergonomic walking stick handle. This evaluation could also be applied on projects with a different chosen device and this will help to find out if standard versions of assistive devices and which ones are more preferable than personalised and control models. Or, conversely, what devices tend to be more beneficial in their personalised version.

It will also be recommended to identify the most preferred or influencing features of the ergonomic handles, this will allow to focus on them and help to establish a range of dimensions for each one, which could be used for reference.

4. The control handle may represent a more uniform variable for all participants if an average handle was created based on all printings. Before obtaining this handle, it is pertinent that each printing was conducted properly and the captured data was verified by the researcher in order to assure that each individual impression is correct and errors are not transferred to the averaged model; examples of imprecisions may be found as extra elongations in length or unnecessary reductions in areas that would affect the average value of the measurements.

   This concept could be tested in further studies utilising walking stick handles or with different devices with the aim of evaluating if the control assistive device was preferred by any participant or not, as was the case in this study, where none of the participants chose it as number one.

5. There are two processes that could be applied in other investigations: the case study device selection and the selection of the most suitable version.

   The device selection could be adapted for other types of AT devices. In this investigation, this process followed seven steps within three phases; the recommended adaptations are:

   The first phase, "definition of research basis" included three steps where each one gathered key existing information about: impactful diseases, activities of daily living and assistive devices that support those activities; as it was mentioned before, in the case of other studies, the content of diseases, activities and assistive devices may change according to the target group's needs. For example, if the target group was adults aged 40 years and over who suffered from numbness in upper limbs, the list of impactful diseases, the affected daily activities and the assistive devices should change because this is a more specific target group than the one mentioned in this research.

   During the second phase, "shortlisting assistive devices", the assessment of level of personalisation per product should be strengthened, establishing more parameters that evaluate each proposed variable or factor (user, product and process). In this second phase it is relevant to contact an assistive device expert, in a more general term, an occupational therapist could be contacted or if the range of assistive devices is more defined, any specialist could be reached for example, an orthopaedist, a prosthetist or an orthotist. Also, there should be an evaluation about the convenience of focusing the project on small or big populations, inter-subject variability or on devices that support gross body/fine motor movements.

In the third phase, "selection of the final assistive device", it is suggested that an increased number of focus group sessions be conducted; according to the target group or the aim of the project, the sessions could be divided by stratums such as gender, subdivision of age, among others, resulting in a higher number of focus groups.

On the other hand, in the selection process of the preferred version, three different sessions were conducted. In further studies, these three sessions could be reduced to two, but this depends of the level of preparation that the printing process requires; if a simple or a standard model is necessary, they can be produced in advance and printing can be conducted at the end of the first appointment. For example, if the selected device was a handle for cutlery, a mouldable model of the standard version could be ready for a hand printing. However, a second session for printing should be conducted if a complex model with pre-selected features was necessary.

The selected assistive device would change the dynamic of the third session, instead of conducting a mobility assessment as was the case in this research, a reaching and management assessment of cutlery during the eating activity could be executed.

Also, it is relevant to investigate the application of texture in other 3D printed assistive technology devices and evaluate possible benefits.

6. Another way to explore further possibilities of AM is developing shapes of handles that can be connected or adapted to an existing walking stick. This recommendation seeks to utilise a new personalised handle in a previous or current user's stick. In this way, users can take advantage of utilising one part of their current device, thus reducing the cost of an entire walking stick.

   Also, depending on the user's requirements, several versions of personalised handles can be developed for the same person and, according to the scenario or need, the handles can be changed from one to another on the same stick. Each handle may have a different type of texture or material and can be used according to the type of activity being performed. This idea can also be replicated for different types of assistive device.

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11 APPENDICES

11.1 Appendix A: Symptoms caused by diseases

DISEASES	SYMPTOMS	Swelling.	Stiffness.	Pain.	Decreased range of motion.	Loss of height over time.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms as stiffness, pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		√ [279]	√ [279]	√ [279]	√ [280]	√ [279]
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8]		X	X	√ When the bone has been weakened by the disease: "Back pain caused by a fracture or collapse vertebrae" [281].	√ [281]	√ [281]
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		X	√ Dementia with Lewy bodies disease [283].	X	√ Dementia with Lewy bodies disease [283].	X
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].		X	√ [284].	√ Pain in joints [284].	√ [284].	√
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].		X	X	X	X	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].		√ **Heart failure** - "Swelling in feet, ankles, legs and abdomen" [286].	√ [298].	√ **Coronary heart disease** - Angina: Discomfort or sharp pain in chest. - Pain in neck, jaw, throat, abdomen and back. **Heart attack** - Chest pain or discomfort. - Upper back pain. - Neck pain [286].	√ [298].	X
AGEING						
a) Ageing "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].		√ Joint deteriorarion [29].	√ Joint deteriorarion [29].	√ Joint deteriorarion [29].	√ [30]	√ [29]
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].		X	X	X	√ [287]	X
c) Hearing impairment It is "a hearing loss that prevents a person from totally receiving sounds through ear" [34]. it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		X	X	X	X	X
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].		X	X	√ [37].	X	X
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	X	X	X	X
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].		X	X	X	X	X

DISEASES	SYMPTOMS	A stooped posture.	A bone fracture occurred in unexpected situations.	Tremors	Painful muscle cramps.	Spasms.	Balance problems.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms as stiffness, pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		√ [279]	√ [290]	X	√ Due to a damage in kidney[292].	X	√ [279]
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8]		√ [281]	√ Fractures produced by small hits, cough or sneeze [281][282].	X	X	X	√ [282]
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		X	X	√ Dementia with Lewy bodies disease [283].	X	X	√ [283]
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].		√ [285].	X	√ [285]	√ [284]	√ [284]	√ [148]
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].		X	X	X	X	X	√ [143].
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].		X	X	X	√ [298]	√ [298]	√ [298]
AGEING **a) Ageing** "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].		√ [29]	√ [29]	√ [30]	X	X	√ [29][28]
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].		X	X	X	X	X	√ [287]
c) Hearing impairment It is "a hearing loss that prevents a person from totally receiving sounds through ear" [34]. it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		X	X	X	X	X	√ [288].
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].		X	X	X	X	X	√ [37].
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	X	X	X	X	X
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].		X	X	X	X	X	X

DISEASES ↓ / SYMPTOMS →	Cognitive dysfunction.	Depression.	Sleep disturbances.	Bladder dysfunction.	Gradual loss of memory.
Arthritis “The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body”. The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms as stiffness, pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.	√ Due to a damage in kidney [292].	√ [291]	√ [279]	√ Due to a damage in kidney[292].	X
Osteoporosis Osteoporosis means: “porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased” [8]	X	X	X	X	X
Dementia This illness is defined as “an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics” [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].	√ [283]	√ Vascular Dementia [283].	√ Dementia with Lewy bodies disease. "Movements during sleep and vivid dreams" [283].	√ [283]	√ [283]
Parkinson's It is a disease in “which part of the brain becomes progressively damaged over many years” [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like “depression, insomnia, constipation, loss of sense of smell and memory problems” [15].	√ [285]	√ [285]	√ [285]	√ [285]	X
Urinary incontinence “It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications” [294].	X	X	√ Noctura: "Waking to void one or more times per night" [22].	√ Storage symptoms as urgency, frequency. Voiding symptoms as slow stream, intermittent stream, hesitancy, straining, terminal dribble and Postmicturition symptoms, this include an incomplete emptying and the postmicturition dribble (this is related to the leakage of urine a few moments after going to the bathroom) [22].	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) “is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)” [23].	√ [301]	√ [299]	√ [300]	√ [298].	√ [302].
AGEING					
a) Ageing “Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation” [27].	√ [30]	X	√ [296].	X	X
b) Visual impairment “Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour” [32].	X	X	X	X	X
c) Hearing impairment It is "a hearing loss that prevents a person from totally receiving sounds through ear" [34]. it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].	X	X	X	X	X
d) Tactile impairment “The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs” [37].	X	X	X	X	X
e) Anosmia (The loss of the sense of Smell) “Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke” [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.	X	X	X	X	X
f) Ageusia (Taste impairment) “The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste” [37].	X	X	X	X	X

DISEASES	SYMPTOMS	Reduction of communication skills.	Difficulty with thinking and reasoning.	Disorientation.	Visual hallucinations.	Indigestion.	Heartburn.	Nausea and vomiting.	Fatigue.	Breath problems.
Arthritis “The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body”. The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms as stiffness, pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		X	X	X	X	X	X	X	X	√ Due to a damage in kidney [292].
Osteoporosis Osteoporosis means: “porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased” [8]		X	X	X	X	X	X	X	X	X
Dementia This illness is defined as “an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics” [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		√ [283]	√ [283]	√ [283]	√ Dementia with Lewy bodies disease [283].	X	X	X	X	X
Parkinson's It is a disease in “which part of the brain becomes progressively damaged over many years” [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like “depression, insomnia, constipation, loss of sense of smell and memory problems” [15].		√	X	√	√	X	X	X	X	√
Urinary incontinence “It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications” [294].		X	X	X	X	X	X	X	X	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) “is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)” [23].		√ [302].	√ [302].	√ [302].	X	√ Heart attack [286].	√ Heart attack [286].	√ Heart attack [286].	√ Heart attack and heart failure [286].	√ Heart attack and heart failure [286].
AGEING										
a) Ageing “Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation” [27].		√ [287].	X	X	X	X	X	X	√ [296].	X
b) Visual impairment “Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour” [32].		√ [287]	X	X	X	X	X	X	X	X
c) Hearing impairment It is "a hearing loss that prevents a person from totally receiving sounds through ear" [34]. it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		√ [297]	X	√ [288].	X	X	X	X	√ [288].	X
d) Tactile impairment “The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs” [37].		X	X	X	X	X	X	X	X	X
e) Anosmia (The loss of the sense of Smell) “Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke” [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	X	X	X	X	X	X	X	X
f) Ageusia (Taste impairment) “The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste” [37].		X	X	X	X	X	X	X	X	X

DISEASES ↓ / SYMPTOMS →	Palpitations.	Hearing loss.	Visual impairment.	Poor visual acuity.	Poor contrast sensitivity.	Poor depth perception.	Visual field loss.	Unable to know where the noise is coming from	Hearing a buzzing or whistling in the ears.	Lack of sensation of external stimuli.	Problems with odours identification.	Decreased appetite.	Problems with flavours identification.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms as stiffness, pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.	x	x	x	x	x	x	x	x	x	x	x	x	x
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8]	x	x	x	x	x	x	x	x	x	x	x	x	x
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].	x	x	x	x	x	x	x	x	x	x	x	x	x
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].	x	x	x	x	x	x	x	x	x	x	√ [15].	√ [15].	√
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].	x	x	x	x	x	x	x	x	x	x	x	x	x
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].	√ Arrhythmia [286].	x	√ [298].	√ [298].	x	√ [298].	√ [298].	x	x	x	√ [298].	x	√ [298].
AGEING													
a) Ageing "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].	x	√ [297].	√ [297].	√ [297].	√ [297].	√ [297].	√ [297].	√ [297].	√ [297].	√ [297].	√ [37].	√ [37].	√ [37].
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].	x	x	√ [287]	√ [287]	√ [287]	√ [287]	√ [287]	x	x	x	x	x	x
c) Hearing impairment It is "a hearing loss that prevents a person from totally receiving sounds through ear" [34]. it can affect one or both ears and can be mild, moderate, severe or profound. People who suffer from mild to severe may utilise spoken language and products such as hearing aids, captioning and assistive listening devices. Deaf people are classed as having a profound level of hearing loss and they do not hear or hear very little [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].	x	√ Problems understanding conversations [288].	x	x	x	x	x	√ [288].	√ [288].	x	x	x	x
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].	x	x	x	x	x	x	x	x	x	√ Not being aware about pain, temperature, pressure and vibration [37].	x	x	x
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.	x	x	x	x	x	x	x	x	x	x	√ [289]	√ [289]	x
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].	x	x	x	x	x	x	x	x	x	x	x	√ [146]	√ [146]

11.2 Appendix B: Diseases and how they impact in activities

DISEASES	ACTIVITIES	Personal Care			Feeding	
	ACTIVITIES	**Dressing (ADL).** Involves: 1. Put on all kind of clothing from underwear, pants, socks, blouses, sweaters, t-shirts. 2. Being able to button shirt and to use zippers. 3. Being able to put on any kind of shoes and socks [2].	**Showering (ADL) [2].** Involves: 1. Coordinate hands and arms to wash the whole body. 2. Grab shampoo and soap. 3. Get in and out of the shower. 4. Operate the taps and regulate the temperature of the water.	**Toileting (ADL) [2].** Involves: 1. Being able to sit on the toilet and stand up from it. 2. Being able to do self cleaning after.	**Eating (ADL) [2].** Involves: 1. Using utensils (fork, knife and spoon). 2. Carry food from plate to mouth. 3. Drink liquids from a glass.	**Preparing a meal (IADL) [2].** Involves: 1. Cut vegetables, fruits, meats, etc. 2. Follow a recipe step by step and keep track of times. 3. Being able to handle cookware, pans and to use stove, oven, microwave and other kitchen appliances.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms stiffnes and pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		√ There is a difficulty because of the inflammation of joints in knees, hips, wrists, fingers and toes, this can limit the activity of dressing [279] [139].	Inflammation and pain in joints in upper and lower limbs inhibits the movements which are required to carry out showering such as pain in knees, toes, hips, wrists and fingers [279] [139].	The arthritis can cause inflammation in knees, hips, wrists and fingers. This makes the action of toileting difficult [279] [139].	√ Similar to preparing food, eating is related to the control of the hand and one of the main difficulties presented by the arthritis is the inflammation and stiffness of the joints and these can appear in fingers, wrists, interrupting the freedom of movements in the hand and limiting the use of a knife, spoon, among others [279] [139].	This activity is related to the control of the hand. One of the main difficulties of the arthritis is the inflammation and stiffness of the joints and this can be presented in the joints of the fingers, wrists, interrupting the freedom of movements in the hand in activites such as cutting, peeling, washing vegetables [279] [139].
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8].		√ There can be problems for people who have suffered a fracture because it can cause fragility in bones and lack of mobility and stability [203] [209] limiting actions of dressing.	The problems with showering are related more to the possibility of a fall than the activity itself. The elderly population is prone to suffer falls when they are taking a shower [313]. If the person has osteoporosis the possibility of suffering a fracture is greatly increased [139] [309].	The problems with toileting are related more to the fear of a fall than the activity itself. The elderly population is prone to suffer falls when they are toileting [313]. People lose muscular strength as they grow older [28] thus activities like sitting down or standing up in the toilet can be difficult and can lead to falls and fractures [139].	√ Similar to preparing food, wrist and arm fractures can cause fragility and lack of mobility and stability [303] [309] in activities as eating, grabbing and controlling cutlery [139].	Wrist and arm fractures are common in people with osteoporosis [309], usually after a fall the mobility and stability are never regained due to weak bones, therefore (wrist fracture) [303], the ability to write, grip and hold things is diminished [139].
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		√ People with dementia struggle with activities that require concentrating, planning, organising, solving problems or carrying out a sequence of tasks [140].	Difficulties in carrying out a sequence of tasks, as taking off clothes, opening the taps, entering the shower, using shampoo, soap, among others [140].	Difficulties in carrying out a sequence of tasks [140].	√ People with dementia may forget to eat or are unable to communicate or recognise if they are hungry or thirsty [293].	People with dementia struggle with activities that require concentrating, planning, organising, solving problems or carrying out a sequence of tasks [140].
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].		Dressing can be more difficult for patients with Parkinson due to the tremor in their hands, this makes them struggle having with buttoning their shirts [141].	√ There is a difficulty because of the presence of involuntary tremors [15], this causes a lack of precision in movements, as well as stiff and inflexible muscles. This can inhibit the activity of showering.	The patients can struggle to take off their clothes in order to go to the toilet [141].	Problems with swallowing, the food can get stuck in the throat. Patients can have problems with breathing and if the person is tired, this condition can lead them to suffer from panic attacks and anxiety. This situation can affect the action of eating [141].	√ There is a difficulty because of the presence of involuntary tremors [15], this causes a lack of precision in movements, as well as stiff and inflexible muscles. This can limit activities as washing and cutting ingredients, put a meal into the oven, taking out food from the fridge, among others.
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].		X	√ Experiencing the need of going to the bathroom while showering (involuntary loss of urine) [294], can cause falls due to having wet feet and trying to move fast.	The involuntary loss of urine preclude the action of arriving to the toilet in time [143].	X	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].		√ There can be spasticity, toe curling, foot drop and lack of balance [298].	1. Keeping the balance [298]. 2. Vision Disturbances [298], which can cause serious damage while showering. 3. Spasticity (cramp) [298]. This can limit the action of showering.	1. Keeping the balance [298], specifically when the person stands up from the toilet. 2. Vision Disturbances [298]. 3. Spasticity (cramp) [298]. This can obstruct the action performed in a toilet.	1. There can be a difficulty swallowing (dysphagia) [298], due to the lack of coordination of muscle movements in the mouth and throat. 2. Spasticity (cramp) [298]. A stroke can cause a brain injury, this can harm muscles resulting in involuntary contracts.	√ There is a difficulty because of the presence of spasticity [298]. A stroke can cause a brain injury; this can harm muscles, resulting in involuntary movements that limit activities as washing and cutting food, take out meals from fridge, among others.
AGEING						
a) Ageing "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].		1. Muscular Strength. Sarcopenia (S) and Dynapenia (D) are diseases that describe the loss of muscle mass (S) and the loss of muscular strength (D) with age. Muscles in the arms, legs, abdominal area and back are affected, therefore activities as dressing, picking up something, standing up or sit down and walking, among others, start being difficult [28]. 2. Joint Deterioration. This condition increases with age and starts to limit the variety and range of the movements that the limbs can perform, affecting flexibility as well. [2][29].	1. Muscular Strength. Sarcopenia (S) and Dynapenia (D) are diseases that describe the loss of muscle mass (S) and the loss of muscular strength (D) with age. Muscles in the arms, legs, abdominal area and back are affected, therefore activities as dressing, picking up something, standing up or sit down and walking, among others, start being difficult [28]. 2. Joint Deterioration. This condition increases with age and starts to limit the variety and range of the movements that the limbs can perform, affecting flexibility as well [29]. 3. Bone strength. As people becomes older they start losing bone mass and bone density, this is due to the lack of calcium and other minerals. This deterioration causes problems when standing and walking and the elderly population is more prone to suffer fractures. [2][29].	1. Muscular Strength. Sarcopenia (S) and Dynapenia (D) are diseases that describe the loss of muscle mass (S) and the loss of muscular strength (D) with age. Muscles in the arms, legs, abdominal area and back are affected, therefore activities as dressing, picking up something, standing up or sit down and walking, among others, start being difficult [28]. 2. Bone strength. As people becomes older they start losing bone mass and bone density, this is due to the lack of calcium and other minerals. This deterioration causes problems when standing and walking and the elderly population is more prone to suffer fractures. [2][29].	√ There is a decrease of the sensory systems, this can lead to the consumption of unhealthy food [31].	Coordination and Motor Skills. Studies have shown that as a person becomes older, there is a decrement in synapsis and neurons, besides this, the nervous system starts to deteriorate resulting in clumsiness, tremors (sometimes), less sensibility to heat, pain and pressure. For this reason the elderly population tends to move slower having difficulties when walking, sway more when standing and are more prone to fall and having troubles with easy tasks as dressing, cooking, among others [2][30].
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].		1. Focus objects at different distances [304]. 2. Low coordination in actions [304]. 3. Poor depth perception [144] and struggle with reaching the clothes.	1. Focus objects at different distances [304]. 2. Low coordination in actions [304]. 3. Poor depth perception [144] and struggle with reaching some important elements as shampoo, soap.	√ The people with visual impairment struggle with depth perception and balance [144], these can cause a fall during this activity, and the situation can be worse if the floor is wet.	1. Focus objects at different distances [304]. When people age, the lens becomes less elastic, this lack of elasticity cause less control in the movement of the eye and triggers slow motion when it wants to focus on close objects. 2. Low coordination in actions [304]. This low coordination comes from the poor relation between hand- eye. "The hand-eye coordination is the ability of the vision system to coordinate the information received through the eyes to control, guide and direct the hands in the accomplishment of a given task, such as handwriting or catching a ball. Hand-eye coordination uses the eyes to direct attention and the hands to execute a task."[306] 3. Poor depth perception (spill food and drink) [304]. Depth perception is "the ability to determine distances between objects and see the world in three dimensions" [307]. To achieve this, it is necessary to have binocular stereoscopic vision or stereopsis. Binocular (both eyes)/ Stereopsis refers to a person who sees with two eyes in a clearly way. "When someone uses both eyes to focus on the same object, their eyes converge. The convergence then stretches the extraocular muscles, and kinesthetic sensations from the extraocular muscles help with depth and distance perception" [307].	1. Focus objects at different distances [304]. 2. Low coordination in actions [304]. 3. Poor depth perception [144] while cooking. For example, taking out ingredients from the cabinets and fridge, cutting vegetables, mix ingredients, etc.
c) Hearing impairment "A hearing impairment is a hearing loss that prevents a person from totally receiving sounds through ear. If the loss is mild, the person has difficulty hearing faint or distant speech. A person with this degree of hearing impairment may use a hearing aid to amplify sounds. If the hearing loss is severe, the person may not be able to distinguish any sounds" [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		X	Trouble with maintaining balance [37] can have a serious consequence if occurs during the showering, as falls and hits.	Trouble with maintaining balance [37] while the person is standing up from the toilet can cause a fall.	X	√ The preparation of a meal can be limited for some activities, for example, if there is something boiling, the sound [34] of the cooking pot can notify when the action is ready.
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].		X	1. Risk of burns because of a decrement of temperature sensitivity [37]. 2. Do not feel pain or overreacting to it [304] if the person suffers an injury during the shower.	√ The people with tactile impairment may clean themselves too hard because of the lack of sensitivity in pressure [304].	X	Because of a decrement of temperature sensitivity [37], there can be difficulties with the risk of burns while cooking.
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	X	X	The patient can have difficulties with eating because they can eat spoiled food [145].	The preparation of a meal can be a difficult activity, this encompasses since the acquisition of the ingredients (selecting fresh food) and during its preparation when a spoiled food can be detected [145].
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].		X	X	X	Loss of interest in eating due to the lack of the sense of taste, this can cause dehydration and malnutrition [146].	People may add too much salt to the meals causing a risk of high blood pressure [146].

"√" States that the activity is affected by the disease.

DISEASES		Mobility			
	ACTIVITIES	**Moving about the living quarters (ADL) [149].** Involves: 1. **Including getting in or out of bed (ADL) [2].** 2. Walking without loosing balance and without the need of help form another person or tool.	**Moving outside the house (IADL) [149].** Involves: 1. **Doing shopping (IADL)**, which includes buying the necessary items, carry the whole purchase and go accompanied in a shopping trip [152]. 2. **Using a map to figure out how to get around (IADL) [2]**, read street names, locate current position and do not get lost. 3. **Transportation (IADL) [152]** as using public transport or drives own car. Plan and follow the road. 4. Being alert to street light signals.	**Exercising (ADL).** Involves: 1. Running. 2. Practicing Sports. 3. Weightlifting.	**Housekeeping or doing work around the garden (IADL) [2].** **Involves:** 1. Light daily tasks as dish washing, bed making, sweeping and moping. 2. Clean surfaces such as tables, bookshelves and other furniture. 3. Being able to handle dangerous substances used in house cleaning. 4. Clean bathroom. 5. **Laundry (IADL) [152].**
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms stiffnes and pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		Difficulties with walking short or long distances, restricting the mobility due to the swelling and pain in joints of hips, knees and toes [279] [139].	√ Similar to walking, there could be a restriction of the mobility due to the swelling and pain in joints of hips, knees and toes. [279] [139].	√ There can be difficulties due to the stiffness and pain of the inflammation in joints [279].	√ There can be difficulties to perform housework due to the pain and the inflammation in joints as hips, knees, wrists and fingers [279] [139].
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8].		People with osteoporosis can suffer from fractured vertebrae, this happens not necessarily because of a fall. Having a fractured vertebrae will cause discomfort while walking long distances, it will also cause back pain and a bent forward posture. Another reason to struggle with walking is due to a hip fracture which are quite common in people who suffer from this disease and that have had a fall [139] [309].	√ Similar to walking, people with osteoporosis can suffer from fractures that cause discomfort while walking long distances, as lesions in vertebrae, leg and hip [139].	√ The bone is porous and as a consequence fragile, the risk of fracture is too high [8].	√ The bone is porous and as a consequence fragile, there is risk of fracture if a fall occurs [139] [309].
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		√ Patients with dementia may present weakness on one side of the body, or they may be less stable [14].	Losing track of the day or date, or becoming confused about where they are [140].	√ People with dementia struggle with activities that require concentrating, planning, organising, solving problems or carrying out a sequence of tasks [140].	√ People with dementia struggle with activities that require concentrating, planning, organising, solving problems or carrying out a sequence of tasks [140] as sweeping, cleaning windows, cleaning furniture, among others.
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].		People can show: involuntary movements, walking slow and shuffling, curved posture and freezing [141].	√ People can show: involuntary movements [15], walking slow and shuffling, curved posture and freezing.	√ There is a difficulty because of the presence of involuntary tremors [15], this causes a lack of precision in movements, as well as stiff and inflexible muscles. This can limit running or playing with a ball.	√ There is a difficulty because of the presence of involuntary tremors [15], this causes a lack of precision in movements, stiff and inflexible muscles which limit sweeping, cleaning surfaces, among others.
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].		There is a link between urinary incontinence and possibilities of falling: "The cognitive demands of performing multiple tasks simultaneously, such as walking, concentrating on controlling the flow of urine, and negotiating household obstacles, in order to get to the toilet quickly may also have a detrimental effect on maintaining balance in older people " [143].	√ There is a link between urinary incontinence and possibilities of falling [143], so, the risk increases if the person is transferring from one place to another.	Exercise may involve repetitive movements which are associated with incontinence [142].	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].		1. Do not walk properly due to a toe curling [298]. The Hammertoe situation is caused by: "an imbalance of muscles in the feet and toes. Brain injury during a stroke leaves survivors prone to neuromuscular imbalances" [298]. 2. Immobility due to foot drop [298]. Foot drop is the condition where the front part of the foot cannot be lifted due to the weakness of the muscle, and the person has to drag it while he/she is walking. 3. Keeping the balance [298]. The body uses 3 systems to keep the balance: vision, vestibular and somatosensory (relating to sensations). The vestibular system encompasses two areas: the central system (brain) and the peripheral system (inner ear). Strokes can affect the central system, having as a consequence dizziness and vertigo. 4. Vision Disturbances [298]. The optic nerve travels through the brain, for this reason there is a connection between them and if the brain suffers damage, the vision system can be damaged.	√ There are limitations as: 1. Do not walk properly due to a toe curling [298]. 2. Immobility due to foot drop [298]. 3. There can be a lack of balance [298]. 4. Vision Disturbances [298].	√ There can be spasticity, toe curling, foot drop and lack of balance [298].	√ The patient can present spasticity, toe curling, foot drop and lack of balance [298]. All these impairments cause limitation is activities of housecleaning as remove off the dust from furniture, sweeping, cleaning the toilet, the microwave, etc.
AGEING **a) Ageing** "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].		1. Muscular Strength. Sarcopenia (S) and Dynapenia (D) are diseases that describe the loss of muscle mass (S) and the loss of muscular strength (D) with age. Muscles in the arms, legs, abdominal area and back are affected, therefore activities as dressing, picking up something, standing up or sit down and walking, among others, start being difficult [28]. 2. Bone strength. As people becomes older they start losing bone mass and bone density, this is due to the lack of calcium and other minerals. This deterioration causes problems when standing and walking and the elderly population is more prone to suffer fractures [29]. 3. Coordination and Motor Skills. Studies have shown that as a person becomes older, there is a decrement in synapsis and neurons, besides this, the nervous system starts to deteriorate resulting in clumsiness, tremors (sometimes), less sensibility to heat, pain and pressure. For this reason the elderly population tends to move slower having difficulties when walking, sway more when standing and are more prone to fall and having troubles with easy tasks as dressing, cooking, among others. [2][30].	√ Similar to walking, there is a decrement in muscular strength [28], bone strength [29] and coordination in motor skills [30], this can cause more effort due to the long distance.	√ There is a decrement in muscular strength [28], bone strength [29] and coordination in motor skills [30].	√ There is a decrement in muscular strength [28], bone strength [29] and coordination in motor skills [30] that can limit actions as pulling and pushing objects, carry boxes, etc.
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].		1. Vision impairment decreases the postural stability. 2. Reduction of depth perception. 3. Lack of balance because vision provides information to the nervous system of positions and movements of our body in relation to other bodies and the environment [144].	√ Similar to walking, there could be: 1. Vision impairment decreases the postural stability. 2. Reduction of depth perception. 3. Reduction of balance: vision provides information to the nervous system of positions and movements of our body in relation to other bodies and the environment [144].	√ 1. Vision impairment decreases the postural stability. 2. Reduction of depth perception. 3. Lack of balance. These conditions will be worse in a dynamic situation [144].	√ 1. Vision impairment decreases the postural stability. 2. Reduction of depth perception. 3. Lack of balance [144].
c) Hearing impairment "A hearing impairment is a hearing loss that prevents a person from totally receiving sounds through ear. If the loss is mild, the person has difficulty hearing faint or distant speech. A person with this degree of hearing impairment may use a hearing aid to amplify sounds. If the hearing loss is severe, the person may not be able to distinguish any sounds" [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		Trouble with maintaining balance [37]. The balance system is formed by the visual, the musculoskeletal system and the inner ear. This inner part sends signals to the brain indicating "direction and speed your head is moving… and detects when you move in a straight line" [308]. For this reason, a deterioration in the inner ear could damage the balance system.	√ Similar to walking, there could be a trouble with maintaining balance [37].	√ There could be a trouble with maintaining balance [37].	√ There could be a trouble with maintaining balance [37].
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].		Because of the decrement of sensitivity in pain [37], people could not realize they have a physical injury if they are damage in feet or legs, deteriorating their wounds.	√ Similar to walking, there is a decrement of sensitivity in pain [37] and people could not realize if they have a physical injury in feet or legs, thus, they can continue deteriorating their wounds.	X	√ There is no a sensibility of pain, pressure or temperature [37]. There can be a risk in specific tasks as clean the stove or the floor.
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	X	X	The lack of smell and the ability to distinguish among cleaning agents (toxic substances) in the house, may cause accidents while the action of housecleaning is performed [145].
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].		X	X	X	X

"√" States that the activity is affected by the disease.

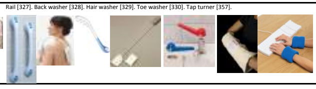
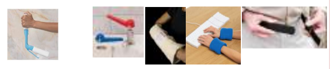
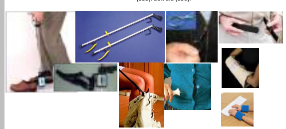
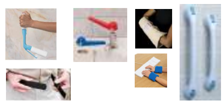
DISEASES	Communication			
ACTIVITIES	**Communicating (IADL) [2].** **Involves:** 1. Speak clearly (speech). 2. Understand what other people say (hearing). 3. Eyesight. 4. Being able to follow a conversation.	**Handwriting (ADL).** Involves: 1. Gripping and holding an article to write. 2. Legible writing.	**Socialising.** Involves: 1. Spend time with other people. 2. Go out to do different leisure activities.	**Ability to use the telephone (IADL) [152].** Involves: 1. Dialing well-known numbers, answering telephone but does not dial [152], gripping and holding the phone.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms stiffnes and pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.	X	√ Writing is related to the control of the hand and one of the main difficulties presented by the arthritis is the inflammation and stiffness of the joints and these can appear in the joints of the fingers, wrists, interrupting the freedom of movements in the hand [279] [139].	√ Disability in recreational and social activities are apparently connected to depression in patients with arthritis [147].	√ The actions of gripping, holding and dialing become difficult because of the inflammation and stiffness presented in the joints of the fingers and wrists [279].
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8].	X	√ In case of a fracture in fingers, wrists [303], elbows and arms, there can be fragility and lack of mobility and stability in activities as writing [139].	√ There are some type of fractures that can diminish the action of socialising, as hip fracture; patients with this type of lesion need more help with their activities of daily routine, also, they have troubles with socialization and lack of confidence and balance when they are walking [314].	√ Fractures in wrists and fingers [303] can limit gripping, holding the phone and affect mobility to achieve precise actions as dialing.
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].	Difficulties following a conversation or finding the right word [140].	√ People with dementia struggle with activities that require concentrating, planning, organising, solving problems or carrying out a sequence of tasks [140].	√ The patient may isolate because of his/her loss of memory [10].	√ People with dementia struggle with activities that require concentration or reminder situations [140], names, numbers, and this affect directly in the action of dialing.
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].	Patients may have problems with their voice and speak slow or fast. They can also have problems with breathing and if the person is tired, this condition can lead them to suffer from panic attacks and anxiety and this can impair their communication [141].	√ There is a difficulty because of the presence of involuntary tremors [15], this causes a lack of precision in movements, as well as stiff and inflexible muscles, that can avoid the control of the handwriting.	X	√ The involuntary tremors [15] cause imprecision in movements, stiff and inflexible muscles, limiting the action of gripping, holding a phone or touching the right key to make a phone call.
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].	X	X	There could be social isolation since spending time with people can be avoided in order to prevent embarassing scenarios [143].	X
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].	√ After having a stroke there can be problems of communication as Aphasia, this is caused by a damage in the brain, the consequences are: difficulties in writing, reading and understanding an speech [301].	1. Spasticity (cramp) [298]. A stroke can cause a brain injury; this can harm muscles resulting in involuntary contracts limiting the action of writing. 2. Vision Disturbances [298]. The optic nerve travels through the brain, for this reason there is a connection between them and if the brain suffers damage, the vision system can be damaged. 3. Presence of Aphasia caused by a damage in the brain, this disables the possibility of writing [301].	√ Emotional problems can be present as depression, people feel hopeless and they prefer do not having a social life [299].	√ Limitations in gripping and holding the phone as well as dialing keys due to spasticity (cramp) [298] and vision disturbances [298].
AGEING				
a) Ageing "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].	√ There is a hearing loss related to ageing, this situation affects the ability to interact. Also, the visual impairment limits the nonverbal communication [297].	√ There is a decrement in muscular strength [28], in coordination of motor skills [30] and also, there can be a joint deterioration [29], this inhibit the activity of writing.	X	√ There is a hearing loss related to ageing [297], this situation affects perceiving a ringing. Also, the visual impairment [297] limits the action of pressing the correct keys. The decrement in muscular strength [28], in coordination of motor skills [30] and also, the joint deterioration [29] can impact in gripping and holding the phone.
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].	√ The visual impairment limits the nonverbal communication because facial gestures also provide a lot of information when we talk [297].	√ For mild cases of visual impairment, one of the difficulties is the reduction of depth perception [144] that limits the activity of writing.	X	√ 1. Reduction of depth perception [144] that limits gripping the phone and pressing their keys.
c) Hearing impairment "A hearing impairment is a hearing loss that prevents a person from totally receiving sounds through ear. If the loss is mild, the person has difficulty hearing faint or distant speech. A person with this degree of hearing impairment may use a hearing aid to amplify sounds. If the hearing loss is severe, the person may not be able to distinguish any sounds" [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].	1. Lack of communication [305]. People can hear sounds but they do not recognize the exact words, they can confuse words for example: tea/pea/key, shop/shot/shock or fine/shine/sign. 2. Struggle with having a conversation, for people with hearing impairment can be so difficult so they may prefer isolation [304]. 3. Fatigue [304]. For a person, who has a loss of hearing, is difficult to have a conversation; they do an extra effort to listen.	X	√ People may isolate because he/she could not understand what people say [297].	√ There can be a lack of communication [305]. People can hear sounds but they do not recognize the exact words or even hear the ringing of the phone.
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].	X	√ There can be a problem with the pressure [37] applied in handwriting.	X	√ There can be a problem with the pressure [37] applied in pressing keys, gripping and holding the phone.
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.	X	X	The lack of the sense of smell does not allow enjoying food, thus, the activity of going out to eat is avoided [145].	X
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].	X	X	The lack of the sense of taste does not allow enjoying food, thus, the activity of going out to eat is avoided [310].	X

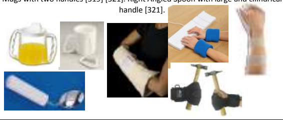
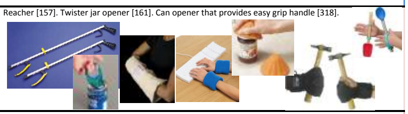
"√" States that the activity is affected by the disease.

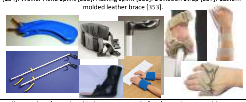
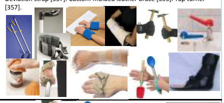
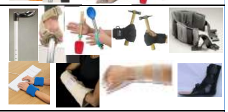
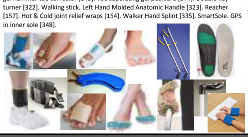
DISEASES		Healthcare			Others
	ACTIVITIES	**Sleeping (ADL) [148].** Involves: 1. Lie in bed and sleep uninterrupted for several hours.	**Safekeeping (IADL) [2].** Involves: 1. Hear alarms and take necessary measures to ensure safety. 2. Smell and interpret odours that represent dangerous situations. 3. Sense extreme heat or cold near their bodies. 4. See and recognize possible threats and dangerous situations, act accordingly.	**Taking medications (IADL) [152].** Involves: 1. Taking medications in correct doses at specific time. 2. Gripping and holding medicine.	**Managing finances (IADL) [152].** Involves: 1. Managing finances independently including revision of budgets, writing checks, paying rents and bills, go to bank and keeping track of income.
Arthritis "The term arthritis is often used to refer to any disorder that affects the joints. These disorders fall within the broader category of rheumatic diseases. These are diseases characterised by inflammation (signs include redness or heat, swelling and symptoms such as pain) and loss of function of one or more connecting structures of the body". The arthritis causes damage in joints, tendons, ligaments, bones and muscles having symptoms stiffnes and pain and swelling (mentioned before) [279]. There are two main types: inflammatory and mechanical.		√ There can be a difficulty due to the pain of the inflammation in joints [279] [139].	X	√ One of the symptoms of the arthritis is the inflammation and stiffness of the joints and these can be present in the joints of the fingers, wrists [279], interrupting the movements in the hand and avoiding the action of gripping the medication.	√ The inflammation and stiffness of the joints presented in knees, toes, fingers and wrists [279] can affect mobility to go to the bank and others movements as writing checks or manage paperwork related to finances.
Osteoporosis Osteoporosis means: "porous bone, is a disease in which the density and quality of the bone are reduced. As bones become more porous and fragile, the risk of fracture is greatly increased" [8].		X	X	√ Fragile bones in wrists and fingers [303] can limit movements to grip and hold medications.	√ Fractures in hips, wrists and fingers [303] can affect mobility or actions as go to the bank, writing checks, manage money or paperwork.
Dementia This illness is defined as "an acquired persistence compromise in intellectual function with impairments in at least three of the following spheres of mental activities: language, memory, visuospatial skills, personality and cognition (e.g. abstraction, judgment, mathematics" [10]. In general, there is a symptom called day-to-day memory: difficulty recalling events that happened recently [293].		√ There can be sleep disturbance, thus, the person with dementia is unable to sleep [311].	√ In case of dementia, the people may not be aware of danger due to memory loss [10].	√ People with dementia struggle with activities that require reminders and planning as taking medications [140].	√ Dementia can affect memory or concentration [140], this limits the action of managing finances, numbers, tracking or paying in specific times of rents and bills.
Parkinson's It is a disease in "which part of the brain becomes progressively damaged over many years" [15]. Some of the consequences are: involuntary tremors, slow movement, stiff and inflexible muscles, as well as psychological manifestations like "depression, insomnia, constipation, loss of sense of smell and memory problems" [15].		√ Sleeping problems as insomnia, nocturia, restless legs, pain due to the medication, among others [312].	X	√ The involuntary tremors [15] cause a lack of precision in movements, stiff and inflexible muscles, limiting griping and holding medicine.	√ The involuntary tremors [15] limit the actions of writing checks and managing paperwork and money. As well, there is a restriction in mobility, causing walking slow and shuffling, curved posture and freezing, affecting going to places to pay rents or bills [141].
Urinary incontinence "It is the involuntary loss of urine and can have a devastating effect on the lives of sufferers with significant economic implications" [294].		Sleep patterns may be altered by urinary incontinence. Going to the bathroom more than once during the night (Nocturia: overactive bladder) can interrupt your rest [143].	X	X	√ Because of the link between urinary incontinence and possibilities of falling [143], there is a limitation in mobility (go to places to pay the rent and bills).
Heart disease and strokes (Cardiovascular diseases) A cardiovascular disease (CVD) "is the collective term for all diseases affecting the circulatory system (heart, arteries, blood vessels)" [23].		√ Presence of sleep apnea, which "is a sleep disorder in which breathing is briefly and repeatedly interrupted during sleep" [300].	X	√ Limitations in gripping and holding medications due to spasticity (cramp) [298] and vision disturbances [298].	√ There are limitations in writing and managing workpaper, bills and accounts due to spasticity (cramp) [298] and vision disturbances [298]. Lack of mobility caused by problems as the toe curling, foot drop and lack of balance [298] (go to places to pay the rent and bills).
AGEING					
a) Ageing "Ageing, an inevitable and extremely complex, multifactorial process, is characterised by the progressive degeneration of organ systems and tissues. It is largely determined by genetics, and influenced by a wide range of environmental factors, such as diet, exercise, exposure to microorganisms, pollutants, and ionising radiation" [27].		√ There are some sleep disorders as: less satisfaction with sleep, more fatigue during the day, sleep fragmentation [296].	√ People with vision impairment may be in danger because of the lack on visual information (visual field and acuity) [32] that indicates risk situations. Related to safety, people who have lost their sense of hearing may experience damage if they do not listen warning sounds or alarms [304]. The loss of the sense of smell can cause problems with the detection of a gas leak and smoke [145] and the taste impairment can cause do not detect flavours and possibilities of eating spoiled food without being aware of it [146].	√ There is a decrement in muscular strength [28], in coordination of motor skills [30] and also, there can be a joint deterioration [29], this inhibit the action of gripping and holding medicine.	√ There is a decrement in muscular strength [28], in coordination of motor skills [30] and also, there can be a joint deterioration [29], this inhibits the activity of writing on checks or going to places to pay the rent or bills.
b) Visual impairment "Vision impairment is defined as a limitation of one or more functions of the eye. The most common vision impairments affect: The sharpness or clarity of vision (visual acuity); the normal range of what you can see (visual fields) and colour" [32].		X	√ People with vision impairment may be in danger because of the lack on visual information (visual field and acuity) [32] that indicates risk situations.	√ For mild cases of visual impairment, one of the difficulties is the reduction of depth perception [144] that can limit the action of gripping medications.	√ 1. Reduction in mobility due to the decrement of the postural stability and lack of balance [144], this can limit go to places to pay rent and bills. 2. Reduction of depth perception [144] to revision of paperwork related to finances.
c) Hearing impairment "A hearing impairment is a hearing loss that prevents a person from totally receiving sounds through ear. If the loss is mild, the person has difficulty hearing faint or distant speech. A person with this degree of hearing impairment may use a hearing aid to amplify sounds. If the hearing loss is severe, the person may not be able to distinguish any sounds" [34]. It can be caused by: "bacterial and viral infections, environmental and work-related noise exposure, genetics, medication toxicity or trauma" [295].		X	Related to safety, people who have lost their sense of hearing may experience damage if they do not listen warning sounds or alarms [304].	X	√ Trouble with maintaining balance [37] limiting going to places to perform payments.
d) Tactile impairment "The sense of touch makes you aware of pain, temperature, pressure, vibration and body position. Skin, muscles, tendons, joints and internal organs have nerve endings (receptors) that detect these sensations. Some receptors give the brain information about the position and condition of internal organs" [37].		X	1. Do not feel pain or overreact to it [304]. There is no sensitivity to pain. 2. Risk of burns because of the decrement of temperature sensitivity [37].	√ There can be a problem with the pressure [37] applied in gripping and holding medication.	√ There can be a problem with the pressure [37] applied in writing in checks.
e) Anosmia (The loss of the sense of Smell) "Smell and taste play a role in food enjoyment and safety. A delicious meal or pleasant aroma can improve social interaction and enjoyment of life. Smell and taste also allow you to detect danger, such as spoiled food, gases and smoke" [37]. This sense could decrease after the age of 70, the causes can be: losing nerve endings and mucus production. There are other causes as smoking and be aware of the presence of harmful particles.		X	1. Having problems with detection of gas leak. 2. Detection of smoke [145].	√ Due to a decrease of the sense of smell [37] there can be problems when the wrong medicine or dangerous substances are ingested without noticing.	X
f) Ageusia (Taste impairment) "The number of taste buds decreases as you age. Each remaining taste bud also begins to shrink. Sensitivity to the 5 tastes (sweetness, sourness, bitterness, saltiness, and umami), often declines after age 60. In addition, your mouth produce less saliva as you age. This can cause dry mouth, which can affect your sense of taste" [37].		X	People, who do not detect flavours, can eat spoiled food without being aware of it [146].	√ Due to a decrease of the sense of taste [37] there can be problems when the wrong medicine or dangerous substances are ingested without noticing.	X

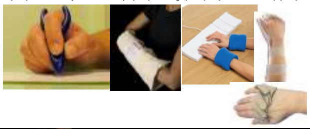
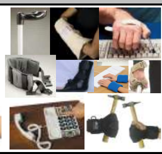
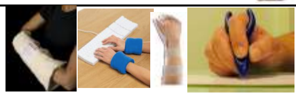
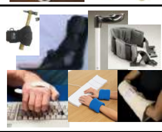
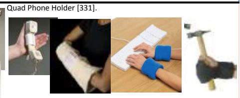
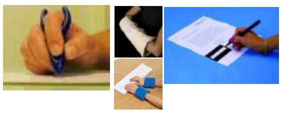
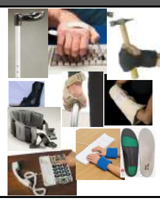
"√" States that the activity is affected by the disease.

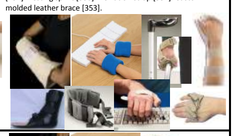
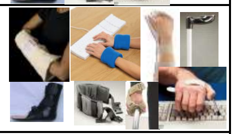
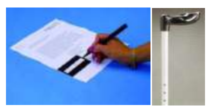
11.3 Appendix C: Assistive devices that support diseases and activities

DISEASES		Personal Care		
	ACTIVITIES	**Dressing (ADL).** Involves: 1. Put on all kind of clothing from underwear, pants, socks, blouses, sweaters, t-shirts. 2. Being able to button shirt and to use zippers. 3. Being able to put on any kind of shoes and socks.	**Showering (ADL).** Involves: 1. Coordinate hands and arms to wash the whole body. 2. Grab shampoo and soap. 3. Get in and out of the shower. 4. Operate the faucets and regulate the temperature of the water.	**Toileting (ADL).** Involves: 1. Being able to sit on the toilet and stand up from it. 2. Being able to do self cleaning after.
Arthritis		Shoe and boot valet dressing aid [315] for arthritis sufferers affected in knees. Reacher [157]. Reacher with hook [158]. Buttonhook [159]. Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. Fasten zipper [355]. Belt aid [356]. 	Rail [327]. Back washer [328]. Hair washer [329]. Toe washer [330]. Thermophore arthritis pads [153] Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. Tap turner [357]. 	Thermophore arthritis pads [153]. Self wipe toileting hygiene aid [160]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. Tap turner [357]. Belt aid [356]. 
Osteoporosis		Shoe and boot valet dressing aid [315] for patients with hip replacement. Reacher [157]. Reacher with hook [158]. Buttonhook [159]. Fasten zipper [355]. Belt aid [356]. 	Rail [327]. Back washer [328]. Hair washer [329]. Toe washer [330]. 	Self wipe toileting hygiene aid [160]. Belt aid [356]. 
Dementia		X	Grab rail, color red, powder coated [352]. Tap turner [357]. Notifier [358]. 	Grab rail, color red, powder coated [352]. Tap turner [357]. 
Parkinson's		Extra-long shoehorn [148]. Buttonhook [159]. Reacher [157]. Fasten zipper [355]. Belt aid [356]. 	Rail [327]. Back washer [328]. Hair washer [329]. Toe washer [330]. Tap turner [357]. 	Self wipe toileting hygiene aid [160]. Tap turner [357]. Belt aid [356]. 
Urinary incontinence		X	X	X
Heart disease and strokes (cardiovascular diseases)		Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Shoe and boot valet dressing aid [315]. Reacher [157]. Hot & Cold joint relief wraps [154]. Fasten zipper [355]. Belt aid [356]. 	Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Rail [327]. Back washer [328]. Hair washer [329]. Toe washer [330]. Hot & Cold joint relief wraps [154]. Tap turner [357]. Notifier [358]. 	Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Self wipe toileting hygiene aid [160]. Hot & Cold joint relief wraps [154]. Tap turner [357]. Belt aid [356]. 
AGEING: a) Ageing		Shoe and boot valet dressing aid [315]. Reacher [157]. Reacher with hook [158]. Buttonhook [159]. Fasten zipper [355]. Belt aid [356]. 	Rail [327]. Back washer [328]. Hair washer [329]. Toe washer [330]. Tap turner [357]. Notifier [358]. 	Self wipe toileting hygiene aid [160]. Tap turner [357]. Belt aid [356]. 
AGEING: b) Visual impairment		X	Rail [327]. Notifier [359]. 	Rail [327]. 
AGEING: c) Hearing impairment		X	X	X
AGEING: d) Tactile impairment		X	Notifier [358] [359]. 	X
AGEING: e) Anosmia (the loss of the sense of smell)		X	X	X
AGEING: f) Ageusia (taste impairment)		X	X	X

	Feeding	
	Eating (ADL). Involves: 1. Using utensils (fork, knife and spoon). 2. Carry food from plate to mouth. 3. Drink liquids from a glass.	**Preparing a meal (IADL).** Involves: 1. Cut vegetables, fruits, meats, etc. 2. Follow a recipe step by step and keep track of times. 3. Being able to handle cookware, pans and to use stove, oven, microwave and other kitchen appliances.
Arthritis	Mugs with two handles [319] [320]. Right Angled Spoon with large and cilindrical handle [321]. Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. 	Twister jar opener [161]. Bread Knife. Easy Grip Angled Handle, allows a natural straight position of the wrist, for patients with weak grip and limited hand control [317]. Can opener that provides easy grip handle [318]. Grip knob turner [323]. Reacher [157]. Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. 
Osteoporosis	Mugs with two handles [319] [321]. Right Angled Spoon with large and cilindrical handle [321]. 	
Dementia	X	
Parkinson's	Mug with two handles [319]. Spoon [349]. 	Reacher [157]. Twister jar opener [161]. Can opener that provides easy grip handle [318]. 
Urinary incontinence	X	X
Heart disease and strokes (cardiovascular diseases)	Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Mugs with two handles [319] [320]. Right Angled Spoon with large and cilindrical handle [321]. Hot & Cold joint relief wraps [154]. 	Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Twister jar opener [161]. Bread Knife. Easy Grip Angled Handle, allows a natural straight position of the wrist, for patients with weak grip and limited hand control [317]. Can opener that provides easy grip handle [318]. Grip knob turner [323]. Hot & Cold joint relief wraps [154]. Flame retardant oven mitt [171]. Cut resistant ambidextrous glove [162]. Talking alarm clock for medication times [334]. 
a) Ageing	Mugs with two handles [319] [320]. Right Angled Spoon with large and cilindrical handle [321]. Eazyhold grip straps [326]. 	Bread Knife. Easy Grip Angled Handle, allows a natural straight position of the wrist, for patients with weak grip and limited hand control [317]. Can opener that provides easy grip handle [318]. Grip knob turner [323]. Reacher [157]. Plastic multi opener [325]. Eazyhold grip straps [326]. Type aid [332]. Notifier [358] [359]. 
b) Visual impairment	X	Flame retardant oven mitt [171]. Cut resistant ambidextrous glove [162]. Talking alarm clock for medication times [334]. Notifier [359]. 
c) Hearing impairment	X	X
d) Tactile impairment	X	Notifier [358] [359]. 
e) Anosmia (the loss of the sense of smell)	X	X
f) Ageusia (taste impairment)	X	X

	Mobility			
	Moving about the living quarters (ADL). Involves: 1. **Including getting in or out of bed (ADL).** 2. Walking without loosing balance and without the need of help form another person or tool.	**Moving outside the house (IADL).** Involves: 1. **Doing shopping (IADL)**, which includes buying the necessary items, carry the whole purchase and go accompanied in a shopping trip. 2. **Using a map to figure out how to get around (IADL)**, read street names, locate current position and do not get lost. 3. **Transportation (IADL)** as using public transport or drives own car. Plan and follow the road. 4. Being alert to street light signals.	**Exercising (ADL).** Involves: 1. Running. 2. Practicing Sports. 3. Weightlifting.	**Housekeeping or doing work around the garden (IADL).** **Involves:** 1. Light daily tasks as dish washing, bed making, sweeping and moping. 2. Clean surfaces such as tables, bookshelves and other furniture. 3. Being able to handle dangerous substances used in house cleaning. 4. Clean bathroom. 5. **Laundry (IADL).**
Arthritis	Walking stick. Left Hand Molded Anatomic Handle [323]. Walking belt padded with 4 handles to allow the carer supports the walker [324]. Hot & Cold joint relief wraps [154]. Walker Hand Splint [335]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. 	Double key turner, this provides a better grip and leverage [322]. Walking stick. Left Hand Molded Anatomic Handle [323]. Reacher [157]. Hot & Cold joint relief wraps [154]. Walker Hand Splint [335]. Resting splint [336]. Deviation Strap [337]. Custom-molded leather brace [353]. 	Thermophore arthritis pads [153]. Active hands for general purpose [165]. Active hands looped exercise aid [166]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. 	Reacher [157]. Thermophore arthritis pads [153]. Active hands for general purpose [165]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. Tap turner [357]. 
Osteoporosis	Walking stick. Left Hand Molded Anatomic Handle [323]. 	Walking stick. Left Hand Molded Anatomic Handle [323]. Standers car caddie, adjustable with cushion hand grip [347]. 		
Dementia	X	SmartSole. GPS in inner sole [348]. A GPS is included in a sole in order to track people who may be lost due to dementia. 	X	
Parkinson's	Walking stick. Left Hand Molded Anatomic Handle [323]. Resting splint [336]. Foot and ankle orthoses [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. 	Walking stick. Left Hand Molded Anatomic Handle [323]. Reacher [158]. Resting splint [336]. Foot and ankle orthoses [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Double key turner, this provides a better grip and leverage [322]. 	Foot and ankle orthoses [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. 	Reacher [157]. Foot and ankle orthoses [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Tap turner [357]. 
Urinary incontinence	X	X	X	X
Heart disease and strokes (cardiovascular diseases)	Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Walking stick. Left Hand Molded Anatomic Handle [323]. Walking belt padded with 4 handles to allow the carer supports the walker [324]. Hot & Cold joint relief wraps [154]. Walker Hand Splint [335]. 	Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Double key turner [322]. Walking stick. Left Hand Molded Anatomic Handle [323]. Reacher [157]. Hot & Cold joint relief wraps [154]. Walker Hand Splint [335]. SmartSole. GPS in inner sole [348]. 	Foot and ankle orthoses [156] [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Toe alignment splint hammer toe [342]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Hot & Cold joint relief wraps [154]. 	Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Reacher [157]. Hot & Cold joint relief wraps [154]. Tap turner [357]. 
a) Ageing	Walking stick. Left Hand Molded Anatomic Handle [323]. Walking belt padded with 4 handles to allow the carer supports the walker [324]. Walker Hand Splint [335]. Resting splint [336]. Deviation strap [337]. Grab rail for home [354]. 	Double key turner, this provides a better grip and leverage [322]. Walking stick. Left Hand Molded Anatomic Handle [323]. Reacher [157]. Walker Hand Splint [335]. Resting splint [336]. Deviation strap [337]. 	Active hands for general purpose [165]. Active hands looped exercise aid [166]. 	Reacher [157]. Eazyhold grip straps [326]. Equipment for cultivating [167]. Grass shear [168]. Active hands for general purpose [165]. Tap turner [357]. 
b) Visual impairment	Walking stick. Left Hand Molded Anatomic Handle [323]. 	Walking stick. Left Hand Molded Anatomic Handle [323]. 	X	
c) Hearing impairment	Walking stick. Left Hand Molded Anatomic Handle [323]. 	Walking stick. Left Hand Molded Anatomic Handle [323]. 	X	
d) Tactile impairment	X	X	X	X
e) Anosmia (the loss of the sense of smell)	X	X	X	X
f) Ageusia (taste impairment)	X	X	X	X

	Communication			
	Communicating (IADL). **Involves:** 1. Speak clearly (speech). 2. Understand what other people say (hearing). 3. Eyesight. 4. Being able to follow a conversation.	**Handwriting (ADL).** Involves: 1. Gripping and holding an article to write. 2. Legible writing.	**Socialising.** Involves: 1. Spend time with other people. 2. Go out to do different leisure activities.	**Ability to use the telephone (IADL).** Involves: 1. Dialing well-known numbers, answering telephone but does not dial, gripping and holding the phone.
Arthritis	X	Ergonomic Ezy-Pen. Gripping and writing control [316]. Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. 		Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Phone aid [333]. Resting splint [336]. Deviation strap [337]. 
Osteoporosis	X			
Dementia	X	X		Phone aid [333]. 
Parkinson's	X	Devices for writing [350] [351]. 		Quad Phone Holder [331]. 
Urinary incontinence	X	X	X	X
Heart disease and strokes (cardiovascular diseases)	X	Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Ergonomic Ezy-Pen. Gripping and writing control [316]. Hot & Cold joint relief wraps [154]. 		Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Hot & Cold joint relief wraps [154]. Phone aid [333]. 
a) Ageing	X	Ergonomic Ezy-Pen. Gripping and writing control [316]. 		Quad Phone Holder [331]. Type aid [332]. 
b) Visual impairment	X	Plastic signature guide [338]. 	X	Phone aid [333]. 
c) Hearing impairment	X	X	X	Phone aid [333]. 
d) Tactile impairment	X	X	X	X
e) Anosmia (the loss of the sense of smell)	X	X	X	X
f) Ageusia (taste impairment)	X	X	X	X

	Healthcare			Others
	Sleeping (ADL). Involves: 1. Lie in bed and sleep uninterrupted for several hours.	**Safekeeping (IADL).** Involves: 1. Hear alarms and take necessary measures to ensure safety. 2. Smell and interpret odours that represent dangerous situations. 3. Sense extreme heat or cold near their bodies. 4. See and recognize possible threats and dangerous situations, act accordingly.	**Taking medications (IADL).** Involves: 1. Taking medications in correct doses at specific time. 2. Gripping and holding medicine.	**Managing finances (IADL).** Involves: 1. Managing finances independently including revision of budgets, writing checks, paying rents and bills, go to bank and keeping track of income.
Arthritis	X	X	Thermophore arthritis pads [153].Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. 	Thermophore arthritis pads [153]. Hot & Cold joint relief wraps [154]. Resting splint [336]. Deviation strap [337]. Custom-molded leather brace [353]. 
Osteoporosis	X	X		
Dementia			Talking alarm clock for medication times [334]. 	
Parkinson's	X	X		Devices for writing [350] [351]. Foot and ankle orthoses [339]. Toe straightener - single toe [340]. Double-stall tubular foam toe bandages [341]. Silicone gel hammer toe corrector [343]. Toe seperating gel pedicure [344]. 
Urinary incontinence	X	X	X	X
Heart disease and strokes (cardiovascular diseases)	Stop-snoring mouthpiece [170]. Talking alarm clock for medication times [334]. Alert system [360]. 		Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Hot & Cold joint relief wraps [154]. Talking alarm clock for medication times [334]. 	Rolyan anti-spasticity ball splint [345]. Deluxe spasticity left hand splint [346]. SaeboStretch dynamic resting hand splint [155]. Hot & Cold joint relief wraps [154]. 
a) Ageing	Stop-snoring mouthpiece [170]. Talking alarm clock for medication times [334]. Alert system [360]. 	Flame retardant oven mitt [171]. Cut resistant ambidextrous glove [162]. Notifier [358] [359]. Alert system [360]. 		Type aid [332]. Plastic signature guide [338]. 
b) Visual impairment		Flame retardant oven mitt [171]. Cut resistant ambidextrous glove [162]. Notifier [359]. Alert system [360]. 	Talking alarm clock for medication times [334]. 	Plastic signature guide [338]. 
c) Hearing impairment			X	
d) Tactile impairment	X	Flame retardant oven mitt [171]. Cut resistant ambidextrous glove [162]. Notifier [358] [359]. 	X	X
e) Anosmia (the loss of the sense of smell)	X	X	X	X
f) Ageusia (taste impairment)	X	X	X	X

11.4 Appendix D: Assistive devices and impacted activities

Assistive devices	Dressing	Showering	Toileting	Eating	Preparing a meal	Moving about the living quarters	Moving outside the house	Exercising	Housekeeping or doing work around the garden	Communicating	Handwriting	Socialising	Ability to use the telephone	Sleeping	Safekeeping	Taking medications	Managing finances	Number of activities impacted
Shoe dressing	✓																	1
Reacher	✓				✓		✓		✓									4
Buttonhook	✓																	1
Zipper aid	✓																	1
Belt aid	✓		✓															2
Relief pads	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓	14
Splint and strap for arms, hands	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	13
Splint and strap for legs and feet	✓	✓	✓		✓	✓	✓	✓	✓			✓					✓	10
Rail		✓	✓			✓												3
Washer		✓																1
Extensions for personal care products		✓																1
Tap turner		✓	✓		✓				✓									4
Self wipe			✓															1
Notifier		✓			✓									✓	✓			4
Adapted cutlery				✓	✓				✓									3
Jar or can opener					✓				✓							✓		3
Walking stick						✓	✓		✓			✓					✓	5
Walking belt						✓	✓		✓			✓					✓	5
Walker hand splint						✓	✓		✓			✓					✓	5
Double key turner							✓											1
Exercise aid/different purposes				✓	✓			✓	✓			✓	✓					6
Ergonomic pen with extra support											✓						✓	2
Telephone aid												✓	✓					2
Type aid					✓							✓	✓				✓	4
Talking alarm clock					✓									✓		✓		3
GPS sole							✓					✓					✓	3
Stop-snoring mouthpiece														✓				1
Glove					✓										✓			2
Plastic signature guide											✓						✓	2

11.5 Appendix E: Assistive devices and population impacted

Population per disease +65	4742650	2411712	773502	118511	3200000	2935384	1437590	6400000		
Disease	Arthritis	Osteoporosis	Dementia	Parkinson	Urinary i.	CVD	Visual i.	Hearing i.	TOTAL population	Population (million)
Shoe dressing	4742650	2411712		118511		2935384			10208257	10.21
Reacher	4742650	2411712		118511		2935384			10208257	10.21
Buttonhook	4742650	2411712		118511		2935384			10208257	10.21
Zipper aid	4742650	2411712		118511		2935384			10208257	10.21
Belt aid	4742650	2411712		118511		2935384			10208257	10.21
Relief pads	4742650	2411712		118511		2935384			10208257	10.21
Splint and strap for arms, hands	4742650	2411712		118511		2935384			10208257	10.21
Splint and strap for legs and feet	4742650	2411712		118511		2935384			10208257	10.21
Rail	4742650	2411712	773502	118511	3200000	2935384	1437590	6400000	22019349	22.02
Washer	4742650	2411712		118511		2935384			10208257	10.21
Extensions for personal care products	4742650	2411712		118511		2935384			10208257	10.21
Tap turner	4742650		773502	118511		2935384			8570047	8.57
Self wipe	4742650	2411712		118511		2935384			10208257	10.21
Notifier			773502			2935384	1437590		5146476	5.15
Adapted cutlery	4742650	2411712		118511		2935384			10208257	10.21
Jar or can opener	4742650					2935384			7678034	7.68
Walking stick	4742650	2411712	773502	118511		2935384	1437590	6400000	18819349	18.82
Walking belt	4742650	2411712	773502	118511		2935384	1437590	6400000	18819349	18.82
Walker hand splint	4742650	2411712	773502	118511		2935384	1437590	6400000	18819349	18.82
Double key turner	4742650					2935384			7678034	7.68
Exercise aid/different purposes	4742650								4742650	4.74
Ergonomic pen with extra support	4742650	2411712		118511		2935384			10208257	10.21
Telephone aid	4742650	2411712	773502	118511		2935384	1437590	6400000	18819349	18.82
Type aid	4742650	2411712				2935384			10089746	10.09
Talking alarm clock			773502			2935384			3708886	3.71
GPS sole			773502			2935384			3708886	3.71
Stop-snoring mouthpiece						2935384			2935384	2.94
Gloves							1437590		1437590	1.44
Plastic signature guide							1437590		1437590	1.44

11.6 Appendix F: Ethics Approval from the University of Sheffield. Focus group sessions

The University Of Sheffield.

Downloaded: 02/04/2020
Approved: 27/09/2017

Karla Huerta Lucio
Registration number: 150256368
Mechanical Engineering
Programme: PhD

Dear Karla

PROJECT TITLE: Collecting information from experts or people related to the use and performance of assistive devices in order to know their missing characteristics and develop an assistive product for the elderly people in the UK.
APPLICATION: Reference Number 014686

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 27/09/2017 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 014686 (form submission date: 20/09/2017); (expected project end date: 08/02/2020).
- Participant information sheet 1032620 version 7 (11/09/2017).
- Participant consent form 1032621 version 3 (05/09/2017).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Anne Bradford
Ethics Administrator
Mechanical Engineering

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/approval-procedure
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

11.7 Appendix G: Mail to participants. Focus group sessions

Title: [student-volunteers] Are you a non-professional carer for an elderly person?

I am a PhD student from the Mechanical Engineering Department and I am conducting research into the development of an assistive device for the elderly population using Additive Manufacturing (3D Printing) technology.

I am looking for focus group participants who identify themselves as a non-professional carer of a person/people aged 65+ or over. During this focus group we will discuss various currently-available assistive devices in order to identify any limitations and key areas for improvement. These discussions will be used to help steer the focus of the next stage of my PhD. More information about the background of the project and details of the focus group can be found in the Participant Information Sheet available at:

https://drive.google.com/a/sheffield.ac.uk/file/d/0ByIN4VrA33iDVGYxUUVRVHhiNHM/view?usp=sharing

The focus group will take approximately one hour, and will take place in early November; refreshments will be provided.

This project has been ethically approved by the Mechanical Engineering Department in accordance with the University of Sheffield's research ethics policy. All responses will be kept anonymous and confidential. This research is being conducted under the supervision of Dr. Candice Majewski (c.majewski@sheffield.ac.uk) and Dr. Jennifer Rowson (j.rowson@sheffield.ac.uk).

If you are interested in taking part of this session or if you have any questions, please contact me at kehuertalucio1@sheffield.ac.uk

Thank you very much.
Karla Huerta, PhD researcher
Department of Mechanical Engineering

For information about this email list, including how to remove your name, please visit https://www.sheffield.ac.uk/cics/email/distributionlists and click the list name.

11.8 Appendix H: Participant Information Sheet

Development of an assistive device for the elderly population
in the UK using Additive Manufacturing technology

Participant information sheet

Information about the study

You are being invited to take part in a research project, before accepting the invitation it is important to understand what the project is about, why it is being done and what your role in it will be. Please read the following information carefully and if you have any questions feel free to ask them, the contact information can be found at the end of this document. Thank you for your time and for reading this.

Purpose of the project

The purpose of the project is to develop a personalised device for the elderly people in the UK using the Additive Manufacturing technology.

Assistive devices

The assistive devices are considered as the products or equipment that help to maintain or recover the functional capabilities of people who suffer from a disability caused by factors as age, illnesses or accidents.

These devices can be developed in a standard size or are adjustable. Some of them have potential to be personalised because they are products that interact with some part of the body and its shape could be modified to obtain a better adaptation in the user.

Some devices are triggered or manipulated using arms and hands, the movements of upper limbs are involved in many activities, even for disabilities of the lower limbs the hand plays an important factor, for these reasons, handheld devices are relevant in this study.

The existing devices may represent a solution for some people with impairments but the products cannot be used by the entire population because the diseases may have different symptoms; therefore, it is important to consider the personalisation, to analyse and achieve a focused solution for each person.

What is Additive Manufacturing?

Additive Manufacturing, also known as 3D printing, is the process of creating physical objects or parts using virtual data through joining materials layer by layer, as it is shown in Figure 1.

Figure 1. Additive Manufacturing process.

What are the characteristics of the parts produced with Additive Manufacturing?

Several parts can be produced at the same time, joined as assemblies; also, the parts can be light and they can have freedom and complex features allowing the production of personalised parts, in this way, they can be adapted to a unique area of the body. An example of the parts created with Additive Manufacturing is shown in Figure 2.

Figure 2. A lamp made of complex shapes.

Personalisation using Additive Manufacturing

Personalisation is one of the characteristics that benefit the most when Additive Manufacturing is used.

Personalised products can be created to be used in hands, wrists, arms, legs, feet, or other parts of the body with unique colours and shapes that will depend on several human factors including gender, age and complexion.

The quality of usage of the personalised products is determined by a reliable interaction between the body and the device, this increases the possibilities of achieving a perfect match and functionality increases and therefore it will help to execute the activities of daily living, improving the independence of the user and enhancing the quality of life.

Examples of personalised products using Additive Manufacturing are shown in Figure 3:

Figure 3. From left to right: 3D printed splint for arm and 3D printed ankle foot orthotic.

Participants

You have been chosen because you have knowledge of assistive devices, or you are a professional carer of people aged 65 and over or you identify yourself as a non-professional carer but you take care of people of the same age.

Focus group process

Your participation will involve being part of a focus group to help choose on which assistive devices, from six preselected devices, will the project focus on.

The types of assistive devices that will be shown during the sessions are illustrated in Table 1:

Grab rail	Relief wrap	Splint for wrist	Splint for legs	Walker hand splint	Walking sticks
					

Table 1. Assistive devices.

During the session, the participants can interact with the assistive devices, where applicable try them on, in order to provide detailed opinions. Also, the participants will help to identify the most dangerous and challenging activities for the elderly as well as which device is the most used among the elder; they will also be required to express their opinion regarding the personalisation of these devices and to contribute with ideas to improve them.

Participation in the study

Participation is voluntary and there will be no repercussions of any kind to those that decline to participate, if you decide to take part you will sign a consent form. If before or during the focus group you decide or have to leave you are free to do so without the need to state a reason. During the focus group questions will focus only on assistive devices but you are free to decline to answer any questions or all of them if you wish so. If you have any complaint about the project or the people involved in it you can write an email to: kehuertalucio1@sheffield.ac.uk *

Benefits of participation
The advantage of taking part of this study is to collaborate with relevant information about current perceptions related to assistive devices and these data will contribute to develop a new product, with the purpose of improving the quality of life of the elderly population, increasing their independence and their role inside the society.

Additional information
The focus group will be 1 hour long, refreshments will be provided on the day.

The personal information will be confidential, opinions might be published but will not be traceable to any specific participant, their anonymity will be respected as Participant #1, #2, etc. The focus group session will be recorded using audio and video devices, the reason for this is to be able to create a script of the session and no one outside the project will have access to the recordings, both video and audio will be confidential and will not be published or used in any other way. You will be required to sign a consent form for the audio and video recordings.

This project research is organised and funded by the Mechanical Engineering Department of the University of Sheffield and CONACYT. The project has been ethically approved by the University of Sheffield Research Ethics Committee. For further information you can contact: kehuertalucio1@sheffield.ac.uk

*If you feel dissatisfied with how your complaint was handled then you can contact to Professor Neil Sims, Head of the Mechanical Engineering Department.

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11.9 Appendix I: Consent form

University of Sheffield

Participant Consent Form

Development of an assistive device for the elderly population in the UK using Additive Manufacturing technology

Name of Researcher: Karla Elisa Huerta Lucio

Please initial box

1. I confirm that I have read and understand the information sheet explaining the above research project and I have had the opportunity to ask questions about the project. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐
3. I understand that my responses will be kept strictly confidential, even if they are cited within quotation marks.
   I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. ☐
4. I understand that my participation will be audio recorded. ☐
5. I understand that my participation will be video recorded. ☐
6. I agree for the data collected from me to be used in future research or publications. ☐
7. I agree to take part in the above research project. ☐

Name of Participant *(or legal representative)*	Date	Signature
Lead Researcher	Date	Signature

To be signed and dated in presence of the participant

For more information contact:
Karla Huerta
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11.10 Appendix J: Participant form. Focus group sessions

FOCUS GROUP 1

Participant No. 1

Gender: ________________

Age Category:		**Status:**	
<30	☐	User	☐
30-65	☐	Carer	☐
<65	☐	Professional	☐

Have you been involved with people suffering from one or more of the following diseases? (More than 1 box can be ticked).

Arthritis	☐	Ageing	☐
Osteoporosis	☐	Visual impairment	☐
Dementia	☐	Hearing impairment	☐
Parkinson's disease	☐	Tactile impairment	☐
Urinary incontinence	☐	Anosmia (loss of the sense of smell)	☐
Cardiovascular disease	☐	Ageusia (loss of taste functions)	☐

Another medical condition:

____

1

Table assistive devices

Rank the following assistive devices from 1 to 6 answering the question: Which of them would benefit the most if it were personalised? Being 1 the most benefited and 6 the least, and why?
Please, fill the form and when you finish, return it to moderator.

Device	Which would benefit the most if it were personalised?	Why?
Rail		
Relief wrap		
Splint for wrist		
Splint for leg		
Walker hand splint		
Walking stick		

2

11.11 Appendix K: Dynamic focus group sessions

a) Welcome and Introduction: At the beginning of the focus group, the moderator provided the participants 1 copy of the "Participant Information Sheet" for keep it (previously sent it by email or post) and 2 copies of the "Consent Form", one for signing and returning it to the moderator and the other copy for keeping.

After this, participants took some refreshments and the moderator explained the following points [141]:

- The objective of the focus group and the research.
- Reasons why the participants were chosen.
- Length of the session (1 hour).
- The procedure of the focus group.

Later, the moderator mentioned that notes and record tape were going to be used for clarification purposes; also, some rules were explained such as members could participate in the discussion one at a time, there were no good or wrong answers, nobody was obliged to answer an specific question and the collected data from the session was going to be only used for research purposes.

b) Topics of discussion:

The focus group collected all the information regarding which assistive device would be more convenient to redesign based on its impact in improving the daily lives of the elderly population.

Therefore, the first topic was about the activities performed by them.

1. Which activities are the ones that present more challenges to the elderly?

[The responses to this question helped to decide on which device to focus in order to have a greater impact on the lives of the elderly].

Continuing with the challenges presented in their lives:

2. What kinds of situations and/or activities are more involved in elderly's accidents? And why?
[It is important to consider dangerous situations for the elderly and to help them avoid accidents, given their ages some of them have already diminished capabilities but an accident can change the rest of their lives forever and the device selected could help in this regard].

After this, the 6 shortlisted assistive devices were shown: a rail, a relief wrap, a splint for arms, a splint for legs, a walker hand splint and a walking stick.

Participants interacted with them in order to perceive more information as weight, resistance, smoothness/ roughness, finishing, stability, among other aspects they could notice.

3. Considering the six devices, which ones do you think are used the most by the elderly?
[Since the objective of the research was to try to benefit as many elderly as possible this question helped to identify which devices were used the most].

4. What would you change/improve on each device?
[It was important to have the opinion of this group since they could have a profound knowledge on the devices. Also, this question was relevant because the assistive device that had more aspects to improve could require more attention to be redesigned].

This project involves the use of the Additive Manufacturing technology, which is a process of creating physical objects or parts using virtual data though joining material layer by layer. The moderator showed some samples of parts made with Additive Manufacturing.
Why utilising Additive Manufacturing in this investigation? One of its best benefits is the possibility of creating personalised parts that can be an attribute for the assistive devices. Therefore, the next topic was related to this.

Before answering question number 5, the moderator provided participants a document; it asked some personal information and included a table with the six assistive devices in order to rank them from 1 to 6 answering the question: Which of them would benefit the most if it were personalised? Being 1 the most benefited and 6 the least and why? The document was returned to moderator when participant finished.

After all participants returned their sheet, the next and last question was:

5. Considering the six devices, which ones do you think could improve more if they are personalised? Why? *[This was an important question because if a device could not be benefited from personalisation then it fell out of the scope of this research].*

c) End of focus group: At the end of the session, the moderator thanked to participants for attending it.

11.12 Appendix L: Transcript of focus group session 1 and session 2

FOCUS GROUPS

Session 1

Non-professional carers

Date: Thursday 07th December 2017

Time: 09:00 am – 10:00 am

1. Welcome

Moderator:

Ok, well, we are going to start. Good morning, my name is Karla Huerta, I am from the Mechanical Engineering Department and I am a PhD student, this is my second year, also, I am working at the AdAM Centre, the AdAM Centre is the Advanced Additive Manufacturing group. This focus group is part of my investigation and as a result I am going to be the moderator of it.

Before starting, I would like to give you a copy of the *Participant Information Sheet*. The Participant Information Sheet is a document that you already received through email and here you can find aspects of my investigation and as well, several important topics as assistive devices and also, what is Additive Manufacturing (AM), what is that technology and what type of characteristics the parts produced with AM can have; also, for example, these are some of the parts that you can get printed with 3D printing. Focused on my investigation, are these types of assistive devices; assistive devices in general terms, are the equipment, the systems or the products that can help you to improve a physical condition, they have a direct relationship between their function and the recovery of the patient or the maintenance of the health. So, in this case, we have two examples, of what 3D printing can do in the assistive devices; these are examples of orthoses, one is for a leg and one is for a foot and actually those are made of plastic. Also, you can find here, which are the assistive devices that we are going to work with and we have six pre-selected assistive devices and also you may find other details of this focus group and also my contact if you want to ask me something further.

So, this is for you to keep it and now, I am going to give you a Participant Consent form, this is for you to sign it, you can tick the boxes or you can put your initials and those are already signed by me. Those explain aspects of this focus group, as your information will be remained and I am going to be recording, I am going to use this camcorder only for clarification purposes, I mean, nobody is going to see this video and also, you are not going to be identified with your answers, I mean, if I have to cite something that you said in exacted words, I am going to keep them within quotation marks and also, participant 1, participant 2.

(The third participant arrived and I explained him what we had done).

And also, I am going to give you (a copy of the Consent Form), this is for you to keep, I mean, you don´t have to sign it again, an extra copy of it.

(Participants sign and deliver the Consent Forms)

Ok, if you want you may take some refreshments.

2. Introduction

Moderator: This focus group is part of my investigation, which is the development of an assistive device for the elderly population in the UK. So, basically, the objective of this focus group is to collect your comments and thoughts about six preselected assistive devices in order to choose one and base my investigation on it. The reason you were selected was because I am going to select the assistive device, which impacts more the elderly population, so, I would like to know what do you think about the situations that the elderly could pass, could have or even what do you think about each of these assistive devices.

3. Development of the focus group

Ok, well, we are going to start, the focus group will be divided in three parts; in the first one I am going to ask two questions and then I am going to pass these assistive devices and if you want to interact with them it is completely ok, and also, in the last part, I am going to give you a form; in that form, you can fill some personal data and at the end, I going to ask you other questions.

Ok, well, this focus group will collect information regarding of the assistive devices, which will be more convenient for the activities of the elderly population.

So, the first question is related to the activities that the elderly population most conduct. This is:

1. Which activities are the ones that present more challenges to the elderly?

- P2: "The first thing, I feel, I have a mother who suffer from arthritis, when she seats on a chair or a sofa, getting up is a really problem to her; she finds very difficult to get up, I mean, immediately, so she needs really something, you know, to hold on, some assistance to get on a position... there is a problem".
- Moderator: "And that impacts in many activities..."
- P2: "Yes, of course".
- Moderator: "Ok, anyone else, I don't know is there another activity".
- P3: "Ok, the splint for legs, is it the one in black? Is it the one?"
- Moderator: "Yeah, these two".
- P3: "Based on that, someone with arthritis cannot, you know, we are thinking about something that will be self-administered that...it has absence, my mum can use it on herself, she can easily to stand up, walk around without anybody helping her, so, if that, the splint for legs can be done in a way that it can be self-administered, it will be great, but, if we look at the walking stick, that one too, you don't need someone to help you to stand up, you can, stand up by yourself, walk around, so I think the walking stick may have attractive over that (splint for legs)... Once saying that is, you know, when you sit down for a long time, specially near of a edge, somehow constraint you from that initial tick, so, I you have been on a bed for a long time and there is no one around, you need that initial rise, because that (splint for legs) cannot give you the assistance, you cannot stand up in the first place before you can use it, so, I think the walking stick which you can easily stand on your own then walk around will have that advantage over that (splint for legs). I don't know if you can see what is".
- Moderator: "Yes, yes, and for example, about the activities, you may mention problems about standing up or maybe walking".
- P3: "Yes"
- Moderator: "Ok".
- P1: "That is a problem... my daddy needs a new knee, he is waiting for a new replacement, so, he walks with the walking stick all the time and like getting in and out of the bath, he got or even at the side of the toilet he got the grab so then he can grab onto that and actually pulls himself".
- P2: "Needs to the supporting the right, plastic one won't do, plastic one is not at all the solution, so they hold body to avoid falls, and they have to, you know, to press and then they should be able to get up".
- P1: "I think that sometimes, those frames they have, they are really good because it can grab on both sides".
- P2: "Both sides, two sides, one side is also not..."
- Moderator: "And for example, you mention that, well, I know, in this case, if your daddy or a person you care of him and her see this type of device (white plastic rail) they does not trust a lot in this one because they need like a frame or something?"

- P2: “No, no, this one (white plastic rail), what I am saying it is made of plastic I believe, so it doesn’t, I mean, hold them right, so, their body and you need two sides, two sides, is not one side, they cannot, for example, they sit on the toilet, they want something (to hold on), at least, toilet is fine because it is very narrow, one hand they can put it on the wall, but seating on the chair or on the sofa, they want to get up and it is not possible and just plastic…they don’t…support their body right, it should be very strong, something should be very strong to hold it”.
- P3: “I can see there is a metal inside… and if there is plastic psychologically it could be…”
- P2: “You know, they would be scared to hold it or touch”.
- Moderator: (She shows the grab rail) “Do you want to see it or touch?… yeah, that it has an aluminium tube inside”.
- P2: “I am not bothered on this part (pointing out the middle-large part), I am bothered about here (pointing out the sides)… so, suppose it comes off the wall, what happens? Because on the body, it cannot break here (pointing out the middle-large part), the problem is this side, these two things, if you are tightening with screws; one screw comes out, what happens? This is the place you need to focus (pointing out the sides), this will be fine (sides), holding it inside is also ok, but this, if this plastic cracks (sides) or a screw comes out”.
- P1: “It needs amount of time of the use in the day as well they are using it a lot of times in the day”.
- P2: “And for everything they need it, they want to get up, they want to go to the toilet, they getting from the bed, they need it”.
- P3: “I think this one (white grab rail) is a fixed device, it is fixed on to the wall, so, I think we need something that can offer mobility, so I think the walking stick is still an advantage over this (white grab rail)”.
- P2: “But walking stick, you tell me, suppose they are sitting on the chair how can they get up with a walking stick, it slips run there and the bottom is a round ball, even if you take it, that it is very tall, so, it is very tall, on that putting the hand, I mean, putting the body weight and then getting up, I don’t think it is easy with the walking stick”.
- P1: “That helps in one stage… of walking around”.
- P2: “Yeah, it depends upon the disability, if that, very light took small problem to the leg they can easily do it, if they have an only big problem, I mean, the legs are paining very much, then, the walking stick would help. Something, which is very strong… they only they can, I mean, trust them and then they can confidently do it on their own.
- P1: “I think the thing is well, if they do sit down a lot, I think very active people then they come to sit down a lot, they do actually poor on weight and they know they are poor on their weight, so I think that is on their mind as well and just thinking, oh that would support my weight now…”

Moderator: “Ok, well, that was the first question, the second question is about, as well, about activities but in this case is:”

2. What kinds of situations and/or activities are more involved in elderly's accidents? And why?

I mean, the previous question was about the activities that were more challenged for the elderly and now are about the accidents.

- P2: "Slipping. Suppose, there is chance, there is water on the floor they tend to slip or something also, people is there, small piece of plastic is there, which they cannot notice it because of their vision or something like that, usually when the children are around at home you find so many things and they put on there and they slip".
- P1: "I think you find as well we do… put the feet up, if they not going outside as much, they usually wear slippers and I have noticed they just do not put the feet up as much as they used to".
- P2. "Gripping on be there not much, not their own grip. Slippers and then, foot on that, so, that will be there, so they don't grip it, so, they find difficult to… walking".
- P3: "Because of their age and health condition now, you know that… since, one of the common accident they have is slip because they have not association with any form of locomotion like we, we can jump, dance and all of that, because they are not associated with all those locomotion activities, they are only just simply to move around, so I think the common issue they have is trip and fall, yeah, slip, trip and fall… maybe because they don't have such a grip like this, they can easily lose control and fall then slipping on the ground because of their weight… then, you know, most of them have visual impairments, some of them can feel dizzy… all of this can contribute to these trips, falls and slipping".
- Moderator: "And for example, what type of activities do you think that could involve that the elderly person could slip".
- P3: "Since all the activities they get themselves involve most times is just for walking around because they are not expected to do much of exercise, so there cannot be activities that can be a sort of they are falling it's, just moving around just walking around."
- P1: "I know, my mum as well, she got arthritis in a hand, she has dropped things as well occasionally so that is like a scalding as well they can scald themselves if they have a hot drink because their arms are not as movable"
- P2: "They cannot bend their fingers properly, holding a coffee cup or anything, you know, suddenly they can do it and they want to do it, they take time, do it slowly"
- P3: "Everything that you expect them to have access to must have good grip like this"
- Moderator: "Is there any period of time before they cannot move their fingers, I mean, is there a period when they realise they are not going to have enough movement or it just happens suddenly"

- P2: “One is with the weather condition if it is cold outside you know, so at times they automatically they feel their fingers are not flexible and in the mornings as soon as they get up or something I fell because you know of the gap, some eight to ten hours they are not moving, suddenly so immediately their first movement or they sit and watch tv for one hour, immediately moving their hands or getting up is a problem, once they start doing it I think it become easy, so initially after the gap of some time, they are fine, everything is difficult and I think walking or gripping, everything”.

Moderator: “Ok, this was the first part and now this is the second part and I am going to pass you the assistive devices”.

- “Well the first one we can start is the grab rail, this obviously is made outside of plastic but it has an inner aluminium tube and for example in this case we have this shape and this is about sixteen inches and the company sells a lot of sizes and also you can find, it is not here, but you can find, here, another type of models I mean you have the straight one and you can also find the angled one and you can use it in several heights and many places, I mean not only in your bathroom, maybe you can use it in another room and for example in this case, well, I am going to pass it around, well if you want to see it again, in order to see that another characteristics of this grab rail and for example, also if you want to read this, there is a characteristic that the information mentioned, for example you can see here, well this is obviously attached with the screws to the walls, and you can have this cover in order to hide the screws and therefore you cannot see it and it is hidden and it is more aesthetic, and also you can see, you can feel different types of materials, I mean, it is only plastic outside but you can feel this is another type, it is a little more sticky in order to prevent…”
- P1: “I think they are a really good idea, but like you say because it is used a lot, it is actually affixing them on to the wall, you are ok at first but they might last for a month or so, they need continuously use them and pulling their weight on them that is why it needs screws
- P2:”This is the portion I am thoughtful about, so, you use it for one month, because by getting your old splint towards your body there is damage happening in here or something possibly and another thing like suppose if they are holding it and sitting for some time this position I feel it is not confortable it is pressing on you because of their design so, or holding like this, it is pressing to my body, this may be, we can think of some other design or maybe like this, it grips I do understand rather than a smooth surface, this is ok but when you are holding it for a long, this will be hurting, I think so, they cannot hold it for a longer time, suppose they want to hold it and sit like that for sometime so holding this will be a problem.
- Moderator: “I do not know if you want to see it again, I am going to pass the other ones”

- P3: " I can see in here that the image here is quite different from this, at this stage now the, like I said, anything they are made for is very serious, and they always question what to hold and eat, and that, I guess psychological perception is very high, in this issue now if they see this that is purely a plastic, they may not be confident to hold it, if this can be given a metallic colour, like I can see here, it can result in their confidence that this can carry their weight, some of them are, like she pointed out, have added much of weight, they stay in one place that is why they get more weight, now that they have this rails they can think it cannot carry them if this can this metallic colour it would I think it cancel the psychological demand.
- Moderator: "if for example, sorry, here the supplier mentions that it has hidden screws, no sharp edges and this can be attractive for the people, but I do not know what would you prefer, if it has rounded edges or if it has, if this type of product has square edges but I do not know, in other material or maybe more robust"
- P3: "I think this design is good cause if it gives you rough edges, sharp edges are a threat, (P2: "cut your skin") imagine someone is falling and it can hit their head on the edge, it is a safety issue, so I think that the cover is aesthetical and safety concentration is ok but if can be given that metallic like I can see it, I think it has strength".
- Moderator: "Now, we are going to see some assistive devices that are used for upper limbs".
- P2: "And, are these devices only for the UK? I mean, only these conditions or they are sold in anywhere else?" Are you focusing only for the elderly in the UK?
- Moderator: "Yeah".
- P2: "Because, a lot of conditions what I am telling is, in my place is gripping and seating for some time, always there is a formation of sweat, then your hands slip, so, you need to consider that as well, but here is not that problem, if there was a warmer condition, so, condition is different".
- Moderator: "Yes, actually I was telling her that this (investigation) is for the UK, and for example if you want to apply this type of research in a another country you have to consider the weather even the people, for example, in my country maybe there are other important diseases as diabetes and in order to get these six assistive devices I had to consider the most important diseases in the UK, yes, so, maybe, in another country would be different devices for research".
- P2: "But I feel this is, irrespective of the disease, this is useful".
- Moderator: "This is the relief wrap". "This is useful for relief pain, or avoid, or prevent, reduce the swelling. It is one size and you can use it for leg or right hand and if you want to use it... for example, right now, you can use it like this, and here you can see an splint, it has the shape of the hand. If you want to, you can cool it or you can heat it, you can put it in the microwave or on the freezer before and you can use it like this and if

you want to use it for your right hand you only need to take this off and then (flip it) there, I mean is reversible.

- P1: “They do actually works, ‘cause I had carpal tunnel and I went for those for a few months when I was waiting for the operation, they are really good”.
- Moderator: “Yes, actually one of their applications is for carpal tunnel”.
- P2: “But I feel the real problem is with the Velcro, you know, stick it to something”.
- P1: “Yeah, if you do, like I did for a few months it was ok, but I can see there can be a confusion with someone to put it on”.
- P2: “Yeah, someone may need some assistance”. “Specially with the age, you know, put it into the right or left”.
- Moderator: “This is another device, this is the splint for wrist, well this is a large size, I mean, you can find, small, medium or other sizes and this is for the right hand, so, if you want to use it for another hand you have to buy another, it is composed by two aluminium studs, here, you can feel one and here is another, and ok, for the right, ok, here, you may feel the stud and you may adjust this part to your hand, then you are going to (close the bandages), so if you want to try it…” “The instructions mention that you can bend the stud”.
- P1: “Right to your hand, ok”.
- P2: “And, do they have, like this many you can use it for six months or one year, the time period?”
- Moderator: “I think, I did not read, actually, but they have to”.
- P2: “Because the use of Velcro I am looking that, because after using it for some days this one… the sticking won’t be there, it starts coming off like this, you know, it could be like this, and after, slowly it goes off, so how many months you can use it, it is used only for three or four months means that is ok, this problem will be with the Velcro. The material is also often fine I think”. “This is basically for giving stiffness to the joint or the fingers?”
- Moderator: “For the wrist. It should be splint for wrists”.
- P2: “This (pointing out the splint for wrist) is for supporting the wrist and this (the relief wrap) is just for warming or cooling, keeping it”.
- Moderator: “Yes, that is only for give you relief in order to reduce the pain or contractions. In order to continue with the upper devices and this is a walker hand splint, this is for using it for a walker, actually, I had (leaflet), this is a walker, the instructions mention that you can adjust three different parts; here, you can adjust this one, that is the wrist part to the patient’s hand and also you can adjust this part, I mean, if you need wider or smaller or even you can adjust the thumb part and obviously if you need more space here and at the end you can use this part (the palm) in order to attach this to the part of the walker. So, as I mentioned, the instructions said that you can adjust those three different parts: the wrist area, the thumb post and the finger plate. And that (splint) is for the right hand”.

- Moderator: "Well, for the lower limbs, I am going to show you two different models of orthosis for legs, so, we have two different designs, and this one can be used for left or right leg and it is available in three sizes, this is the large one, is unisex, it is basically an ankle foot orthosis, so you are going to use it if you have had a break or if you want to avoid some excessive rotations in your ankle in relation to your foot and also, it has straps in this part, is rigid (the structure) and this is more comfortable (inner part).
- P1: "It feels would be confortable".
- Moderator: "If you want you can try it on".
- P2: "I feel this material slips on the wooden floor, so they can have this and sit in one place but not on the wooden floor, on the carpet it is fine but not on the wooden floor because this is so smooth (sole), even here is so smooth (pointing out the front part of the sole – near to the fingers)". P3: "But there is a...", P2: "That doesn't give, but is not fully complete (pointing out the sole), you know, what happens to this place", "and after walking for some time on the carpet you know, the cotton balls and all come and stick here (outer sole), this (outer sole) also, looses the grip, so this is not the right thing for this, I don't feel because, this should not be that smooth, that doesn't give any grip at all, easy to slip, see, this (heel) is also... so suppose the legs go like this (slipping), you know.
- P3: "Even, give it some colocation".
- P2: "Yes, some rough surface, you know, like mate finish or something like that, that would be better rather than smooth".
- Moderator: "Even, you can use this part (a plastic plate that is added to the sole in a perpendicular direction), if you want to have an extra control of your movements, I mean, in order to avoid you have it in this way and also, if you are lying down you can have your foot and leg and is going to control the movements as well".
- P2: "Wearing this, you cannot walk?"
- Moderator: "No".
- P2: "Just for seating, or..."
- Moderator: "Yes, maybe you can walk but a little, I mean, you can transfer from one place to another place".
- P2: "From one chair to another chair or something like that, because as I said, you know... even this also (pointing out the attached part of the splint), it is not... I think...just for seating maybe..."
- Moderator: "We have this other model and those are from different situations, this (robust splint) is for stabilising your leg and for example, well, this (thinner splint) as well but you can use it while you are walking, this is as well an ankle-foot orthosis and it comes in four sizes, this is the large one and this is for the right foot. Maybe you can see it pretty similar to the left one but if you see it closer you can find the curve is different from here (its sole) and also, well, this part (calf) is more rigid than this one (sole) and you can also adjust this part (calf) to your limb heat it, I mean you can heat it (calf) and then moulding it a little bit and, also, this

part (sole) is thinner than this one and you can trim it in order to personalise the splint to your limb and also, it (the entire limb) helps to the foot-drop and it improves a toe clearance in a normal gate. If you want to see it".

- P2: "This is also again… for seating in one place, not for walking "
- Moderator: "No, you can walk, actually".
- P1: "So, you put your shoe on?"
- Moderator: "Yes".
- P1: "So, this is inside your shoe".
- P2: "The size and all, you know, imagine that one you are putting in your shoe and then doing it, the shoe has to be wider than this, definitely better get that size of shoe… no".
- P1: "It probably, would be better, it if was, something might that struck around your leg, so your leg was stick not this bottom part in it (inside sole)".
- Moderator: "Actually, there are other models, I mean, from other companies that have two straps, one here (upper calf) and one here (middle calf)".
- P1: "Wouldn't be for a long term use. Not for using everyday (grey splint for leg)".
- P2: "Not for daily, I think, maybe one day for some particular purpose".
- Moderator: "And at the end, we have these walking sticks, those are used for the right hand and also, you can adjust the height and the difference could be, this (black one) is smaller, the handle is smaller than this one (ergonomic stick). Also, another difference, is in this case, with this stick (black one), you can have your weight in the centre of all the device and this depends of the person, maybe you can use it more comfortable than this one (ergonomic stick), I don't know. And for example, this (ergonomic stick) is as well for right hand, this is wider, I mean, the surface is wider than this one (black one) and it can support all your hand and for example, if you want to adjust the height you need to push this (ring located in the large part of the stick)".
- P1: "I think these (sticks in general) are much better now, you know, one time there were just one height you couldn't adjust them, it was only like one straight across here (pointing out the surface of the handle) and that was the walking stick, while, this is much better because you can adjust the height, it can say you walk for your hand, difficult of long way walking sticks, they are much better now".
- Moderator: "And if you want to adjust this one (ergonomic stick), it is a little bit different, here you have to push in order to take off the ring and then (adjust the height) and then (put again the ring)".
- P1: "That is probably easier to adjust but if you like this top as well, whatever is easier for you "
- P2: "Even this is walking around the house right, they can go for longer walks"

- P3: “Well my dad uses one when he goes out, see because of his hip replacement”
- P2: “This place I feel it hurts your finger in the longer time, even this thing I think I do not know, this portion, when you are going for a longer walk, maybe within you are around the house, one room to another room, could be for few minutes, you can do that, but once again my worries are about this thing on a wooden floor, this is again sleeping you know, possibly, because they do not always put it something like that, put something like that more danger of sleeping”.
- Moderator: “It (ergonomic walking stick) is pretty similar to that one (black walking stick)”.

3. Moderator: “Ok here comes the third question, it says: considering the six devices which ones you think are used the most by the elderly?”
- P3: “These two (both walking sticks) I think”
- P1 and P2: “Walking (sticks)”
- Moderator: “Sorry, the six, in this case eight because we considered two models for walking sticks and for splint for legs, so considering the eight models or the six type of devices which one do you considering”
- P2: “Grab rail it is really very very useful, good design one, then the walking sticks, for their daily activities, everyday they want it, these are the two things they want every day, other things they may not depending on the conditions”
- P3: “I give it to the walking stick”

4. Moderator: ”And, (question) number four: what would you change or improve in each device? I am going to start with this one (grab rail), what would you change or improve?”
- P1: “How you actually put it on to the wall, how you fix it on to the wall, if that could be improved, then the colours on these as well”
- P3: “The colours yeah”
- Moderator: “In order to notice that it is strong”
- P1: “It could be plastic but just something for psychologically so they think ohh look it is metal it can handle my weight”
- P3: “Then if you can for hygienic purpose, you can see the handle in that things that you regularly touch some stainless steel material rather than plastics because of germs because they get easily attached to plastic and they can survive there longer time that metals, so if it can be metallic it would be better.”
- P2:”The design on that, yeah on this one rather suppose I put two fingers like that, this is too irregular I mean the level of the surface, that hurts here rather than what I feel this in itself you can make it you know, some rough surfaces, without these things, surface is rough so they can hold it and then you can get grip, because this surface not designed, not designed like this, but this itself it is not to be smooth, some you know something rough which would not slip, that would make it a thing

- Moderator: "About the relief wrap, what thing you could improve in it?"
- P1:"I suppose the Velcro, if you going to use it a lot I do not know what else you could do it, cause Velcro is used so much now and it is a really good product, it is just long term use and if they are using it everyday"
- P2:"That looses its grip, and even sometimes, you know, suppose with these hand they are coming to their hair or something and their hair sticks to that and it is a very irritating thing for them."
- Moderator: "About the splint for arms, for wrists sorry, what would you change?"
- P1:"It is the Velcro again"
- P2:"Design wise it is ok but the Velcro, it does not last long, everyday you are pulling, taking it out and then put it in"
- Moderator: "and did you feel it was confortable?"
- P3:"Sure yeah"
- P1:"They adjust well, I found they adjust well to your hand because you can move it"
- Moderator: "I am going to continue with this one, about the walker hand splint, what do you think it could be improved?"
- P2:" So for walking, wearing that, holding it and walking it is fine, suppose when they are taking a walking, they want like they want to hold something else, they have to take their hand out and then do that and then comeback, you know, that will be there so they cannot do that, only for this purpose that it is good, just for holding it and then walking is good, with the walker, suppose when they are taking two steps, they want to move this chair and then again, it is at that time, your hand it is not free, you have to take your hand out of that, then move the chair a little bit and then put your hand, hold it, move the walker, so that place it is, just for gripping I think it is fine"
- Moderator: "And about the adjustments of the splint in your hand, in the patience hand or in the users hand"
- P1:"It looks as if it is have plenty of places where you can fit it in your hand, it looks like it is well design"
- Moderator: "Well, about this one, what do you think that could be improved?"
- P3:"You know, we talked about the corrugation on it, you know for friction"
- Moderator: "Ah ok, this part"
- P2:" Smooth surface, just for wearing and sitting it is ok, otherwise it is very scary to look it, you know, imagine people walking in that, it is too scary, you can wear it, sit in one place without moving your leg, yes it gives the support so they can sit"
- Moderator: "And this one"
- P2: "Very flexible"
- P1: "You would just have to get bigger shoes with those in"
- Moderator: "You can cut it"
- P1: "Ohh you can cut it down"

- P2: “Under it, the width, so will that be going into my shoe if I put it, it is, it looks wider”
- P3: “It is not going into the shoe, the shoe sits on it”
- Moderator: “This is a large size”
- P2: “Yeah, it does not go inside the shoe, I am not talking about the length, this one, this one is wider than the shoe”
- Moderator: “Ahh you mention for example, if you order small size and it continues wider for putting it in your shoes”
- P2: “Even smaller also, I do not know if we have to put it in the shoe, it should go inside the shoes but it does not looks like it goes”
- Moderator: “Ahh ok, because of the material, I mean the size”
- P2:”The size of it, you see this much, my shoe is not, there is no space of this width in my shoe, so this one, and it is very stiff material also, moving your leg also inside will be very difficult”
- P1:”I do not know if you can walk that, I know this thing, what that it is, but I would still find it difficult to walk, your foot is very flexible, but I suppose it depends on what is wrong with the person, they might need to keep the foot rigid”
- P2: “Wearing it and sitting in one place it is fine”
- Moderator: “yeah, well actually, the description it says that it can help you with the foot drop, foot drop its when you cannot, when you have, sorry, when you”
- P1:”Ohh I see, when the arch of your foot, isn’t it?”
- Moderator: ”Sorry?”
- P1:”The arch of your foot, is that what it is?”
- P2: “At the back”
- P1: “You know in the middle of your foot”
- P2: “Ok, that is here with the shape, with the shape, not complete, but the design itself, how long you can wear it and sit it, when they want you to put it inside the shoe which means that you have to walk, when you are sitting there you can put it and this one is directly you can put it and sit it, you do not need a shoe just for sitting, no shoe is required just for sitting, you can wear it and sit, when you are putting it inside the show means you want them to walk, there is no grip in here you see, it goes inside the shoe, but there is no grip, there are chances of leg coming out like this on that because there is no grip here see, even if you put your shoe lace, but still that moves I suppose what happens when your leg slightly moves here, see here it is, up like this, it hurts so much, suppose my leg is not like this, it is moving like this, my fingers are moving, something like this and in this place, so it hurts a lot, so walking, for walking it is not suitable at all they can just wear it and sit, but not inside the shoe”
- Moderator: “So it can be used when you have a foot drop, foot drop is when you cannot up your, this part of the foot, I mean you have this problem, like this one and you cannot, you need something to support that part, so, mhh, well, and the last, these ones, well, this one what do you think that could be improved?”

- P3: "I think, the only thing is the tip, you can have"
- P2: "Yeah for the grip"
- P3:"Just here in case, like she pointed out, usually comes at an angle, if here it can have further gripping, I think that is the only thing, because it is sliding you know, they cant control it"
- P2: "It is very dangerous, and usually what they do when they are sitting there, they do not hold like this, get up and then they are just fine, first they start like this the put their hand like this and it is very long or something, it is always like they try to put it like this and then get up, more chances are there, so they do not make it straight and then get up, so that is the portion that needs to be"

Moderator: "Next, I am going to give you the final form, this is related to these assistive devices".

- P2: "So this gender, is it my gender or the patients? Oh it is about me?"
- Moderator: "yeah, it is about you"
- P3: "So, what is the status, should it be carer or professional?"
- P2:"Just carer"
- Moderator: "Yes, on the second page I am going to ask you to please to answer, well to classify each of the assistive devices that we already saw and we are going to rank these devices from 1 to 6, and answer the question which of them would benefit the most if were personalised, being 1 the most and 6 the least and why?, why am I asking about personalisation? Because one of the benefits of additive manufacturing, which is as well my subject, is the chance, the opportunity you have to personalised things to create complex things or even you can produce a lot of shapes so I would like to apply this technology into the assistive devices and personalisation is as well one of the characteristics that can be used in assistive devices, because many of them are in touch, are in direct touch, contact, with the person, with the limbs, so that is basically what I am asking you to rank, which, if I have an assistive devices and maybe I can adapt it to a person which would have most benefits if I do, if I conduct this type of, if I produce this type of devices, so we have at first the rails, then the relief, and which do you think will be "
- P2: "I would like to rank one both walking stick and rail, both are equally important for me, so rail it could be used anywhere like getting up from next to the sofa, or in the toilets, anywhere it could be so, for me they are very important I think, I do not know, I just put one and two, but I cant differentiate which one is the first one"
- P3: "Mhhh the walker hand split"
- Moderator: "Yes?"
- P3: "It must not be made for walker, you can make it flexible in a way the patient wears it a longer time of the day so they can hold the bed, anything you want to hold"
- Moderator: "No, it is just for the walker, or maybe if you have a rail"
- P3: "Why am I asking? Imagine if you have something the diameter is"

- Moderator: “Ahh ok, well it is supposed that you can, for example, you already have your walker and it has a smaller diameter than this one, so you can bend this one to adapt it”
- P3: “You can bend it?”
- Moderator: “The instructions mention you can do it”
- P3: “Ok”
- Moderator: “yes you can, this one”
- P3: “I mean this diameter is the one I am talking one, so what if you have something like you know the hand rails, walkways, maybe the rail is more than this”
- Moderator: “Ahh ok, you mention another rail, I mean not only the walker”
- P3: “Yes, that is what I am talking about”
- Moderator: “I do not think it could work”
- P3: “I mean, larger than this, what if the rail you want to hold has a different configuration from circle, I mean square or flat, I cant use this”
- Moderator: “No, you cannot”
- P3: “In that case, this is only made for the walker, that is what I am saying, if we can make it in a way that stiff material there is not there, what it just needs is that the friction in here, the moment you fix this on your palm, it can be flexible then so you can hold anything”
- P2: “Multipurpose, you can use it anywhere you want to”
- P3: “So, that will be an improvement for it, so you can make it multipurpose, other than the walker”
- Moderator: “Yes, actually, it has velcro in order to attach it better to an specific walker or maybe several walkers but with the same characteristics, the same diameter”.
- P3: “So, the moment you are on the walker you get this off, when you want to go on the staircases, you need to put another…”
- Moderator: “Yeah, maybe, you have another splint…”
- Moderator: “For the questions, for example, if you are writing number 1 for the walking sticks, are you suggesting that you need personalisation in these type of devices, right?”
- P2: “Yes, it is required because height of the person just like is there, then, you need personalisation and then hand grip as well, so it is not suitable for everyone”.
- P3: “Is it (black walking stick) usable for left users?”
- Moderator: “No that is only for right hand, I mean, if you want to use it with your left, you have to buy another. Yes, you cannot use it, it feels so strange”
- P2: “But I feel should be common, design should be common, you know, not only… right/left…”
- P3: “You know, our hands are different, what applies here (left hand) definitely won’t apply here (right hand)”.
- P2: “Because, after walking for some time they want to change their hand, you know, they cannot buy two things”

- Moderator: “In the description (of the black stick) it says this is ideal for people with small hands. I think this (moderator’s hand) is an small hand and it fits well, and if you have a wider hand you can choose other ones (ergonomic walking stick)”.
- P3: “Because, you know, the traditional one that is cylindrical if you keep using it you find that the tip of the hand get blisters with time, specially for most of them that walk a lot and before you know it there will some strains around that so these very good modification, it spreads the stress”.

5. Moderator: “In order to finish the focus group I just want to ask the last question, and it is about the answer that you wrote, it is considering the six devices, which ones do you think could improve more if they are personalised, I mean it is basically your answer, the answer that you wrote”.

- P3: “ Like the walking stick, if you can add mhhhh higher grip, that would be great and since it has no popularity giving it that sense of mhhh advantage over others so and if you can add that additional it will give it a better outlook, then since we are mhhh the next thing is grip, if the grip can be giving that we talk about, making it metallic, we talked about giving it this screw, the screw too, you know, the wall like in my country, someone cannot use the wall is concrete, if it depends on that tiny screw, maybe if you can employ a better joining process other than the screw, it would be better”
- P2: “To add to that, the screw, riveting is better, like you know you weld it and put something like that, so riveting can be done to wooden surface you can do that, so rivet can be better but the fixing must be very strong, the thing should not come out because people put a lot of weight on that more than the surface and this, just the screws, that is the portion you have to concentrate, specially on the top more than the bottom one, on the top usually they tend to hold it closer to the top portion so those have to be stronger”
- Moderator: “And about the shape, for example of the grab rail, because of, mhh, the personalisation is a little bit more related to the shape maybe of the device”
- P1: “You can buy them in different shapes though, cant you? Depending on where you want it.
- Moderator: “The part that attaches, maybe that can be a requirement for several people and if you want to personalised that device, the grab rail it could be something related to the shape or, I do not know, handles”
- P2: “The thickness of it could be, you can, and now that it is fine but for some people you can reduce the thickness, it is very hard it is very difficult for them to hold it like that, they can close it completely because it is a little bit thinner but it is still strong, thin and strong”

- P1: "Because some times if they got really bad arthritis as well, they cant actually put the hand fully out"
- P2: "Yes, they cant bend their fingers completely too, so in that case if it is thinner you know"
- Moderator: "And about this, sorry, the splints, do you think they are ok as they are"
- P1: "It is just the Velcro, I do not know what you could do about that"
- Moderator: "And about this one"
- P2: "That also"
- Moderator: "And about the splints for legs"
- P1: "It is just that one that goes into your shoe, but if that is meant to be for your foot I do not really know what you can do"
- Moderator: "Ok, well, that is the end of the session I do not know if anybody has any questions about it or further comments, and you can also send me an email"
- P2: "This kind of devices, that you say, the company, this one, this is the company that manufactures"
- Moderator: "That is the logo of the ADAM centre which is where I work"
- P2: "This are not manufactured there, you are just design it"
- Moderator: "These are, I did a search on google and I just choose them"
- P1: "Are they the most popular ones that the elderly use?"
- Moderator: "...In order to select these assistive devices I had to do an investigation based on which assistive devices impact in more activities for the elderly population, as well as which ones impact in more illnesses, I mean these can be used maybe for a person arthritis or a person who has suffered from osteoporosis, so we have several illnesses, I mean several persons with several illnesses and so as a result I got these six assistive devices, over the UK, yeah, these are in the UK. But the ADAM centre, is the logo of the group, the research group, and CONACYT is the sponsor in my country"
- P2: "One more I expected is the knee portion, you know, people with arthritis, knees are most difficult one, there you can get the bending, the join, lot of trouble with the knee, you could choose that device as well"
- P3: "Yes, because I was looking at this and among this I do not think any of them relates to the knee and if you can, if you could go to the hospital now you would notice that even the one that came for maybe arm or whatever would be limping because of the knee and wait, so if you can have some braces that would be for the knee because I know that if you can wear something that is flexible but something like that needs to be flexible as well if you can wear something at the knee that can be flexible that holds the skin and bone intact because I think arthritis is all about locomotion, so something that gives you a better locomotion feeling for the long time because when you keep the knee or the elbow stiff, in place, for a particular position for a long time, there are some constraints that when it is for a long time to now moving the knee or hand becomes an issue which now becomes this arthritis issue, so if you can have

something that can be flexible but at the same time help to keep massaging that place, might be good, and then you look at how it would be it can apply to different mhh, to be warm, to be unisex, it also be, yeah like I said flexible"

- P1: "soft"
- P3: "Yes, because if you talk of strength, if it is so stiff it wont have big pore, if it is too soft it would have them but, so it needs to be at the average, then it also have some hygienic purpose, cause anything that is close to the skin I know they may not have all the time to clean themselves up so it needs to be very easy to clean, when they remove they can just throw it into the bath, pick it up and it is clean or if they want to change it they can just rinse it in still water or just add some soap, something that is very easy to clean, so one it needs to be unisex, flexible, warm and easy to clean"
- P2: "The same thing but maybe have splints for the hands, I think more or less it suits the knee portion, the material is fine, everything is fine, because usually, athletes for you know, running people, running race and all, they get this problem, sports people they use it, this knee support, same thing for the arthritis people also but maybe a little bit more medical, fitted band, so they can put it around the knee, knee is the most difficult problematic one for the arthritics people, they suffer a lot, just like you want this thing for the knee also they need supporting, suddenly they cannot never get up, a lot of problem with the knee."
- P3: "It could be some aesthetics design, because sometimes some patients with disease… so if it has some aesthetic attraction and the acceptance, I think these 4 things should be considered. I know since Additive Manufacturing has this advantage of customisation and ability to manufacture complex shapes, so, if you can have it in a way that becomes, you know, our legs come in different shapes, like me, I have a curve leg and a right leg, it can have in a way it can be customised to someone's need, the patient's need".
- Moderator: "Ok, that is important as well"
- Moderator: "Well, thank you very much for being here, if you want you can take some refreshments, thank you".

Session 2

Professionals who have worked with assistive devices

Date: Tuesday 12th December 2017

Time: 01:00 pm – 2:00 pm

1. Welcome

Moderator: Hi, good morning, thank you very much for being here, my name is Karla Huerta, I am PhD researcher from the Mechanical Engineering Department and I work at the AdAM Centre, which is the Advanced Additive Manufacturing Group and I will be the moderator of this focus group.

Before starting, I would like to give you 1 copy of the *Participant Information Sheet*, this document is the same that you already received through email and it is yours to keep, here you are going to find what is the aim of focus group, what is AM, the assistive devices and benefits of participation, also, I am going to give you 2 copies of the *Consent Form*, one is for you to sign and return it to me and you can keep the other copy. After this, if you want, please feel free to take some refreshments.

2. Introduction

Moderator: This focus group is related to my investigation, which is the development of an assistive device for the elderly population in the UK using Additive Manufacturing technology.
Specifically, the aim of this focus group is collecting opinions and thoughts about six preselected assistive devices, this information will help me to select one of them and base further research on it.
As the project needs opinions about six assistive devices, it was important to consider participants in this session who have been involved with this type of products, this is the reason why you were chosen.

Does anybody have any questions?

3. Development of the focus group

Ok, well, the session is divided in three parts, the first one I am going to ask some questions, in the second one I am going to pass around those assistive devices and if you want to can interact with them and in the third part I am going to give a form and it is going to be related to those devices.

Ok, this focus group will collect all the information regarding which assistive device will be more convenient for the elderly population based on its impact in improving the daily lives of the elderly population.

And based on this, this is going to be the first question, which is:

1. Which activities do you consider are the ones that present more challenges to the elderly?

- P3: "Are we primarily talking about mobility things?"
- Moderator: "Ok"
- P3: "No, I am asking you, do you mean mobility or do you mean literally anything"
- Moderator: "Anything"
- P1: "I suppose my first thought is that is quite difficult question because elderly to me you know what is elderly, you talking somebody is 95 or 100, or somebody who is 65 and retired, so I think it varies across that life course, that could still be thirty forty years somebody is considered elderly, so"
- Moderator: "I am considering in this study elderly as people of 65 years old or over"
- P3: "Ultimately do we not think obviously you get old old and if you like old, and that you are right, there is not an homogeneous group, there is forty years and you get a lot of variation in there but often we think of things like, my point of view is eating and drinking obviously, so its been able to do those things independently but in terms of some other things we see here, obviously it is bathing or it is about dressing and things like that, so there might be things that we think about can people dress themselves, wash themselves, feed themselves and how well can people manage this processes"
- P2: "The other thing is, one way of looking at your question is to say simply say which are the most commonly provided devices and one of the top ones must be walking sticks and therefore at a population level the walking stick probably has a bigger impact than many other devices, there are absolutely essential for some people, but not as many in acute services, typically hospitals would have, they do not have an standard walking stick in these centres, there is one and they provide that one to everyone, they are either adjustable or they come in different lengths, different heights, which they choose for the individual so, nominally you could produce something like that"
- P3: "And, certainly if you look at Cambridge University inclusive design tool kit, from their inclusive design agenda, what they are saying what is the biggest problem would be on there is locomotion, getting about is what they would define as, now we can talk about what that is then subsequently define, but in terms of the biggest nominally issue is locomotion and getting about. That is actually a good source of

information beyond this focus group, ask for the house of panels survey they have it broken down and talk about what are the issues around other populations”

Continuing with the challenges presented in their lives:

2. What kinds of situations and/or activities are more involved in elderly’s accidents? And why?

- P3: “These are very big questions, falls, obviously we know it is a big issue, and the one I, in falls there is a lot of people doing research on that, I did see a presentation by a guy from Birmingham University who did a study that suggest there are two types of people in this world, there are those that look where they are going and those who do not, he is basically saying we are task focus and others are project focus if you like, my mother is one for instance, if she is gotta, she is an adult person obviously, if she needs to walk into the kitchen to get a spoon she keeps saying I need a spoon, I need a spoon, I need a spoon, and what is happening in between in inconsequential and she is more prone to fall over and they made some studies what they will do in that is sort of a motion caption with boxes on the floor and asking people to stand in certain things and different people and they said you are more prone to fall if you do not actually look where you are going which is sound, I have always said this research just proved the obvious, and this is true. Falls are very common for older people.
- P2: “There is literature around that that will tell you the reasons why people fall, there would be reviews of it”
- P4: “There is this paper coming out where they list the reasons people move out of their home and into care homes, and falls was the number one reason, they did not feel comfortable at home, why you can imagine having some assistance will make it easier for them”
- P2: “And normally the reason involves what we call co-morbidities, so it is more than one factor, so for example you might think that sight loss is that is likely to cause falls, in its own it does not, is with other things”
- P1: “Like hearing also, it is really big issue, it is very hard kind of just saying that is the reason because it can be condition specific, medication related, someone's whole personal history fitting in to why they fell on that day and I am sure there is still a huge chunk that I do not know”
- P1: “There are a lot of major studies on this, looking up this there will be stats on what happens and why?”
- P3: “But, can you repeat your question, because obviously we said falls but what was your question again”
- Moderator: “The question was what kind of situations and or activities are more involved in elderly accidents?”
- P3: “ Well, we will bring our own knowledge to the table, my passion is about feeding and drinking so I can give you anecdotes till forever about

people being surrounded by crisps and biscuits and not eating properly and all that sort of thing so I would say quite naturally getting people to eat proper amount and nutrition and all this sort of things is a big issue that is because what I bring it over, whether that is in the top 10 or in whatever, you know, it is for me, feeding is, so when I think about assistive technologies I am passionate about spoons and forks and plates and all other things"

- P4: "Maybe there were accidents or a product you can think of"
- P3: "Exactly, that is what I would say because it comes back to the things around helping people do the task, so if we go back to your first questions, in the context of me I would say obviously locomotion, then there is also bathing and dressing, they may not have accidents, you know they may have some accidents, but they are separate, they could be separate from falls, if that makes sense, it does not comes under the fall category per se although they might do if you are in the bath or something like that, but, yeah, so I mean I do not know if that is helpful but certainly there are issues around a bath, bath again or whatever it may be, a shower, there are issues around, people struggling to clothe themselves and things like that as well"
- P2: "So, another generic group that is not specific to a particular condition its got to be memory, memory failure"
- P1: "I think yeah, about older people, the things you might think about yeah, it would be cover difficulties that people that do not ... people or living with symptoms of dementia, whether it is diagnose or not, that might affect, you know, how they plan and carry out activities or they do not remember to do certain things that might be safe or that they have done previously in their life, and then yeah the sensory impairments like sight and hearing, really affect people's ability to balance and walk, so you know, there is like I said before, can be really difficult because if you just took old people, and all of those conditions that affect older people, and all the functions impairments regardless of illness and conditions, so yeah if you think of the four, five senses really"
- P3: "You bang on the money when you say that there is rarely that is one, because you might start with one early, it could be arthritis or whatever it might be, but then you move into loosing bit of hearing, loosing a bit of sight, and then they get cross, so you might have arthritis and poor hearing and poor sight, and then you might I do not know, hit your hip and have a hip replacement and so on, so this things build up and it is rare that is is just one, one thing, but again Cambridge University have done quite a lot of work on that and keep looking at percentages, what percentage of the population is this and this and this, it is quite a lot of work"
- P4: "It is difficult, I met a lady yesterday I went to see because she had diagnosed dementia, but actually the biggest problem for her was her sight because she had macular degeneration so she was registered blind, she could see a bit but barely, and she had two knees replacement and

ankle replacement or something, actually the thing that was stopping her living life really it was her sight and her mobility and she was falling you know, so she barely went out of the house and if she did it was a major prohibition, very nervous, and would really be at risk of falling, so that is like an example of actually so you can see there is one condition but there are other issues coming in like you were saying"

- P1: "Assistive technology often needs something acute, like a fall to sort of ohh in that case we need to bring in this and that, but something like dementia or hearing loss is progressive and so, could happen put attention much early but probably it takes a long time before you do anything at all, like hearing loss generally from my research, people tend not to be seen well enough to be fit with a hearing aid, by which time the brain has forgotten how to hear so you never recover, it is not like glasses where you can recover so we all ought to be seen at this age, but even the people working in hearing companies don't"
- P2: "What you also have is that there is a lot of old people, like my parents, they have a strong sense of independence and so issues that we might thing, issue, like you just said reminded me of something, do not get flank up until something serious happen, does that makes sense, and even there people will try to hide in some way, many older people are almost reluctant to get old if that makes sense"
- P4: "My father is the perfect example, he is 88 now, he has macular degeneration, he is pretty deaf, pretty much deaf, without the hearing aid he is totally deaf, his balance is an issue, he is starting to sway a little bit, and he is said to me I am not getting anything until I fall, so be it, then I will deal with it, because he wont use the stick, he lives in London he goes into central town and he wont use a stick, he feels stigmatized or whatever"
- P3: "So what you actually have if you think about your model for this, if you think about it in some way it is actually not sort of white and black, it becomes this grey transition where this points in space where in a perfect world we could somehow understand that transition and intervene earlier but it actually becomes quite difficult because we cant observe it well enough so we cant be in everybody's house or time I mean, and personally it is very good actually because we bring it in as researchers anyway don't we, we know and sometimes deep down it is what motivates sometimes to do, because I know for my own, my dad died four years ago, but for about 8 months I did not know half of the problems my mother was having, she would not tell me, so he took him to the house to get him upstairs and he was vomiting and shitting himself and all this was going on and I asked everything alright, yeah everything is fine, it is clearly not, by the time you bring in social services in and everything else as you just said it is way down line because my dad needed far more than a visit from social services you then take it to the and yes we are looking into it and by the time it is looked into it he is dead. The reality is that older people don't, we don't, I don't, you know, I

still want to play football, I still want to do all sort of things, we are reluctant ageist if I may say so"

- P4: "It is funny, it is like glasses, there is not much stigma to do with that, but hearing aids people do not really want".
- P3: "Glasses are one of the things that inclusive designs has held up as a great thing, don't they?, because everybody holds glasses as a positive thing whether there was a phase sometime, were trendy young things were buying glasses and were just playing glasses and because it was a thing to be seen, so it held up as a, I do not wear them, but my wife does and she is all ahh we are on Westfield I cannot afford this, do you think, are they good and everything else and they are a fashion item and they held up as a thing where you get right almost obviously, but the cost and then there is an exclusion because of that, but in terms of an assistive device people go wow I do not mind having one of them, glasses are held up as one example, going back to yours peter, I remember a presentation years ago where somebody said in Victorian society a man would not be seen without a walking cane, you know, and you think about it, now we would not have one, we do not have one, in a way what a wonderful world when we are talking about people falling over and needing a walking stick, what a wonderful world it would be if you make it a trendy thing, I am emphasizing a point rather than saying we could do it, make it happen, what I am trying to say culturally a walking cane was a thing a hundred a twenty years ago say, and what a thing would it be if it was because all these older people could feel cool and trendy and part of something, but we do not, we got rid of them we do not have them, so, some of them critic and theories it is obviously and when you are talking, I guess it will come into that, when we are thinking about personalisation, when we are thinking about ownership, we have to think about the context in the space time, because there is this reluctance, and this is what personalisation might be able to do actually because it might facilitate people wanting it, but it might go the other way as well I guess we will come that, but nominally you can see why, yeahh ok, if we can make this sort of acceptance things because these are the issues"
- P2: "The other side of the coin can be painted in the sense of a very negative act, for you all people openness to use devices, mhh, there is a positive sight to them being independent because if they are over reliant on the technology they are then afraid to use it and to lose it"
- P3: "Wasn't there an amazing piece of research, I remember seeing some of it, I looked it up because I was interested in it for a while, but we are all busy, I think I saw a piece of research, some psychologists have done that, I did read about it again because I was fascinating by it, they put some people, put some older people, in a house and decorated in 1970s wallpaper, 1970s stuff, and they were all quite ill, and then they filmed them and they did all this stuff and they found the become more mobile, more less sedentary and all different things, they did all this stuff, they took them back and realise some of old age is in your mind if that makes

sense, in the sense you go I am infirm I need to be like this because, it was quite an interesting piece of research."

- P2: "Have we answered your question?"
- P1: "Yeah, do get us move along, we need to get through the all the questions".

3. Moderator: "That is ok, well, the next part will be, I am going to show six preselected assistive devices, we have eight actually because I picked up two models of canes and two models of splints for legs, so if you want we can start with these, this is the grab rail, well, we have seen many of these and in this case I am going to pass it around and if you like to touch it and grab it in order to notice things"

- P3: "You must have seen a few of these"
- P1: "Well I have, but not in my recent life, it was my student life from my occupational therapist background, so occupational therapist in their training they are trained to fit grab rails and so on, but I did it in my training and then never did it in a sense, so I do not have a lot of experience, but my dad again, has an absolute aversion to it, did not want any grab rails in his bathroom at all, he has a high bath I do not know if you know, like a traditional English bath and it has not change since 1969, really high to step over and I have talked him about getting a grab rail, dad why don you just think about it and we can afford it, money is not an issue, absolutely wont do it, he does not bath either, he is not like I am really into a nice relaxing bath, he just showers, he has always being a person who showers, he finally got a grab rail fitted about a couple of years ago, and he is like, ohh it is really good, it does makes me a lot more confident but you know"
- P3: "The issue all the time, is people hospitalisation of home, there is this reluctance of this idea of bringing the hospital into the home, and that is exactly a part of that isn't it, and you see it all around, cause it also flags these things particularly inside the home, you walk pass the house, you walking around and you see the grab rails on the outside, don't you, by the door or something and straight away all this mental pictures go through your head about the person who lives there, well, that must go through their heads as well, that makes sense, so this is the issue, why plastic piece this here, you know, in the end if you are thinking about personalisation, if you are thinking about making it, does it has to look like that exactly, you know, can it be cool, funky, can it come in different colours, can it come in different textures, can you put things on it, people like football can it be made in Sheffield Wednesday colours, you know what I mean, can it made part of somebody's life story"
- P1: "Can it coordinate with your bathroom, you know"
- P4: "Because it stands out, doesn't it, if it is like that"
- P1: "People put a lot of effort into their homes"

- P3: “Yeah exactly, can it be made as part of the bathroom, that would be an element down the line of it”
- P4: “You can probably avoid, prevent lots of accidents, by just actually making something people would want to have rather than getting it by force when they have their first accident”
- P2: “Or make it a standard fitting of bathrooms”
- P1: “Yes, do all bathrooms have it?”
- P3: “ Yeah, which comes back to the thing I said, do all bathrooms have it”
- P4: “Yeah because we probably already have things that are for safety”
- P2: “Lots of hotels have them”
- P1: “Well, given how people change houses as well, you could have it in all bathrooms, small children could probably benefit from rails at time, would they not, you know”
- P3: “Absolutely, well, you could, exactly, you can change the nature of baths themselves”
- P1: “I am just thinking, you know, like, I went to somebody's house and they have a plug socket that came up and down in the middle of their kitchen unit they put it away like we do, you know, would you have a grab rail that pop out but secure, this one was a little bit wobbly, so if you, like if it was fitted standard in all bathrooms, then if the house got bought by someone who needed a grab rail then grab rail it would be like active grab rail, but if you are a family that did not want a grab rail could you just deactive the grab rail, you know what I mean, it is hidden or something”
- P3: “It is moving this thing to the norm isn’t it, and usually those sort of thing come through from legislation, as I was explaining and I do not know if you have seen it but plug sockets on new houses are up the wall, aren’t they? From legislation, protect things from flood risk and from bending down to plug in things, you will manage to get that, you don’t have to bend down quite as much to do it, so you could, you know, try influence building requirements in some way, you have to have a grab rail in the bathroom, in somewhere hidden or not”
- P4: “If you go down the road of doing a bathroom accessories, there is this company called (inaudible)”
- P3: “Vitra is one we have done a lot of work with”
- P4: “Is it Vitra?”
- P2: “No, I cant remember the name”
- P4: “They basically do fashionable looking bathrooms that you would not know they come with assistive technology even for very severely disabled people and they look really nice, they put a lot of effort into the design, so even, regardless of what you are doing, it would be interesting to have a chat with them and just hear their experience of what, you need to decide what level of design you want but actually I would not mind having that on my house”
- P3: “To go back to this point as well, it is interesting about why wet rooms aren’t considered, you know again going back to building them or something, you say build wet rooms, who wants to have a hand grab rail

on a wet room anyway, then you think why isn't that a norm, why don't we do that, it is the future, wet rooms, you go and shower, how many of us really have a bath nowadays, changing cultural norms can be problematic".

- Moderator: "That was the first one that appears in the table".
- Moderator: "Now I am going to pass this relief wrap, this is a removable splint that it helps to reduce the swelling, also relieves pain, you can put it on the microwave or in the freezer. This splint is reversible, for example, if you want to use it on the right hand you need to wrap it in this way, if you want to use it on the left hand you just have to take this stud off and then (flip the stud and put it inside the splint), yes, you can feel the line of the support".
- P3: "And what is to be used for, Karla, who use this?"
- Moderator: "People who suffer from inflammations in limbs (P2: "so, arthritis"), well in their hands".
- P3: "And is it over the counter, I think?... is it some buy on…"
- P1, P2 and P4: "I think so… it looks like… yes".
- P3: "So, something you would buy over the counter".
- Moderator: "Yes".
- P1: "Yeah, that says pre limited use, (P3: "yeah, that is what I was going to say") it may work, you know, for some people may like the thing on back on there, swelling joints".
- P4 to P3: "That is the wrong side".
- P2: "Or are you going to weaken your joint".
- P3: "Exactly, I just tempted not thinking on putting on".
- P4: "Maybe temporary".
- P1: "Good have is an over counter option but person if you got really choose with you and be want and be one and to see an specialist, he will prescribe personalised splint for exactly problems".
- P2: "Potentially, I mean, looking at this that the next one you get is the splint, I know that in the eclipse services they have major problems in making the bespoke splints, they would love someone to come along and say here is a new way of making this and it would be really good and it will be better than they can do now because they have to use water baths, getting to the right temperature is this warn bath is falling and they put the material into the water baths to folding ran and all this kind of things, it is really messy someone has set process they would like to change".
- P4: "And is it quite of portrait, it fits…"
- P2: "Yes, because when you get to those you are supporting all the muscular or ligament all nature".
- P4: "So, it is has to be an automatic way of measuring and then producing fabric, can you print fabric, fabric like stuff?"
- P2: "Would be really good".
- P2: "And if you want to talk to the orthotist who do this things contact me, and I would be able to contact people in Sheffield Teaching Hospitals and

then they should be able to get you, to meet the orthotist to do this and you can see what they do".

- Moderator: "Yes, thank you very much".
- P3: "Well, can I just come back a little because is an important point here about if you are personalising things and how".
- "From my point of view, if you compare the two things, because if this is something I buy the personalisation is very different than if something I get given to me by service, so, if you think about that because, if I got to go and buy this (relief wrap) from the shop then personalise for me is very difficult because it's going to be ten thousands… so personalisation if I go to an occupational therapist becomes… these are different things 'cause I am assuming that something that is given by the therapist services that splint 'cause that would be something more professional, is it still something I would buy?, 'cause that makes differences in the context, how personalisation works, 'cause how would you made personalisation work in a retail environment".
- P2: "Get different versions".
- P3: "Yeah, exactly, but I wouldn't be personalised, it wouldn't".
- P4: "It is done by Velcro".
- (Laughs) P3: "But it wouldn't be personal (P4: "no") or the only personalisation you can do or it be very complex personalisation, you get a colourisation on the personalisation, you know, you get an splint, you name on it".
- P2: "Unless there is a machine in every shop".
- P3: "This is what I saying to you (moderator), how would that, so, there's a context, how long that works, because if it is in shop and it's Boots and you get Boots, the chemist is helping you with your hand splints and is in the shop and your machine is in the shop, that is a different context than going to an another general hospital speaking to the orthopaedist. Now that might be a great context actually 'cause I'm sure that Health Service should love it the Boots in pharmacies would do it rather than the health systems…"
- P4: "If you have the right machines, it wouldn't be different than having an artist, they send off with measurements and they come back with something that fits".
- P3: "But you have to think, that is what I am saying, you have to think on the environment on which you want the things to be used to, because they are something different, aren't they? And one might be, 'cause I don't know the rules, 'cause that makes sense, is it be, you know, what kind of pharmacies do suppose to occupational therapists, I don't really know, but the personalisation for those products should be very different or would have to be very different".
- Moderator: "Actually, I got all the assistive devices through online and I didn't need a prescription for them".
- P4: "So, even this thing (pointing out the splint for wrist)".
- P2: "Can imagine self-prescribed the first".

- Moderator: “The thing is, for example, that one (relief wrap), I think is one size and it is reversible”.
- P3: “It is actually where we going, so it is important to understand where actually going with all of these stuff”.
- P2: “It is dangerous to prescribe that for yourself (the splint for foot)”.
- P3: “We cannot going down the roots of all most buying stuff… with your own personal budget type, so we never going that but we have to think about how that works, I am not sure if we know. But certainly, there are differences if you talk about personalisation”.
- P2: “But it is interesting ‘cause if you take examples like that in France, you might get a prescription from a doctor in the hospital or GP, ‘cause I have seen this happen to someone, and they rent to the chemist, they find the right equivalent to a chemist of a pharmacy and they have all there and then they have to measure you, to pick the right one, so the pharmacies actually doing that already in France a decade ago”.
- P3: “But we know that yet”.
- P2: “No”.
- Moderator: “Ok, this (splint for wrist) third device has bought, this is the large size and you can ask for the x- small, small, medium and extra large, and this is for the right hand, so, basically, you have two aluminium studs there, inside, and you may use it like this and then this is for the thumb”.
- P4: “It is so risky to put it on”.
- P3: “You read my mind, I would say, one, when we talk about mobility, of you have (low condition) in one arm…(is it reliable on the other arm?)”
- P1: “I mean, one of the things that worry me about an older person, specially perhaps an older older person ‘cause is people get old skin, is very fragile and that is why, you know, someone actually got an injury or condition that means that hand needs to be supported, need it to heal or just to function every day, things like, you know, this could shave them, this could pressure on them, I would be very worried, you know, I wouldn’t want a relative of mine wearing anything like this without being supervised by a professional who knows about, you know, whether is a pharmacist…the actual idea that you can just go and get something through internet… maybe it could be too tight and someone with bad circulation, I wouldn’t select one of this for this project, within my point of view, you know, I think there are too many issues with it”.
- P4: “Are you picking one of these products and then developing…”
- Moderator: “Yes”.
- P1: “It seems there are a lot of problems, potentially, someone could harm their hands with that”.
- P3: “But, that being said, it is an interesting question that exist though, (P1: Yeah, I mean, also these stuff exist, doesn’t it?) Yeah, exactly, that is a good question in itself (P1: Yeah, I mean, any of us could do a self-damage with it, just becomes even more over risk)”. P3: “I mean, in a wider context, I think, what is consistent across these things is there is a horrid colour, is a low low low quality thing, and what you see consistently

across of all these things is… you know, when you are looking in a shop… and it's closed… if you look through the window you just see a sea of beige and a sea of brown (P4: "I just thinking, this is no one's skin colour") and one of the things and you got a device, your walker hand splint, again, it's a sea of beige, isn't it? And we see this all the time, why do these things have to be these colours, see if you not picking that…"

- P4: "So, in fact if you buy this one (splint for wrist) for sport injury I bet you it would be black or something like this, I just bought insoles for my daughter' shoes… and the ones for sports are blue, green, red, you know, they are like funky colours and this if you have like… you wouldn't have this colour".
- P3: "So, if you are old or if you hurt yourself… it's that, but if it's like you say, if you sporting you get a nice name as well, you get an school's name, you know, power, power grab or something, on that, or anything like that, you know what I mean, you will have anything gives you design".
- P4: "Sometimes, one day, you know, when we get this age, we will produce something like this and we will want more…"
- P3: "Well, that is what are we saying all the time, you know, even if you believe into generation, the reality is that even if you, yeah, basically, we can design for ourselves… if you don't have the ability to do, you can design for yourself".
- Moderator: (passing around the walker hand splint).
- P4: "What it's meant to do?"
- Moderator: "It's a walker hand splint".
- P1: "It helps to position your hand correctly on the walker".
- P1: "So many problems with this. I mean, firstly, if somebody needs a walker, if you are thinking in an older person, I would say that they may have cognitive problems, I mean, cognitively, Jesus, so I mean it's quite challenged for them to work on how to do it".
- Moderator: "That is for the right hand". "It is one size for the right hand".
- P3: "It's amazing these stuff have these guys made, doesn't it, somebody does".
- P1: "I mean, you just never going to use it outside, if you need a walker and you first have to put this on, for your usual walker, I mean, ha! What, this incentivise to every walker… anyway, you'll be like ah! People are desperate of trying these things…"
- P4: "It's also, seems like, sort of thing if you didn't have the muscle to grab on…what you want use for life… definitely won't have, you know, ever trainers"
- P1: "It could actually be risky, circulation again with the tabs if people do them too tight, unsafe if they didn't too loose and it falls off and then trip I am afraid…" "It's like you say (P4) you might loose function…"
- P4: "And you are not going… (on/off) when you finish walking…"
- P1: "What are you going to do when you want to drink a cup of tea?"
- P1: "I think it is really unsafe, actually".

- P2: “It’s a lie, because in the picture it shows someone actually grappling the hand in angle to grip, you try doing that without”.
- P1: “So, there is no individuality, you know, what if your hand, doesn’t go into that shape, I mean, someone got arthritis and they got contractions… ”
- P2: “It’s clear this walker (picture on the leaflet) the dimensions on the bar are smaller than this (walker hand splint)”
- P1: “This is somebody just trying making money out it”.
- P2: “It is a bad example what is trying to be”.
- Moderator: “The instructions mention that you can bend this one (finger-part)… the thumb part”.
- P2: “Who is going to bend it?”
- P1: “Again, a person wouldn’t be able to do it”.

- P3: “There is a question, here, Karla, whether you could in theory, I don’t know what the full length of your PhD is, but you could in theory highlight a lot of problems, couldn’t you? And use your PhD to highlight things that are really not fit for purpose in some way? I don’t know because clearly from this discussion… two of the things that are you picked out people suddenly not fit per purpose, so you picked them and here they are, so this is the reality, it’s about taking this ‘cause you could have a direction where you go, I am going to take this mass of stuff, previous not fit per purpose in somewhere and then think about how it could be may to be fitted per purpose and that corrects all significance interests. ”

- P2: “So, what you could imagine is if someone knows they want to use the walker they can tell you the diameter of the walker, you can then have manufactured one of this (walker hand splint) well fitted”.
- P4: “Or nice grip onto it (a walker), that fits their hand”.
- P2: “Yeah”. “That is more interesting than that (pointing out the walker hand splint)”.
- P3: “Yes, that is what I’m saying. What I am trying to get with that comment is just where are we going… here is a walking stick and we will go: Hurrah!, it’s a walking stick, that’s low commercial and you go, well, modifying just the handle of the walking stick… a PhD, at the end, really, in many ways… you want something that meets in different multi fasten layers in many ways and try to come to solutions. When you start several here are mass of stuff, then doesn’t work, then you try a large and do the same things, what I was saying is, how can Additive Manufacturing cope through that, so that actually what you do is create high quality personal solutions that are functional, ‘cause there are things, some of these devices don’t work full and ask people around this table who are sort of health care professionals… that starts to afraid me, for me, it seems to me there are a lot of things here, that you know, you wouldn’t play with along another adult…”

- P1: “If you think about it, somebody wants to use a walker, they want to walk somewhere, maybe not very far, but they may want to go to the toilet or to make a cup of tea, then, they go get these things off their hands, so it’s just really impractical, I would be really interested to know if physician or a team is working or other people who use frames, well I think of it, I can imagine they used it very often and I suspect they get them online from a private catering… (and that is probably the sales team is not always helpful)” “And the fact yeah, and then is got sticky in that, so the idea is stick it to the frame… then, there attach to the frame, my God! (P2: “you fall, you have a heart attack”) No, definitely no go with that one”.
- P3: “But it is try to solve the problem that you could try to solve (P1: There is always an issue with people, gripping that frame is difficult) and so, it might be… gripping things, let me see, always there are risk issues, opportunities, arthritis, I mean, particular if you said, if you can manufacture materials, if you can do analysis on material, you start moving spaces that is quite interesting, is that what you can do”.
- P2: “Also, in terms of walkers or rollator, you know what rollator is? Similar to walker, that is a shopping bag, typically, in it and it will have three wheels often, occasionally they are four, but anyway, the point of that is, both of those is that the NHS is very desperate to get as cheap or cheaper rollators that are reliable because currently, they foster into buying the cheapest which then fail within days of being provided because they are so weak and flimsy, so even, they come back on the problem through Additive Manufacturing and the personalisation you are going to win it but that is just an example”.
- Moderator: “Yes, ok, these are two models of canes, those are for the right hand and you can adjust them and this (black walking stick) is better for smaller hands and this is a little bit wider”.
- P2: “So, from what I’m seeing in Sheffield Hospitals these are for the trending set…’cause they don’t get these ‘cause sticks they get the old fashioned wooden ones (P1: Do they still give wooden sticks them?) I have seen them”.
- P3: “What would you personalise? The grip?”
- P1: “Maybe the grip is personalised, you know, because people have different issues, the height, …if people have different grip issues…”
- Moderator: “Sorry, these are the splints for legs, those are different because this one is more rigid (robust one), you can stabilise the ankle with the foot, also this the large size, it’s available in three sizes and this one (the thinner one) is available in four sizes, this is for the right foot and this (robust one) is for the right or left foot. This one (thinner one) can be modifiable with heat and also, you can cut here (sole) according to your foot (P1: “with heat, so you can do it by yourself”). Yes, it’s modifiable to your limb and also, and cut and it can be used under the shoe” “And that (robust one) is for just stabilise, actually you can use this one (perpendicular single piece on the bottom) in this side (bottom) if you want to avoid more movements”.

- P2: "Can you imagine walking? Standing still maybe".
- P1: "Yeah, like put your foot on, elevate it or something and it needs to be kept dead still or something I suppose"
- P4: "Are you thinking about choosing a product which people will be using for a longer time, I am thinking it would be a bit more expensive if you personalised or have it printed, so if I want to think about how long people I mean is this prescribed for short time or is this something people have it for life, I do not know, like a walking stick"
- P2: "Mostly for short time I would think, those for a long time"
- P4: "That is what I think, something like this you put the effort in making it nice and comfortable and more secure I guess, because people will wear it or use for the next twenty or thirty years"
- P2: "I mean, a completely different one would be, and I am not so sure, I am guessing at least for some people, who are recovering, or not fully recovered from a stroke, may have walking sticks, but their abilities change over time, so the ability to change the handle over time and actually supplies to eating as well, like cutlery, their ability to use any piece of cutlery will change over time those that aren't fully recovered, there is a period during which they can improve, and there is all kinds of things that you can think about doing in there, maybe to rehabilitate them try to restore function by using that, it may be that they have better functionality, but some other day or later they become tired and are unable to use it so then they need a different grip, there is all kinds of things there but there is a different kind of problem to what you are trying to do"
- P3: "Cause you are a bit ...., obviously you could with these things think about different grips and modified them for different people and modified them for the same person during the day like he just said, you know what does texture, how does texture makes you feel, because if you feel these they feel very different when you touch them, you know, and experiential and all the rest of it, and how does that feel, and I know my mother uses one of this, she uses a commercial one, she uses a wooden one but without, shape, handle, what does it says, it may be plastic, I know that is part of her, does that makes sense, so she owns it so it comes back to you know can you make people want to own this I guess our opening conversation, can they look cool and trendy and the rest of it, and then from a different point of view I have always found the same with children toys actually my little boy as a bike I can never reset the height on, because these things are absolutely big and I have normally good strength and normally good dexterity, but if I am struggling with it, I am sure other people might too, how can be create better adjustment for people I wonder, is it necessarily set inside the shop or set inside, and I am going back to your point about changing during the day, mind that with arthritis, serious arthritis and fibromyalgia and depending on the day, back is more bend some days than others, there is nothing unusual in that, so the actual height of the stick could do with good changes as well,

so actually this idea of creating variability and flexibility, because I see advance manufacture, it is about flexibility and variability and if you can reduce in costs, get a superior product but reduce or for the same cost, cause cost is the big elephant in the room all the time”

- P1: “And I might be interest to know like, because I think it is a really nice thing to have a stick that goes into a handbag, my friend carries a stick in her handbag and she takes it out when she needs it and she got a nice flowery stick and she is kind of content with flowery, she is alright with it, but I kind wonder how light you can go, will it still be stable enough, and supply of the materials I do not know anything about it, to have a portable version that is still steady enough”
- P4: “That is another problem, I guess with this kind of problem is why people have a stick and they put it down and it falls over, nonstop, or they put it in a corner”
- P1: “Could you have, you know, like harry potter, come in stick”
- P3: “I trip over my mothers, my mother has developed a technique to pick her stick off the floor and I tried to do it for the first time ever, she has a technique she stand on it like that and does that and picks it up and does that, but, well she is quite clever, and I was like that is pretty clever, but she leaves it there and I fell over, thanks mom, so, the reality is you know that people develop attachment to these things, in some ways the world of my mother will be looking at redesign and I would say you need to be very careful, you do not want to put it in a box and say redesign this, because the world that my mother has, there might not be space to do it
- P2: “This kinds of things are very high product, so I was surprise years ago when I went to (inaudible name of company) used to manufacture wheelchair, and their main store was in Sheffield, they got something like 60,000 wheelchairs, manual wheelchairs, in this place, in Sheffield, and it was just amazing to walk in it and see all of these, and it gives you an indication of the actual consumption in the uk of these things, well, they are going to be even more numerous, but it is highly competitive”
- P3: “Yes, that is what I am saying, that could be problematic in finding space to do search into it”

3. Moderator: “Very quickly, considering the six devices which ones do you think are the most used by the elderly, you mentioned something about”

- P1: “The stick”
- P3: “It is he stick, it is the walking stick”

4. Moderator: “What would you change or improve in each device?”

- P3: “We have covered that”
- P1: “Yeah, I think we have covered that”
- P3: “We have, we have given you lots of food for thought”
- P4: “So the most used may not necessarily means the one that is most useful for your PhD”

5. (Providing the form to participants and there, it is the fifth question: "Considering the six devices, which of them would benefit the most if it were personalised"). Moderator: "In the first page, well it is about some aspects about you, some personal aspects, and in the second page"

- P4: "Professional, is that kind of a researcher?"
- P3: "I think we are professionals, have you been involved with people who have suffered one or more of the following diseases, throughout our work or just in general?"
- Moderator: "Sorry"
- P4: "Have I been involved with people suffering from one or more of the following diseases, through work or personally?"
- Moderator: "Both"
- P1: "I suppose, me, I am not even clear, when you say personalised do you mean that the individual who will use will be able to set certain things about it for them?"
- Moderator: "Yes"
- P4: "What is tactile impairment? Is that mobility or tactile as feeling?"
- P2: "Loss of feeling"
- P1: "Loss of sensation in you, that is how I interpreted it"
- P4: "You haven't got mobility in here or is it just me?"
- Moderator: "Mobility? Mhh you may"
- P4: "Ahh ok, I was just thinking given that is covered well, we talk about it a lot"
- Moderator: "Ahh ok, you may write it in here"
- P3: "I do not know the answer to the back, what I would say I would, cause"
- P2: "Do you mean, when you said it benefits the most, you mean produce the greatest uptake or you know, people would accept it more or do you mean that it would be potential for better outcomes"
- Moderator: "I think, well for example, if you want to personalised the handle of the stick, it would be more beneficial to personalised this walker hand splint, I mean which, with which improvement the people would have more "
- P2: "So you are looking for impact then?"
- Moderator: "Yes"
- P3: "Because it is a very complex question, cause what comes out of here it depends on what you want to do with your PhD though, I know I am not your supervisor and nobody in this room is, because it is different"
- P4: "I guess that is covered by this question, I guess benefit its the definition, your definition of benefit"
- Moderator: "Ahh ok, my definition is that the people, the elderly, can you sit more comfortable"
- P3: "ok, so it is more comfortable for you to use, so it is safer to use"
- Moderator: "More comfortable, safer, getting more advantages while using it"
- P3: "But the problem is, if I tick here the handrail, say, the scope for doing

research and added to the manufacture around a hand rail”
- P4: “That is not what she is asking, she probably got manufacturing people”
- P2: “It is the design”
- P3: “Ok, alright, fine, well”
- P1: “I mean it is difficult because in some way, if that is what you are interested in, which product would benefit from being personalised more, actually apart from that walker hand splint, then the splint could potentially benefit a lot from being personalised and change, I do not know if people really used them, I do not know enough about the product now to know how people use them now”
- P3: “Exactly, and that is what I was trying to come to through the conversation of this focus group, and the two things are linked I believe, because actually there is a big blob of space in the middle of what is happening in this conversation about those splints and things like that, about how they could be made, how they are used, what the benefits, for me clearly if they are used then if you get them right the biggest benefit change would be from doing those, but they are also the worse product and you might not want to go near them, so that is what I am trying to say, it is very hard to say now, because from an interest point of view it is the splints, but actually they are also weak products that might not be used very much, alright, I am only going to mark one and two, and six, I am sorry Karla, it is time to go I going to have to go”
- P1: “What I said here, I think that the group you are using for these products particularly they have a lot of risk and they need to be put in a fashionable way, I guess they could benefit from improvement, but I am not sure if being more confident around them is important”
- P3: “Nice to meet you all, have a good Christmas everybody, my pleasure, take care you all”
- P4: “I haven’t put anything here cause it is way out my, because I do software, so I think you are better off not taking my input in general, but yeah my advise in general would be to ask lots and lots of people about what is benefit and think about what it is you want to impact, so it kind of boils down to what does this means, and lots of people will tell you lots of different things, so that is the challenge of trying to find it in this long big mess”
- P1: “I think she is right, what benefit is is really key, you know, my dad, what he thinks would benefit him will be different from what I think would benefit him and that would be different from what a physiotherapist or a doctor might say, it is actually quite difficult thing, what you try to improve, you know, because he says I am just trying to get uptake, trying to get more people to use walking sticks”
- P4: “The intersection of the need of people to have better and personalised assistive technology and your ability as an engineer to do something, that is sort of the intersection in the middle which is what is interesting for your research, other people can do will do other things,

see you need to find also that your technology is not suitable for all improvements that are needed"

- P1: "You need to narrow it down"
- P4: "Yes, what are the benefits of your production method like that, what can it bring that is not already there, and then, to me it sounds like you could have picked 100 assistive technologies and none of them are perfect, in some ways you can improve everything out there"
- P2: "Well, one area, one part of an assistive technology system that I am aware of, it is a very large R&D field in its own right and you are going to be surprise, it is sitting, particularly in wheelchairs, where people are wheelchair bound and they have to seat all their lives, it is a huge research area and there is a lot of work been done into trying to get the seating right and still it is active today and it is something really simple"
- Moderator: "Yes, something that you may think it is not so common"
- P4: "I worked with a lady who had cerebral palsy and she waited for a whole year to get a new wheelchair, it is very fancy, it is electric, it came with a very comfortable kind of cushion, it was designed and personalised for her, went back to see her so how are you getting on with your new wheelchair, it is pink, she loves pink, and it is all kind of personalised, and she says ohh it is too warm, so it fits her perfectly but it is too warm for her, so all you know, the whole list of things and they created another problem, it is too close to her body, so she is overheating, cause she cant take her clothes off easily, you know, take her cardigan off, she did not like it, so add the cost of it, and wait for year and then the whole thing, it was warm, it was like this sort of mattress, kind of foam that sits around you, so I think as engineers we can do lots of things but we really have to listen to the users and go back all the time to kind of get lots of input, that what makes us able to solve a real need, because I know also we have all the facts but we have to listen to what they really want, which might be something much more simple to what you are imagining"
- P2: " I would recommend, whatever you are leaning toward picking, find some professionals who uses them and find patients who use them, and hear from them and what they say are the problems and the issues because we have expressed opinion, but that isn't necessarily, in general, it isn't going to be, because we have particular expertise in splints for example, I am not someone who meets people ever to give them a splint but I have talked with people who do"
- P4: "I think your suggestion, once you pick something then try to hook up with whoever gives people this, in a hospital, or maybe just observe what they do for a couple of days and talk to them about what are the problems, because they are on the ground, they would know exactly why do people come back, for example if a few days later is broken then you get to find out really what is wrong"
- P2: "If I can help with that I am happy to do it. And in this business putting things on and taking things off, that being really simple and easy to manage for the person, it is extremely important, cause I have heard in

many different scenarios where something does not happen that the medical people want it to happen, because the patient cant manage it or they forget to do it"
- P4: "Well, actually all of these apart from the walking stick are fiddly"
- P2: "Cant you imagine a 70 years old lady being able to deal with this"
- P4: "It is not going to happen"
- P2: "Maybe you get some kind of measurement and then manufacture it remotely and then it is sent to the person, this kind of model might work for this kind of scenario, lots of different ways of finding a solution, rather than simply producing lots of variation that people order from that, that is one solution but it may not be the best"
- P4: "You have to think of methodology as well to arrive at something that is useful, it is very interesting, it is a little bit outside of what AM tends to do, it is a different application".

11.13 Appendix M: Details of focus group session 1 and session 2

Focus group 1

The details of the session with non-professional carers were:

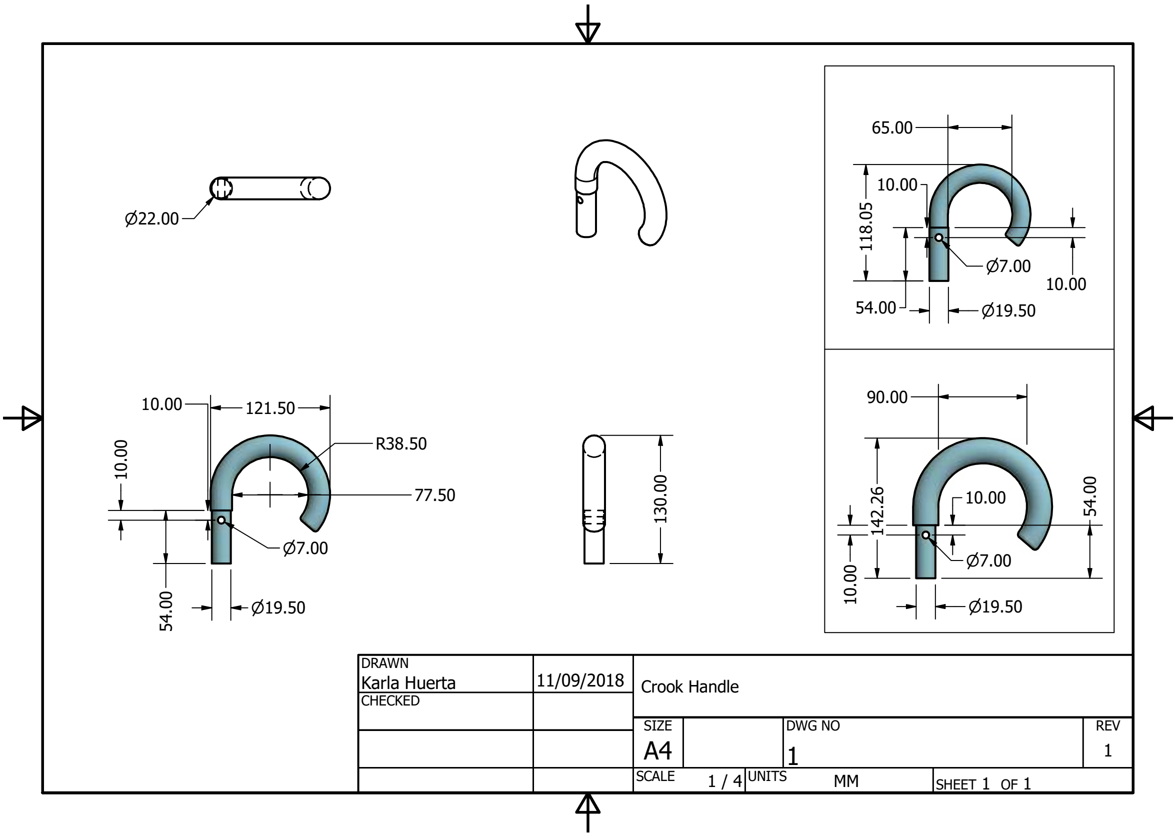
- The session was conducted on Thursday 07th December 2017
- Time: 9:00 am – 10:00 am
- Venue: 2.07 -Tutorial Room 11 (Second Floor) at 38 Mappin Street, University of Sheffield's facility.
- Refreshments were provided.

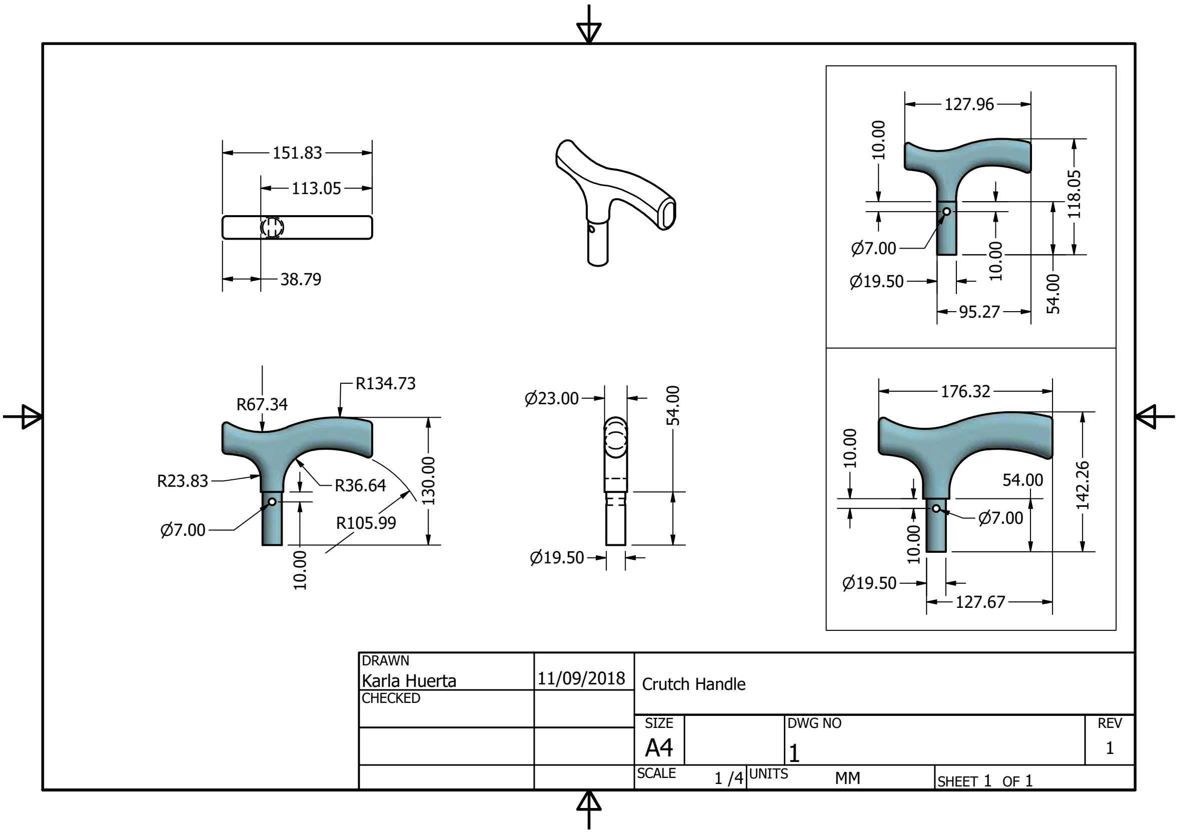
Focus group 2

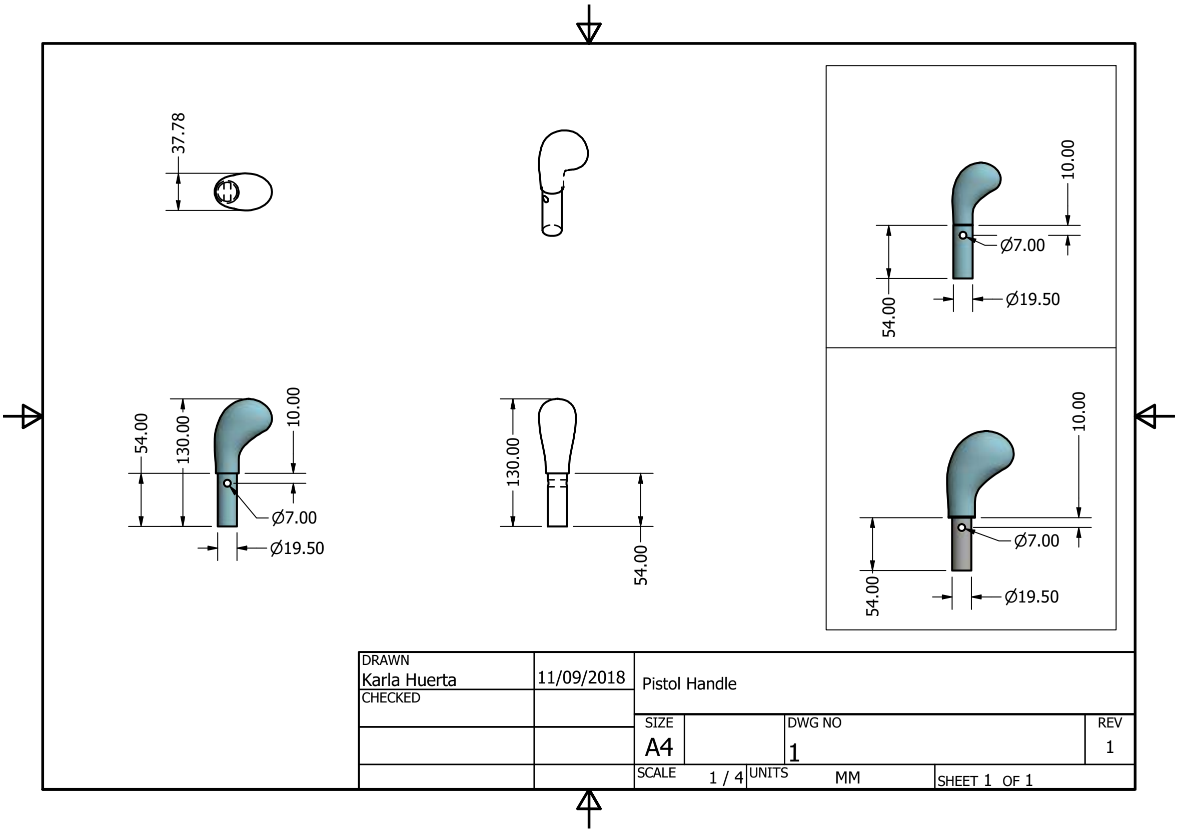
The details of the second focus group were:

- The session was conducted on Tuesday 12th December 2017
- Time: 1:00 pm – 2:00 pm
- Venue: 2.04 -Tutorial Room 10 (Second Floor) at 38 Mappin Street, University of Sheffield's facility.
- Refreshments were provided.

11.14 Appendix N: Drawings of handles



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DRAWN
Karla Huerta
11/09/2018
CHECKED
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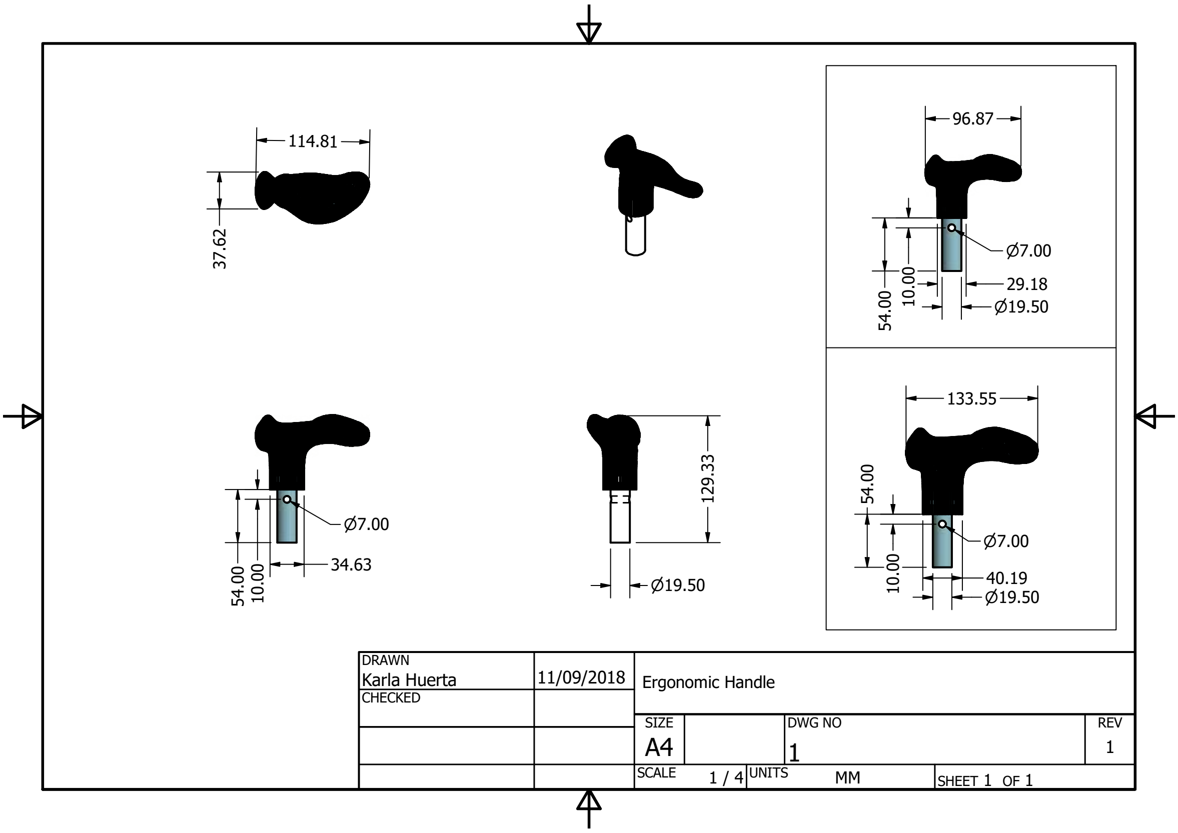
DWG NO
1
REV
1
SCALE
1 / 4
UNITS
MM
SHEET 1 OF 1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133.55
54.00
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10.00
DRAWN
Karla Huerta
11/09/2018
CHECKED
Ergonomic Handle
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A4
DWG NO
1
REV
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SCALE
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UNITS
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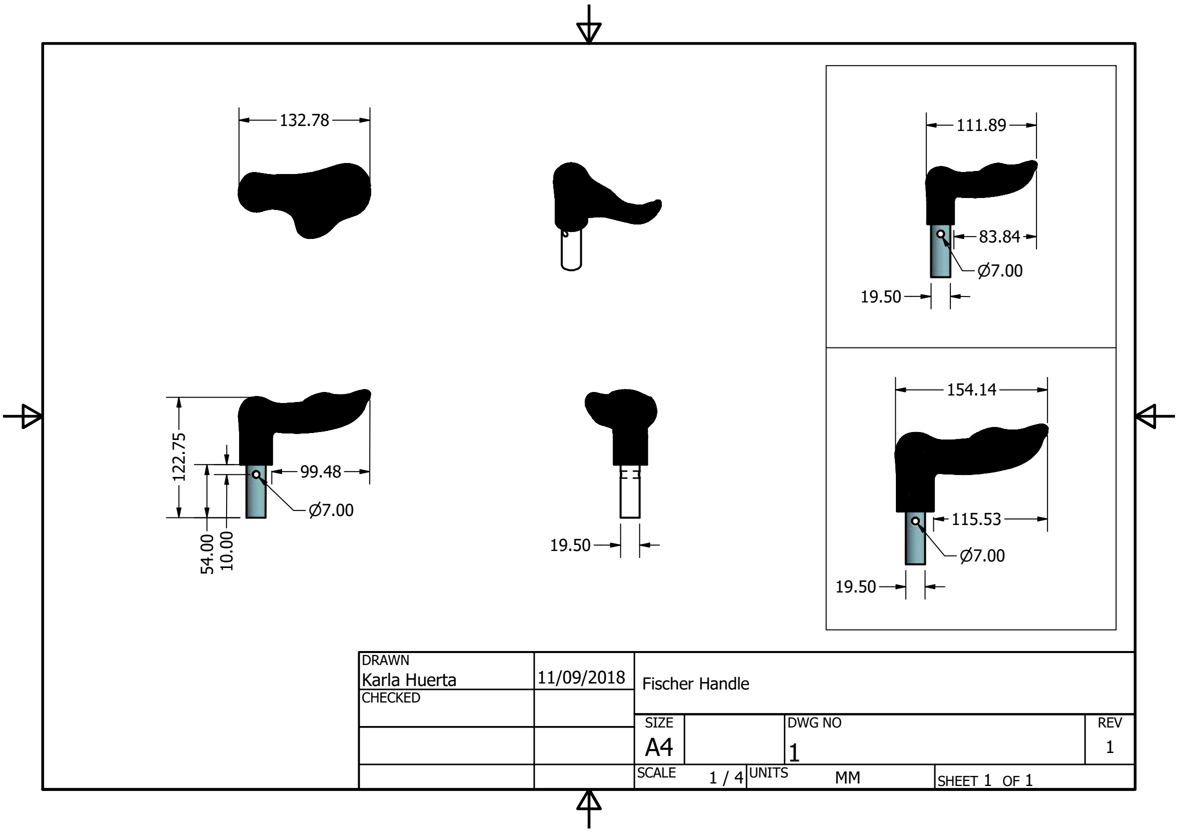
SHEET 1 OF 1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115.53
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19.50
122.75
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10.00
19.50
DRAWN
Karla Huerta
11/09/2018
CHECKED
Fischer Handle
SIZE
A4
DWG NO
1
REV
1
SCALE
1 / 4
UNITS
MM
SHEET 1 OF 1

11.15 Appendix O: Ethics Approval from the University of Sheffield. Individual interviews

The University Of Sheffield.

Downloaded: 02/04/2020
Approved: 14/01/2019

Karla Huerta Lucio
Registration number: 150256368
Mechanical Engineering
Programme: PhD

Dear Karla

PROJECT TITLE: Interaction and evaluation of different types of walking stick handles.
APPLICATION: Reference Number 023696

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 14/01/2019 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 023696 (form submission date: 21/12/2018); (expected project end date: 29/03/2020).
- Participant information sheet 1053103 version 2 (21/12/2018).
- Participant consent form 1053104 version 2 (21/12/2018).

The following optional amendments were suggested:

There is far too much detail in the Methodology section, as it means that it is hard to be clear about what is being undertaken within this ethics application. It would be better to start this section from step 2, and not state that there are four steps as not all steps are undertaken in this application and they are intermingled with other numbering systems within your methodology. Then state the objectives once and not repeat the aim of the sessions throughout the methodology. The methodology can give a more general overview of the sessions and state possible questions, the detail given means that any changes to these questions would mean a new ethics application would need to be submitted. Is it possible that fingerprints will be permanently cast into the imprints of the hand shapes taken in the clay mould, such that it makes all linked data identifiable to a person? Please clarify that the hand shape imprints cannot be used for personally identification.

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Anne Bradford
Ethics Administrator
Mechanical Engineering

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/rs/ethicsandintegrity/ethicspolicy/approval-procedure
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

11.16 Appendix P: Recruitment email for individual interviews

Re: [volunteers] Are you or do you know a walking stick user? Study involving participants aged 65 years and over.

Dear all,

I am a PhD student from the Mechanical Engineering Department and I am conducting research into the development of a walking stick handle for the elderly population using Additive Manufacturing (3D Printing) technology.

I am looking for participants aged 65 years and over who use a walking stick. The complete study consists in attending two sessions; during the first session the subject will interact with different options of walking stick handles and their preferred characteristics will be considered for a further construction of a 3D printed personalised grip. For this an impression of the participant's hand shape will be taken in clay.

In the second session, the researcher will provide the 3D printed personalised handle to the participant and will collect his/her thoughts and perceptions versus a standard walking stick grip. More information about the background of the project and details of the sessions can be found in the Participant Information Sheet available at:

https://drive.google.com/file/d/12DddXMPKgBXciuq-jhJlPyKqOHLkTZYG/view

The two sessions will take approximately from 30 to 45 minutes, and will take place in February and March.

This project has been ethically approved by the Mechanical Engineering Department in accordance with the University of Sheffield's research ethics policy. All responses will be kept anonymous and confidential. This research is being conducted under the supervision of Dr. Candice Majewski (c.majewski@sheffield.ac.uk) and Dr. Jennifer Rowson (j.rowson@sheffield.ac.uk).

If you are interested in taking part of this session or if you have any questions, please contact me at kehuertalucio1@sheffield.ac.uk

Thank you very much.

Karla Huerta, PhD researcher
Department of Mechanical Engineering

For information about this email list, including how to remove your name, please visit https://www.sheffield.ac.uk/optin and click the list name.

11.17 Appendix Q: Participant information sheet for individual interviews

Development of a personalised walking stick handle for the elderly population in the UK using Additive Manufacturing technology

Participant information sheet

ADAM The University Of Sheffield. CONACYT

Information about the study

You are being invited to take part in a research project. Before accepting the invitation it is important to understand what the project is about, why it is being done and what your role in it will be. Please read the following information carefully and if you have any questions feel free to ask them; the contact information can be found at the end of this document. Thank you for your time and for reading this.

Purpose of the investigation

The purpose of the investigation is to establish the best type of handle design of a walking stick and to analyse whether personalisation can make it better.

This aim will be achieved through the developing of a personalised walking stick handle, according to the particular needs of its user, and also, through the creation of a standard handle; both will be built utilising Additive Manufacturing technology, which provide advantages as production of organic and complex shapes.

Some of the concepts of this project that you should know are:

What is Additive Manufacturing?

Additive Manufacturing (AM), also known as 3D printing, is the process of creating physical objects or parts using virtual data through joining materials layer by layer, as it is shown in Figure 1.

Figure 1. Additive Manufacturing process.

What are the characteristics of the parts produced with Additive Manufacturing?

AM is great at producing complex shapes, meaning several parts can be produced at the same time, joined as assemblies or can be light weighted. This freedom also allows the production of personalised parts. In this way, they can be adapted to a unique area of the body. An example of the type of parts, which can be created with Additive Manufacturing is shown in Figure 2.

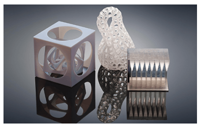

Figure 2. 3D printed shapes.

Personalisation using Additive Manufacturing

Personalisation is one of the characteristics that benefit the most when Additive Manufacturing is used.

Personalised products can be used in hands, wrists, arms, legs, feet, or other parts of the body with unique shapes that may depend on several human factors including gender, age and complexion.

The excellent performance of personalised products is determined by a reliable interaction between the body and the device, this increases the possibilities of achieving a perfect match between them and its functionality will increase.

Therefore, a good functionality of a personalised device will help to execute the activities of daily living, improving the independence of the user and enhancing the quality of life.

Examples of personalised products produced with Additive Manufacturing are shown in Figure 3:

Figure 3. From left to right: Splint for arm, ankle foot orthotic, exoskeleton and hearing aid.

Current Walking Sticks

Most walking sticks are usually provided as standard devices with multiple options in terms of handle shape (Figure 4). None of these are produced following the particular physical hand shape of its user.

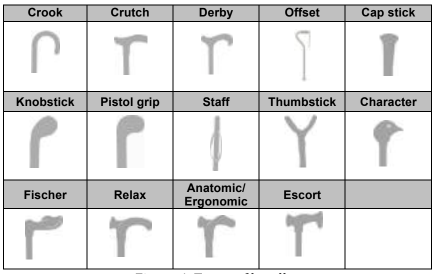

Figure 4. Types of handles

This research will create and test personalised grips versus standard handles in order to analyse whether there is a better adaptation of the user to the handle with the personalised option.

Participants

You have been chosen because in this phase of the investigation it is necessary to collect the opinions, insights and experience of walking sticks users to know why they consider some characteristics in walking stick handles better than others.

Testing process

This test is divided in two sessions, and your participation in both is requested.

Session 1. You will interact with some of the different options shown of walking stick handles in order to provide your opinions. Then, you will select your preferred characteristics and the information will be used to create a personalised grip that will be tested in a further stage. Also, you will be asked 15 questions regarding your experiences with walking sticks and other possible desirable characteristics that you would like to add to the personalised handle and in the third part of the session your hand shape will be printed in a piece of clay in order to obtain the personalised handle.

After this first meeting, the researcher will manufacture your personalised grip and in a second session its interaction will be tested.

Session 2. In this last session it will be determined if a personalised handle shape is better than a standard one and also, it will be defined which is the best combination of properties regarding size, shape and texture. In this second appointment, the handles will be tested and your perceptions and opinions about its performance will be collected.

Participation in the study

Participation is voluntary and there will be no repercussions of any kind to those that decline to participate. If you decide to take part you will sign a consent form. If before or during the test you decide to leave you are free to do so without the need to state a reason.

If you have any complaint about the project or the people involved in it you can email: kehuertalucio1@sheffield.ac.uk *

Additional information

Each test will be 30 to 45 minutes long and it will be conducted at the University of Sheffield.

All personal information will remain confidential. Opinions may be published but will not be traceable to any specific participant; your anonymity will be respected as Participant #1, #2, etc.

Each test will be recorded using audio and video devices to allow the research team to review the session. No one outside the project will have access to the recordings, both video and audio will be confidential and will not be published or used in any other way.

This project research is organised and funded by the Mechanical Engineering Department of the University of Sheffield and CONACYT. The project has been ethically approved by the University of Sheffield Research Ethics Committee. For further information you can contact: kehuertalucio1@sheffield.ac.uk

*If you feel dissatisfied with how your complaint was handled then you may contact to Dr. Candice Majewski, Senior Lecturer. Mechanical Engineering Department.

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11.18 Appendix R: Consent form for individual interviews

University of Sheffield

Participant Consent Form

Development of a personalised walking stick handle for the elderly population in the UK using Additive Manufacturing technology

Name of Researcher: Karla Elisa Huerta Lucio

Please initial box

1. I confirm that I have read and understand the Participant Information Sheet explaining the above research project and I have had the opportunity to ask questions about the project.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.
3. I understand that my responses will be kept strictly confidential, even if they are cited within quotation marks.
   I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research.
4. I understand that my participation will be audio recorded.
5. I understand that my participation will be video recorded.
6. I agree that a physical impression of my hand shape will be taken and used to produce a physical handle.
7. I agree for the data collected from me to be used in future research or publications.
8. I agree to take part in the above research project.

Name of Participant *(or legal representative)*	Date	Signature
Lead Researcher	Date	Signature

To be signed and dated in presence of the participant

For more information contact:
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11.19 Appendix S: Questionnaire form for individual interviews. Session 1

SESSION 1

Participant No. __

Gender: _________________

Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

____

Questionnaire

Please answer the following questions.

<u>Condition of the participant</u>

1. If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

2. Can you provide a few details of how this condition affects you?

3. Does this condition vary during the day?

4. Do you have any physical issue in your hand? Do you receive any rehabilitation?

<u>Walking sticks</u>

5. How many walking sticks have you used? (In the past and currently)

6. If you have used more than two walking sticks, why?

7. How did you choose your current walking stick?

8. Do you consider your walking stick is useful to accomplish all your daily activities?

9. Which are the best aspects of your current walking stick?

10. Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

11. What type of finish do you like on a handle? And why?
12. Have you experienced any issue when you grip or manage the handle of your walking stick?
13. If so, what do you think could be the reason? (Example: shape, material, changes of your condition during a short period of time, etc.)
14. Besides the walking stick, do you use any other form of walking aid?
15. If so, do you consider it has any advantage over the walking stick?

Selection of alternatives

Please tick the preferred option.

I. Shapes

1. ☐ 2. ☐ 3. ☐ 4. ☐

5. ☐

b) Why do you prefer this shape?

II. Sizes

1. ☐ 2. ☐ 3. ☐

c) Why do you prefer this size?

III. Textures

1. ☐ 2. ☐ 3. ☐ 4. ☐

5. ☐ 6. ☐

a) Why do you prefer this texture?

11.20 Appendix T: Detailed session for individual interviews. Session 1

The first session will follow this sequence:

1. Welcome

In this part, the researcher will introduce herself and the basic documents for conducting the session will be delivered.

Researcher: *"Hi, good morning, thank you very much for being here, my name is Karla Huerta, I am PhD researcher from the Mechanical Engineering Department and I will conduct this session.*
Before starting, I would like to give you 1 copy of the Participant Information Sheet, this is the document that you already received through email or post and you can keep it; here you can find the objective of this session and details, talking of topics as texture, shapes and sizes of the handles of walking sticks; also, I will give you 2 copies of the Consent Form, one is for you to sign it and return it to me and the other is yours".
The researcher delivers the Participant Information Sheets and the Consent Forms and waits 2-3 minutes for receiving the copy signed.

2. Introduction

The researcher explains important points of the test:

<u>Objective of the investigation</u>

"This session is part of my investigation which consists in developing a personalised walking stick handle according to particular needs of its user and also, in creating a standard handle. Both will be built using the Additive Manufacturing technology considering its advantages of producing organic and complex shapes. The study has the aim of assessing the potential of AM in personalised assistive devices through investigating if there is a real advantage in the usage of personalised handles".

Objective of this first session

“This session has three objectives:

- *Each participant should select their preferred characteristics of handles among different options and this information will be used to create a personalised grip which will be tested in a further stage.*
- *To ask experiences and comments about the usage of the walking stick”.*

Profile of the participants

“You were chosen because in this phase of the investigation it is necessary to collect the opinions, insights and experience of walking sticks users and utilise this information in the development of a personalised handle”.

Technical points of the session

“I will mention some relevant aspects of this meeting:

- *The length will be between 30 to 45 minutes.*
- *Notes, audio recorder and camcorder will be used only for clarification purposes.*
- *Collected material from this session will be only used for research purposes”.*

3. Development of the session

Before starting the test, the participant should be sit in front of a table and the researcher details the procedure of the meeting:

“During the previous part of the investigation were determined a set of characteristics of a handle that can influence their interaction with the user and therefore affect its performance. These features selected by the user and combine them in a single product may bring an improvement in its usage. The aspects that influence the interaction of a user with a handle are:

- *Size*
- *Shape*
- *Texture”.*

"I am going to present to you several alternatives per each aspect (size, shape and texture); for example, for textures, I will show you different surfaces with different textures and you will let me know which one is the most suitable. After each election, you will respond some questions related to it".

The investigator will have a form to be filled by herself according to the participant's answers. This document is divided in three parts. In the first one, there is a question related to the physical condition of the participant; in the second section, there are 15 questions that will be make to the participant and in the third segment of this form, the investigator will tick the preferred option and will ask the future user the reasons of his/her responses.

"In a second session, I will give you a piece of clay and you will print your hand shape as if you were gripping a handle of a cane. This model will be used to create your personalised handle and will be produced utilising the Additive Manufacturing technology, which will be tested in a further meeting".

"Do you have any question or comment about it?"

After this, the investigator will perform the following actions:

1. Ask the physical condition of the participant.
2. The investigator will ask the participant the 15 questions written in the Form.
3. Putting in front of the participant a wooden display with the 5 different shapes of handles. After the interaction with these variations (it can be conducted only with the hand or the handle can be connected to the commercial stick), the preferred option and the reasons will be asked.
4. Subsequently, the alternatives of "Sizes" and "Textures" will be shown and after the interaction with each one they will be asked what option prefers and their reasons.

4. Conclusion of the test

Finally, the investigator will thank to the participant and she will make a reminder about the second follow-up meeting where the handprint will be obtained.

11.21 Appendix U: Transcripts for individual interviews. Session 1

SESSION 1
Participant No. _1_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: I have a balance problem.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Better normally.

R: Can you provide a few details of how this condition affects you?

P: I have difficulty standing still or changing direction quickly or not looking straight ahead when walking.

R: Does this condition vary during the day?

P: It varies from day to day.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: No.

R: How many walking sticks have you used? (In the past and currently)

P: One.

R: How did you choose your current walking stick?

P: Given to me by the NHS physiotherapist.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: I do not use it in the house as I prevent falling by holding furniture or walls.

R: Which are the best aspects of your current walking stick?

P: It gives me stability when there is nothing else to hold on to.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: Pressure more evenly distributed over the palm but still allowing firm grip.

R: What type of finish do you like on a handle? And why?

P: Smooth, polished or padded.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: Hand becomes painful after a very short time if I am not wearing a glove.

R: If so, what do you think could be the reason? (Example: shape, material, changes of your condition during a short period of time, etc.)

P: Wrist also due to angle of the crook as discussed with you.

R: Besides the walking stick, do you use any other form of walking aid?

P: No.

R: If so, do you consider it has any advantage over the walking stick?

R: Additional question. Does the NHS provide you a different walking stick every specific time? For example, maybe one cane every two years... or they provide you a cane every time that you request it? Also, did the NHS charges you for the walking stick? and did they offer you to choose among different options?

P: I have only had a stick for two years and I am not expecting to return to the hospital nor receive another stick from the NHS. If I need another I would buy it from a shop. It would probably be a folding one as the stick is an encumbrance on stairs, especially going down as I need to use the handrails. I was only given the choice between two lengths, same type. I did not have to pay for it.

R: These were the questions, now we are going to go to the section number 2, in this one I am going to show you different types of walking sticks, handles and then I am going to show you different textures and I will also show you different sizes, I am going to collect your answers in order to create a model.

P: I use a glove.

R: Why?

P: Because it is hard around here so wearing a glove softens it and pads it a little bit.

R: If you dont wear it it could become sore?

P: Yes.

R: Are you right handed?

P: Yes.

R: This is what I got, these were produce using additive manufacture process.

P: This one will not do for me.

R: Because of the size?

P: It is the size but also this bit catches me.

R: So the shape bothers you because it presses on your wrist.

P: Yes.

R: Do you have any pains on your wrist?

P: Not normally but on this one all the pressure is on one small area, I know it is easier on the palm and on the size of the hand but I dont know how you would hold it.

R: You would hold it like this.

P: Is that for a left handed person?

R: Well, actually I didnt explain this but these three types you can use it if you are both right or left handed but these two that are ergonomic types are exclusively for right handed.

P: That one seems alright, that does spread the pressure over the whole hand, I mean that wouldnt be so bad except it curls up too much for me.

R: I see.

P: I dont mind this one very much but it is not an improvement over the one I got, the one I got is a little bit wider than the ones you got so it is better so that one would be too narrow for me because mine is wider and spread the pressure more.

R: What about this one?

P: It is not bad.

R: People grip it like this.

P: I couldnt do it like that because there is too much strain between these two fingers, I wouldnt hold it you see, that is uncomfortable spreading the fingers like that but because this is wider or thicker than this one it is better and also better than this one but I couldnt hold the back end.

R: If you want we can put the handle on the walking stick so you can see.

P: Ohh that is very clever.

R: Try not to put a lot of weight on it because it is not entirely functional. I have seen it in images and people walking on the street I have seen it they grip it with this finger here.

P: I see, well that is not comfortable for me. Can I try that one?

R: Of course.

P: That one is better, there is no point in trying that one and I didnt think I was going to like that one but this one at the end is no different from mine and it is narrower.

R: Yes they are very similar.

P: Yes, that is not bad, not bad at all actually because the weight goes more or less straight up the arm, with this one you happen to bend your wrist, do you see what I mean?

R: Yes.

P: So that shape, the wrist is straight on this shape so I think that one is better I think that one as I said I dont think I would like that so much apart from the part that it has the disadvantage I just said with my one that the writs bends and it has all the pressure there so it doesnt feel secure so of those five you show me that one is the one I would prefer.

R: Actually I was going to mention that you say something about this one was ok but that it has this shape.

P: Yes, that shape interferes with my wrist.

R: Maybe a smaller size would be better?

P: Yes we can try it.

R: Because this part is smaller so it might be better for you so we can try it.

P: Yes yes. Mhh it still curls too much around here, it still not comfortable just here around the wrist, you see what I mean on that bone there, I dont know what that bone there is called, it is just not comfortable there whereas that one does not curl at all.

R: Actually the point is right here.

P: Well you see you slip down on this one, you cant do anything else because of the shape of it.

R: Yes.

P: I hope what I am saying is helpful.

R: Yes it is, thank you, so lets continue with this preferred choice, it is called ergonomic handle, this is called fischer after its creator doctor fischer, this is the pistol type, here is the croach and here is the crook which is the one you have.

P: Well I am used to the crook now but I still get pressure on it and although it is smoother than yours obviously because it is polished I still need to wear a glove to stop all the pressure on my hand.

R: I see, I am watching that it is wide.
P: Yes, wide than that one, I wouldnt find that one comfortable because it is too narrow and doesnt spread the pressure that is why that one is better because it spreads the pressure and for some reason the way it is it doesnt make your wrist bend or at least doesnt make my wrist bend so the pressure goes straight up the arm.

R: So this was the first aspect which was the types and now I am going to show you different.

P: I was going to say I wanted a smaller version of this one.

R: We have small and big version for all of them.

P: I wanted to see the smaller version of this one, can I try it now?

R: Yes of course.

P: Thank you. that is still quite good, that is not making me bend my wrist, it is good but not as good as the one I tried there.

R: Ahh ok, so this one is better.

P: Yes, that one is better.

R: This size is better then.

P: Yes.

R: The second aspect is the texture.

P: Well I like it smooth but then that doesnt matter much if I am wearing a glove you see.

R: I see.

P: And it saves some of the pressure on the hand.

R: But maybe with a more convenient shape you wouldnt need a glove and you could have a preference for a texture.

P: It doesnt has to be like you have it there, you could polish it or cover it with some material.

R: Yes, there are a lot of textures out there and we have six different types.

P: I would go for the smoother one, a soft but firm, something glassy, smooth or polish. I mean this is actually polished, not by me but it is being polished, it is different from the others, I see what you mean now that they are here. I would cover it anyway but I would definitely not want it bubbly or like that one because it doesnt spread the pressure evenly. This one actually seems rougher than this one.

R: Yes, the other one is smoother and the difference between them is that that one is cracked texture.

P: I didnt like that one but this one is not that bad strangely enough so I would say this one is the best and that one is the second best, I dont like the rest at all.

R: So for the type of handle that you chose that was the ergonomic and this is the handle with the two textures you liked.

P: I prefer this one.

R: The smooth one.

P: The other one is not bad but the smooth one is better. This is the rough one and this is the one I said didnt like.

R: Yes that is the cracked one. Do you want to try the handle with the texture on the stick?

P: Are they the same size?

R: Yes but they might feel different because of the different textures and how they feel.

P: I definitely prefer this texture.

R: Good, the third aspect is the sizes but we already discussed this and we have here the smaller and bigger versions of the type you like.

P: Yes, I tried this one and I didnt like it, that one is alright, what size is this?

R: That is the medium.

P: I see, I am a little bit undecisive mhh I think this one could be better.

R: Do you want to try them on the stick?

P: Yes please. I think that it is as comfortable but slightly more secure because I can grip it more, I mean I am not holding it like you said, that is very uncomfortable but having my whole hand on there the pressure is spread across the whole of my hand and I can grip it with these two fingers.

R: I assume that with the medium size your middle finger is on a different position.

P: Yes and the grip with my thumb and index finger is better if you see what I mean.

R: I see. So which size do you prefer in the end?

P: I think this one is more stable, yes.

R: Ok, so we will go with medium.

P: The whole pressure is spread across my hand and straight up, not bending my wrist as you can see.

R: Yes. So we are going to use this one for putting the clay over and then you are going to press your hand so we can obtain your hand shape. I am going to use this polymer clay which is similar to plasticine but it is more used in sculpture, this clay is oven dried but with the air I feel this will get harder so that is why I am opening right now, what I am going to do is I am going to use a press over there in order to get a thin layer and then put it over the handle. You can stay here while I do it or you can come and see.

P: That is fine.

R: So I am going to put the material here and there.

P: There is a small part there missing.

R: Yes, we actually need more material so I am going to make it bigger. Can you please grip it as tightly as you can and try to print your fingers as well on this part. Will you be using it in that position? Are you comfortable like that?

P: Yes, this is how I am comfortable. Do you want me to grip it underneath?

R: Yes please. Do you feel the size is till fine after we added the clay or do you think it is bigger?

P: It is fine like this.

R: Its size increases a little bit with the clay so that is why I ask.

P: It does feel a little bit bigger.

R: If it is bigger and uncomfortable we could use a smaller size and put the clay on top of it.

P: You are definitely right, I just dont want you to have to do all the process again.

R: Tt is fine and it is actually better if you feel it is too big.

P: I thought the clay was going to go hard very quickly but it didnt.

R: Do you want to try with the other size?

P: I am amazed with this and how it didnt stick and it didnt go hard very quickly.

R: Do you feel you could print on it? Was it too hard?

P: No, it is just that I am too weak you know.

R: So this is another type of clay that is more malleable and we will use it on the medium size handle. Can you try it and let me know if the clay is more comfortable to print the shape of your hand on it.

P: Do you want me to press down but not too heavily?

R: Yes please.

P: How long does it take to set?

R: I think it is fine now.

P: I have funny hands.

R: I was watching your fingers and I think here on the bigger size we have a more define hand shape, how did this clay feel? Better?

P: Yes I think so. I dont think there is much to chose between them.

R: So you think they are very similar?

P: Yes, maybe I didnt hold this one too tight I think but I still think it is better even if it didnt come up very well.

R: I think it is a good impression anyway. In terms of sizes which print do you think is better for the thumb?

P: I think this one but they are similar.
R: But size one this one is better.

P: Yes, it fits better. I didnt know was as ridgy as this?

R: That is normal, when I did the test on myself I also observed the wrinkles on the print.

P: That one is comfortable, thank you.

R: Ok, so I will use this shape to create a 3D print model, the areas that are untouched I will improve myself. You can use the toilet or these wipes to clean your hand.

P: That is fine.

R: Good, on the next session I will bring the part so you can test it.

SESSION 1
Participant No. _2_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Yes, my aphasia disease syndrome, paresthesia, polyarthralgia, peripheral neuropathy and soft tissue damage.

R: And those have been present since?

P: Since I was tortured in Chile in 1973 and most of the things related to torture were not know in this country by the medical professional, only experience the doctors had was with greek torture of the feet because not many people were coming as refugees, political refugess to this country, asylum seekers.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Continuous degeneration due to the lack of mechanical assistance.

R: Can you provide a few details of how this condition affects you?

P: Chronic pain when walking and extreme weakness on my lower extremities and my left hand.
R: Does this condition vary during the day?

P: No.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: Not really, only because of the shape of the handles of the walking sticks and the way I have to walk and have to use what is available.

R: How many walking sticks have you used? (In the past and currently)

P: A lot, most of what is available in the market, orthopedic, clinics, from NHS too and some from the internet and see if it would fit or not.

R: If you have used more than two walking sticks, why?

P: Because I need to walk and stop falling, with some walking sticks I fell down two or three times a week.

R: How did you choose your current walking stick?

P: I use elbow crutches, I dont use a walking stick because they are not suitable for my conditions.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Yes, I also have additional support which I didnt bring now but it helps my leg and stops it from bending. I also have a shoulder brace.

R: Which are the best aspects of your current walking stick?

P: That it helped me to walk and move around and I could lean on it.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: Changed the form because standard devices do not fit my hand well. The one I have is personalised, an orthopaedic doctor helped me produce one personalised for me, they took my impression on clay and they used that to create the handle, this was back in 1979.

R: What type of finish do you like on a handle? And why?

P: One that fits like a glove and that meets the natural angles of my hand position with respect of the walking stick, some of the standard ones are just unnatural, you cannot bend your hand in a right handle and because of that it applies particular pressure on some parts of the hand. The finish must be anti slippery as well.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: Yes, because it doesnt fit like a glove, the body as to adjust to the length of the walking stick since they cannot be adjusted.

R: Besides the walking stick, do you use any other form of walking aid?

P: Elbow crutches.

R: If so, do you consider it has any advantage over the walking stick?

P: The provide more support, they have an ergonomic design since they are not standard.

R: When you went to NHS did you ask for a walking stick?

P: No.

R: But they provided you with one right?

P: Yes, it came through the course of a conversation I had with a professional about how best to deal with my problems and to stop the occurrence of continuous falling which are painful.

R: Was your first walking stick provided by the NHS or did you buy it from a store?

P: There were no stores on those years for disable people, we are talking about 40 years ago

R: So you went to a clinic?

P: I just asked around where people that used a walking stick got them from.

R: The second part of the session will be me showing you the different types of handles I chose so you will let me know which one you consider is better for you, here we have five different shapes: crook, croach, pistol and these two are ergonomics, one is the fischer and the other one is just called ergonomic.

P: This is the one that fits better

R: There is no doubt? If you want we can put it here so you have more freedom to check it.

P: The problem it is that it is badly design, if you see I cannot fit my whole hand into it, it is short here and here, if I grab it you can see.

R: You need more surface.

P: And here there is a line of pressure point that goes through the index and the thumb and goes up the arm into the elbow so when you put pressure into it it is not working.

R: Have you tried this particular kind of handle?

P: Yes, since it is available on the market. Mine is the best I could get or that is available here.

R: Ahh ok, this one, because the one that you obtained the mould is that one.

P: Yes, I can grab this one with the least discomfort possible.

R: It looks well manufactured.

P: The problem is this part here, there is some pressure over this line.

R: Was it made for your hand.

P: Yes, they used a clay mould and then some plastic resin to make it.

R: And it is the best you have tried?

P: Yes, the best so far.

R: That is quite interesting, that work.

P: Yes because it needs to be custom made for people and this is the kind of adjustments you can make adding resin to this point.

R: They were commercial ones then?

P: Yes, and what was my proposal and we couldnt agree on a price is to get something like a ring on this part so you can adjust the length and not have to keep with what you can get between this point from the hand to the floor, that is something that can be improved, you can out a ring here and when you start turn it in it will put this part on a strong position so it doesnt move up and down and that you can do it yourself and adjust the length so you just start twisting and get it, there is a section that it is not working and serves no purposes, it is from here to here, you do not need all this.

R: Ahh ok, yes. So, from this five types which one would be the best option for you.

P: This one, I tried all other shapes and I have to take into consideration where I need to put the pressure of the hand for the persona that it is going to use it.

R: Good, I will show you know the different types of textures. Then I will show you the chose option for type with the chose option for texture.

P: This one is too sharp, it needs to be something like this, anti slippery so if your hand is wet it wont move. In my opinion all of them will have one problem or another with the person that it is going to use them. I feel more comfortable with this kind of texture on the device, that one is too smooth.

R: Why do you think that these ones are not very useful?

P: Because as soon as you get your hand wet and most of the people are not using the walking stick as they should in coordination with the affected leg or side. I suffer from the left hand side so always my walking stick goes parallel and synchronised with the affected side to provide balance and equilibrium. If you sweat and the handle is plastic it will get slippery.

R: What about this particular material and texture?

P: I think this material will be something like that which is strong at the angle of the joint and I think it is cheaper to work wit.

R: So from those textures you think this one is the best?

P: Yes definitely.

R: So I am going to show you now the type of handle you selected with the texture you liked the most. I am guessing you are wondering what is all this, basically these are all the possible combinations with all types and textures.

P: So the one in your hand is the best one for me.

R: Yes, it is the combination of shape and texture, we also have three sizes. I am not going to show you the smaller one because you said the medium was small so here is the big one, how do you feel it?

P: It feels better than the medium, but these area is still useless and it is too wide around this area because when the fingers bend at this part it doesnt go with the arc of the fingers at the joint here, it is too straight, there is a void here a vacuum so when you start pressing you will see there is a irregularity the way the hand is going to grab the handle and here it is the same so if we keep that shape would you take that into consideration.

R: Actually the third part is that we are going to obtain your hand shape.

P: That is fine, but if it is going to be mass produced or mass designed then this needs to be taken into account, that this part serves no purposes whatsoever and that the width here is too big.

R: I am going to put some clay on top of the handle.

P: Can I try that other shape? Lets see how it fits my hand, it is better than any other shape because it has this bits, so this part of the hands rest ok in this part which doesnt happen on that other shape.

R: So you want to use that shape then.

P: Another thing to take into consideration for the design and the concept of ergonomics, how the hand shape is and by looking into the internet or a medical encyclopaedia to check what are the pressure points, the nature nerves that go through these fingers and this side because when you grab the handle you put pressure in your hand and that is transmitted to the rest of the body.

R: Yes, it is important to know how it affects other parts of the body. Is it fine if I used the medium size for this handle because I am going to add material you are going to feel a difference here and here so it is going to feel thicker.

P: Yes, I understand what you mean, the medium size is fine.

R: What kind of clay was used for designing your first walking stick.

P: It was a grey clay but that is all I remember, also plaster. Plasticine didnt exist at the time or at least was not easy to obtain.

R: Now a days we have more options but some of them are not made for this kind of application, they are usually made for doing pottery or sculpting.

P: You can try to soften the clay like if you were making bread.

R: It is too hard for that but I am almost there.

P: I think there is going to be a problem Karla because these are all for right handed people and I am left handed.

R: I didnt know, I had that in consideration but when you used the walk sticks I thought you were right handed, I can try mirroring the file.

P: In my case, my hands are not symmetrical, you can see that this hand is on a different position, the thumb and the index are different to my other hand and you may find there are left and right handed people. Mirroring may work anyway, we can try it.

R: Do you think this could be larger? I mean, I can do it a little bit larger.

P: I think it is too wide.

R: Ahh ok, but do you think this distance is fine, the material here is fine or do you need more?

P: Maybe a little more.

R: Ok, I am going to make it a little bit bigger with the metal press.

P: It is like a pancake press. What kind of engineering is your study?

R: It is part of the mechanical engineering.

P: Mechanical, in what sense, like auto mobile.

R: More like anthropometric and industrial ergonomics and processes. Can you try the handle again? Please press on the clay, yes, like that.

P: If you could extend it a little bit here.

R: Yes, that will be fine. That was a pretty good print for the first try, thank you. I will get in touch in 3 or 4 weeks, thanks again for coming.

SESSION 1
Participant No. _3_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Well I have trouble breathing, I have a condition bronchitis which is slowly taking over, it got worse 20 years and now I find that it limits my ability to walk far, I used to walk far but now I have only limited ability to walk from the bus stop to the shops.

R: And any condition that affects your sense of touch?

P: No, I have only osteoarthritis in certain joins but I dont have rheumatic arthritis so just osteoarthritis and limited breathing.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: It has been going on for 20 years since I was diagnosed with a lung condition, it has become worse.

R: Did you use a walking stick 20 years ago?

P: No, I have only used the walking stick for around 4 or 5 years.

R: Can you provide a few details of how this condition affects you?

P: Well, I have limited ability to walk up stairs for example and I have limited ability to walk uphill, I can walk on flat surfaces for a couple of hundred yards with no problem but as soon as there is an elevation that is when I have difficulty particularly.

R: Does this condition vary during the day?

P: Yes, I am probably more fit in the morning that I am on the evenings, it gets worse during the day I would say.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: Osteoarthritis, I dont have any medication for this particular condition, you can get creams which you can rub on your hands but it doesnt make a lot of difference.

R: Are these creams to decrease the swelling?

P: They help to loose the joints if you rub them in but I dont use any cream at all.

R: How many walking sticks have you used? (In the past and currently)

P: I had another one before this one, it was a standard NHS walking stick with a plastic handle and it was adjustable. This one is a folding one and this one I use downstairs and outside the house and I use the NHS one for upstairs.

R: Do you know it its shape is the crook one?

P: Well it is made of plastic and not wood.

R: Is it like this one?

P: No, it is more like this, no, like this one.

R: And when the NHS gave you the walking sticks did they show you different options or how they decided that one was for you?

P: It was a physiotherapist who gave it to me, they adjusted the length but that was that, no lessons on how to use it.

R: Why did you decide to change to the one you use now?

P: Well this one is fordable.

R: So that is more convenient.

P: Yes, you can take it when shopping and it is more elegant, the NHS is aluminium with a plastic handle and this one has a wooden one.

R: If we compare the handles between this one and the NHS one, which one is better?

P: This one is better, when I used the NHS upstairs I feel my sense of balance is not the same.

R: Did you buy this one?

P: Yes.

R: Did you receive any support or help when you went to the store?

P: Yes, I got it from Clarke's which is a local equipment shop and they told me roughly how to use it but no lessons, just over the counter kind of discussion.

R: Did they show you different option?

P: I dont remember but I wanted a folding stick so that was the main reason for choosing this handle.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Well, I dont use it in all circumstances, I dont use it much on the ground floor, I only use it upstairs if I wake up in the middle of the night but I dont feel it is necessary on the ground floor but I would use it if I go out into the garden or outside.

R: Which are the best aspects of your current walking stick?

P: It is foldable.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: I would like it to be more elegant, I have seen some with different colours and patterns, that would be nice. I would also like something that would fit my hand because it is cripple with arthritis, it is deformed compare with other people so

I was expecting you would be able to design something that is better for me because this one is not good for my hand, I understand that is the purpose of the study, to have individual handles which are adapted to each hand.

R: What type of finish do you like on a handle? And why?

P: I dont know much about handles, I have not considered it but a shiny surface like that, I dont necessarily want a plastic surface I think wood might be ok.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: As you see I obviously knock it and it falls down.

R: And when it falls you can pick it up?

P: Yes, the other thing is to produce a walking stick that would stand by itself when you take your hand off for example when you shop it can be a bore.

R: What about the cord?

P: It helps but not much really.

R: Besides the walking stick, do you use any other form of walking aid?

P: No, I recently bought a stroller, it does gives you balance on both sides of the body.

R: And do you use it in your home or outside or in which circumstances?

P: It is new so I have not use it a lot so far, I just got it a couple of weeks so I have not had a lot of practice with it but it is insofar it provides balance on both sides of the body, I mean some people advocate to walking sticks, one for each sides.

R: I have not seen that.

P: Some people have two walking sticks and use them. For my sense of balance it could be an advantage.

R: But there are more people using strollers instead of two walking sticks don you think?

P: Yes, some people will use the two sticks for long distance walks, they call this nordic walking but really part of it is sense of balance.

R: But now you are more comfortable using just one walking stick?

P: Yes, or the stroller too although I have not use it enough so far.

R: Does the stroller has a seat?

P: This one doesnt but it can be added.

R: If so, do you consider it has any advantage over the walking stick?

P: Well, it is more portable, you can carry about because what I have noticed is that I cannot get off the bus with the stroller but that is easy with the walking stick.

R: So those were the questions, on the next section I am going to show different types of walking stick handles, I have already define 3 aspects that could be important for the user, they are: shape of the handle, the texture and the size. First of all I would like to show the five different kind of handles, these are the five different types of walking stick handles that I have chose, this one is very similar to the one that you have and this one is pretty common, there is also this shape that is called pistol, these three can be used by right and left handed people and these other two are ergonomic.

P: I dont like that.

R: I can put the handle on the stick. Which one is more comfortable for you? That one?

P: I didnt realise that this provided support to your hand.

R: We can try it with the walking stick.

P: This is like my NHS one.

R: Actually at the beginning I thought yours was adjustable in height but I couldnt see the holes so I was wondering how you adjust it.

P: The shove adjusts it.

R: Try to not put too much weight since it is a prototype.

P: That is quite good, I didnt realise that you rested your hands on this part, that is interesting.

R: Do you want to try that one.

P: No because it is like mine, that other one is too big.

R: Those are regular sizes.

P: They are too big, this one is quite good.

R: This is called the ergonomic, as you already chose the shape now I am going to show you different types of texture to see which one is more preferable for you, there are six options, first I am going to show you the textures on this cylinders.

P: Can you open this for me, that is one other thing I have to ask on the shops for help.

R: No problem, here you go. So here we have these cylinders.

P: This is too rough and this one too.

R: What about this one, this is called cracked.

P: It is better, this one is also alright but I prefer this one.

R: Ahh ok.

P: This one is the best one and this one is the second best.

R: Why is this one the best for you?

P: It is not smooth, it has the right degree of roughness, these are two smooth and these are too rough.

R: I was thinking about, I already know that do you not prefer these types and I forgot to mention why.

P: They are all to big.

R: What about this one.

P: It doesnt provide support.

R: And this one.

P: That one hasnt the right shape for my hand while the one I chose has a better shape for my hand, that other one has no shape at all, it is too lose.

R: As you chose the ergonomic one plus this texture I am going to show you the combination. First of all you can see I have a lot of handle here and the reason is because I have the 5 different types with every texture so I have all options available for the participants. The one you chose is this one but you can change your mind.

P: That is alright, I think this one.

R: So that one is fine, the third aspect is the size, all of these are medium size and here we have small and large size, for example for that one we have the smaller.

P: No no, it is too small.

R: And here is the large one.

P: This is too big.

R: Do you wan to try them on the walking stick?

P: It is too small.

R: I see.

P: Yes, it is too small. That is good.

R: As you already chose the type, texture and size now I am going to take your hand shape with clay.

R: Here we are now, please grip it as tightly as you can and try to print the fingers as well over the entire handle. You can do it standing only if you want.

P: It is much better than mine, having the rest for the hand is better.

R: Ahh ok, the support in the wrist.

P: Yes, support for the back of the hand and the wrist, yes definitely. I dont know what my finger is doing over here, I would say that it is better than my present stick.

R: Good, I think this is your thumb here on the clay, ahh ok, wait it wasnt, it is here ok and here is your little finger, I can see the index, the middle. And what do you think about the mhh you have already chosen the side which was medium and then I added material so it becomes bigger, what do you think about the width now, the layer applied wasnt too thick.

P: No it wasnt, it is not too big. So you added.

R: I added plasticine, the clay.

P: It was very thin, yes, makes no difference, that is good.

R: Now that we have the clay so well the next thing is that I am going to work with 3D printing part and the scan and then I am going to send you an email for our second and last test, it would be in three weeks maybe four, anyway we will see the dates in order to have the meeting, so that was all for the first section, thank you very much for being here and for your time.

SESSION 1
Participant No. _4_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Yes, I got one knee that has been replaced already and the other is not yet ready but it will be at some point in the future.

R: And why did you need this?

P: Wear and tear, I didnt have a fall or anything.

R: And any condition that affects your sense of touch?

P: No.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Generally it is getting worse but quite slowly I think.

R: Can you provide a few details of how this condition affects you?

P: Well, it means that it is quite hard when you are use to live with it to figure it out, I suppose I cant run, I can just about to do it. I use a pole when I go out, two poles if I am walking, I do go for long walks and I love doing that and I dont want to stop doing that, I can do that still but with two poles it means some of my weight is going into my arms which is bad. What else, mhhh, I suppose stairs are always the worse thing, because in Sheffield in most small house the stairs are very steep so I go down backwards which is much better and then it doesnt put too much pressure on my knees.

R: Does this condition vary during the day?

P: It doesnt vary a lot no, sometimes I think the weather affects it more but not a lot really.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: No, my hands are pretty good.

R: How many walking sticks have you used? (In the past and currently)

P: Probably about 3 although I lost a lot that were not very good.

R: If you have used more than two walking sticks, why?

P: No particularly good reason, I just go to a shop if I need to get a new one and I tried them out how the feel on my hand, is it going to take my weight well and all that, you need to make sure that it tightens properly so I just go to the shop and get one I can use. Often I lose then, at least one or two got lost and sometimes they stop being reliable.

R: How did you choose your current walking stick?

P: I just went to a shop.

R: Did you receive any support from the staff?

P: No, I didnt feel I needed it because I know my needs better than thy do, and it wasnt an expensive one, I went to store decathlon so I just tried a few and thought this one will do me.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Yes, I do, I mean I dont need it for all the activities in the house, I dont use it much in the house probably very little because I have carpet and everything but when I go out I need it for that.

R: Which are the best aspects of your current walking stick?

P: Well, it is hard to say really, it wasnt a very expensive one so that is a plus in some ways, it doesnt have much giving in it, some have a sort of spring thing in it I have had those, I wasnt sure I like it because I wasnt sure if I could trust it I wasnt sure if it was going to spring or not to spring, in a sense I prefer this, it is simple and I know what it does.

R: Why did you prefer this type of handle?

P: I didnt particularly, it was the one that was available, I did try one of those long ones like the one you have over there, I didnt like them, I feel more in control with this one because there is a direct line to down there and it is adjustable as well.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: Well yes, the handle what I dont like about this handle is that it is too smooth, I would like this separation here to be a little bit stronger so it would make my hand stronger, it is a little bit slippery, too smooth and you want to be able to grip it specially if you are going down on a steep.

R: What type of finish do you like on a handle? And why?

P: This one is too smooth, I have had a more expensive one a while back and that one had, this part was more jutted out and it had I think a few little gripping things down here, going around, little raised parts that kept your hand steady, that was definitely better but it was a more expensive one but I lost it sadly, it happens.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: This one I can say it is too smooth, I prefer a handle that goes like that over there, I have tried some like those other on the shop. I dont think there is anything else about the handle particularly but it is the important bit really for anyone, you really need to know you can trust that bit and that it can take your weight and all that.

R: If so, what do you think could be the reason? (Example: shape, material, changes of your condition during a short period of time, etc.)

P: Surface is too smooth.

R: Is your answer related to the shape?

P: One that can support me better.

R: Besides the walking stick, do you use any other form of walking aid?

P: No.

R: So those were the questions, now I am going to show you several types of walking stick handles and you are going to tell me why do you prefer one over the others. So here we can, well obviously we found more models outside in the market, here I chose five because there were some models were very similar between them so I decided to chose the crouch and the derby because they are very similar, and of these ones I took the fisher and the ergonomic, so these three are made for left and right handed people, anybody can use it and these two are the ergonomic ones, if you like we can try whatever you want here in the walking stick, do you want to try them all?

P: Can I?

R: Sure.

P: Might as well

R: Some participants do not want to try them all but it is fine.

P: We give it a shot. This one is quite uncomfortable, it is kind of of squashed, the curve of the handle is not good. Hopefully I will not be taking too much of your time.

R: Not at all.

P: I wouldnt like that, this will be annoying after a while, my fingers wouldnt know where to go, I wouldnt like this one, maybe I need a bigger hand, perhaps it is better if the person has a huge hand.

R: Is the height of the stick fine?

P: Yes it is but I dont mind. This one is ok but still has the problem of where your fingers go, like this, like that, I personally wouldnt like this one either.

R: No problem, next one then.

P: Is this one right handed?

R: Yes.

P: It is quite comfortable, still not sure what to do with the fingers, whether they go here or here, it is quite comfy, it is nice and it fits your hands nicely, yes that is nice I like that one.

R: Good, last one.

P: Yes, it is very comfortable, probably not good for long walks but it is good, it could be, it is so comfortable, it doesnt feel like a walking pole, it fits your hand so nice, very nice yes, I dont think I have had anything like this before, it is interesting, it makes your hand feels very good.

R: All of them are on the market, do you want to try these two again so you can chose one?

P: Yes, yes, if I need to chose one.

R: You already know, this style which is the ergonomic one, it already has a texture over, did you feel it?

P: Yes.

R: The thing is that I have the other two with the same finish

P: This one is nice, just the question of where the fingers go I cannot quite decide what would be the right place be, where would you say.

R: Like this, one finger here and the other there.

P: That is not very comfortable for me.

R: Ahh the position of the fingers.

P: Yeah, for some reason it isnt. Let me have the other one. It takes a little bit to get use it but it is comfortable, very comfortable, I suppose it feels a little bit funny because I am used to have some part of it going around my wrist because that is the case with my poles if I go around walking I am used to have something around my wrist so it feels like I cant let go, it doesnt feel as firmly attached, I mean this is my ordinary pole here and I have a lip around, I mean this, the handle itself is not comfortable, this one is much nicer but it is good to have the lip around it.

R: So this one is the best one.

P: Yes, for me.

R: So the fischer would be better. Since we already picked the type we are going to see if there is any texture that would be more comfortable for you.

P: That is interesting.

R: Here we have like a lot of printings here but the thing is that, mhh first I print six different textures on these cylinders in order to avoid preferences if you see them on a shape.

P: That is a good idea.

R: So after you chose the texture I am going to show you the type that you chose with the texture you selected.

P: This one is prickly, let me try that one, I dont like this one or that one.

R: What do you think.

P: This one is too prickly, that one could be ok, these two are very similar, that one is too smooth so I dont like it too much. This one is quite nice, this one I am not sure if I like it or not, mhh tricky.

R: Actually we can try every texture on the type of handle you already chose.

P: That will be good, that will sort things out.

R: So we can try the cracked, bumped and the medium textures, I was telling you that for example that here we have a lot of options but that is because here is the part of the textures so you chose this one which is the fischer and these three, this is the crack, the bumped and the medium texture so these three we are going to try on the walking stick. Maybe there can be a little bit of difference.

P: It is a slight difference, they are similar. It is nice, slightly prickly but not much, it feels good, yeah I like that.

R: That was the bumped, now we are going to try with the cracked texture.

P: It is not prickly, it is a surface you can feel easily, it is not too smooth which is good.

R: Now we are going to try with the medium texture.

P: Mhh yes, good, it is difficult, it is very comfortable this one I must say, it is very comfortable.

R: We could combine the textures in different areas of the handle, do you want to try them again?

P: I will try the prickly one again, I think that is the favourite to me.

R: The medium.

P: Yes, it is just the right amount of traction in your hand, you know what I mean, I could feel it but just enough, not too smooth, you dont want it too smooth, I guess for some people, particularly people that lose sensation will like the other ones better.

R: Would you like the texture over the entire handle?

P: Yes.

R: That is fine, so at the end we have the fischer plus medium texture and now about the size, in this side of the table we have three lines, the first one is the smaller sizes, the second one the medium ones and the last one is the large ones. We tried with the medium and we have here the smaller version.

P: It is too small.

R: And this is the bigger one.

P: Mhh, the medium is the right one for me.

R: Ok, now I am going to use the medium one of this shape and I am going to put the clay on top so we can get your impression. So I am going to ask you to press as tightly as you could and to be sure that the fingers get printed.

P: Can I walk around with it to see how it fits.

R: Of course.

P: Ok, it is good, It is a little too wide just here between the fingers I think it would get me after a while, just here on the fingers is a little bit too much.

R: I see, here and here.

P: It is a very exact science this and the hand is very sensitive very special.

R: This is fine, do you want to try this one? Grip it tight.

P: This is better, I can grip it well, it is nice, it might be still a little wide and just between these two fingers, I dont mind it too much at the moment but after a while I think it will start bothering me.

R: The thing is that because I added material maybe that caused this.

P: It is fine, it is fine, just saying if I was on a very long walk maybe this will be too much. This was very interesting, thank you.

R: So here we can see your thumb yes, and other fingers. I actually did some trials myself with the clay and I had to try two to three times to get a good impression.

P: It is a very individual thing, each person is different but this is great it is a good thing to do.

R: Here we have your index finger, one two three fingers yeah.

P: Yes those are my fingers there yes, that is great, very comfortable.

R: Do you want to try again or is this ok with you?

P: It is ok.

R: Here we can see a wrap here but it is ok because your hand causes it and it means it is the best grip, this is your grip.

P: That is alright that, interesting.

R: It is a similar situation with hearing aids because we see only the aid and maybe if we see an organic and complex shape and we think what is this but that it actually fits in your body.

P: It is a good thing what you are doing, it is important work.

R: Thank you.

SESSION 1
Participant No. _5_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: I have a knee problem, I have a brace on the knee that helps me support it, it may be a tendon problem, so I need a walking stick which I find it is a great help I can get around no problem with he help of the walking stick but without it I am not, so it is very important to me.

R: Do you use it at home, I mean everywhere?

P: Yes, I take it everywhere with me because i need it for walking purposes.

R: And any condition that affects your sense of touch?

P: No.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: With the aid of the brace it has helped and my stick I can manage.

R: And the brace, do you take it off at some point during the day?

P: Yes, at nights.

R: Can you provide a few details of how this condition affects you?

P: Well, it limits me, I have to take it steady around steps and stairs but with the help of the walking stick I can get around ok.

R: Does this condition vary during the day?

P: Not really.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: No.

R: How many walking sticks have you used? (In the past and currently)

P: Just two and I find the one I have currently quite useful for this.

R: If you have used more than two walking sticks, why?

P: Because of this (Participant placed walking stick on his forearm). Sometimes at work I need to use both of my hands so yeah.

R: How did you choose your current walking stick?

P: Somebody gave me to me, and old lady gave it to me and I took it and it felt alright, it could be a lot better perhaps.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Ohh yes, it is essential.

R: Which are the best aspects of your current walking stick?

P: I find it supports me, it helps take the weight from my left leg and I can you know, carry on without using it (placing on forehand)

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: Nothing spring to mind, nothing straight away, I guess the grip could be better, being round perhaps, could be a better grip I think.

R: What type of finish do you like on a handle? And why?

P: Not sure really,I have never though about it I have always used the wooden ones, I have no experience with any other materials.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: I havent much experience with handles but perhaps a better handle or better group could be better for me.

R: If so, what do you think could be the reason? (Example: shape, material, changes of your condition during a short period of time, etc.)

P: The grip would be very important.

R: Is your answer related to the shape?

P: Yes, I suppose, if I didnt use this walking stick then perhaps the shape could be better for the grip.

R: Besides the walking stick, do you use any other form of walking aid?

P: Yes, I could use a trolley a bit but I do not really need a trolley but I have use it but I do not really like it, I find the stick better. I got it because somebody thought it could help me but it wasnt that much better, I have used it but the stick is more useful at the moment.

R: If so, do you consider it has any advantage over the walking stick?

P: With the walker I get more support than with the stick, I can lift and use my leg better with the stick though.

R: This were the questions, now we are going to go to the section number 2, in this one I am going to show you different types of walking sticks, handles and then I am going to show you different textures and I will also show you different sizes, I am going to collect your answers in order to create a model.

P: The handles are there arent they, you made all those?

R: Yes, with the 3d printer, there are a lot but they are different versions, they are similar, I will explain this in a little bit.

P: What is the material.

R: Plastic, as we know there are a lot of shapes out there so basically if we see here I made a chart with a lot of types of walking stick handles, some of them are very similar so I made a filter and that is why we have only 5 of them, what we can see as well, all of these are on the market and their size is regular and they are all right handed, as we can see we have five different types and these three are for both right and left handed and then this are the ergonomic ones and they are for, well this one in particular is for right handed people so it is good that you are right handed. Would you like to try them? So in this case you are going to tell me which one you prefer.

P: Maybe this one.

R: If you want we can take it off, we have a commercial stick.

P: Alright.

R: Yes and we can put in the.

P: You can put the handle on the stick.

R: Yes, do you want to try all of them or just a few?

P: I would like to try all of them.

R: First we have this one which is quite common, well actually yours is like this one which is the crook style, try not to put a lot of weight on it since it is not entirely functional.

P: Yes, it feels good.

R: And then we have the crotch, do you want me to adjust the height?

P: The height is alright, so yes this one is fine too.

R: Next one is the pistol handle.

P: Yeah.

R: Now the ergonomic ones.

P: That was quite ok.

R: And now the last one.

P: That was quite comfortable and I did not think it would, I think this one is the most comfortable, I think it uses my hand more and I like that, for the simple reason that there is more of my hand, it cover more of my hand I did not think it when I looked at it until I tried it and the feel is good I find, for me you know.

R: And for example the difference, how did you feel this one in comparison with that one?
P: Mhh, I prefer this one the last one but let me try the other one again and I will tell you in a minute.

R: Ok.

P: It is ok but I still prefer the other one for hand comfort.

R: And the other three, the crook, the crotch and the pistol ones?

P: They are ok but this one was more comfortable, I did not expected it by looking at them but after trying them this one was better. If I had to pick just by the looks I would have picked the tradition ones but after trying them the ergonomic ones are better, specially that one.

R: Good, now I am going to show you different options of texture with these cylinders in order to avoid some preferences, I mean if you see them on the different types of handles. So we have six different ones and I am going to pass them over to you to have a feel of them. For example that one is the bumped texture. What do you think about it?

P: It is ok, it wouldnt be handling that much.

R: That would be placed on the handle.

P: Ohh I see now.

R: The idea is that after this I am going to show the handle you selected with that handle.

P: It definitely provides more grip.

R: Ok, lets try the next one, it is the raw one.

P: Ok.

R: This one is the cracked one.

P: Yeah, that would be ok.

R: Then the smooth texture.

P: Of course yes, yeah ok.

R: Now the circle texture.

P: Ahh yes, ok.

R: In the bumped there is no space between the spheres.

P: Ahh yes yes.

R: Now that is the medium.

P: Ok, yes.

R: So now we need to chose which one do you prefer, we could try all of them on the handle you selected.

P: I would say that one and that one.

R: Ok so we are going to try the bumped and circle ones.

P: The give you a better feeling, the smooth one is not good, the texture should improve the feeling of the walking sticks.

R: Ok so this one is the bumped, because it is a texture when you print textures over different surfaces sometimes it is not exactly the same because it is a texture so lets try fischer with bump.

P: Yeah.

R: How does it feels?

P: Good.

R: Great, no we are going to use the fischer with the circle texture.

P: Yeah, that is quite nice.

R: Which one do you prefer?

P: Perhaps this one, the circle one.

R: So fischer with circle texture. Do you want to try other textures?

P: Yes.

R: Lets try the cracked texture with the fischer.

P: I would definitely stay with this handle, makes me feel much more secure than the other ones, if I were to get one tomorrow I would definitely buy the fischer or the ergonomic.

R: Here is it.

P: That was nice too, I do prefer the rougher ones so I would stick with this one, with the cracked one.

R: What about a combination of textures in a handle.

P: Yeah, perhaps a combination of those three perhaps.

R: I would like to know where would you prefer one texture or another.

P: I think the cracked one was more comfortable alongside the palm of my hand.

R: Is it one texture better or do you want two?

P: Perhaps a little bit of that one over here.

R: What about having cracked texture in this area and on this other are a different texture.

P: Could you do that?

R: Yes I can do it but we need to say where each texture would go, it is the same to me.

P: One texture is fine I guess.

R: Ok so we are going with the fischer with the cracked texture. Now, the third aspect being considered is the size, as mentioned before this one is the regular size of handle, we have also a large one and a small one.

P: Bigger I would say rather than smaller so lets try the bigger.

R: Ok, lets try the bigger fischer, here you go.

P: Mhh no, the medium was fine for me.

R: So now I am going to put the clay over the medium fischer and then I am going to bring it to you in order to get your hand shape. Ok so we have the clay over the handle, what I am going to ask you is to grip as tightly as you can so we can.

P: Leave a print on it.

R: Yes, please be sure that each of your fingers get a print.

P: So just hold it tight.

R: Yes please.

P: Should I walk with it.

R: That is not necessary, just hold it, it is like a plasticine this material, it is a moulding clay that is usually oven dried but I am not going to dry it, I am mentioning this to let you know the behaviour is similar to plasticine.

P: Yes that is correct.

R: Just let me know when you think it is ready.

P: I certainly like the idea of this handle, I think it is very supportive because all my hand is playing a part which makes this better I think.

R: I was going to mention, now the handle is a little bit bigger because I added the clay on top of it, does this size is still fine.

P: I think so.

R: Anyway the thickness is not so much and it will be thinner in some areas due to the pressure, for example around here it will be around 2mm of thickness but you will not be using that area.

P: The part I am touching is ok, so shall I stop now.

R: Yes, that is fine, we can see the four fingers and your thumb here.

P: I think that because the handle is spread out it makes it better, it gives more support, I would definitely go for the fischer type and I would definitely recommend it to others too.

R: There were other models but they varied the tip, heights, colours etcetera but there was not many different handles.

P: When you look at it you wouldnt expect it to be good but when you hold it.

R: Some people think there could not be a big difference but when you use it you can feel the difference.

P: That is true, a good stick can make the difference .

SESSION 1
Participant No. _6_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Well I am profoundly deaf, partially sighted more or less and I have mobility issues.

R: And the mobility issues are because?

P: I had surgery down on one of my legs but it didnt go well so I cannot apply pressure to it and also my brain doesnt recognised it exists so I have to use the stick.

R: And any condition that affects your sense of touch?

P: No.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Mhhh, I have to take a lot of medication to numb the pain, it is painful, so I am on very heavy dose of medication to allow for numbness so there are good days and bad days, when it is bad I cant walk at all and otherwise it is fine but I try to walk a little bit everyday so that the movement is always there rather than not doing anything.

R: Can you provide a few details of how this condition affects you?

P: So, I had to change my bathroom because I could not go in the bath, I cant lift my leg up so I had to change to have a walking shower so I just walk. I had to change because in my house there are two doors and I had to had them redone so I can walk with handle bars all around so that is the external. How it affects me? When it is bad, when it is very painful I just cant do anything and sometimes in the morning it takes me a long time to actually make that movement because it is just so painful and numb so it does affect my everyday life.

R: Does this condition vary during the day?

P: Yes, I think it is always a difficult start of the day and then it is very difficult towards late afternoon where going to bed, in between is when I try to do a little bit of walking so I manage my pain, if for example if I walk for ten minutes and it is painful then the next day I would only walk nine minutes and then stop because I know at ten minutes it will start to be painful so I will do nine minutes for a few days so I feel strong and then I will go back to ten mins, but that is when it is good, when it is bad there is nothing I can do.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: I have problems with my carpel tunnel, I have had surgery for that because it is very painful and it numbs my arm very quickly and it is very painful in bed, I am having surgery on that nerve that goes up the arm, but that is it.

R: Is it because you use a walking stick?

P: For this hand it is definitely the walking stick that made it worse but I have got the problem on both arms so it is not just the walking stick, I was involved in a car crash and my head got damaged and some nerves paths got damaged and with age it is getting worse.

R: How many walking sticks have you used? (In the past and currently)

P: Initially I was on crutches for a long time, not these here, they were elbow ones. Then I had physio and I was determined because with two crutches you cant do anything like shopping so I was very determined and now I have one stick. I think I have had this one for quite a long time, it was provided to me by social services because of my sight and my hearing so it is white for the sight and red for the hearing for those that I dont know I have to explain.

R: Is social services related to the NHS?

P: Yes.

R: So you have used only one walking stick?

P: Yes.

R: How did you choose your current walking stick? NHS was involved?

P: Yes, I think at the beginning I had mhh not this type, yes that kind of thing that is what I had at the beginning and then it became really impossible, it was not safe enough and it was really hurting me so I had to see social services again and they gave me what they call the ergonomic.

R: So at the beginning you had the crutch one, so I have a question, if the NHS gives you a walking stick and if it is not right for you then you can come back.

P: Yes, but it takes a long time, doctors need to get involve and you have to have the physio but this is for me for long term so that is why I needed something a little bit better.

R: So in case you wanted another, the process takes time?

P: Possibly, I dont know since I have not asked for another but the big problem with this for us girls, maybe boys too, it is that technically speaking you are suppose to be able to shorten it or make it longer but because you use it all the time, this part that needs to move it is hard, froze, probably rusty, you can press and press and there is nothing so this means that if I want to wear heels or if your shoes are slighting different then that it is not really always correct for me because I cannot even change that any more so I ought to go back to social services and explain to them but at the moment with the NHS having so many problems I try to create any, I dont want to hear anything negative.

R: Actually, I havent seen this type of walking stick, with the ring, I also tried to modify the height and I just couldnt do it, let me check this one right here.

P: Is it working?

R: Yes.

P: If it is new it is ok so you can easily just you know you do this, and even that people that have problems with their hands that is extremely painful, I couldnt do it.

R: For me, it works better if I do this, focus on the plastic, although this is new.

P: When you use it all the time you put a lot of pressure, let me try it, mhh no I think if I try it I could break it so I dont want that but I might ask social services and ask but it is not a big a problem any more since I dont wear heels but for somebody else yes.

R: So that was the second option they gave you.

P: Yes.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Yes.

R: Which are the best aspects of your current walking stick?

P: Well, for me in all this the best feature would be the handle because, mhh can I have one of your samples so it is better to explain, do you have a normal one, these are not bad at all they are quite thick but a lot of them are much thinner than that, much much thiner and it is very painful when it presses like that you can feel all the pain going on but with this one you see it is really good so for me that is the best aspect, the worst aspect is the end bit because I use it all the time you cant ask for the NHS to give me 5 or 10.

R: To have spare ones?

P: Yes so I have to wait for it to go kaput and then I have to go all the way to the hospital and ask them, please can I have, because that goes ever so quickly and also probably because of what you say, what I understand that you check the way the people wall, but the way I walk obviously you can see there is more pressure on one side than in the other so very quickly this go through the metal and because I cant chose it like this I have to use it like that then every two or three months I have to go and change so that is the worst and because it is old that is, there should be a better system than this, particularly about the metal because it rust with rain and water.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: For me personally, I think this way of a handle is good, I would love for this to have like a permanent, because when you go, if I put it like this it goes, it falls, so, but also something that would be more versatile, you have to have quite a very angular, and then I just do this.

R: I was going to ask you about that.

P: Look, this is perfect because now my hands are free when I am in the bath or whatever, but if the table is thicker or round it doesnt work so it would be nice to have different ones but what I would like is one that is permanent, this very quickly comes off unfortunately.

R: Did you buy it?

P: Yes, I had to find it and then I ask somebody to made me this. The problem it has is that sometimes you are like this talking and then it just disappears so this allows me to have my hands free but it would be nice to have some accessories to go with that and I know a lot of people that dont know me that stop me and ask me where did you get this because it is isnt on the market, you have to know about it but it would be nice to have for different types of tables, there is a niche and to have this so that we can do this.

R: Yes, I have seen this one.

P: In leather no?

R: No, in fabric in a black colour.

P: Are you sure about it? I am pretty sure it is leather because I made this one myself and it is useful so this little accessories makes it very easy honestly because if you dont have that it is very difficult to let go and sign a piece of paper or whatever.

R: Or as you mentioned, you need to find a surface to put it.

P: Yes, like this that it is very low, the height might be an issue, if I didnt have my things you could slide it like this, but because I have all my things it doesnt.

R: So that would be the best thing.

P: Yes, for me it is the handle as I said and what is not good is the end bit and also what I dont like but maybe there is nothing we cant do, the metal is always cold so if you have to keep it between your legs it is so cold, it never warms up so I dont like that when I am wearing a skirt but it is a matter of personal choice.

R: What type of finish do you like on a handle? And why?

P: Matte, I will tell you that because they fall very often I am concerned they might break, because when it falls on the carpet it is ok but on hard surface, when it falls I am like oh no so as long as it is something that it is sturdy because a lot of people drop it all the time, sometimes you put it like this and then somebody passes and it falls, that is my worry but this ones are hard plastic, I like matte, mhh I dont know that I really want a smooth finish, I dont know, I dont think so somehow, I think a better grip, maybe, you know what I mean but it is alright otherwise.

R: Are you talking about the shape with a better grip.

P: Yes, the shape but rather than smooth, rougher texture so that is you know, I think, maybe but this is just my imagination really because I have not seen different texture, when you said what finish are you talking about colour or what?

R: I am talking about the properties of the surface.

P: Yes, that is what I mean, this one here is not bad so I cannot say I have had problems but maybe a surface that it is more rough so that it doesnt slip, maybe.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: Not really because I really hold it, what I find hard is perhaps with the handle maybe because it is not mine, if I wear gloves it is very difficult to have the stick, in here you need gloves sometimes since it is quite cold and then holding that becomes a difficulty I have to say, maybe because the gloves are thick so there isnt as good a grip as I could have.

R: Yes the gloves can be a problem.

P: Definitely when you have the glove it reduces, if you want, the combination of my hand shape and the handle, the glove stops that and that makes it harder actually that is what it is, yes.

R: I think with gloves everything becomes harder.

P: There is a difference, isnt it, because the gloves are rigid so when you hold this it doesnt take the shape.

R: Besides the walking stick, do you use any other form of walking aid?

P: Yes, if I am in the toilet that is not so good for me, I have to have an special aid in the toilet so I can feel secure when I have to go up or down.

R: Is it like a walker?

P: Similar, but it is rigid so in effect what you have are bars like this and at the bottom there is another bar that goes by the toilet.

R: Ahh ok, it is fixed.

P: Not fixed but it is rigid, you can move it around.

R: If so, do you consider it has any advantage over the walking stick?

P: Only for static situations, the walking stick is better for movement of course.

R: So this was the first part of the session, for the second part I am going to show you different types of handles, then different textures and finally different sizes. Here we have the shapes.

P: I know them, this one I dont like it, that one is not secure at all.

R: The crooked one.

P: This one is not good, you cant put your weight on, I know that, if you see people with this type is because they dont lean on them, me I need to lean, this is for people that are not confident but they walked normally so they just use it for security, but this, if I were to lean on it I would fall and hurt myself that is for sure so that is a no no for me. This one is the one we talked about, that they are manufactured thinner so it hurts more but this is similar to this one and you cant really lean on it, this one I have never seen but that would kill me, can you see but again if you use any of these three in my view you dont put weight on, people feel secure you know. Then we move on to this one, the ergonomic,

R: These two are for right handed personally.

P: I dont like this one at all but this one yes, this one because.

R: It fits exactly.

P: Yes.

R: So you say you prefer the fischer.

P: Yes.

R: Now I am going to show you different textures, first I am going to show them to you in a cylinder in order to avoid any thoughts if I showed them to you in a handle directly.

P: That is what I was trying to say earlier when I was talking about this one.

R: Yes, this is the bumped texture.

P: I dont mind.

R: Then it is the circle or sphere texture.

P: I prefer the bumped one.

R: I am going to show you the cracked texture.

P: I prefer this one.

R: The bumped. This is the medium texture.

P: Yes, I think this one is better than this one.

R: You prefer the cracked.

P: And this are all matte.

R: Yes, but there is a little bit.

P: There is a little bit, again I would chose this one.

R: Ahh ok, so you would say that between these two, the smooth and the rough you prefer rough.

P: And out of all of them I prefer this one.

R: The bumped texture. Now I am going to show you the handle which was the fischer with this texture.

P: Yes.

R: Would you like to try another texture, the same handle with another texture I can .

P: Yes, please I would like that, I like this one.

R: This is the sphere.

P: I like this one too but I prefer.

R: The bumped.

P: Yes.

R: This is the cracked one and this is the medium.

P: I think I like all of them, if I was to compared with a smooth, any but smooth are ok but if I want to show, this is the last one for me.

R: The last one would be the medium.

P: Then this one.

R: Then the cracked, then the sphere and first place the bumped.

P: I am still with the bumped.

R: So, I am going to put it here.

P: Ah, ok.

R: Try not to put a lot of weight because it is not entirely functional.

P: What is it made.

R: Plastic.

P: Still fragile.

R: Actually I tried and it was ok.

P: So what would you like me to do, just to hold it?

R: It is just to be sure of your selection.

P: Yes for me, definitely, definitely, I really like the feel.

R: Ok, so at the end with have the fischer with the bumped and now the third aspect is the size, this one is the regular size, I think yours.

P: Is similar, isnt it?

R: I am going to show you, this is an smaller size, it is the same one.

P: I dont like it.

R: That is the smaller and this is the bigger size.

P: I think I prefer this size, I feel like my hand is a little lost around here, if you look at this here it really seems to hold as well but if I do that maybe people who have bigger hands and that is why it is important to have different sizes, can you see the support is non existent here and actually would perhaps hurt here, you see? Yes it would, it is like buying a bigger sock and all your socks come up to her, this is too long it is the same. But this one, yes it is just shaping, is that medium size?

R: Yes.

P: Yes, definitely.

R: Now for the third part of the session I am going to put clay over the medium fischer and you are going to print your hand, please wait some minutes. Here you can see the layer, this is clay for sculpture so I am going to put it here and I am going to ask you please to press as tightly as you can.

P: Do you think it has?

R: Yes.

P: I dont think I can do any more.

R: It varies per person.

P: Here, voila.

R: Very good, here we have four fingers and the thumb, ok so we already have it, thank you very much, that was quick. This is the end of the session, thanks again for being here, I will keep in touch, I am going to spend a few weeks in order to evaluate and take the data for making the 3D Printed handle so I am going to send you an email in order to set the next session.

SESSION 1
Participant No. _7_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: I have some arthritis, osteoarthritis, which affects my knees and my hips so I am less mobile than what I used to be and also my ankles are weak so my ankles fall in, the muscles around my ankles are not holding straight but that is different. Touch no, my touch is fine.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: I suppose its slowly getting worse but it has been affected by injuries too so say last year when I injured my hip flexor that has improved so soft tissue injuries have improved but the arthritis will just slowly deteriorate I guess.

R: Can you provide a few details of how this condition affects you?

P: Right, mhhh, well I dont walk as far as I used to walk and it does mean this knee I have, it can be a little bit painful straighten it, this hip I have some mild pain and also if I sit down for any length of time my knees become stiff so when I want to stand up it takes time to straighten my legs but once I am walking the stiffness improves so that is good.

R: Does this condition vary during the day?

P: I tend to be stiff when I wake up in the morning and then it depends on how much time I spend sitting.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: I got some arthritis here and here but I dont receive any rehabilitation.

R: You dont need it?

P: I guess they think I dont because it is very mild.

R: Do you use any product or something to feel better.

P: No, I do go to a pilates class, I do that.

R: That helps you.

P: Yes, I think the more I use my muscles and joints the better.

R: How many walking sticks have you used? (In the past and currently)

P: I used a stick since I was a child, mainly because in my family we had dogs and when we took the dogs for walks we took a stick not because we needed to use a stick because having a stick could be useful you know in various ways so I just got use to having a walking stick and then I also had dogs myself so I tend to have a walking stick I could use most of my life and then when I became older I particularly found having a stick helpful, say in the winter if it is icy I was anxious about slipping because if it is snowing the council will grit the roads but the pavement just becomes compacted ice and they are not very pleasant to walk on sometimes so I would use my walking stick then because it gave me that way to contact with the ground which kind of reassures me that if I would slip the walking stick would help to keep me up right but then when I started to have, at times, mhh I saw a physiotherapist when I started having the stiffness on my knees and unfortunately he didnt examined me properly and just gave me some standard exercises and after a week I actually damaged this knee doing the exercises and so that was two and half years ago and initially it was extremely painful so again I used a stick then and it is never completely recovered but it is a lot better so I tend to use the sticks when there is a problem and as I said to you when I damaged the hip flexor on my right hip I had some physiotherapist again, privately this time and the physio did suggest walking poles could be a good idea so I bought a pair of walking poles last summer.

R: So when you were a child you used a regular walking stick.

P: Just a wooden stick.

R: Ahh ok, and then you used a regular one to help with your problems with the knee and the hip.

P: Yes, until last summer if I thought I wanted some sustain I just used my ordinary wooden walking stick.

R: And then you changed to.

P: Walking poles yes.

R: If you have used more than two walking sticks, why? You already mentioned you changed because the physiotherapist suggested it right?

P: And also I suppose there are another two poles arent there so it helps balances you but also she actually was a great advocate or nordic walking, the poles I have got are not nordic poles, but another friend of mine she is been recommending this poles by her physiotherapist.

R: What were the advantages that she mentioned those types of poles have over a regular walking stick?

P: These poles, the ones I bought, my friend recommended because the have a different grip, she is someone who had knee replacements and had quite a lot of problem with her knees and she just found that these particular poles the grip was more comfortable than the sort of grip she had on other walking poles which tended to go into the palm and hand whereas this you rest your thumb in it and then put our fingers around the handle so it is really my fiend saying that she found them you know the best ones that she has used.

R: Are they, I didnt see but are they adjustable.

P: In the height yes.

R: Next question is how did you choose your current walking stick but you already mentioned the physiotherapist and your friend.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Around the house I wouldnt use it at all no, so I tend to use it if I go out and I do find that I walk a little bit faster if I use the poles but also it does seem to help in terms of my hip and just general movements.

R: Also, I dont know if using the poles avoid that you get tired or not.

P: Well I wouldnt carry on walking, I would just stop.

R: That will be then because you are using it for walking outside because you could be faster with those ones.

P: Yes and they give me support.

R: Which are the best aspects of your current walking stick?

P: Mhhh, I do find that when I use these walking poles you are suppose to have them so the height, your forearm will make a 90 degree angle and I suppose that should be the correct height but I do find that sometimes my shoulder would start to ache.

R: When you use it with a 90 degree angle.

P: Yes, I dont know if that is because I am not using them as I should, it said that on the instructions that your shoulders should be back but it doesnt always feel comfortable.

R: That is something we didnt realise we were like that after a short period of time. So as you realised the shoulders ache you tried other angles.

P: I try not to hold it quite loosely so than rather than pushing it on the ground it is just touching it.

R: So with that type with your current walking stick your arms are not any more on 90 degrees.

P: Yes they would.

R: Sorry, I understand that it aches when you have 90 degrees but anyway you are using them.

P: But it will be after a while, might be after 15 minutes, I would stop for a bit.

R: What do you then when it starts to ache?

P: If it starts to ache, well if I were using say my wooden walking sticks, if it wasnt a walking stick made just for the right hand I would swap to the other hand but you cant do that.

R: So the best aspects could be that you could use it more.

P: The grip is quite comfortable, it feels natural and it keeps the wrist straight and possibly because I have arthritis in my thumbs that for me is a better grip.

R: And the height is ok.

P: Yes.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: I mean the material it is made of, if it is a hot day you know it can get a bit sweaty.

R: Is it easy to change the height.

P: Yes.

R: Is the tip ok?

P: Seems to be.

R: The tip, does it last longer?

P: The tip?

R: After you using it for certain period of time, the tip remains with its shape or do you see any.

P: Well I bought the sticks in August and they are fine but if they wear out I can buy new ones so I just have to get some more, they are a sort of rubber, hard rubber.

R: What type of finish do you like on a handle? And why?

P: What sort of finish, I think that something that is foam but not hard so it doesnt feel hard and as I said in the summer something that would not make my hand sweaty, I dont know what type of material you could use, I mean with a wooden walking stick you dont have that problem but they are hard arent they although you could wrap something around the handle if you want to, mhh I am not sure.

R: And for example on cold weather you feel the handle and materials to be ok.

P: Yes, I have been wearing my gloves today and it is fine.

R: And with your gloves, is it ok to handle it, have you experience any problems holding it with your gloves.

P: No, one thing I can see is that having two sticks is helpful and also you dont look so much as an old person with a walking stick, you know, hikers use walking poles dont they but on the other hand if it is raining you cant use two sticks and hold an umbrella so you know you got to sort something out havent you.

R: Yes, it depends on the condition but it is more comfortable only having one because you need to grab with the other hand.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: No, I did worry you know about it getting caught and tripping but no I got use to it.

R: Besides the walking stick, do you use any other form of walking aid?

P: No, I was prescribed some orthotics for my ankle but the physiotherapist I was looking wasnt every impressed with orthotics and he said it would be better to try to strengthen the muscles.

R: So somebody recommended another type of walking aid?

P: No.

R: Ok, these were the questions so now in the second part I am going to show you, I am going to bring them here.

P: That is ok.

R: The first aspect that I considered important in a walking stick handle is the shape so now we have here five different shapes and as we can see these three, this is the crooked that is common, this is the crutch and the pistol and these two as we can see the shape is curvy and those are ergonomic. The first three can be used by right and left handed people as we already mentioned and these are for right handed, so basically you can touch them and you are going to tell me which one do you think it is more comfortable to use and for example in this case that we are with the crooked style what do you think about it?

P: Well, this one, I think the curve is too tight for me, my walking stick is curve but not as tight as that so. I suppose this other one you hold it like that.

R: Or like this.

P: That wouldnt be comfy for me so I would hold it like that.

R: If you want we can put the handles on the stick.

P: Yeah.

R: Here, we need more height right.

P: A little bit.

R: Try not to put too much weight because it is not entirely function, I mean the stick is real but.

P: Yeah, I think for me I need it to be a little bit higher.

R: Ok, so basically your thoughts about the crook style is that the curve is too tight for your hand. Now we have the crutch style.

P: I have never used one like that so I dont know how to hold it.

R: I have seen something like this.

P: So my finger goes around the front, I dont think I like that, so like that.

R: I think it could depend on the person.

P: Yes, no I dont like it like that.

R: Now we have pistol.

P: It is wide.

R: Ahh ok, for the pressure that you are putting on it.

P: Yes and also they dont feel comfortable to me.

R: Now we have the ergonomic one.

P: And how would you hold that.

R: Here goes the thumb and then three fingers here and the other like that.

P: Ok, no, it doesnt fit my hand.

R: Actually I have bigger and smaller sizes for the models, do you want to try the bigger.

P: Yes probably because my hand would come off that. Mhh I dont think it works good with my hand because the design has a curve here you see and my hand is more straight.

R: It simply doesnt have the same shape.

P: I dont think it works well with hands, my tendons see would be like that so not good.

R: Ok, this was the larger ergonomic, now we have the medium size of the fischer.

P: And how do you hold this.

R: Like this.

P: So not around the front, all four fingers at the side.

R: Yes, I think it depends, for example I am holding it like this and it is ok but when I want to walk I feel like I need to put something here in order to grab it better.

P: Yes, so this one works better than the other one, mainly because it has the rest at the back so it supports that part but it also pushes up, this part pushes up so it is comfortable here but not comfortable there.

R: You feel it is a little bit high that part.

P: It definitely works better than that one. So of the five this one and this one are the more comfortable for me.

R: The crooked and the fischer. Now I am going to show you different textures in cylinders in order to avoid some perceptions if I show them on a handle so I am going to show you first the bumped texture.

P: Yeah.

R: What do you think about it?

P: I think it might be a little bit sharp.

R: The second option is the sphere texture.

P: I dont think I like the little pricks.

R: Now we have the cracked texture.

P: That is ok.

R: And now this is the medium texture.

P: Yeah that would be ok as well.

R: And now we have these two.

P: I think probably I would like the smoother texture, that one.

R: That is smoother than all of them so from this six options you prefer the smooth. Do you want to have a second option? Because now I am going to present you the handle with the texture but I dont know.

P: Yeah, the two smoother ones I think, would the handles be in this material.

R: Yes, it is a plastic, what do you think about it? All of them are printed on the same one.

P: I think they would be better with something over them like you know, a slightly spongy sleeve.

R: Like rubber?

P: Yeah.

R: Are you talking about that because of the flexibility or the sense.

P: Because of the flexibility but also this to me feels brittle and hard and I myself I prefer a something with a little bit of give in it.

R: So it can be bend a little bit.

P: Yeah, so say slightly soft but with a firm core but when you hold it it would have a little bit of give so the way your fingers put pressure on it would dip a little bit, slightly spongy it wouldnt need to be thick but just a thin layer to make it not as harsh on the hand.

R: Can I see your walking stick.

P: That isnt spongy but it is.

R: It has a sensation, a feel that you could mould it with your hand but cannot because it is hard for the support. And for example when you touch this handle the level of roughness is ok for you.

P: Yes that is fine.

R: And if we compared with those ones, I mean with the four textures, these four are so rough.

P: Yeah, I definitely wouldnt want anything like that.

R: Like the sphere and the bump.

P: And that is quite harsh so of the textures the smoothers one I prefer or the least textured.

R: And for the six it would be this one.

P: Yes this one because I think these would hurt if you held them for long you know, you might feel ok and that you are not going to slip but I think the little prick shapes would hurt.

R: And actually these ones are the smoother ones, actually for everything I have a bigger version, do you remember that it was a little bit tight with your hand the crooked.

P: I suppose I would straighten it out a little bit so it wouldnt curve around.

R: Now this is the raw texture means that as I receive the part from the machine that is the material and with this one we use sand paper.

P: Yeah to smooth it, cause I think the rough ones will chafe and make your skin sore so I think smoother would be better, it wouldnt irritate.

R: Yeah because of the inherent characteristic of the process you can see here the lines which are the layers that were build, that is why we have here we can see the shapes and we have the last layer here so here we can see as well the layers but the sensation is different.

P: Yeah yes, to me that is a kinder surface.

R: Ok, the smooth. Now we have the smooth in the fischer.

P: Yes, I want the smooth rather than rougher surfaces.

R: Ok so the final selection was the fischer with the smooth surface. Now the last part is that I am going to put clay on top of this one so you can press it and have our hand shape. So I am going to ask you to press as tight as you could, ahh ok so you are going to press it like this so that means that I will need here.

P: Sorry.

R: I will need clay in here.

P: Alright.

R: Because I was thinking about this but if you are, mhh ahh ok.

P: Ready?

R: Yes.

P: So hold it tight.

R: Yeah and make sure this fingers also hold tight.

P: How long?

R: That is fine, ok, let me see your index, your thumb and here we have the other fingers, that is fine.

P: Will that work for you?

R: Yes, thank you very much.

SESSION 1
Participant No. _8_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Yes, slip discs in my back L4, L5 slip discs and possibly a hip problem and I also have arthritis in my knees and feet. My sense of touch is fine, no problem.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Worse, well no lets say constant.

R: Can you provide a few details of how this condition affects you?

P: I cant walk for any distance unaided which is why I started using a walking stick, my feet hurt, my knees hurt and particularly my hips and backs hurt, it means that I dont go for long walks any more with my dogs or kids, I cant do gardening.

R: Does this condition vary during the day?

P: Yes, it is very bad first thing in the mourning, it is very good I have two rails on my house because I hold to them going down the stairs, so first thing in the morning and late in the evening after 4 in the afternoon are the worse.

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: I have some arthritis on this joint here, they keep finding arthritis but it doesnt affect me much.

R: How many walking sticks have you used? (In the past and currently)

P: Two kinds, the crook, I have that kind as well, I have tried it but didnt use it, my mother in law had it but it has a brass handle but it is awful, I have tried that kind and that kind as well and also that kind, and the reason why I didnt take that one is because it wasnt very tractive, the fischer or ergonomic so I havent tried them really, it felt comfortable in my hand. So first you had the knob and then I tried that one from my mother in law and that is what I have been used the most, the crook.

R: Why did you change from knob to crook?

P: Because the knob was too small handle and it was a brass handle, the other one was totally wood but it didnt provide me I actually had to hold on to it in a certain way in order to use it, that is best but like I said the other day I noticed this part of my hand was so sore from use it.

R: How did you choose your current walking stick?

P: I suppose because that is all I ever seen people use, I didnt know about any other kind until I went into the charity shop and so you can get others and I thought the decorative ones were just decorative but the crook it was just default I didnt think there was anything else.

R: And did the NHS was involved in the purchase or did you just go to the charity shop?
P: Yes, my back was sore so I just went into the shop, I didnt go to any physiotherapist or anything like that and I didnt know what height or anything

like that and I knew that is what you should do but I didnt think I needed a walking stick for very long but now I do.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Not all of them but I would say about 30% of them yeah.

R: Which are the best aspects of your current walking stick?

P: Well it was cheap, it is handy, you know, I can just it is just behind the door so whenever I go outside it is there, I like that it is made of wood so it is not so unforgiving as the brass head on the other one.

R: Is it adjustable?

P: No.

R: So you just checked it was convenient to you height and that was it.

P: Yes.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: The entire thing is I find it it is attractive, attractive in a sense people dont look at you and it is almost fashionable, almost. I see you came with with the holes in it and I am thinking I dont want that because then people will be like can I help you madam and that kind of thing whereas when I have the wooden walking stick it is just like a fashion accessory, nobody treats me differently.

R: Well about the handle, you mentioned sometimes it hurts.

P: Ohh yes, yes, it is totally inflexible and the crook is a crook that was made so it doesnt necessarily fit my hand and certainly for any prolonged use it hurts my hand.

R: What type of finish do you like on a handle? And why?

P: Not smooth, not totally smooth because then I would feel my hand would slip, I little bit knobby suppose but so knobbly.

R: Have you experienced any issue when you grip or manage the handle of your walking stick?

P: Yes, it just isnt comfortable I mean I use it but it is just it isnt comfortable.

R: If so, what do you think could be the reason? (Example: shape, material, changes of your condition during a short period of time, etc.)

P: I would say probably the material, I would say that if possible some flexibility, just a little bit more give so when I am leaning on it you know it will compress a little bit.

R: Besides the walking stick, do you use any other form of walking aid?

P: No, although when I go to the stores, to the shops, the first thing I do is I get a shopping trolley and I use it as a walker to walk around, my kids will say I take the trolley and I say no, I need it that is what I use to walk but I do not have a walker and I am not ready for one.

R: So this was the first part, on the second part I am going to show you different types of walking stick handles, as you see in the participant information sheet I showed some of them but I realised many were similar so I made a selection.

P: Alright, ok I see.

R: These were produced with a 3D printer.

P: Ok so that is what I use one.

R: Yes the crooked one.

P: And that is actually a good example why it is not totally suitable for me, it is ok I mean use it but it is just that for any amount of time for example if I go for a walk I wont be able to use it because the space here is not enough and it will hurt all along there, I dont have one of those and I have never used one of those, this one again if you see I have to hold on to it so I mean it even affects the grip and it is just too small. Now this is like the one I saw on the charity shop and I thought ahh that could be very good because.

R: That is the ergonomic.

P: Because that would be, specially if it were in a material that kind of gives that would be great because when I press down the pressure will be here and here and not all there.

R: That is the fischer model.

P: Wow, it is much more comfortable.

R: These are all medium sizes, these three can be used by both right and left handed and these two just for right handed.

P: The thing I like about this is that it has that which really friggles your hand so yeah I like that

R: So out of the five models which one is the best.

P: That would be first choice and that one is the second.

R: So it will be this one, the fischer. I am just going to put it here, this is a commercial stick.

P: Yes yes.

R: Try not to put a lot of weight because it is a prototype.

P: That feels very comfortable because of that lip.

R: Now we have the fischer.

P: Should I try the others.

R: Not but if you want, there are some people that want to try several but that is because they have the idea that maybe one of the others could be right.

P: I could try that other one.

R: The type of handle is the first aspect that I consider is important in the design of handle.

P: Absolutely, the reason I dont like that one is because my hands slips, it feels like my hand slips off, in fact it feels I would feel unsure walking because my hand slips here.

R: Now the second aspect is the texture, so I am going to show you textures, six different types, well there are a lot of textures out there but I made a selection and I am going to show you in cylinders in order to avoid maybe if you see them over the handle you are going to think maybe this could be good. First we have the bumped texture.

P: No, too rough, if your hand slips after any length of time I think you will begin to get a rash or a grazing with that, you know.

R: Ok, yeah, this one is the sphere texture.

P: Mhh no, it feels prickly.

R: Here we have the cracked texture.

P: That is better.

R: This one is the medium texture.

P: Mhh no, no.

R: Ok.

P: And those two would be too smooth.

R: Do you want to try them, they are different.

P: Yeah, no again because if I use this for longer I would like to go for a walk in a park for instance so if it is a long walk my hand will get sweaty or it might rain so I need something I can continue to walk with so my hand will not slip, these ones irritate my hand so I can see grazing.

R: With the sphere and bumped.

P: This one I can actually see, this one is my preferred.

R: Ok, the cracked. Now I am going to show you the handle that you picked with the texture you selected, as you can see I have several samples, they are the different models with different textures.

P: I would be hoping to use this long term and that is why it would have to be comfortable, the crook, the one I got from the charity shop will do me for the short term but I can see me needing this for the long term so that is why even though the crooked is ok the last one, the fischer appeals to me most. Mhh, yeah that is ok, it is rougher than I thought.

R: Well, I think here the texture is more subtle.

P: Yes, right.

R: In some areas we can see there is no much depth.

P: The crevices are not as deep, gotcha, still I prefer it over the others.

R: What I can do is for the new 3D print I can do the texture a little bit.

P: Slightly yes, not as deep, ok, I still say that would be the best texture and the best shape. Yes, my hand you know I immediately notice my hand didnt slip, that is good, I am not putting too much pressure on it but it is good.

R: I was going to tell you if you want to try again with the other one, actually this texture is the smooth one.

P: Is it? I am sure I want it, I am absolutely sure that I want something and that is ok, if you can set it, which you can, so that it is not as deep the crevices that would be slightly better.

R: Like in some areas.

P: More like a leather, what do you call it.

R: Yeah, actually that was the idea of the cracks of the leather.

P: Yeah, exactly, when I saw this that is what I thought of and I thought yeah because those cracks are going to be enough so your hand wouldnt slip but not too much so they would cause grazing.

R: And what do you think about having the same pattern but smaller.

P: I dont think it would make any difference, no, mhh no as I say it is mainly if I sweat or if it is rainy it is not going to be, I dont want my hand to slip out of it I still will be able to use it, it is very comfortable and as said if it could be a little bit softer. Do you have the handle in that?

R: Yeah but not here.

P: That might be ok actually.

R: I showed to you again because you like the texture that is not too smooth.

P: Yeah because when I get a grip on it my hand doesnt slip, that might do actually. As you get older your skin gets thinner so one of the things I have a problem with is that I would get bruises and I would get scrapes and I am thinking how did I get that and it is because my skin has become thinner, my mother in law, she was 94, rest in peace, and she her skin was really thin so I actually I think that might be better when I think about it because I can already feel it here, a chafing.

R: So you think it would be better in the medium texture instead of the cracked with less depth.

P: Yes I prefer that, but with less deep crevices.

R: So we returned to the cracked.

P: Yes.

R: Now the last part is that I am going to get your hand shape but I am going to put the clay over it, when I put it over we can see the volume increases because we are adding material.

P: Yes yes so what do you want me to do.

R: It is fine, if you sit I will wrap the handle with the clay, I didnt mention as I saw that you were comfortable with the size I havent I didnt show you I have bigger size and a smaller size than this.

P: Ohh I think that is fine but maybe the bigger one.

R: This is the smaller one.

P: Definitely not.

R: This is the bigger one.

P: Mhh let me try it out, ohh my goodness, way too big.

R: Ok, I am going to use the medium one then. Can you please as tightly as you can?

P: Is that good?

R: Let me see, can you press it a little bit more.

P: Like this.

R: Ok, so your thumb goes there mhh let me get some material for here.

P: This is cool so you can take this of this form, it doesnt go hard.

R: No.

P:Ohh cool, ok, right so pressing my fingers there.

R: Yes.

P: And my thumb there.

R: Ahh your finger goes there, ok.

P: Do you need.

R: I can cut it, I have the opportunity some little changes with software.

P: Yes yes, this is my index finger so it continues down here.

R: Ok, yes.

P: That will need to be longer wouldnt it.

R: Yes, that is fine, thank you very much.

P: You are very welcome.

SESSION 1
Participant No. _9_

R: Are you suffering from any condition that affects your mobility and/or your sense of touch? If so, could you please mention it?

P: Sense of touch no, mobility yes. I have got arthritis in both knees.

R: If you have stated a condition that affects your mobility over the past years, has this become worse/better/constant?

P: Worse.

R: Can you provide a few details of how this condition affects you?

P: First some background, I am haemophilic I have a condition called haemophilia the condition of my joints is a side effect of having haemophilia, the quality of my joints has progressively deteriorated over the years, right now I have reduced range of motion in pretty much all my major joints but the arthritis and pain in the knees and left hip it means I cannot walk over long distances and I need a walking aid to be able to move with minimal pain the distances I am able to walk so yes I live on analgesics.

R: Does this condition vary during the day?

P: It varies based on activity, the degree of pain and discomfort is subject to how active my day has been, otherwise it doesnt really vary with the day it is pretty much the same.

R: Ahh ok, for example if you are sitting all day long does that make you feel uncomfortable?

R: Do you have any physical issue in your hand? Do you receive any rehabilitation?

P: Not really, there is pain and discomfort from using the walking stick but otherwise nothing.

R: How many walking sticks have you used? (In the past and currently)

P: Quite a bit, right now I own about five yeah.

R: If you have used more than two walking sticks, why?

P: Most of the time it is because I am trying to reduce the pain on my wrist and hand from having to place too much weight on the walking stick when I am moving around so I have change a couple of times trying to find something a little bit more suitable.

R: So basically the problem is with the handle and support it provides to your wrist.

P: Yes.

R: How did you choose your current walking stick?

P: I just saw it in a shop and tried it.

R: Did they provide any support or help regarding the walking sticks?

P: Not really.

R: Have you thought about going to the NHS and physiotherapist so they can recommend you a walking stick?

P: I never had a conversation about getting a walking stick recommended, I have never had a conversation about, it just been yeah you need a walking stick get one.

R: When you have appointments with the doctor, did they have recommended some walking aids?

P: I have used a pair of crutches but it is I would only use them when there is a significant degree of discomfort when it gets really bad and I need to move around.

R: And the crutches were suggested by the doctor?

P: Yes, they were provided by the hospital.

R: And you changed to a walking stick due to a suggestion of a doctor?

P: Yes, so a lot of the decision is left to me if I feel I can, it is all about my stability with respect of my degree of pain and feeling, if I feel that even the degree of pain I might be unstable it is best I use a walking stick, it helps me get better support and reduces the weight my limbs are bearing but if I feel ok and I am in a position where I can manage without the crutches I go with the walking stick but the choice of walking stick has never been discussed, I have never thought about bring it up anyway its always been ok this feels uncomfortable I will go and get another one.

R: Do you consider your walking stick is useful to accomplish all your daily activities?

P: Yes, continuous usage, I have been having conversations with my doctor about trying to find some other solution that doesnt require me using a walking stick quite as often because I have joint issues so progressively the use of the walking stick and the fact my upper limb is bearing quite a bit of my weight which the upper limbs were never design to bear so this means I am beginning to develop upper limb issues so it is best I find a good solution so I do not end up having additional issues to the ones I already do.

R: Yeah, for example if you are pressing a lot here.

P: Yes, pain in the elbow and in the shoulder, pain in the back sometimes.

R: Which are the best aspects of your current walking stick?

P: Good base, non slippery.

R: I think it is a little bit thick.

P: Yes, it provides good stability, if you have limb issues tripping just makes it worse so you dont want to slip or trip, as much as possible non noisy this one is already becoming a little bit of an issue when it hits the ground, you walk around a long a quite corridor and you can hear the noise, it is not nice. And yes the arm support, it needs to be good, even this is just the best I found so far.

R: And about the noise that you mention, does your walking stick makes that noise?

P: Yes, every walking stick will eventually get that specially if you have one that is adjustable because eventually it would wear if you keep it tighten and stuff the noise reduces but eventually all of this wears and it increase the frequency in which the noise comes starts to increase, everything wears down because it is wearing and it starts making this noise it progressively gets noisy.

R: What about the best aspects.

P: Like I said the tip.

R: Ohh yes the tip and the handle were the best aspect.

P: I still would like to have a customised walking stick or maybe during a careful search, having a walking stick that is not adjustable means that it would not make noise because there are no parts that could wear out in between but it also means that I would need to have like three of them because I do have to adjust the height occasionally depending of the degree of discomfort in my elbow, if it gets really uncomfortable sometimes you want to make it just a little bit shorter so you have an straight elbow against a bend elbow when you are having your muscles bear the weight, with an stiff elbow your joint can bear the weight for a while without the additional muscular support.

R: Is there any desirable characteristic you would like to add to its handle or to your current walking stick?

P: Maybe something cushioned, not necessarily cushioned, cushioned is the word but not with a padding, a material that is firm but wouldnt collapse under my weight either, that way it feels a little bit more.

R: Adjustable to your hand.

P: It doesnt, what is the word, it doesnt have pressure points because one of the issues with this is that these are pressure points along this part so I end up with pain just along there because those are pressure points, if these were softer or if it could collapse a bit it could distribute the pressure a little bit.

R: You mean that when you remove your hand the material reverts back to its shape.

P: Yes, it is not about having a cushion on it because if it has a cushion the pressure points will be there anyway.

R: Like some of those memory foam pillows.

P: Even with those the pressure points are still there by the time you, it just improves it but by the time you use it for a while you will feel the pressure, some people use basically a walking stick for managing the stability, I have seen people walking around with walking sticks and I can tell when someone is not placing a lot of weight on it, they are very forward and walk, for many of those people if someone kicks their walking stick they probably wont stumble because in the forward stride they are not placing as much weight on it, with me on the other hand I do place a lot of weight on it so on a forward stride if someone kicks it for example I would stumble because I would be leaning on it and lose my step and I would fall so yeah.

R: So the desirable characteristic would be based on the handle.

P: Yes, the stalk of the walking stick is pretty much done, except for being able to adjust the height I need it for or when I am getting into a plane the fact I can collapse it and put it overheard, otherwise I would prefer something that doesnt collapse, if this could collapse and still not get clicky after a while I would prefer something like that which is very significantly stiff and not noisy throughout the lifetime of usage, just like a piece of wood but it still offers the option of collapse it.

R: By collapsing you mean making it shorter.

P: Yes, like with this for example I can push it in to store it overheard, my other walking stick breaks in three places so I can pull it apart and then just fold it on three part so I can store it. I usually travel with that one.

R: What about the handle?

P: The handle is different, it is more like this so I have this, this and this, now this one is different.

R: That is the fischer.

P: I also have that one.

R: The escort ok, do you feel better with that handle rather than with the crutch one.

P: I use this more often but sometimes I really cant stand because after a while of continuous pressure on the same point I cant stand it any more so I have to switch to something else to change the pressure point for a while.

R: So you change it for the foldable one.

P: No, I change it to redistribute the pressure, I just chose a different walking stick when I have to use one as I said I have like five of them so if this one is becoming uncomfortable because of the continuous pressure I just chose a different one which means that the pressure is now applied to a different part of my palm.

R: So you have five models of walking stick but this one is the one you use the most.

P: Yes.

R: What type of finish do you like on a handle? And why?

P: I have not really given that a thought really, I am not really interested in aesthetics I am more interested in the functionality of the walking stick so it really doesnt matter too much to me as long as it is comfortable and as long as it is not bright red or black in terms of the look, I dont like bright colours.

R: What about the feeling of the surface?

P: I prefer it a bit rough instead of it being very smooth because that will give a better grip and when your hand is sweaty if the handle is smooth your hand slips quite a bit so I prefer it rough.

R: Have you experienced any issue when you grip or manage the handle of your walking stick? You already mention that pressure points are a problem.

P: Yes and then because of the weight, how much I put on the walking stick I do tend to give it a pretty firm grip which means that if I have to walk a long distance it would mean say walking from here to Subway just around the corner. Given the grip my fingers would ache sometimes because I am giving it such a firm grip, sometimes I feel if the head could be slightly bigger so I dont have to wrap my fingers around it so tight, perhaps that would help.

R: Besides the walking stick, do you use any other form of walking aid?

P: Just the crutches sometimes.

R: If so, do you consider it has any advantage over the walking stick?

P: It depends on the situation really, if I am in significant pain then yes the crutches have a great advantage but they also get on their way more because both hands are occupy.

R: When do you use them?

P: In a situation with great pain and where I need stability. If I am experiencing more joint pain then I would need to use the crutches to better distribute my weight.

R: Ohh with the crutches you can rest your arms.

P: I dont use those, I use the ones you grip, the elbow crutches.

R: So it depends on the day so you can rest a little bit better with the elbow crutches. That was part one, as I already mentioned there are several types of handles and I made a selection and this were 3D printed so here you can see these three.

P: I have never use that one before.

R: These can be used for both right and left handed people and these two are just for right handed only.

P: I am right handed.

R: Which one do you think is the better one.

P: I have used this one before, this doesnt feel I dont have a good grip because it is small relative to the size of my palm so it doesnt feel suitable for me.

R: This is the bigger size.

P: Ok so with this if I grip it you can see that, there is no support at that end so for me to get that support I have to move in and do that and if I am doing that it strains this finger.

R: Even with the correct support here.

P: Maybe if I get a better support here but the way it is I have to move my hand forward like this because I need to keep the grip in, right, so when I move it it doesnt swing away from me but with this one I can do that.

R: With the fischer.

P: I can keep this grip in towards my hand, however even with this right you can see it but there is a void right here so that means that there is like a point here that is kind of like an arc so you get tired after a while. This I have never tried because for some reason it just doesnt look right.

R: The knob.

P: Yes, it just doesnt look right, to me it just not design for weight bearing right and giving the small surface area it is going to place a lot of weight a lot of pressure on my palm which is difficult. This I use already, this is the other walking stick that I use somewhat more frequently but whenever I use it I dont hold it this way I hold it this way.

R: Ahh ok, you feel that is better.

P: Yes because when held this way right it is you know I mean the weight distributing goes that way, when held this way there is a vertical distribution of the weight down, towards the stalk of the walking stick, this way is difficult it just ruins your joint.

R: And you need to, you feel you are bending your wrist more like that.

P: I can show you.

R: I can put it here on the stick.

P: This way right, it is really not that stable, that is number one, number two given how much weight I place on it you can notice it is kind of acting like a fulcrum, a point of bending right there so whenever I press down on it the vertical weight goes this way so it is acting like a fulcrum. This way on the other hand the way is vertically on the stick, the problem with holding it this way however is that there is a lot of pressure that way so it has benefits and demerits. This other one I have never tried, I have no idea what this would be like, but again because of the shape I have always being discourage by it I think it is not suitable, there is too much pressure in the centre again because the handle doesnt have this bend it doesnt match overall for the position of my hand, it is not a good shape for the hand to fell in, maybe if I wasnt putting so much weight on my walking stick this wouldnt be a problem because what this is, it is just a hook for holding a walking stick, something you use to hold the walking stick and not for weight bearing, when it is bearing weight it doesnt do a good job.

R: So which one would you say is the best option.

P: That one and this one.

R: The crutch and the fischer.

P: Again, they both have their own issues, this to the fact that I need to put a lot of weight on my walking stick and you can see why this is also useful because I can actually let go, relax my palm when I am having a conversation, and when I dont have the hook rope and I need to keep holding.

R: If we need to pick just one.

P: If I have to pick one I will go with this right now because it is the one I use most often, still if I could find something better then yes but this is what is available and what works best for me given the degree of weight I need to place on a walking stick so this works the best because it kind of falls into the shape of the hand, you can distribute more of your weight along that surface.

R: One of your handles has some peaks, that one.

P: Ohh this, this is for when lets say I am walking like this and I need to put my walking stick here so it keeps it from sliding.

R: Ahh ok. Now I am going to show you some textures, if you want I can bring them to you.

P: No that is fine.

R: There are six different textures and you are going to tell me please what you think about this one which is the bumped texture.

P: I like this, but in long time usage this will start to dig into the palm but it does feel nice and firm but for long time it will dig in. This looks more like.

R: The cracked one.

P: yes, it looks more practical for long usage when you are bearing weight because it is rough, it helps with the grip but it would dig into the palm quite as much, if the bumped were less, were flattened out because right it is almost like a point, some of them, but it flattened out this could work, it offers a good grip. This ones bothers me, right from the moment I saw it because it looks like it could be prickly, it gives a firm grip but for weight bearing I do tend to have to grip very firmly partly I am conscious I dont have to give it such a firm grip but at the same time I am conscious of the fact I am using a walking stick and it is somewhat unnatural so I give it a firm grip because it gives me a sense of control so giving this a firm grip will end up being prickly for me.

R: What about this one, the medium texture.

P: This is ok too, that is ok as well maybe a little bit too smooth for me but it is still fine.

R: If you want you can sit.

P: Yes, thank you, these two for me are no noes, too smooth.

R: Which one would you say would be.

P: My first choice? In this order, first choice, second choice and third choice.

R: Cracked first place, second bumped and third one the medium and this will be fourth place the sphere. So I am going to show the fischer model with the cracked texture.

P: This is fine.

R: It also it depends on how I applied the texture, it can vary a little bit for example here.

P: Yes, this is less dense and there the bumps are smaller, closer together, but yeah this is fine, they are both good really, frankly I think using it with the handle and the smaller bumps I actually prefer this, it just gives you the haptic feedback that you have to have, there is a feedback you get from holding the walking stick right and this just makes it easier for you to feel it, it makes it a lot easier for you too feel it and gives a firm grip.

R: Besides the firmer grip you mentioned the feedback, that means in certain points you have more security when using it.

P: Yes, so lets say you have sweaty fingers and palm, this gives you a greater comfort a feel that it is safe, that is one, two, it also kind of keeps you away if your walking stick slips slightly in your palm so this keeps you away because if your walking stick slips just slightly it affects the entire weight distribution so it is easier to be aware where everything is because of this.

R: So you would say that the fischer with the bumped texture.

P: Yes, I like it, I really like it.

R: What do you think about the size of the bumps?

P: Smaller.

R: What about the depth?

P: Yes, something more like that.

R: Yes, because in this areas here we can find the depth is.

P: Too deep, remember I said this could become uncomfortable for long term usage and firm grip but this less so.

R: So you preferred it like this.

P: Yes.

R: So fischer and bumped texture and that one.

P: The crack is still good but that one is better.

R: So this was the second part of the session and the third and last one is that I am going to get your hand shape so I am going to put some clay so it would take a few minutes. Here I have the larger and smaller sizes so I dont know how you feel them.

P: This is a bit too big for my palm.

R: So we will use the medium.

P: I wouldnt use that one, it is just too small, too tiny.

R: I am going to ask you to grip it as tight as you could and as we know the volume it is going to increase a little bit because of the layer of the clay, how did you feel it with that increased volume?

P: It is fine actually, I think I prefer an slightly bigger larger volume. Strangely it is kind of nice because the clay is sticky so my fingers are stuck to it, it is not nice that is sticky but it is nice that it is not falling out of my hand because sometimes with a handle you just want to relax a bit you want to let go just relax your grip but you cant always relax your grip so much because once you let go it slips away and you have to grab it and with this for example whenever I relax my grip this happens, it basically stands and when I have to walk again I have to do this so sometimes I am kind of searching for walking stick and it keeps going away, this for some strange reason it is nice because if I let go it will stay. It is nice knowing it sticks and that I can relax my fingers and my walking stick is not running away. I can let go now.

R: That looks really nice.

P: Like I said to you I do tend to because of I try to use the same amount of grip I usually do so I do tend to have all my fingers in.

R: As we can here, well, that is the end of the session, thank you very much.

11.22 Appendix V: Results session 1

1. Reasons for changing walking sticks

One of the first aspects that the session covered, were the reasons why the participants have changed from one model of walking stick to another. 8 out of 9 have used more than one type and the reasons are shown in Table 1:

P1	Not applicable. Only 1 walking stick has been used.
P2	Several walking sticks. Because the participant wanted to stop falling (this happened 2 or 3 times per week).
P3	2 walking sticks. The first one was provided by a NHS physiotherapist, it was a standard and adjustable model with a plastic handle. It was the only option provided and there were not lessons about how to use it. The second option is a folding crutch walking stick that is more convenient and elegant for the participant because it has a wooden handle instead of the plastic one provided by the NHS.
P4	3 walking sticks. There was not a particular reason for change. Maybe 1 got lost. The walking stick model stopped to being reliable and today the participant uses a pole stick.
P5	The participant has used two models (two including the current one). The reason of the change was because they can handle the current crook walking stick better than the previous one. When they need to use the hands they put the walking stick over the arm and hands are free.
P6	In the past, the participant used 2 elbow crutches but it was not possible to do anything with the arms, therefore, they decided to use a walking stick. They had a crutch model but it hurt them and it was not safe, therefore, Social Services provided them a Fischer walking stick and they have used it for a long time.
P7	The participant found useful to utilise a walking stick during the winter because of the icy pavement and for avoiding slipping. Later, they started to have stiffness in one knee and they used a regular walking stick. After this, their hip flexion was damaged and a physiotherapist suggested the use of walking poles. Therefore, they have been using them for about 7 months. Also, one of their friends made the same recommendation as he/she has had knee replacements and he/she had found the walking pole's handle very comfortable.
P8	The user had tried the knob stick that should be held it in a certain way for using it. Then, the character model was tried but the handle was too small and the material (brass) did not have elasticity. After this, they tried the crook style that after a period of usage causes pain in the lower area of the inner palm (close to the thumb).

P9	P9 owns 5 different models. The participant has changed from one model to another in order to find the most suitable and reduce the pain on wrist and hand caused by the usage.

Table 1 - Reasons for changing walking sticks.

2. Best aspects in the current participant's walking stick

The best characteristics per each walking aid are mentioned in Table 2:

P1	"Stability when there is nothing else to hold on to".
P2	Do not add pressure points over the hand and arms.
P3	Foldable. The user would like to use a more elegant model as a multi-colour model or with a floral pattern.
P4	It is used mostly for going outside. It was no expensive. It does not spring, so it is easier to trust in it. They use a pole walking stick because they like the straight line from the handle to the floor and there is more control of it.
P5	It supports the user with the weight laid on the knee and depending the circumstances, the participant can hold it on the arm and carry on.
P6	Its handle is the best aspect because other models, as the crutch caused a lot of painful on the inner palm and the surface of the current handle (Fischer) is wider.
P7	The grip is really comfortable. It is a more natural grip and it keeps the wrists straight rather than bent.
P8	The price was cheap (crook style). It is handy. It has a better grip because it is made from wood not from other materials as brass. Also, it is attractive, almost fashionable. With a metal walking stick people would treat the user different, as if he/she would require more assistance.
P9	Good base, non slippery and it provides a good stability. The handle (Fischer type) is the best that the participant has found.

Table 2 - Best aspects in current walking sticks.

3. Issues when grip or manage a handle and reasons

The issues during the grip are cited in Table 3:

P1	"Hand becomes painful after a very short time if I am not wearing a glove. Wrist also (hurts) due to the angle of the crook".

P2	The handle slips because: “it doesn’t fit like a glove”…“and because the walking stick is not adjustable, the body has to adjust to the best length you can get from any walking stick”.
P3	At the end of the day, the participant gets tired to hold it. The handle is knocked because it falls. The walking stick immediately falls when the user takes the hands off and the cord that usually comes with it is loose.
P4	The handle is too smooth. The user would prefer a handle perpendicular to the stick.
P5	Handle does not provide the correct grip.
P6	It is not possible to make the walking stick longer or shorter because the lock ring of the stick is so hard and rusted, and if it is moved it can be broken. Although the walking stick was new, there are some lock rings that are too hard and people with problems on hands could straggle to change it of position. Other issue are the tips, the rubber tips are worn and the participant should go every two months to the NHS to request another tip since it is not possible to ask few spare tips in advance. The material of the stick (metal) never gets warm and it feels cold when it is hold between legs.
P7	Walking pole. No issues with the handle.
P8	The handle of the crook style is inflexible, does not fit the hand because of its shape and for a prolonged usage it hurts the hand (inner palm below the thumb). Uncomfortable.
P9	Pressure points. Ache in fingers after walking long distances.

Table 3 - Issues in gripping and managing a handle.

4. Desirable characteristics to add to a walking stick or its handle

Table 4 shows the desirable features in a handle mentioned by the participants:

P1	“Pressure more evenly distributed over the palm but still allowing firm grip”.
P2	“Made to fit. Not a standard device”.
P3	A better fit on hand which is injured due to arthritis.
P4	The handle is too smooth (the material is similar to PU foam). The user would prefer the separations of the fingers (on handle) stronger and that would allow a firmer grip: “the handle is a little bit slippery”.
P5	A better grip.

P6	An additional fixture for holding the walking stick, currently, the user should find a very angular surface in order to rest the walking stick. A variety of accessories that can be used in different surfaces are desirable. Straps for holding the walking stick. Faster replacement in tips.
P7	A proper material. If the weather is hot, the material of the handle can be sweaty.
P8	A better grip. A little flexibility to provide comfort. Something that the user can lean on it (pointing out the below part of the thumb).
P9	Firm material but collapses a bit for distributing the pressure points. A foldable stick but not noisy while it is used.

Table 4 - Issues during gripping.

5. Most liked finish in a walking stick handle

The preferred finish is shown in Table 5:

P1	Smooth, polished or padded.
P2	One that meets the natural angles that the arm has with respect to the walking stick. Made of plastic. Anti-slippery.
P3	Shinny, wooden surface.
P4	Raised parts in the handle to improve the gripping and maintain a steady hand.
P5	The participant only has used wooden walking sticks, therefore, there is not experience with any other material.
P6	Not too smooth finish, a rougher texture. More sturdy.
P7	Something firm but not hard. Some material not too sweaty in high temperatures.
P8	Not totally smooth because it can cause a slip.
P9	Not interested in the aesthetics of the stick or in a specific colour as long as it is functional and comfortable. Having preference on rougher surfaces rather than smoother ones.

Table 5 - Preferred finish in a handle.

6. Preferences and comments about the type of walking stick handles

The comments about the 5 different types are mentioned in Table 6:

P1	CROOK. It is too narrow for the participant. Their current crook handle is wider and spreads the pressure more, but despite this, the participant feels pain in the inner palm. CRUTCH. There is no improvement over the current participant's walking stick (crook). It is uncomfortable spreading the index and middle finger around the stick for holding the handle. This crutch model is wider and thicker than the crook handle, which is consider better for the participant. PISTOL. It is straight. The wrist is bent. The user has all the pressure in the centre on the inner palm. "It does not feel so secure". The hand could split easier around it. ERGONOMIC. It is fine; the pressure is exercised over the whole hand. With the crook handle the wrist has to be bent and there is pressure. The wrist is straight on the ergonomic handle. FISCHER. Not good in size and the peak located at the ending and raised part of the handle presses the participant's wrist.
P2	CROOK, CRUTCH, PISTOL AND ERGONOMIC should take into consideration where to put the pressure in the user's hand. FISCHER. That was the best design for the participant, but the whole handle cannot fit into it (medium size). If the user grabs it, the index finger did not fit and there is a line of pressure that can goes to the index finger, then goes to the wrist and then inside of the elbow.
P3	CROOK. It was considered too loose and it did not have the right shape of the participant's hand. CRUTCH. This model has a better shape than the crook style. PISTOL. The participant did not consider at all try this model. "It wasn't provided support". ERGONOMIC. Using this handle, the participant found a comfortable position in wrist and arm. FISCHER. The participant considered this too big.
P4	CROOK. The handle is uncomfortable because the fingers should adapt to the curve of the handle. CRUTCH. This is better than the crook style but still uncomfortable. PISTOL. There is a lot pressure in an area. ERGONOMIC. It is nice but still thinking about where all the fingers should be. FISCHER. It is comfortable. The hand feels very nice.

P5	CROOK. “It feels good”. CRUTCH. The user also found right this handle. PISTOL. “It is quite ok”. ERGONOMIC. “(It is) quite ok”. FISCHER. “I like that, it covers more my hand. The feel is good for me”. It provides hand comfort. If the participant should not have tried the ergonomic handles, probably, the crook or the crutch would have been chosen because they are more traditional. It provides more safety than the ordinary straights.
P6	CROOK. It is not safety. The user cannot put the weight on it. “People with this type don’t really lean on it”… “it is more for people who are not confident but they walk”. CRUTCH. It cannot be used for really lean on it. Those that are in the market are thinner than the 3D printed and they hurt more. PISTOL. “You cannot lean on it”. ERGONOMIC. The shape of the handle does not fit well with the user’s hand. FISCHER. This model adapts better for the user’s hand.
P7	CROOK. The curve is too tight for the user. CRUTCH. It is not comfortable gripping it. PISTOL. It is not comfortable for the participant. During the gripping, the hand is under a lot of pressure. ERGONOMIC. The hand comes off with the medium size. With the big size, the hand tends to slip off, also the curves do not coincide with the inner palm. FISCHER. It is more comfortable than the ergonomic model because there is support in the backside on the palm, but the middle curve pushes up the inner palm.
P8	CROOK. It is not totally suitable. The space of the curve is not enough for the length of the hand and it will hurt it. CRUTCH. It does not feel good for the participant. PISTOL. The participant has to hold on to it and it affects the grip. Also, it is too small. ERGONOMIC. The upper curves of the handle are comfortable and when it is hold the pressure is in the middle of the palm instead of below the thumb. Also, the hand slips off. FISCHER. This is more comfortable than the other 4 models. The backside of the handle cradles the hand.

P9	CROOK. The handle does not have the shape of the hand. CRUTCH. The user already had experience with this handle and it was not very stable and if it was gripped in other direction there was a lot of pressure on fingers. PISTOL. The handle's surface is small and when it is griped, all of the pressure is in one area. ERGONOMIC. The medium size is small for the participant's palm and with the bigger size there is a lack of support between the inner palm and the handle. FISCHER. It is ok. The best option, also in regular size.

Table 6 - Preferences and comments about handles.

7. Preferences and comments about textures

The different textures were tested and the comments are shown in Table 7:

P1	SMOOTH. The participant suggested: "You could polish it or cover with material or anything". Smooth, soft but firm or glassy smooth. In fact, the participant did not like at all the raw, cracked, circles and bump texture. RAW. The participant preferred the smoother texture over the raw one. MEDIUM. "This one is not bad. Strengthened enough". CRACKED. "I don't like that". CIRCLES. "Definitely not. It doesn't spread the pressure evenly, not to me". BUMP. "Definitely not. It doesn't spread the pressure evenly, not to me".
P2	SMOOTH. Too smooth for the participant and cannot provide enough grip if the person sweat or the hand is wet. RAW. It cannot provide enough grip if the person sweat or the hand is wet. MEDIUM. This type is anti-slippery but a little bit smooth for the participant but the crack texture represents a better option. CRACKED. Anti-slippery: "If you sweat or your hand get wet it won't move". It is more comfortable that the medium texture. CIRCLES. Too sharp. BUMP. Too sharp.
P3	SMOOTH. It was all right but too smooth. RAW. It was all right but too smooth.

	MEDIUM. The participant preferred this texture. "It is not smooth, just the right degree of roughness". CRACKED. This was better than the bump and circles. CIRCLES. Too rough. BUMP. Too rough.
P4	SMOOTH. Too smooth. RAW. Too smooth. MEDIUM. "It is just the right kind of amount (and) gives attraction in your hand. It is just enough, not too smooth". CRACKED. "It is not prickly… is not too smooth…it is good". CIRCLES. Too prickly. BUMP. "Slightly prickly but not too much".
P5	SMOOTH, RAW, MEDIUM are fine for the participant. CRACKED. Texture is ok. The user prefers rougher textures rather than plains. CIRCLES. It is fine for the participant. The user feels the texture "quite nice". BUMP. "There is more grip, would be a grip naturally".
P6	SMOOTH. It was smooth for the participant. RAW. Raw texture was better than smooth. MEDIUM. Cracked texture was better than medium. CRACKED. Neither bad nor good. The participant prefers the bump. CIRCLES. This texture was good for the participant, but the bump was preferred because the user was more aware of the texture. BUMP. It is ok for the participant.
P7	SMOOTH. Comfortable. RAW. The participant prefers the smoother texture over raw. MEDIUM. It is fine for the participant. CRACKED. It is fine for the participant. CIRCLES. The participant did not like the little pricks of the texture. BUMP. It is sharp.
P8	SMOOTH. Too smooth. After a long walk, the hand could get sweaty and would be necessary to have a rougher texture. RAW. Too smooth.

	MEDIUM. Smooth. CRACKED. This is better than the bump and circle. Best texture and correct amount of roughness. CIRCLES. It feels prickly. BUMP. Too rough. After a length of time the hand could begin to get rash.
P9	SMOOTH, RAW and MEDIUM are too smooth. CRACKED. It looks more practical for a long term use than the bumped. It is rough but it wouldn't dig into the palm. CIRCLES. It could be prickly. BUMP. It is nice and firm, only, in a long term, the spheres could dig the skin.

Table 7 - Preferences and comments about textures.

8. Preferences and comments about sizes

Table 8 summarises the comments about the different sizes:

	Small	Medium/Regular	Big
P1	It was not so good.	The medium size fits better than the big one.	It is comfortable; the user can grip more area. The whole pressure is spread on the hand and straight up without bending the wrist.
P2	The small size was not shown to the participant because the medium size was already small.	The original medium size was small for the participant because all fingers except the thumb needed more space to fit. Despite this, the medium size was better than the big one.	The ending part of the handle close to the wrist, was too big and wide for the hand, so, there was remaining material. The edge of the handle that supports the fingers is too straight comparing to the natural shape of the handle.
P3	That was too small.	Best size for the participant.	Too big.
P4	That is too small.	This is the right size.	Too big.
P5	Too small.	The size of this handle is right for the participant.	It is big.

P6	Small.	Better size. The backside of the handles shapes the hand.	The user feels the hand a little bit lost when this size of grip is held. There is no support for the hand in the backside.
P7	Too small.	This is the most suitable.	Too big.
P8	Too small.	Right one.	Too big.
P9	Too small.	The correct size.	Big for the palm.

Table 8 - Preferences and comments about sizes.

11.23 Appendix W: Detailed steps of production of personalised 3D printed handles

Production of personalised 3D printed handles

The production of personalised 3D handles encompasses two main phases: I. Hand printing process and II. 3D printed production. The details are:

I. HAND PRINTING PROCESS

The steps of the hand printing process are:

1. Production of a clay model from a 3D printed standard handle.

Involves

- Production of a silicone rubber mould.

a) Place the 3D printed standard handle previously chosen by the user inside of a container.
b) Mix 1kg of silicone rubber with 100g of catalyst; mix ratio 1:10 (1-silicone rubber / 10-catalyser).
c) Pour the silicone into the container up to cover the handle.
d) De-mould after 24 hours.
e) Split the mould into two halves with a snap-off knife.
f) Remove the 3D Printed part.
g) Join the two halves with rubber bands.

- Pouring clay.

h) Place around 125g of Monster Clay (soft type) into an oven dish.
i) Heat it and soften it at 75°C.

j) Pour the clay into the silicone mould (mould release agent is not needed).

k) De-mould after 2 hours.

2. User's handprint. This will be conducted during session 2.

Involves

a) Heat 1L of water in a microwave for 3 minutes.

b) Pour it into a flask and transport it to the session.

c) Immerse the clay model into this warm water for 1 minute.

d) Take it out of the water.

e) Print user's hand.

f) Add Fimo Clay in the areas where the user requires more support.

II. 3D PRINTED PRODUCTION

After session 2 but before session 3, 3D printed production is conducted. The personalised 3D printed handles were produced also using the EOS Formiga P100 Laser Sintering machine. The detailed steps are:

3. Scanning of the clay model

Involves

a) Place the clay model in the centre of a table.

b) Scanning the part by walking around it.

c) Save the file as .stl

4. Post-processing of 3D files.

Involves

a) Open the file in Meshmixer software, modify, smooth the surface and save it as .stl.

b) Open the .stl file in Fusion 360 Autodesk software and convert the mesh into a solid, save it as .iges.

c) Open the .iges file in Inventor Autodesk software and add a stem to the handle, it will connect it to a commercial stick for the trials, save the file as .stl.

d) Open the .stl file in 2 different software, in Meshmixer to create the "Circles" texture and in 3DCoat to create the "Medium", "Bump" and "Cracked" texture, save every model as .stl.

e) Open the .stl file in Magics software and create a label for a better identification, save as .stl and send it to print.

5. Print the parts.

Involves

a) Utilising the EOS Formiga P100 Laser Sintering machine.

6. Clean the parts.

Involves

a) Utilising the air compression machine.

11.24 Appendix X: Dynamic Session 3

The dynamic of this third test will be:

1. Welcome

The researcher will thank for the attendance of this follow-up meeting:

Researcher: *"Hi, good morning, thank you very much for being in this third and last meeting. Today it will be the evaluation of your personalised walking stick handle and it will be compared with other handles".*

2. Introduction

The researcher explains:

Aim of the third session

"This session has the following objective:

- *To determine which is the most suitable handle for the participant".*

Technical points of the session

"There are relevant aspects that also were mentioned in the first meeting:

- *The length of this session will be between 30 to 45 minutes.*
- *Notes, audio recorder and camcorder will be used only for clarification purposes.*
- *Collected material from this session will be only used for research purposes".*

3. Development of the session

The researcher explains:

Breakdown of the session:

"In this session I will introduce three different walking stick handles, please interact with them and try each one out, and then I will ask some questions".

Three walking stick handles will be shown to each participant:

- A standard handle.
- A personalised handle.
- A control handle. This model has been produced considering the hand grip of the researcher that means, this is another personalised option but based on someone else.

Each 3D printed handle will be fixed to the commercial stick and it will be displayed.

During the trial the user will not be notified about the type of cane that they are using it with the intention of avoiding influence their judgment.

They should interact with the handle either:

- Hold it while they are seating.
- Hold it while they are standing up.
- Walk with it.

The action will depend of the participant's capabilities. It is relevant to recommend do not put a lot of weight over the walking stick during its use, as it is a prototype.

The order in which these three handles will be shown to the participant are displayed in Table 1:

Participant	1st option	2nd option	3rd option	Size	Type	Texture
1	St.	Ctrl.	Pers.	Regular/Medium	Ergonomic	Smoother
2	Ctrl.	Pers.	St.	Regular/Medium	Fischer	Cracked
3	Pers.	St.	Ctrl.	Regular/Medium	Ergonomic	Medium
4	St.	Pers.	Ctrl.	Regular/Medium	Fischer	Medium
5	Pers.	Ctrl.	St.	Regular/Medium	Fischer	Cracked
6	Ctrl.	St.	Pers.	Regular/Medium	Fischer	Bump
7	Pers.	St.	Ctrl.	Regular/Medium	Fischer	Smoother
8	St.	Ctrl.	Pers.	Regular/Medium	Fischer	Cracked
9	Ctrl.	Pers.	St.	Regular/Medium	Fischer	Bump

Table 1 - Order of interaction with handles.

"Now that you have tried all three handles, I would like to ask you some questions..."

After the interaction with the handles, the investigator will place each handle on a large coloured circle, for identification. And then will ask the following questions:

1. Which is your preferred handle?

2. Can you please explain what do you base your preference on?

3. Could you please assign a score from 0 (zero) to 100 to each of the three handles? Using a rating line from 0 to 100 and small coloured discs for them to place and discuss. Where 0 is the lowest qualification and 100 the highest. (The researcher will present each option to the participant in the order they were introduced to the participants for evaluation of the individual stick handles). **Get the participant to check their rating and confirm they are happy with what they stated.*

4. For each handle, could you please describe what you like and dislike about them. (The researcher will show each option to the participant in the order they were introduced for evaluation).

5. I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of these factors are (out of 10). They are shown in Table 2:

	Participant importance rating of the factor
1. Comfort on hand	
2. Comfort on wrist	
3. Intuitive shape. How do you grip it? (Where to place palm and fingers).	
4. Ease of maintaining grip while it is used	
5. Enough support for the hand and fingers	
6. Stability in the user in static posture	
7. Stability in the user during movement	
8. Appealing to the user	

Table 2 - Factors that could influence in the selection of a handle.

5b. Would you add any other factors that you consider as important?

6. Could you please assign a score from 0 to 10 to each factor per every handle?

For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect. In this way, will be easier for the participant to make a comparison among the models. Table 3 shows the form for assigning scores to each factor.

The average of the scores per handle should coincidence with the provided ranking of the question #1.

	FIRST OPTION	**SECOND OPTION**	**THIRD OPTION**
1. Comfort on hand			
2. Comfort on wrist			
3. Intuitive shape. How do you grip it? (Where to place palm and fingers).			
4. Ease of maintaining grip while it is used			
5. Enough support for the hand and fingers			
6. Stability in the user in static posture			
7. Stability in the user during movement			
8. Appealing to the user			
9. Personal factors rated			

Table 3 - Score assigned to factors that could influence in the selection of a handle.

7. Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

8. Going back to the original ratings, you rated the three experimental handles with the following.... (return to ratings*). Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

After these 6 questions, the researcher will reveal the identification of each handle.

4. Conclusion of the test

At the end of the session, the researcher will thank to the participant for his/her time invested in the investigation and they will be asked if they want to be added to the distribution list with the aim of sharing the results of the research.

11.25 Appendix Y: Transcripts for individual interviews. Session 3

SESSION 3
Participant No. _1_

R: "Hi, good morning, thank you very much for being in this second and last meeting. Today it will be the evaluation of your personalised walking stick handle and it will be compared with other handles".

"This session has the following objective:
To determine which is the most suitable handle for the participant.

"There are relevant aspects that also were mentioned in the first meeting:
The length of this session will be between 30 to 45 minutes.
Notes, audio recorder and camcorder will be used only for clarification purposes.
Collected material from this second session will be only used for research purposes".

"In this session I will introduce three different handles, and you can interact with them as in the previous session and then, try each one out, and then I will ask some questions".

R: "You are fine there. There are three options and this is the first one". "You can touch it or walk a little bit". "Just try not to put a lot of weight because it is still a prototype".

P: "Yes...fine, yes".

R: "So, this was the first one (standard) and I am going to show you the second one (control)".

P: "This one isn't so easy to grip". (After finishing) "Right".

R: "Ok, and finally, the third one (personalised)".

P: "Thank you".

R: "You're welcome".

P: "I think this one (personalised) is the best". "That one (standard) is the second" (pointing out the 1) "and that one is less good" (2 handle-control). "I hope that is not the one that... anyway that (3) is better". "I like the palm on this one (1), but this finger (index)... does not go around there as well as it (3) does on this one". "So I get my finger around right". "Yes. Right".

R: "Now you can have a seat and I am going to bring closer the options". "The first, the second and the third". "Now that you have tried the handles, I am going to ask the questions".

R: Which was the preferred handle?

P1: "That was the first" (3-Personalised).

R: Can you please explain what do you base your preference on?

P1: "It had a good rest for my palm and I could get my finger roundly, round the knob so I could hold it firmly".

R: "Ok".

P: "I mean, that is what were doing when you were making it. Yes. I didn't realise that you are going to make several similar".

R: Now I am going to put this line and it has some numbers, it has... it is from 0 to 100 and now I am going to ask you please to rank each of them. So, I am going to give you one little circle from each colour in order to... that you put some scores there. The 0 is the least that you liked it and the 100 will be the highest qualification. So if you like to rank please each of them.

P: "Well that one (1-Personalised) is something like that... this one (2-Control) was more like that and that one (3-Standard) was more in the middle"

R: For each handle, could you please describe what you like and dislike about them.

P: "Well I've already said about this one (3-Personalised), haven't I? Yeah, is got, I mean I can grip it better and is got the firm palm (pointing out the bottom surface) for resting on. This one (1-Standard) has a very firm palm, and I like that, I like that better than that one (3-Personalised), but, this one (1-Standard) I can't get my finger comfortably round there, and this one (3-Personalised) you smoothed the top there (pointing out the bottom area of the knob) and is not so smooth off there (knob area of the 1-Standard), so I cannot get my fingers roundly like I would like to, but the palm is definitely better, it seems to be bigger, I don't know whether it is or not, but it just feels slightly more comfortable (than the personalised), yes, I think... yes, it is a bit bigger (Standard). R: "ah ok, is a little bit bigger the surface of the yellow one?". P: "This one, the yellow one, it's a bigger palm, firm, than this one (Personalised)".

"(Personalised) It doesn't cover as well, although I get my finger around I can grip it but it doesn't cover the whole of my palm which this one (standard) does. So the yellow one is definitely… that (upper surface - standard) is better that that (upper surface - personalised) but that (below area of the knob - personalised) is better than that (same area in standard)".

P: And this one (Control-2), well I don't know, somehow, I can't seem to hold it properly, there is more… the palm, I think, doesn't seem to be in quite the same place, and I can get my finger round it comfortably. That's the green one, I'll put it in…that is the order that I would chose if I was choosing one handle… well, alright, I can put that one a bit further on (giving more score to the standard handle), ok?

R: "Yes".

R: "When you mention the palm, you are talking about the entire surface, I mean, the upper surface, this one, all of this?"
P: "Yes, that isn't, that doesn't seem… somehow, it is not fitting quite as well, I mean, that it is not bad but it just I can't put my hand on there and get my finger round… something, I don't know what it is… it's not… you see? when I put my hand on there it comes right up, you see? And I get my finger round if so, I've been I got a firm grip and I got a rest for my palm, this one I can't if I put my palm is not doesn't cover right down and that is knocked, I can't get to the knob, you see? I mean, it doesn't fit that way, is that, if I come up to there, I mean, that is so uncomfortable on that finger, but if I come up right to there then it's wrong for the palm, see? It's not in the right place, so, can you see? Or am I supposed to show it in that way? You see what I mean? So I am not getting the support from the palm of my hand, and is so uncomfortable here and if I put it where is more comfortable for my palm, I can't grip the knob. You understand?".

R: "Yes".
R: "Now, I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of this factors are (out of 10):

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	9
4. Ease of maintaining grip	10
5. Support on hand/fingers	10
6. Stability in static posture	10
7. Stability in movement	10
8. Appealing to the user	2

R: Would you add any other factors that you consider as important?

P: “No”.

R: Could you please assign a score from 0 to 10 to each factor per every handle? For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Standard	**SECOND OPTION** Control	**THIRD OPTION** Personalised
1. Comfort on hand	6	1	9
2. Comfort on wrist	7	2	9
3. Intuitive shape	7	3	10
4. Ease of maintaining grip	7	2	10
5. Support on hand/fingers	7	3	10
6. Stability in static posture	7	2	10
7. Stability in movement	7	2	10
8. Appealing to the user	7	2	9

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Yes. It fits my particular size and my way of hold.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: Zero because there is strain in wrist.

Well, now I am going to tell you which one was your personalised walking stick.
R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.

Thank you very much.

SESSION 3
Participant No. _2_

R: "Ok, so, we are going to start, this is the second and last meeting. Thank you very much for being here. The objective of this session is that I am going to show you your personalised walking stick handle but also I am going to show you other two handles in order to know which is more suitable for you".
"So, what are we going to do is, well, in your case as you are left handed I am going to present you 2 groups of 3 handles each one and then I am going to ask you some questions".

R: "Ok, so the first one, if you want I can bring you the options".

R: "Ok, so first, I would like to show you those that are for the left hand (the first one is the control handle). And the height I don't know… is it good for you?"

P: "Ok. This is the left hand?"

R: "Yes".

P: "This bit here:

"…is not comfortable for my hand and I don't know at other people. What happens with the angle normally the nerve system is not considered for each one to make if it is purposely made or personalised. This is what I cannot do with this handle. See, how I rest. I'll show this to be recorded by the camera, look what happens with this".
R: "For example if I see…"
P: "This part and the bottom need to, in my case I need to grab, it is a bit short in length from there to the first finger. Look how it looks there…"

R: “Ah ok, the distance from here to here or to here?”

P: “If I could suggest to you to take a picture of my walking stick, front or left/right and then with the other one you can compare picture with picture what is the difference and what I am trying to explain, why is hurting me here (inner palm) and it does not suit me for the reason”.

R: “So, the first option of the left handed was this, so...so you mentioned the distance is not according to your hand, is short?”

P: “The length here, that is about half and inches or ¾ of inches too short, and that makes me to force my hand to go and grab but to do that is going to affect tendons and ligaments and the palm or my arm forces the rest”.

R: “Ok, so this is the first option and I am going to give you the second option of the same hand”.

P: “This (personalised) is better than that”. It’s a bit too narrow here (width)...”

“... so if it were half an inch wider... can you see? R: ”Ah ok, from this distance or from this distance?” P2: “The width”. R: ”Ok”. P2:”The length from there to here it is fine...”

R: “Ok, and now I am going to give the third option (standard one)”.

P: “It fits ok in the palm of the hand but is too short...”

..."but here (upper surface) it sits ok, the palm of the hand sits ok, there are no pressure points, but is one finger width too short, so probably if it were a bit longer from here to here"...

..."To fit ok the hand is too short" R: "You mean from this to here (the length of the handle from the stem to the end)". P2: "Yes, so from the index finger back is ok"...

..."the difference, the length of this finger (index) will affect the grabbing between the index and the thumb. Of the three this is the best".

R: "Ok, if you want you can seat here because I am going to start the questions. Ok this is the first option, this is the second and this is the third one. If you could please assign a score, well, actually we have here a line with some values, the zero is the minimum value and the 100 is the highest and if you could please assign a score to each one, which will be, for example this (green circle) is for marking the score for the first option (Control), this for the second one (personalised) and this for the third one (standard) that you tried before, so which would be the score for the first option?" (Control handle).

P: "And score based on what?"

R: "Based on which was your comfort, which do you think is better, how did you feel it. These marks, I mean, the value marks as well your preference"

P: "The preference is given by how well it fits"
R: "Yes".

P: "So, that is why I cannot understand the reason of the score and how do I score that".

R: "Ah ok, for example, if you think, the handle that you use currently is pretty good for you maybe you will give a 90 or a 100, you know, in terms of comfort or that if it fits to you very well your current handle or a handle and for example the first option you mention some points and maybe those ones could help you to give or rank".

P: "This is the best (standard handle). And this is based on... that it fits better in all the different points in my needs and must be comfortable with the stick, that is to say that, because I rely a great degree in the handle to fit for purpose it chooses or must suit the best possible way my degraded position, so for that that is the best. This other (personalised) is only technicalities, that more to do the way are you measuring or you moulded, what they don't fit. This I cannot grab it (personalised) and that will give me... it will not provide me with the sense of security that I need for the stick to have and to help me with, but to give a 10% or a 90% there is not a scale to qualify in the sense, so that is the best, the other two need... they need more way to do".

R: "Ok, and for example, if you can put a score out of 100 which will be for the yellow one (standard)"?

P: "For that, 90, the difference... the 10 points is because what I pointed to you with the shape, a little bit short".

R: "So the yellow will be 90. So, the best things about it...".

P: "The best, fits better and sits better in all the different part of my hands".

R: "And the disadvantages with that one, you mentioned...".

P: "A little bit short".

R: "Yes, for putting the index finger".

P: "In the length on that, see how it grabs, my thumb. R: "Ah ok, your thumb is over... on your index finger". P2: "But this will be ok as it is, it will suit or will work with any person with my condition with no difficulty... because is better made to suit the shape of my hand".

R: "And an score for the blue option?"

P: "I will say 50 for those, because I don't know how to measure. (Blue one) It doesn't sit on the palm of my hand, is too short on the critical part on the bottom of the handle, and is too moulded, is not that smooth on the top to sit at the palm of my hand when it bend. The shape is too sharp". R: "Too narrow?". P2: "No, sharp, I would say, the angle, this middle angle they are too thick, this part of the hand... (pointing out an angle of the top surface) is too sharp, too narrow and too bulky, I would say...so that clear the probability that it will not..."

R: “Ah, ok, you mentioned that, sorry, that for example, your inner palm is composed of, is made of curves, soft curves and then the surface of that one (pointing out the top surface of the personalised) it has...”.

P: “This is too narrow (pointing out the personalised handle), it will not provide me with comfortable grab or grip, and there isn’t... the length, at the bottom... I don’t know what purpose, is different to that (standard) because that is moulded and serves the purpose, it assists with my arm resting, more comfortable but that (surface of the personalised one), there is no point to work, isn’t smooth sitting on my hand”.

R: “Ah ok, and do you consider is there any advantage with this (personalised) type? Is there anything that you like about this?”

P: “Nothing. I cannot use it because it is more a problem than a solution, because the critical part is the shape where the hand sits in a handle.
This is closer (green model), it just it is a bit... about half an inch too short (length from the index finger to the vast) between this grab and some there to the palm” ...

... “But here is the same difference, if you compare I’ll round there (bottom side), that meets the shape of the gap between the fingers but when you close your hand is not the shape of your hand, but this one is better (Standard), would you find the word? What I am saying it’s assists me better (Standard) because of the shape of that, I don’t have problem with oh it is going to hurt or inserting, the minor adjustment, yeah? With the lesser part of the body or the stick, the lesser part is between the some and the stick but the main component which is the handle itself that, this is the one that is ok (Standard)”.

R: “And if you could assign a score for the green one?”

P: “Sorry, I can’t understand you, how to score given all those considerations, in a general way I’ve given to you. It’s not a matter of 2 plus 2 is 4, so if that is a 3 is wrong, isn’t it? What I am saying is, the moulding wasn’t suitable for the result, so there is a problem when you measure, and we call it moulding, measure and the result, so, in that sense, it failed”.

R: “Yeah, but for example, the result, the last shape, the last handle, what would you say that is a qualification, well, a score for it, you know, this (standard) is 90, this is 50 (personalised) and that one? It can be, I mean, whatever value”.

P: “I would say, instead of a value, I’ll say it’s not suitable”.

R: “Ah ok, so, you would say 0?”

P: “That is, too drastic to say 0. See because we are talking at a level where things are or not. It is a PhD language the way that we are talking here Karla, so if I go too deep or too stick in something that is too subjective it would…” R: ”Well, actually this your perception about…” P2: “My perception does you cannot quantify and put a value to the different shapes you made, different moulds you made. The other thing that exists the idea that is one that provides me with the more comfortable use… R: “Yes”… P2: “than the other 2”. R: “This one”? (Standard). P2: “Yes, so the moulding for that (standard) or when you were making that, that produced a better result. It can be seen from the top as well, how you put the pressure in my hand and the mould to get the shape, how this got too lumpy (personalised), anything out to the vertical or out of… some surface. And this is (control one), there is no need for that (pointing out the indentations for fingers) in terms of *inaudible*, it’s a bit too short, but out of the 3, this (control) is the nearest to the best or the better one”.

R: “In terms of shape, yes, but I don’t know how did you feel it (control) in comparing to that one (standard)”.

P: “If I were to chose it I’ll go for this (standard), this is the best one, with this one (control) I’ll have difficulties after a few minutes of use”.

R: “Ok, so, that one (standard) will be 90, 50 (personalised) and the other one?”

P: “50”.

R: “Ok”.

R: “I am going to mention factors that could influence in the selection or in the preference of a handle, a walking stick handle. I would like you to rate please how important is for you out of 10 the following aspects. For example, the first aspect… I am going to mention aspects and the first one is:

1) Comfort on hand.
How important is for you out of 10 having comfort on hand when you are using a walking stick handle”.

P2 “The very top, extremely, extremely important, it must be extremely comfortable”.

R: “The number 2 aspect is:

2) Comfort on the wrist”.

P: “You are entering into a personal and particular criteria”. R: “Yes”. P2: “But, it’s not measurable, you cannot do that, because the origin of the problem how we may risked is different to any other person that it could be *inaudible* or malformation mine was man-made”. R: “Which was?” P2: “Man-made, this condition”. R: “Yes”. P2: “Is because what they did to me and not receiving medical attention for years the body took the shortcut and fit any or how”.

R: “Yes. And… for the comfort on the wrist, I mean, how important is for you having that aspect in a handle out of 10. You mentioned 10, I mean, the maximum value for the comfort on the hand and what do you think about the wrist?

P: “It’s important for me how the hand fits in handle, that gives me some confidence in assisting me with walking because of the problem I have with walking and not having additional stresses or pressure causes in my hand which is transmitted to my elbow, to my shoulder it is very very important. So, the better fit reduces the other problem I have which is the swelling of I don’t know, sort of… how the joins were fitted”.

R: “So will be as important as the previous one, as the comfort of the hand”.

P: “What I am using now is the result of years and years and years of going to, to different department and different practitioners here in this country, orthopaedics, nerves, soft tissue. So, that is the best available (the one he has), the next best will be what you made there, the yellow one, nothing in shop would sort of fit like that”.

R: “So, well, for comfort of hand we have the factor of importance (the importance factor) is ten, and then for the comfort on wrist the importance factor is…”

P: “They are very important…”

R: “10 as well”.

R: “The third aspect is how important is for you that a handle has an:

3) Intuitive shape”

“That means that you can know how to place your hand, where to put it exactly, where to put your fingers, out of 10 how important is for you”.

P: “The better the fit, the lesser the pain and the pain is chronic so a bad fit will be very painful for me, a good fit will be less painful so, that is the scale how I measure things”.

R: “Ok, so, if you assign a number out of 10, when you mention the…”

P: “10, with the consideration I *inaudible*”.

R: “Thank you. The other aspect is the:

4) Ease of maintaining grip while it is used”

R: “The ease of maintaining the grip while you are using the handle, I mean, how important is for you that you can keep your grip while you are using it”.

P: “Is more comfortable to have it in my arm and the *inaudible* leg or the one that assists me better with my problem with my left leg and the handle is important”.

R: “And if you could assign a number out of 10?”

P: “An 8”. “I cannot find in your questioning and you are question any room to accommodate a proper answer, so that conduce to give you an estimate or approximation... R: “Yes, that’s fine”. P2: “because these are areas that cannot be quantified and qualify and cannot be scaled or part of an scale from 0 to 10 or 0 to 100. Is either fit or doesn’t fit, doesn’t *inaudible*, it can’t to that point”.

R: “Yeah, but well, I think sometimes, we need to quantify things that at the same time cannot be quantified, for example how important is for you to keep your children’s safety? I mean, it’s a complete thing that we want, so will be a 10, you know, it’s like a ... it’s part of the perception”.

P: “Carry on, because what you are saying is part of something that you are interrupting when you mention your child, for you what is important when you mention your child to be what or to be in what circumstance, because what I am pointing out here is that the... you should do something that suits and fits the needs and wants of the patient, no the other way round, and what you are asking is the other way round”. R: “The other way round?” P2: “Yes, if for me to adjust within your criteria I’ll that fit or not, and an analysis of your question leads to that. By that I mean that a condition or that at the one... a chronic are constant, for that I provided you with time to do some moulding that could give me the best result possible and after all those sessions there is one that provides me better satisfaction than the other two, is only a minor detail that can be corrected at the time of fabrication, and comparing the three moulding you made, you can see what is the difference between the two that I rejected because they are going to hurt me more than help me is where the point is.
So, how can I provide you with a score for not to 10 based on that, because there are so various, so many conditions that are different to the other person or the other people you have talked to and you have made some moulds, because how it happened to them, how is affecting them and how they are living with, and those conditions in any of them there are no comparison *inaudible* excepts that each of one of them needs a walking stick. But based on that as a base *inaudible* you have noticed that mine have an additional component to be an a walking stick to be

a crutch because having that extension help me with the wrist and assisting me with the wrist and with hand it's help me with the elbow, and help me with the shoulder, so that is the chain, are you putting in your work all those considerations? All those criteria? That could they be in the subjective part of the brain or in the objective one based on some reading that you may have done and some investigation you may have done. Sorry I don't know if I am explaining myself on what I am trying to say".

R: "Yes, you are mentioning that you find that is not logical to you assign a score to something that is perceptive for you because... a particular situation, right? Is that what you are mentioning?"

P: "It's trying to accommodate a subjective value to an objective thing. The objective component of the question is the handle, the subjective is how good or bad that fits or suits me with my condition, so how do you do... do you make that connection for the best possible answer that can be given. So that is why I gave you the reason about what happened and the differences between that (standard) and the crutch I have and the difference between the better and, the other best handle and the other two. So that (standard) is suitable, is ok, the others are unsuitable."

R: "Ok, and for example, the aspect that I mentioned is in general, I mean, it's not considering each one, well, at this point because later I am going to ask you which do you consider is a score for the aspects that I am mentioning but considering each option, so..." P2: "Carry on". R: "Yes, we are almost finish".

R: "The other one, the other aspect is:"

5) Enough support for the hand and fingers".

R: "Which will be the value for you, I mean, if it is so so important or if it is ok having..."

P: "It's extremely important".

R: "So that will be obviously a 10".

P: "The other aspect is:"

6) The stability in the user in static posture".

P: "The what?"

R: "The stability, that you have stability".

P: "Extremely important".

R: "So that will be as well the maximum value... yeah, the thing is, I cannot put the value, I mean, even if it is obvious, I cannot say the value".

R: "10. How you connect that? The stability and using that stick because this leg (left) has a problem with the knee and the kneecap and contrary to the physics of the human body it doesn't bend like this, it bends inward, so my leg cannot go like that, it would be like that, what happens, using the stick, using the crutches and the other device I have it doesn't allow the leg and the knee to bend on its own, that is why is important for the stability, it's important for, for the rely how important is for me to have one".

P: "Ok, and the other one is the:"

7) Stability in the user but when you are in movement".

P: "(Saying yes with the head) Because of that, is a component of that".

R: "Ah ok, so this aspect could have the same value than the previous one? Because the other was, when you are in static posture and this one is when you are in movement".

P: "I need the stick in standing position, in seating position and in walking position". R: "Ah ok". P: "Any class of moment, yeah? I need the stick for my body to feel comfortable and not to bend and to be waved". R: "Ah ok, so will be the..." P: "It's the very top and that is why you will see that is very different to other people". R: "Yeah". P: "If you notice something for you to make a comment which I mentioned to the department".

R: "What do you need?"

P: "I am going to stand". "If you see people using the stick, you will see, you will notice that they don't go with the leg for the movement as an extension or an additional movement, they go..." R: "Ah ok, sometimes there are people that..." P2: "Normally they do that, so, that seems provides them, push and some help and stability when they are walking, not because they are using how it should be, the walking stick in general or the crutch, it should move the same as the leg, that's what I made the different *inaudible*. The different way with other people".

R: "Ok. And about this aspect:

8) Appealing to the user".

R: "How important is for you that talking about aesthetics... how important is for you in a walking stick handle".

P: “I understand the question. In a simplistic way but at the same time complex, we like to, to show off using the stick, to make a distinctly, to make something that shows in a certain that it is an important part of your life, so it should look ok, it should be shaped ok”.

R: “Yes, and if you could assign a number?”

P: “The top wherever your score is”.

R: “Ah ok, the top is 10”.

R: “Ok. Would you add any other factors that you consider as important when you are looking for a walking stick handle?”

P: “If it provides the best possible resting for my hand and gives support to my body”.

R: “Ok, so will be… You mentioned support, supporting the body, yeah, but I think it’s pretty similar that stability, you know, I already mentioned stability in the user in static posture and during movement”. P: “Yeah”. R: “So, I am not going to write it because I consider it’s inside, pretty similar to the 6, number 6 and 7”. P: “You mean, it is implicit in other”. R: “Yes, implicit. Ok. Did you mention another? You mentioned…”

P: “But I mean, you are going to write it as part of the last answer you provided me with the, the confidence…”

R: “Confidence of using it?”

P: “The psychological confidence to make the physical problem less on that… it affects in a lesser manner to the person”.

R: “I am going to write: Psychologically confidence to use it, to use it the handle”.

P: “Yeah, should give that component”.

R: “And, is there another factor that you consider as important? Besides that one”

P: “No, not at the moment”.

R: “Ok. Now, what we are going to do is I am going to mention the previous aspects and then we are going to rank it out of 10 each of the options. For example, the first aspect is the comfort of the hand, which would you consider was the comfort in the… in this option (standard handle)”.

P: “Is a problem of communication… *inaudible* to understand, to understand each other on, you question for me to give you what I am…” R: “Yeah, is the perception that you…” P2: “Yeah, is how we use the language and how we are used to the use of the language in terms of you’re being from a country and me from another, to sometimes we give you slighter different meaning to a particular word, can you ask the question again please to give a score for what?”

R: “Ok, I am going to mention the previous aspects that I did before and you are going to assign out of 10 a score for each of the options”.

P: “Yeah”.

R: “So for example for this option, the yellow one, which would you say will be the comfort that you felt in your hand when you used it”.

P: “Yes. Understanding that, the purpose of me being here is to find the best possible walking stick”. R: “Yeah”. P2: “And that walking stick has two components. The straight part and the one where the hand is”. R: “The straight part”? P2: “The straight part of the stick”. R: “Ah ok, only we are focusing on the handle”. P2: “That is why I am saying that of me being here is to provide the better walking stick or the best walking stick possible by measuring it or moulding to the hand, to the accommodate for the problem that a person has, so in that sense that provides me with the better, better possible support, ok? So that is the answer”.

R: “Yes, and in a number? Out of 10, and the 10 will be the highest value”.

P: “Yes, put the top. A 9. 8 or 9. Because there is a small detail that it can be corrected at the time of fabrication”.

R: “Ok, and, 8 or 9, will be? Sorry I need to put a number. I mean, or if you want I can put something in between or?”

P: “That will be a 9”. R: “Ah ok, yeah”. P2: “And the difference between the 9 and 10 would be…” R: “Yeah, the thing that you mentioned”. P2: “And that would accommodate better to the hand of the user”.

R: “Ok and the comfort on hand with this one (personalised)”.

P: “They are unsuitable. So anything below 90 or 9. How do I score that? My answer is that, that both are unsuitable”. P2: “Ah ok, those ones? (personalised and control)”. P2: “Those two”. R: “The green one and the…” P2: “But when you write your paper you have to use vocabulary that justify your research, your investigation and your final product. So, if I say to you that is rubbish, you will have to be strict with that, and follow the protocol or that answer and say rubbish, because will be transmitted the answer I gave you but that is not the case, so, one is fit for purpose (the top one), the other, because of the configuration of my hand they don't fit as good as the top one. Is a problem of moulding or, I don't know, so, in that sense, is how you need to put it into words, what it is, it's not negligence, it's not careless, it's not lack of consideration. You did it in a way that the end result is not for the person you made that mould".

R: "And if you could say a value for each one, I know that you mentioned that 'not suitable', I think those are the words, but from 0 to 10".

P: "Put it 75, or 7.5".

R: "To each one? I mean, to the blue one?"

P: "Both".

R: "Ok, the other aspect was the comfort on the wrist, so that one... for that one will be?"

P: "On top 90 or 9.0".

R: "Ok, and the other two options?"

P: "On the same, 7.5".

R: "Yes, ok".

P: "And that score is repeated for anything that has to or rely to comfortability".

R: "Well, actually we already finished with the comfort. And the other one was the intuitive shape, how do you grip it. I mean, each handle has an intuitive shape, so what's the level of intuitive shape in each one".

P: "The shape is important". R: "Yes". P: "That's why I gave you a 9 or 90".

R: "Ah ok, so, for this one (standard) will be?"

P: "9 or 90, I don't know your score".

R: "Ah ok, yes, 9. For the second option? (personalised)"

P: "Is the same, 7.5 or 75 or in percentile 75%".

R: "And the third option?"

P: "The same. And those values repeat through all your scale". R: "Ah ok, in every aspect?" P2: "In every aspect, repeated".

R: “Ah ok, so ease of maintaining, will be 9, 7.5 and 7.5”.

R: “Enough support for the hand and fingers? As well?” P2: (Yes).

R: “The stability? As well?” P2: (Yes).

R: “Appealing to the user?”

P: “That is different because one, one is the chosen, so it’s ok, I like it, is the closest to a good fitting”.

R: “Ah ok, so this one (standard), which value will be for this one?”

P: “Could be a 9, the same, because this a bit of length affects everything, affects the comfort on my wrist, affects the pressure of nerves and tendons and ligaments on my arms and those carry on between the wrist and the elbow and between the elbow to the shoulder, so here, here, here, so by having that extra bit added evolved, solve the problem that I have at the moment”.

R: “Ok, and about the value of aesthetic that you could give to this yellow option out of 10, which will be?”

P: “10 or 9. 10”.

R: “10. Ok, this one? (personalised)”.

P: “The same, 7.5, 75”.

R: “Ah ok, and the green one?”

P: “The same”.

R: “Ok. And the last aspect that you mentioned was the psychologically confidence for using it, so, the value for each one, which will be?”

P: “The value must be 10, must be the top”.

R: “Must be the top for this one? (standard)”

P: “Yes”.

R: “Ok, and for the other ones?”

P: “Because the green discarded”. R: “Yeah”. P2: “It goes with the 75 or 7.5. R: “Ok, both, right?” P2: “Because, neither of those two fit me or suit me, that is the best score possible”.

R: “Ok, now focusing on this one (standard), that was that you chose, do you think that this handle could provided you more, could provide you a high level of comfort or improve your freedom or assist you more than the commercial walking stick handle that you used?”

P: “No”.

R: “Ok, why?”

P: “I will not use that as a walking stick because I need the other component which is the elbow extension”.

R: “Ah ok”.

P: “Yeah?”

R: “Yeah, and when you used a walking stick?”

P: “I cannot use a walking stick because I need the extra support to provide me with the security on the wrist which is weak”.

R: “Yeah, I remember you mentioned that you had used some in the past”.

P: “Yeah, because they didn’t exist, this type of design or the ergonomic or the work didn’t exist too”.

R: “Yeah, and comparing to the walking stick that you used or the last one that you used and this one? Would you say this one is better? Or the other one was better?”

P: “Is a progression from the first one”.

R: “From the one that you used?”

P: “In that sense, yes. What I cannot understand and fit is the question within that. I explain to you how I got to have that crutches and the principle, how it began, yeah? And it was me looking for the best possible option out of nation and then, if it was available in the commerce, and then, by those things of life, I met this person and then I could express my idea or what’s the idea of a walking stick palm rest should be and it was made and the rest is history, so how it (was) developed”.

R: “So, your answer would be, I mean, if we could compare the handle of this one (standard) with those one (the handles of the crutches), the best one will be that one (handle of the crutches)”.

P: “The difference will be the extra bit of length, but that is the closest approximation to the one I am using now”.

R: “And, this one (standard) sorry I got lost, this one will be better or that one? (handle from the crutch)”.

P: “That one is better”.

R: “That one is better, ah, ok”.

P: “So I compared everything in relate to that ”.

R: “Yeah, and if we compare the last walking stick that you used with this one (standard) which would you say was better? Or will be better?”

P: “It that’s impossible answer Karla”.

R: “Why?”

P: “To your question there is an impossible answer”.

R: “Why?”

P: “Because there are thirty, forty years in difference”.

R: “Ah ok, you need to… it is difficult to compare what you…”

P: “For many reasons, I was younger, I was doing something different, the walking stick was provided me with the assistance I needed or the security I needed to walk or to do what I was doing in that moment in time”.

R: “Going back to these ratings, could you please assign a score from 0 to 100 to your current walking stick?”

P: “A 9 or 90 or 9.0”.

R: “Ah ok, to the current ones?”

P: “That is 10 or top”.

R: “Ah ok, that one…”

P: “And compare to that, that’s the closets approximation”.

R: “Yeah”.

P: “So, if that is a 90, well 90 is”.

R: “That will be a 100”. P2: “That will be 10”. R: “A 100, and this 90 as the top. Ok, that’s fine”.

R: “Ok, as you are left, well, I don’t know if you remember, we already tried with the left handles and these ones are made, well, were made for your right hand, just I would like to know how do you feel… if your preference is the same that you mentioned or can vary. So these are only… other three options were made to the…”

P: (Participant tries the control-right handle)“No, short and tough, doesn’t fit”.

R: “The second one (personalised-right handle)”.

P: “No. How it’s still here”.

R: “And the last one (standard)”.

P: “Yes”.

R: “Ah ok, so from those three that were made for the right hand, your preference which one will…?”

P: “This one (standard)”.

P: “And it has the same issue, the short of this beat”.

R: “Ah ok, that you mentioned, yeah”.

P: “From there (index finger) to the back of the hand is ok”.

R: “Ok, and if you could assign a score again from 0 to 100”.

P: “I would duplicate the score”.

R: “Ok, and the reasons?”.

P: “And the reason is because one help the other and one assists the other, and my condition needs one to the ok for the other to work or to help me”.

R: “Ok, so, you mentioned the values are the same and the likes and dislikes about each ones?”.

P: “I like the one that I scored 9”.

R: “And about, for example the things that you didn’t like and did like about each one”.

P: “They don’t fit my hand, so I cannot score in that, they are unsuitable again”.

R: “Ok”.

P: “And how do you score that? Because I couldn’t grabbed them, they didn’t fit my hand, they didn’t fit any way I could hold them, any of the two”.

R: “Yeah, but anyway I am putting the... as you mentioned, I am going to put the value for each one as the previous one that you mentioned, for example, the first one, no sorry, the last one will be 90”. P2: “Yeah, the same, duplicate”. R: “Yeah, you mentioned duplicate, ok, that’s fine”.

P: “And then the condition would be different or the reason would be different ”. R: “Yeah, just I would like to know if I...” P2: “Both physical condition”.

R: “The things that you like and dislike about it? Well, you mentioned something that, well, it didn’t have to much space between here and my index finger and, I don’t know, would you say are the same things that you like and dislike from the group for lefties or left handed?”

P: “Is not the question I like or dislike is that, that is one that fit and I can use it and the other two I cannot use any of the other two, because of the shape of the other two but not because I like it or not, just that they don’t go with my body or my hand”.

R: “And is there anything that you like about the previous... (participant laughs) ... if not, it’s ok, but is there anything that you like about the first and the second option?... If you want I can...”

P: “It will be substantiation to the answer I gave you for this (standard)... because this (standard) gives me the comfort and a level of security to use it and to go walking with them”.

R: “Yeah, the yellow one”.

P: “It won’t be the same because I need both of them, only for short distance I can use with one but after a few meters, yards I need to, to use the crutches”.

R: “So, I am understanding that the things you like about the first option and the second option of this group of right handles will be the same that, that those ones that you mentioned for this group of lefties”.

P: “Yeah, because I couldn’t grab them, I couldn’t hold them, I cannot give them a value because...”

R: “You cannot mention like a like...things that you like”.

P: “Is not any short like or dislike”. R: “Well, you already mentioned that”. P2: “Is an issue of shape, yeah? And from them everything drives, yeah? That’s the origin of everything”.

R: “Ok, and about...”

P: “In summary, is how important and critical the design of the stick handle is for the person that is going to use it, if will give confidence, trust and every reason for them to use it”.

R: “Ok, and if you need to assign again the scores out of 10 for each one mentioning each aspect that I mentioned previously, which will be the values or do you consider are similar like these. We can do it again but I don’t know if you...”

P: “I am trying to, there is a problem of understanding here, assumption is missing in translation. This one (standard) fit to the highest qualification any and all the questions you made, the other I couldn’t give them a 9 or a 0 because I couldn’t use it and I cannot use it because the shape and the design are not suitable for my hand, for the shape of my hands, so that’s why I didn’t go below these ¾ percent or the 75% and I couldn’t go to 100% because that may be a centimetre for you but for the user it is an important one centimetre”.

R: “Yes, I understand completely about this group, about the group that is for left handed but right know we are talking about those ones that are made for right handed, so I would like to know which is the comfort of the hand for each one”.

P: “That’s ok, is the same score”.

R: “Ah ok, do you consider is the same score? Than the previous one?”

P: “They are almost identical and it’s still short there”. R: “Yeah”. P2: “And it is short there. And then the results for the rest, duplicate for each question and for each circumstance and situation”.

R: “Ok and I understand that you are giving the same values than the group for lefties (than the lefties)”.

P: “Yeah”.

R: “So, the answer for this question that, focusing in the first one, in your first option, that would be the third one (standard), that could not improve a higher level of comfort that your current walking stick aid, well walking aid, right?”

P: “The difference that exist in the first set remain with the second set you show, that centimetre difference, it is still there, and that is the bit importance because is the one that allow me to grab or not grab. R: “Ah ok, so, did you mention…?” P2: “Or to over grab and then something, that bit is missing in lengthwise. Sorry If I am being to difficult”.

R: “No, that’s fine, actually we already almost done. Only one question, so, this set, I mean the right ones, compering to the left ones, the difference, I mean, because we have different hands will be in the… the main difference where will be?”

P: “That the top score repeats the same difficulty or the same difference and the same consideration that I gave a 9 to the first set, that centimetre difference makes the 1 difference between the two sets”.

R: ”Ah, so the difference between the two sets will be? sorry”.

P: “One centimetre in this part of the top handle”.

R: “Ah ok, so you feel better the right one?”. P2: “Pardon?”. R: “You feel better the left one? For example, I am going to give you…”

P: “This (standard-left), again repeats… you see?”.

R: “Well, I can see them similar, like equal, but I don’t know how do you feel them”.

P: “Yeah, they are similar because it’s a duplicate of the other, but that similarity it means that is a shortage on lengths in this part, can you hold this? At that means that at an overall stage, the thumb and the index to make a better grab”.

R: “A ok, so you feel…”.

P: “For that (standard-left), the position of the thumb is ok, look where my index finger need to be, and then when you walk, there are different movements, that way, that way, if I do this (hold the standard-right), is the same, is the difference of the finger”.

R: “Ah ok, so, is there a difference for you between this one (standard-left) and that one (standard-right)? Do you feel a difference?”

P: “Is this bit of length, can you hold it? Because my hands are almost the same, almost the copy one and other, so that’s why what happens here would be repeated to the other”.

R: “So, there is no difference between this one and this one?”

P: “In what sense?”

R: “In what sense? I mean, you are mentioning that your right hand and your left hand is the same, are almost the same, so, I would like to know if there is any difference between the right handle and the left handle”.

P: “In shape, there is, this bit of difference and that bit of difference cause me different effects in my left hand which compromise my hand, the wrist, elbow and shoulder, to the right hand that compromise half of my hand, half of my arm, and the shoulder, and having that it affects the other problems with the hip and the spine, yeah? So 1 cm affects different condition or problem that I do have I’ve been to specialists in this country for”.

R: “Ok, so, what you are telling me is that the short part, that is the same in this one (standard-right) and this one (standard-left), affects differently in one of your hands because of the nature of your hand…”

P: “In one, the left, it affects in a different in this and this and this, and the right, this, and this and this and this and all the physical condition caused by the same situation but affect it in a different manner”.

R: “And which hand will be affected more?”

P: “The question… in summary, I was suspended from a…*inaudible* in the air with my hand and the back and a ‘capuchon’, I didn’t see who were the torturer, and when I was in the air they applied me an electric shock and one on those session, this shoulder dislocated because of the convulsions and this was what happened and they didn’t provide medical attention so I repaired this shoulder myself, when I was in the solitary confined on the cell, I used my trouser I knotted on one to the wrist and the other to a bar in the cell and I left my cell dropped and then hitting, hitting until I put my left shoulder in a better position in that time”.

R: “Ah ok, ok, I understand because of the thing that you mentioned…”

P: “So, that effect on that. The other two happened, at the second time they throw me out of a helicopter, on to…I can’t… I don’t know the high but *inaudible* and that’s it, so, I think my body when it failed it landed most on in my right leg than on my right side of my body than left side, that’s why there’s no a duplicate of all the conditions. So it’s not the case of arthritis or rheumatoid, or rheumatism, or for or something that any other person may they have here in this country or the other you have seen. The cause and the consequences, you know, there are differences. That's the reason of my score and why I give you that, not because your work is a poor work, is just that, it help me better one design than the other two. I felt more comfortable in every sense, in walking, and for me to stand up, to walk and go out.

R: "Ah ok".

P: "This is the mental thing. Physically, none of the two will make any difference at this moment and time of my life, nothing surgical *inaudible*. Well there's surgery but I cannot have that".

R: "Ok. I understand".

P: "So, how you can put that into your work. I don't know. Is up to you".

R: "And did you feel pretty same this one? (personalised-left). I think this one is for the (left)…this (personalised-right) is for the right and this one with the…did you feel them similar?" (both personalised handles).

P: "My hands are almost identical one to the other, so, these fingers (right) will not provide the… with the grip for this (personalised-right handle), so it could easily be so soft and slide off my hand, if I trumped or loose stability for one reason because I tempt to fall, this (personalised-right) is going to fall out my hand because I am not grabbing it. This one (personalised-left) would be almost the same the effect of the knock, but mean, I am not holding the (handle). Must of the times I felt down using the crutches, I ended with the crutches still in my hands, the right hand no, why? I don't know. I am looking for the better".

R: "So, do you consider your hands are similar?"

P: (Yes).

R: "And the shape similar, so the difference will be with the time while you are using it because of the problems that could be transmitted into other parts of your upper limbs".

P: "That have been used for totally different conditions, and it will have different effects because of that".

R: "Ok, but did you feel them similar? Because the shape of your hands are similar".

P: "I cannot do anything with this (personalised-left) because no fitting, not being able to grab it".

R: "But did you feel the same with this? (personalised-right)".

P: “Not being able to grab it like this (standard-left). I cannot make any comparison, if it is going to help me or not because it is moulded, rounded to different part of the…”

R: “Well, but you can compare the same… you can still comparing them because you didn’t like them”.

P: “I couldn’t hold them to provide you with a precise answer, because not being able to grab and to use it while I walked in, which is the reason why I’m here. I cannot compare one that I feel better than with the other”.

R: “Ok, that’s fine. Well, this is the end of the session, thank you very much for being here. Well, the one that was personalised for you was this one, so that is the last thing that I would like to mention”.

Summary of the answers:

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	10
4. Ease of maintaining grip	8
5. Support on hand/fingers	10
6. Stability in static posture	10
7. Stability in movement	10
8. Appealing to the user	10
9. Psychological confidence to use it	10

Score from 0 to 10 to each factor per every handle.

	FIRST OPTION Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	7.5	7.5	9
2. Comfort on wrist	7.5	7.5	9
3. Intuitive shape	7.5	7.5	9
4. Ease of maintaining grip	7.5	7.5	9
5. Support on hand/fingers	7.5	7.5	9
6. Stability in static posture	7.5	7.5	9
7. Stability in movement	7.5	7.5	9
8. Appealing to the user	7.5	7.5	10
9. Psychological confidence to use it	7.5	7.5	10

SESSION 3
Participant No. _3_

Researcher: "Well, thank you very much for being in this second and last meeting. Today I am going to introduce three different handles and one of them is the personalised one. First I am going to request that you interact with each of them and at the end of the interaction I am going to ask some questions and that will be the end of the session and the aim of this is to know which is more comfortable to you".

R: "Well, so I am going to bring them closer (each option), so, this is the first one".

P: "Yes".

R: "Yes, so if want you can walk a little bit avoiding please to put a lot of weight because it is still a prototype".

P: "It's a little bit high".

R: "Oh, yes, sorry, sorry".

P: "Well, there is a lot of support around here... there... so, I don't know, that's good. The support is good. Yes".

R: "Now I am going to give you the second option".

P: "Mmm, that's good too. That's good. That's good support".

R: "I am going to show you the third one".

P: "Yes, well, it is difficult to choose".

R: "If you want, I can give you again all the options".

P: "Yes. This one (third option), I don't know, I don't like this one as much as the other two".

R: "Ah ok, so I can give you...this is the first option".

P3: "No... I found this a little bit short. No... second option".

R: "Do you want to try again the option?"

P: "Yes, I'll try it".

P: “I think... this is the best”.

R: “Ok. I am going to bring closer the handles, so if you want to seat please for the questions”.

R: “After this interaction...”

R: Which one do you say is the best one, your preferred one?

P: “That one (standard)”.

R; Can you please explain what do you base your preference on?

P3: “Support for the palm of the hand. It gives good support round the hand and palm”.

R: Well, actually I have here, a line and it has from 0 to 100, so I am going to ask you please that you rank each option between 0 to 100, and the 0 would be the worst score and the 100 will be the best one. For example, this one (personalised) if you want to take it... P3: “Which one is that”? R: “That was the first one”.

P: “First is... none of them are bad, so 50 (personalised)”.

R: (Researcher gives the standard handle to the participant):

P: “That was the best one”.

R: “Ok, yellow 90. And the green one?

P: “70”.

R: “For this one (green), the third option you mention that it was the least that you like it, just I want to double check because here (in the line) it says 70 for this one (control) and for that (personalised) 50, I don’t know if you want to...”

P3: “What makes the difference between these two?”

R: “Ah ok, what makes? You mentioned this one (control), I mean the third one, you mentioned - I don’t like, I think you mentioned that, but if you want to try again”.

P: “Well I have to try. I am going to change. They all are good”.

R: “Ah ok, but in this case you will say, that the first option that you tried was the worst among the three?”

P: “Yes”.

R: “Ah ok”.

P: “And the green was the second option as not is quite as good as the yellow. The yellow was not perfect”.

R: “Yeah, because it was a 90. And when you were there, you tried again these two (blue and yellow) because you want to know which one were the best and this one (control) you discard it at the first. Just I want, if you want we can, I mean, this score can be like that right know, just I want to double check that, or if you want to try I can bring the stick to try, just to double check. Because if you check it, actually you can change your mind, just I want to be sure that this was not the least that you... That was the third, the green one that you tried”.

P: “That was not as good as this one (yellow one)”.

R: “Ok. And between these two? (Green and blue). If you want I am going to change”.

P: (Trying the blue one) “Is good, they are all good. So, I think, they are all good, it is difficult to discriminate. Now I’ll think about that”.

R: “So, between the three, the yellow one is the best” P3: “Yes” R: “And as a second place?” P3: “Green one”.

R: “Ok, the green one and then this one (blue). Ok. Green 70. Yellow 90 and the Blue 60”.

R: For each handle, could you please describe what you like and dislike about them, so, for example, for this one (blue) what do you like about this handle? Or is there anything you like?

P: “Yes, I like it, it’s a good representation of my hand but not compared with the others, you see, I am making a comparison and it’s good, they all are good”.

R: “And, what do you dislike about it (blue)? What would you say?”

P: “Not quite so much support for the palm. I think that one (yellow) was a good support for the palm of the hand”.

R: “And are you referring to the size? I mean, to more space or because of the shape? I mean, why do you consider that one doesn’t have much support?”

P: “It seems to be short on this side (rear area that supports the inner low palm). Short on the wrist side”.

R: “And about this one (yellow)? What do you dislike? What will be the dislikes?”

P: “None of them have the finger thumb, so, there is a gap here, between the finger and thumb, otherwise, there is nothing I dislike”.

R: “And what do you like about it (yellow)?”

P: “It’s good support around the palm side, good support. It’s definitely a good support”.
R: “Related to shape and size? Or only in one of them?”

P: (Green handle) “That is good too. It’s hard to make... It’s difficult to decide”.

R: “And for example, with this one (green one) what do you like most?”

P: “What do I like most?”

R: “Yeah, with the green one”

P: “It seems closer here (reduction of the gap between the thumb and knob), in the finger thumb”.

R: “And about the surface? How did you feel about the surface? I mean, when it is in touch in your hand?”

P: “It’s ok. My hand is deformed anyway but it’s close enough”.

R: “And what did you do not like about it”

P: “What do not like? It is not as good as that one (yellow)”

R: “Ah ok. Related to what aspect?”

P: “Related to... that’s a best fit (yellow). That’s the best fit”.

R: “Ok, the yellow... so that one (green) wouldn’t have, doesn’t have good grip as the other one, as the yellow”.

P: “No, it doesn’t. I can’t... I think is not too good round here (knob of the green one) Is not good on my index finger”.

R: “Ok. And that one (blue), what do you think about that one?”.

P: “I think is just sort of support for the palm”.

R: “Ah ok, and about this area? Where you put your index and thumb”.

P: “That’s ok. Possibly too close. This (index) finger is a bit close”.

R: “A bit close to what? To the other (thumb)?”.

P: “No. To the handle”.

R: “Ah ok, to… like a… going there (to the end of the knob)” P3: “To the knob”. R: “To close to the… ah ok”.

R: Now, I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of this factors are (out of 10):

	Participant importance rating
1. Comfort on hand	9
2. Comfort on wrist	8
3. Intuitive shape	9
4. Ease of maintaining grip	10
5. Support on hand/fingers	9
6. Stability in static posture	9
7. Stability in movement	10
8. Appealing to the user	8
9. Material	9

P: Would you add any other factors that you consider as important?

R: “Material”

R: Could you please assign a score from 0 to 10 to each factor per every handle?
For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Personalised	**SECOND OPTION** Standard	**THIRD OPTION** Control
1. Comfort on hand	7	9	8
2. Comfort on wrist	9	10	9
3. Intuitive shape	8	10	8
4. Ease of maintaining grip	7	10	9

5. Support on hand/fingers	7	9	8
6. Stability in static posture	8	10	9
7. Stability in movement	7	9	8
8. Appealing to the user	8	10	8
9. Material	8	8	8

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Yes, because it provides palm support comparing to the current walking stick (crutch walking stick).

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 30 because of the support it provides.

R: Now I am going to tell you which one was your personalised walking stick.

P: Yes.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.
Thank you very much.

SESSION 3
Participant No. _4_

R: "Well, thank you very much for being here, this our second and last meeting. So, what we are going to do today is, that I am going to give you the personalised handle that has been made for you, but at the same time, you are going to compare it with other two handles. The aim of this session is to know which will be more suitable for you".

P: "Ok".

R: "Yeah, so, the dynamic will be that I am going to bring them closer and you can interact with them and I am going to ask you some questions and that will be the end of the session. So, basically, well, the dynamic is similar to the previous one".

P: "What you mean by the dynamic?"

R: “Ah, dynamic is the steps that we are going to be following”.

P: “Right, ok”.

R: “Yeah, in this session, basically we are going to... the meeting, this session will last around 30 minutes – 40 minutes and I am going to use the recording equipment in order to... only for research purposes, I am not going to use it for identification and these things”.

P: “Yeah, yeah , that’s all right”.

R: “Well, so, what I am going to show you is... I have three handles, so, what I am going to ask you is what I did the previous time that I am going to put it here (inserting the handle into the stick) and then you can interact with it. I don’t know if you can walk a little bit but try do not put a lot of weight because it is still a prototype ”.

P: “Right ok, ok”.

P: “Do I hold it like that? (with the left hand)”

R: “Sorry, with the right (hand). And I don’t know if the height is ok for you?”

P: “Let me just walk around a little bit”.

R: “Because it has been used by other participants”.

P: “It’s quite high, It’s quite high. Bit too high for me, bit too high”.

R: “Ah ok, yes... ok, let’s try with this”.

P: “That’s right. That’s better, that’s much better, yeah. Yeah, that’s good”.

P: “Yeah, that’s fine, that’s good”.

R: “So, this was the first (standard). This is the second one (personalised)”.

P: “This is getting be tricky. What’s the difference? What’s the difference between this one and this one?”

R: “Yeah, I cannot tell you, I mean, right now what’s the difference but if you want we can try again the other one”.

P: “It’s interesting. They have a different texture. It’s interesting. Is a hard lip any difference in terms of what I feel”.

P4: “Yeah, ok. Yes, ok. It’s very light the other one but maybe slight because I don’t know quite why is it”.

R: “Yeah, and the last one is this one”.

P: “Yeah, this isn’t quite so good, it was released not for me. It’s somehow too big. My hand is a little bit loosing it, yeah. For somebody with a bigger hand it will probably be ok, but, yeah, it’s just a little bit big, yeah, that means, it’s less *inaudible* they doesn’t. Yeah, yes, so is not so much this one. It may work with somebody with a bigger hand...”
R: “So, I don’t know if you would like to try a little bit again”.

P: “Yes, let me try this. Can I try that one (second option) first?”

R: “Yes”.

P: “Oh. Ok, that’s good”.

P: (Now trying the first option) “This one is better. I don’t really know quite why but it is. It’s just slightly... it doesn’t grip me too much, it gives me more flexibility, I think. For me, anyway, it probably *inaudible* different people. Yeah, I like this one”.

R: “Ok, now, if you would like to seat”.

P: “Yeah”.

R: “Ok, so, I am going to bring them closer to you. What I am going to ask you is, well, you already tried them, you already tried the handles. Well, we have a line here from 0 to 100, so could you please assign a score to each option from these values and being the 100 the maximum one”.

P: “Ok, which was the one I like better?”

R: “Yeah, the first one (standard) was the... yeah, that one was the first one that you tried”.

P: “Yeah, that was the one I like best, wasn’t it? Ah ok, let’s... ok and these ones are the? Let me just have another little look. I just check it out (grabbing the standard, the personalised and then the control handle). Yeah... that one is... ok, yeah, ok”.

P: “Right, I think this one (standard) is sort of 75, you know, splendidly. The other two, are... they are different but all is in my... for me anyway, can be different for another people. I like this one (standard) better because it doesn’t... these ones (personalised and control) enclose the hand more I think, they feel a little bit more, for me, this is how it feels. This one (standard) just feels like I got a bit more leave way about how I do it, these ones (personalised and control) are bit like call around there, they make it less easy for me to relax with. I think. If that makes any sense.

R: “No, no. That’s fine”.

P: “These two (personalised and control), let me just see which one I like least. I think I like that one second (personalised) and that one third (control). That one (standard) I like best”.

R: “And if you could provide a score to the blue one?”

P: “Right, blue one. I’ll put it down here, for me it be… say about that, and that one (control) a little bit lower”.

R: “Ah ok, so will be a 50 or a 55?”

P: “Yes, something like that, yeah about 55”.

R: “Blue 55 and the green one will be?”

P: “About 45”.

R: “Ok, you preferred the yellow one because you feel…?”

P: “It feels like it gives me support without losing control, is that balance, isn’t it? Between, you know, because it’s quite… it’s… these ones enclose your hand more, let’s say that that would work, well for another people I guess, but I quite like this feeling of it, not, you know, wrapping around me, I don’t want that, you know, is easier for me, you know, I prefer that, yes, yes, it feels like I have more control”.

R: “Ah ok, and is there anything you didn’t like about the yellow one?”.

P: “No, I like that one”.

R: “So, the qualification, I mean, the score is 75 because…”.

P: “Because, yeah, that I felt, gave me control but supporting me within that, yeah. It didn’t feel like it was… these ones (personalised and control)… they were trying to say ‘this is what, you know, this is how you would to be, you know, they were, sort of…”

R: “Yeah, and about the things that you like about it, about them, what was?”

P: “The things that I liked?”

R: “Yeah. About the second option”.

P: “I mean, I didn’t like either them so much, but I guess that some people would quite like that because they wrap around you more, some people would find that more, that they feel safer, perhaps with that, but it wouldn’t work for me. I think that’s it. I think, you know, I am sure, you know, for different people different things will work but that one was the best one for me”.

R: “And about this one? (control), the things that you didn’t like it”.

P: “That’s similar, that’s similar to this one (personalised). Again, it encloses a little bit more and I don’t like that too much, but some people will like that”.

R: “Ok. Now I am going to mention some factors that could influence in the way that you select or you have more preference for a handle”. P4: “Right, ok”. R: “So, I am going to ask you please that you rate out of 10 about how important they are for you. So, for example, the first aspect is the comfort on your hand. So how important is for you having comfort while you are using a handle out of 10”.

P: “Out of 10?”

R: “Yeah”.

P: “Oh, I should think, that is pretty well”.

R: “Yeah, only it’s about what do you think, I mean”.

P: “That would be 10, wouldn’t it? Really, otherwise you wouldn’t be holding it easily”.

R: “The second aspect is the comfort on the wrist”.

P4: “On wrist?”

R: “Yeah”.

P: “Well, that’s absolutely vital actually, isn’t it? They both are... I would say that has to be 10 as well really, I’m sorry if that’s... you know, they are bit maybe something but... that’s the most important part, isn’t really to me. *inaudible* Has working, you know, you can support it, you got, strength, yeah”.

R: “Yeah, ok, the other one is having an intuitive shape, I mean, how do you grip it. That you can know... P4: “All right”. ”R: “Where to...”

P: “That’s very important, that’s very important, that will be very different for different people”. R: “Yes”. P4: “And yes, probably made a lot of difference be wouldn't that I decide it on, 'cause that one for me, 'cause I have quite big hands for a woman, and you know, it's… that's much more comfortable for me, it doesn't… they these ones felt like they were enclosing me or wrapping around me too much and I didn't like that and yes, what else can I tell you about that?"

R: "About… if you can give a score". P4: "A score. Right, ok". R: "About the… having…" P: "The importance of it".

P: "Yes, that's very important, yeah, I am afraid is another 10".

R: "No, that's fine, if you want to…"

P: "Yeah, to me…that is".

R: "Ok, and, the other aspect is the ease of maintaining the grip while it is used".

P: "All right, maintaining the grip". R: "Yes". P4: "And what about that, what's the question".

R: "Ok, how important is for you that when you are using the handle, I mean, your hand keeps in the position".

P: "Right. For me, not to important. I quite like I don't; you know, I don't want to be constrained by it. So, for me, I quite like the freedom to decide what I do with my hands, you know, I don't want to be wrapped around it too much or to look after me, but, for a lot of people they would need that, so, yeah, so, that's why, but it wouldn't work for me, not at the moment, anyway".

R: "And if you could assign a number out of 10".

P4: "Give me the question again".

R: "Yeah, well the aspect is the ease of maintaining grip while it is used, while the handle is used".

P: "Ease of maintaining grip".

R: "Yeah".

P: "Is a tricky one to answer, isn't? Really? Yeah, I mean, I found easy to maintain this grip (standard), which is nice and is because it doesn't enclose me too much. I don't know. I don't know the answer to that really. The ease of maintaining the grip and I got to give you a number. Well it's very important, certainly. Yes, I mean, whichever, whatever, when you like or suits the person that's got to be one of the most important things, because otherwise it wouldn't be safe, would it? so, yeah, that's got to be a high, a high number, so we're talking 75 again really, 'cause I don't see how I can make it less really".

R: "7.5 ok, that's fine. The other aspect is enough support for the hands and fingers".

P: "Yeah, is a save individual, aren't they? But for me, I don't want too much support for the fingers myself, but that is for the moment in my life, I can grip ok. As I get older, is quite likely that I won't be able to grip, well and then it become very important, that would make a lot of difference to most people as they grow older, yes, so ask me the question again".

R: "Yeah. Enough support for the hands and fingers".

P: "For me, at the moment, that's not really that important, so I put it sort of 55 to 60 type, I think. Yeah, around that area".

R: "So will be 55 or 60? The thing is I should..."

P4: "60, 60, yes".

R: "Ok, the aspect is stability in the user".

P: "70".

R: "Stability in movement".

P: "Appealing to the user"

R: "60".

R: A summary of the participant importance of the factors out of 10 are:

	Participant importance rating of the factor
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	10
4. Ease of maintaining grip	7.5
5. Support in hand/fingers	6
6. Stability in static posture	7
7. Stability in movement	7.5
8. Appealing to the user	6

R: Could you please assign a score from 0 to 10 to each factor per every handle? For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Standard	**SECOND OPTION** Personalised	**THIRD OPTION** Control
1. Comfort on hand	10	6	5
2. Comfort on wrist	8	4	4
3. Intuitive shape	10	5	5
4. Ease of maintaining grip	8	4	4
5. Support in hand/fingers	7	4	4
6. Stability in static posture	6	3	3
7. Stability in movement	8	4	4
8. Appealing to the user	8	4	3

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Not too much at the moment because I am not disabled enough.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 70 (provides support). The fingers are able to hold it solidly.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.
Thank you very much.

SESSION 3
Participant No. _5_

R: "Hi, good morning, thank you very much for being in this second and last meeting. Today it will be the evaluation of your personalised walking stick handle and it will be compared with other handles".

"This session has the following objective:
To determine which is the most suitable handle for the participant".

"There are relevant aspects that also were mentioned in the first meeting:
- The length of this session will be between 30 to 45 minutes.
- Notes, audio recorder and camcorder will be used only for clarification purposes.
- Collected material from this second session will be only used for research purposes".

"In this session I will introduce three different walking stick handles, please interact with them and try each one out, and then I will ask some questions".

R: Now that you have tried the three handles which one do you consider was the best one for you? If you want we can try them again.

P: The yellow one.

R: Can you please explain what you base your preference on?

P: Why do I prefer it?

R: Yes.

P: I felt it more ahhh because between the yellow and the green I felt it was more secure more firmer basically there.

R: Could you please assign a score from zero, well actually I put this line with scores from zero to one hundred in order to rank each option so could you please, I am going to give you little circles with the same colours in order to rank each one, could you please provide a score with one hundred being the maximum the best one. For the blue one.

P: Mhh.

R: Ahh ok, and for the green one.

P: Ahhh.

R: Ok ok, and for the yellow one. Could you please describe what did you like and dislike about each option. For example for the first one the blue one, what did you like about it?

P: Not as firm, not as good a grip.

R: Ahh ok

P: And the green and the yellow I found better both, not a lot between them but I would go for the yellow.

R: And about, if you want to say what you like about the first option, the blue one.

P: Yes, it was quite nice and but having tried the other ones afterwards I felt they were superior or better for me.

R: Ahh ok, and for this one, for the green one which will be the thing that you liked the most about it?

P: Again, grip.

R: The grip.

P: The grip yeah.

R: And what you didnt like?

P: There is nothing I didnt like but I prefer the yellow grip.

R: And is there anything that you dont like about it, about this one?

P: No.

I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of this factors are (out of 10):

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	9.5
3. Intuitive shape	9
4. Ease of maintaining grip	8
5. Support in hand/fingers	9
6. Stability in static posture	10
7. Stability in movement	8
8. Appealing to the user	7

Would you add any other factors that you consider as important?

Could you please assign a score from 0 to 10 to each factor per every handle?
For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Personalised	**SECOND OPTION** Control	**THIRD OPTION** Standard
1. Comfort on hand	8	9	10
2. Comfort on wrist	8	9	10
3. Intuitive shape	8	9	10
4. Ease of maintaining grip	8	9	10
5. Support in hand/fingers	8	9	10
6. Stability in static posture	8	10	10
7. Stability in movement	8	9	10
8. Appealing to the user	8	10	10

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Yes, because of the grip and it provides support.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 20 because of the comfort and grip. (It is necessary) better support.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.

Thank you very much.

SESSION 3
Participant No. _6_

R: "Hi, good morning, thank you very much for being in this second and last meeting. Today it will be the evaluation of your personalised walking stick handle and it will be compared with other handles".

"This session has the following objective:

- To determine which is the most suitable handle for the participant.

“There are relevant aspects that also were mentioned in the first meeting:
- The length of this session will be between 30 to 45 minutes.
- Notes, audio recorder and camcorder will be used only for clarification purposes.
- Collected material from this second session will be only used for research purposes”.

R: Now I will introduce you three different handles and I would like you to interact and try each one out and then I am going to ask you the questions so this one will be the first one the first option.

P: I have a question for you when we finish this.

R: If you want to walk a little bit, try not to put a lot of weight in it please.

P: Yeah, is that enough walking?

R: Yes.

P: Well, my first reaction.

R: Sorry, can we have the reactions.

P: After?

R: Yes please, because I am going to ask a lot of questions. This is the second one.

P: Mhhh, yeah.

R: And this is the last and third one

P: Interesting, yeah.

R: Ok, now I am going to bring closer the models and I am going to ask the question, this was the first, the second and the third. Now that you have interacted with the handles can you please tell me which one is your preferred one?

P: Can I hold them again?

R: Yeah yeah if you want to.

P: Just to hold just to hold. For me personally it would be this one, the second one. Can I try again? Sorry, yes it is the second one, yes.

R: Can you explain what do you based your preference on?

P: The physical contact, tactile, for starters, mhh I liked that it is raised you know, this one is not as raised, it is different to me but also how my hand feels more secure around it, it seems to shape wise I feel comfortable, yes I think its all to do with how my hand holds it and it is the tactile feel for me. And what I want to say about, because I remember how we did the mould and I am very impressed that it is very similar to my hand, do you understand what I mean, I really feel like it is nobodies, it is mine because it feels comfortable around when I am holding it and everything so that is very good.

R: Now, could you please assign, I am going to give you little circles for each option and can you please assign a score for zero to hundred for each one, the zero will be the least.

P: For each one?

R: For each one, for example.

P: For that one, may I? If I was to buy it in a shop I will probably give this one perhaps sixty I think. The orange one, I dont believe in hundred percent because otherwise there is never room for improvement so I would give it, for me for me, that here.

R: 85.

P: Yes, just because mhh I dont know or I am being, I am not being, yeah I will explain why. And the blue one, the blue one mhhh is this and that is interesting because I do remember when we add to add the little bit more of clay, it is interesting to see the different results.

R: Ok. For each handle can you describe what you like and dislike about each one?

P: Ok, so this one is definitely the feel is very comfortable.

R: The green one.

P: Yes the first one and it goes nicely around my hand and that is fine but the problem, the reason why I gave this one it is because they are very similar if you think about it they are quite similar, to me that was the raise it is interesting because these are bigger raises but I prefer this one, I feel secure with both of them, I feel secure if I had to had them and leave the room I could use either of them really I either of them. So for me, it should be this one, this should be more this side, I will move it a little bit, this one I am not moving it, interesting this one is a no no so again why this one was the least likeable ehmm if I want to use a word maybe it was not ergonomic enough for me, it just sits on this here, it is too narrow and yet it is my hand because I remember when we did that I do but it is not I dont feel at all secure I was not walking properly.

R: Because of the width?

P: Possibly, I think it is around this bit but also I noticed in all three of them if we want to, this is obsolete, this doesnt do anything at all it doesnt play a role, does it, you can see.

R: Yes.

P: And this one not either, it has to be.

R: Shorter?

P: Yes, a better fit, like a glove that should have been more, yeah? But I find this too narrow which is similar to some of the sticks that people buy from ordinary shops and instead of because this is similar of having an ergonomic one they just have and then go and say I cant chose those, they are not steady, this one it wasnt steady when I walked at all, I would not trust it.

R: So the reason was because, sorry, the reasons were that this part.

P: This here, either mhh it is interesting, it is interesting because this is both me. All these little, maybe this was an issue for me ironically enough, too narrow a neck for me but they are similar, it is ironic, so is it because all these little curves here means that, is it also the weight of this that means that maybe it plays a role with gravity I dont know.

R: These areas.

P: Yes, maybe it made it tilting and not secure, it was not secure.

R: Ok.

P: For me it is all too thin here, it is interesting because they are very similar but without being stupid I find that if you look at the differences, this side and I think that is probably it, this side goes down, can you see that? Whereas this here is not going down, whereas this one, yes I think has this been slightly up I think, in my thinking, and therefore you see why they are not there if we were talking and it is the same with these ones as well because you can see.

R: Ahh yes.

P: So dont think that yours is not good, all of them, but what we want is bespoke that is the ideal because we all have different hands so the idea is to have the mould and then make it, for me why these ones have not been a hundred I would have like these to be.

R: Shorter?

P: No, too mhh.

R: Bend?

P: Yes, slightly, so my hand is well prostrated so that is how I would and I like that sometimes your hand, mainly when you sweat, it becomes a little bit difficult, and this even in the real ones it doesnt do anything but if they were slightly more against the skin of the hand you would feel more comfortable like it is in a nest. This front here is very good and the reason why raised is better is because when you sweating, this is smooth so when you are sweating it is not so comfortable, this is the fact that they are all of them raised and ironically I prefer this one because they are more dense, yes, and these are spaced so this one I dont like its surface, for me, but it is better than what I have ironically. This one for me is number one.

R: Sorry, and about the shape, between this one and this one?

P: You are right, there is a difference, is it that this one is very similar to what I have and therefore I, my brain automatically recognises it, maybe, but these are completely different and it is something to do with around here that doesnt feel and maybe slightly, it is not so much thinner but curver, the curve is deeper and so it means that when I hold it and that is what I hold, it is too thin and it is almost like you know these people that have sticks and then they have three at the end of, if you notice it, I have just like this but some people have three and if you notice then therefore that is better surface holding on. This and this one, I just find like it is like if I was holding an umbrella, that is how it feels to me. This one I feel, but maybe because it is very similar to what I have maybe.

R: If you consider only the shape, the results would be similar?

P: Yes, it is again this one.

R: Then this one and this one the order.

P: Yes, one two and three. And if you have a look now that they are sat like this they are quite different, arent they, just around here, this will loose a lot of, can you see? Now I can see better, there is less of a dip and here it is large, but this you can see a good pile of that is obsolete, it doesnt do anything and perhaps makes the weight, the balance different. It is fascinating.

R: I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of these factors are (out of 10):

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	10
4. Ease of maintaining grip	10
5. Support on hand/fingers	10
6. Stability in static posture	6.5
7. Stability in movement	10
8. Appealing to the user	5

R: Would you add any other factors that you consider as important?

R: Could you please assign a score from 0 to 10 to each factor per every handle?
For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Control	**SECOND OPTION** Standard	**THIRD OPTION** Personalised
1. Comfort on hand	8	10	3
2. Comfort on wrist	8	10	3
3. Intuitive shape	8	10	3
4. Ease of maintaining grip	8	10	2
5. Support on hand/fingers	7.5	10	2
6. Stability in static posture	8	10	7
7. Stability in movement	8	10	2
8. Appealing to the user	10	10	10

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Yes. It provides rougher feel of it and the contact is strong.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 80. Because it is preferred a rougher surface.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.

Thank you very much.

SESSION 3
Participant No. _7_

R: Thank you very much for being here, this session will last around 30 minutes and what we are going to do is to show you your personalised option among other options, other handles with the aim of you chose which one is more suitable for your so what we are going to do I am going to show three different options of handle and then you can interact with them, walking a little bit and then I am going to ask some questions.

P: Ok.

R: So, the first option is this one.

P: So, it is a spline, you wont tell me which handle is which.

R: At the end I am going to tell which was.

P: Before I used them?

R: No.

P: Ahh that was what I was thinking, afterwards.

R: So this would be the first option.

P: Ok.

R: Yeah, I think I need to adjust the height a little bit.

P: Yes, it is a little bit low.

R: Let me, a little bit higher?

P: Yes, a little bit higher yeah.

R: Ok, I can see the I thing there, I am going to put then ring.

P: Yeah.

R: Now I am going to show you the second option.

P: Ok.

R: And now the third one.

P: Yeah, well I straight away not this one.

R: Ok, now if you want to sit please. Now that you have interacted with the three handles I am going to put them here and I am going to ask you some questions.

P: Yeah.

R: Now that you have interacted with them which one you consider to be your preferred one?

P: To be honest, the metal one. I can feel this one has got my fingers marks in it so I could feel those but I can feel when my own fingers have been in this one but this felt a bit thin and also this section here kind of flapped a bit against my wrist as I walked whereas this one felt a little bit more substantial here and this fitted better around my hand, it wasnt getting in my way as I moved my wrist so although I can feel this one is a different shape it was this bit that is not right so that one was the best one and the blue one is second best and this one wasnt going to work at all.

R: Ahh ok.

P: So it looks as though the standard one is, that to me, the metal one, felt more like a standard one.

R: So, your preference would be based basically on the shape.

P: Yes.

R: Ok and because of the way that you feel?

P: Yes, as I said this felt kind of thin here, maybe I gripped too tightly.

R: Yeah.

P: And this section here which seemed to hit my wrist as I walked.

R: Ahh ok, and could you please assign a score to each one, for example I am going to give you circles with different colours and zero will be the least and the hundred the best one.

P: Ok.

R: So for this one the blue option, which would be the score?

P: I put that there.

R: Ahh ok.

P: I will put this one sort of down there and this one up there.

R: Ok so it would be, the green would be like five or zero, I put this little line in order to mark the five

P: Ok.

R: So it would be five, the blue one would be 60 or 65?

P: Sort of, well give it, I never really know how to do these scores, mhh 60.

R: And the yellow?

P: 90.

R: Ok.

P: Well, I just sort of, it has not anything for me to slot my fingers but it is better here so whereas this one has a place I can slot my fingers but it doesnt quite work.

R: Yeah, actually the next questions is for each handle can you please describe what you like and dislike about them.

P: Ok, well the blue as I was walking it felt a little bit thin and insubstantial here and I did have to move my fingers around to find the grooves for them to fit into, also when I put my hand on it first they didnt automatically fill the groves and as I walked and moved my wrist the bit at the back should support the heel of my hand, it seemed to move and hit me here so it was pressing in, can you see? It presses here which was uncomfortable. I wonder if I gripped too hard when we were forming it, might be that I pressed too hard with my fingers and thumb and made it a little bit thin here.

R: Is there anything that you like about the blue one?

P: Anything that I liked? Mhh well.

R: Any answer is fine.

P: Mhh I wonder if it should drop a little bit low here, mhh what do I like? Well, I think if it were, if this were a bit lower it would feel comfortable, having grooves for my fingers, you know, it is quite comfortable, the only thing is that it doesnt give me any option to move them anywhere else, my hand gets tight and if I wanted to change my grip a bit that would be difficult because it got precise places to go but as I said I think if this were altered it would be more comfortable.

R: And how do you feel about your inner palm in this area, I mean about the curves between, or is there any gap that you feel?

P: I mean, where my thumb goes that is fine, where the thumb fits it fits here and around there, that fits. The bit where I had to feel around was the sections for my fingers so I think the bit that works best is the channel for my thumb.

R: And what about this area, the contact between your inner palm and.

P: Yeah, the contact is good, yeah. The contact here is good and the contact between here and here that works well that is supportive.

R: And about this one, what do you like the most and dislike?

P: What I liked was that it felt more substantial here so in a sense I wasnt gripping quite so hard, with this one because I think, I mean it is comfortable as I was walking, I think I gripped quite hard whereas this one, I mean it feels more substantial here.

R: In this area., ahh ok.

P: It is a little bit less comfortable for my fingers there but it works better with the heel of my hand, it doesnt extend so much.

R: And about this area but in the upper part, this area, this one, how do you feel them?

P: Yes, this one is definitely more comfortable for this part of my thumb where I got arthritis because it matches it, it holds it. This one certainly isnt quite as a comfortable for my thumb but it is not bad and this part works better than that part on that one. Underneath there is nothing particularly for my fingers but I do have the option to change my grip if I want to move my fingers a bit.

R: And about this one, what did you like and dislike please.

P: When I held it it didnt seem, I just felt it wasnt as comfortable as the others.

R: And is there anything that you liked about the green option.

P: I think I didnt really walk with it, didnt I? Because since I held it I thought ohh no. I can see it has been a little bit moulded, to me, it feels as though everything is on this side of the hand and there is not much for that side.

R: Like there is a gap there.

P: Yes, yes, so it sort of feels this side is supported but this side isnt, it is a bit halfway.

R: Now, I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of this factors are (out of 10):

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	10
4. Ease of maintaining grip	7
5. Support on hand/fingers	10
6. Stability in static posture	10
7. Stability in movement	10
8. Appealing to the user	8

R: Would you add any other factors that you consider as important?

P: No.

R: Could you please assign a score from 0 to 10 to each factor per every handle? For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Personalised	**SECOND OPTION** Standard	**THIRD OPTION** Control
1. Comfort on hand	6	8	4
2. Comfort on wrist	2	8	4
3. Intuitive shape	7	8	7
4. Ease of maintaining grip	5	6	4
5. Support on hand/fingers	7	6	5
6. Stability in static posture	6	6	5
7. Stability in movement	5	6	4
8. Appealing to the user	4	5	2

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: No because during the use of the current walkigng stick it is not necessary to twist the hand, wrist and arm.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 90 because if it is used for a long time (around half an hour) an ache in the shoulder starts to appear.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.
P: Yes.

Thank you very much.

SESSION 3
Participant No. _8_

Researcher: "Hi, good morning, thank you very much for being in this third and last meeting. Today it will be the evaluation of your personalised walking stick handle and it will be compared with other handles".

"This session has the following objective:

- To determine which is the most suitable handle for the participant.

R: Well the technical point of this season is similar to the previous one, the length will be 30 minutes or a little bit more, a recorder will be use for clarification purposes.

P: Ok.

R: In this session I am going to show you different handles and then I am going to ask you some questions.

P: Am I ok here?

R: Yes you are fine. I am going to introduce three different handles, please feel free to interact with each of them, I dont know if the height is fine for you or if you want it higher?

P: I think, I dont know, how is one supposed to?

R: I think.

P: I cant remember how, you and I are both of the same height.

R: For me it is a little bit high, maybe for you is a little bit.

P: Mhhh.

R: How do you feel the height, maybe a little bit.

P: Yeah, possibly a little bit higher, just one notch I think. Yeah yeah, ok, now mhhh, first impressions.

R: Sorry, if you want I am going to give you each one of them.

P: Right, ok.

R: So now I am going to make the questions. The first one.

P: The yellow yeah.

R: The second handle.

P: Yeah.

R: And the third one. Which one do you prefer?

P: I actually prefer the last one, I was going to say the middle one but ok the last one.

R: Ok, the last one. Can you explain what do you base your preference on and why?

P: Yeah, this one was too rough on my hand, I could actually feel it abrading on my hand so I didnt like that, this one was much more comfortable in my hand but it didnt, this one seems to fit better, that is all I can say, you know, it is just it gave me a lot of support in here and it is not as rough and I know I asked for a slight roughness otherwise in sweaty times it gets slippery but this one was too rough so I would say number three.

R: Now, I am going to move this things away.

P: Taking all refreshments away.

R: Now I am going to put this line and then I am going to ask you to assign an score of each one so I am going to give you small circles so for example if you assign a certain score to that one you can put it here and in this case I am using colour because in this case we are not going to mix or being confused which handle is which and also with this line we can see how closer or how far away is one from another, I mean it is just for visualisation this line.

P: So compared to, if I were to put lets say this one.

R: Sorry, I forgot to mention that zero is the lowest grade and the hundred is the highest, the perfect one.

P: Right, ok, mhhh that one was good.

R: Actually, if you want I can put them again if you want to try them.

P: No that is ok, I am going to put that one at 50, because it fit my hand so much better, I really like that but as I said because it was so rough that is why I wouldnt that is why it is only 50. Sorry, is it ok for me to try these again?

R: Yeah.

P: Ok, that one is very very close I would say at 80, now, mhh ok, if this one was an actual cane, I am actually going to reverse this, I am going to make this a 90 and this one at 80, in other words this one is the better one and the reason why I am saying that because remember what I said to you that when you are using a cane you feel very obvious, this is very comfortable but I am afraid it is large and people would identify you as having a disability you know so this one is actually rather unobtrusive even though this one perhaps fits better but you can really see if someone saw me with that on the street they would know that I am disable so I am changing my opinion now so the one I actually prefer is the green one, that is pretty close but it is only because it is so large and that one is in terms of fit it is good it just that this is too rough.

R: And about the shape?

P: Ahh lets see, in terms of the shape very little difference between the yellow and the green, very little.

R: Actually putting it here, I mean using it as a prototype it could feel different and it is completely fine if this change your mind because I want to double check with the handle inserted here. If you want.

P: No that is ok, that is one of the things I use the cane for, getting up. So this one, the shape of it is good, it really does have to do with the texture, it gives good support and right there.

R: Ahh ok, that area.

P: Because that is for my finger, it would be better if there was an indentation there, now lets try the green one.

R: Yes.

P: It is funny because it feels like there should be an indentation there, mhhh lets see.

R: Do you want me to remove the bag.

P: Yes please. Thanks. How odd, it doesnt feel as comfortable. Right, could I try the other one. Wow, for comfort sake that really is good, yeah, in fact my hand even fits under there. We will change it again, yeah, this is much better I was just concern about you know the size there, but.

R: In general.

P: In general I would say this one is better of the three. Yeah, not only for the texture because it is softer but my finger fits underneath there so it doesnt feel like it is on a ridge like there and I feel well supported yeah, no I am sorry I am going to have to take it back.

R: It was fine, change your opinion I just wanted to let you know that having walking with the handle it is different than only because you dont know how you are going to put your weight.

P: You are right and definitely that one is more comfortable walking.

R: So this 50 is an 80 and this one is 90 or 95.

P: I would say 90 for that one, that is 80 and I am going to move that one up to 60 because the fit is good so it is just the rubbing so that is how I would.

R: Ok, for each handle could you please describe what you like and dislike about the handle? Well actually you already mentioned some things.

P: Are you ok with that, of course it is on tape.

R: Yeah.

P: And did you, well you would have caught this on tape but the only thing is that that one is definitely most comfortable and definitely the most supportive but it just that it is so bulky that, it would be very obvious I think.

R: Very obvious?

P: That I am disable, you know, it is not discreet if that is the way to put it. I find that more people when I use this, they would say: can I help you? And I am not, I am not really old, I am not really disable and it is very kind of them but you know I just need it for support so yeah I would say.

R: So your worry with this one would be that the part that is.
P: Yeah.

Now, I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of these factors are (out of 10):

	Participant importance rating
1. Comfort on hand	9
2. Comfort on wrist	6
3. Intuitive shape	7
4. Ease of maintaining grip	9
5. Support on hand/fingers	10
6. Stability in static posture	5
7. Stability in movement	9
8. Appealing to the user	8

R: Would you add any other factors that you consider as important?

R: Could you please assign a score from 0 to 10 to each factor per every handle? For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Standard	**SECOND OPTION** Control	**THIRD OPTION** Personalised
1. Comfort on hand	8	8	10
2. Comfort on wrist	7	7	7
3. Intuitive shape	6	6	9
4. Ease of maintaining grip	5	6	7
5. Support on hand/fingers	8	8	10
6. Stability in static posture	9	9	9
7. Stability in movement	9	9	9
8. Appealing to the user	8	9	6

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?

P: Yes. Because it is customised to the hand, do not hurt to the palm and there is anough space for placing the hand, unlike the crook handle. It also provided good support because of the contact area and it was less likely that the hand could slip.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 20 because it has a reduced surface to grab it with comfort.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.

Thank you very much.

SESSION 3
Participant No. _9_

R: Ok, well thank you very much for being here, this is the second session and today I am going, well we are going to evaluate your personalised handle and also it will be compared with another models with the aim to determine which one is more suitable for you and the technical aspect of this session is going to be around 30 minutes, more or less and also I am going to be using the recording only for clarification purposes. I am going to introduce three different models and then you can interact with them and try each one and the the others and then I am going to ask you some questions, so three models and this is the first one, we are going to use the same walking , well the same stick from the last time and I dont know if they height is ok for you.

P: Yes it is fine.

R: Ahh ok, so if you want you can use it.

P: How strong is this material?

R: Well the material is strong but the thing is the connection between the handle and the stick it is not so try not to put your weight on it.

P: I am just walking and thought perhaps I might cracked but it is fine. It is nice. Can I try the others?

R: Yeah, so this is the blue option, if you want I can, yeah that thing is a little bit tricky ahh ok.

P: You have been in the lab quite a bit, it shows on your palms.

R: The palms?

P: I said you have been walking and you have your hands on this stuff quite a bit with your palm.

R: Ahh ok.

P: This is better, it feels positively better however, I think I have raised this part of myself I think it should be closer to but because it is hot and because I am bearing down on it I can imagine that after a while using it because it is hard I this part of my palm will get a little bit sore, it feels firm and comfortable otherwise but I keep thinking that by the time I start using it is fine then I felt that having that support is good and I still think so but because it is hard right, if it was a soft surface right, I think I might be ok with it, otherwise I think this is a good one.

R: And this is the last one.

P: Ok, I think this is just like the normal, normal type of handle.

R: Actually I cannot tell you, I am going to tell you which one is the personalised one but at the end.

P: This one fits my palm quite well, that is my impression.

R: That is fine, you can everything you want.

P: This is, this is just this feels like my normal, I have used this kind of walking stick with this type of head so it feels like the normal standard stick, for me, I am familiar with this feel.

R: Ok, now I am going to ask the questions. I am going to bring them in the same order that you tried them. Ok now I am going to ask the following questions, which one was your preferred handle?

P: Blue.

R: Can you explain what you based your preference on?

P: Well it felt like it was, it basically moulds into the shape of my hand, it is my grip, I just felt better and it felt suitable for my grip and the way I use a walking stick yeah. The only issue I have with it is what I mentioned earlier that this bit presses against there, while it provides support, simply because it is hard and by the time I bear down on it, you know, this part of my palm is bearing down on this hard surface I have concern that although it is comfortable this could quickly become an issue with long time use.

R: And when you are mentioning about that part.

P: If it was a soft surface, perhaps that would be fine, I am ok with the texture and everything.

R: And for example the part that is doing pressure on your hand it is because, I mean, is this side?

P: Yes, right here.

R: Ahh ok, I thought it was as well the vertical.

P: Let me show you again, when I hold it that way, that part, by the time I bear down there is a push towards here.

R: Yeah, so it is when you are in movement.

P: But otherwise it is nice and it has a pretty good firm grip, it is comfortable, I dont feel myself straining to hold it because it feels a bit too small in the hand, closing your fist in tight just to get a grasp of it but this feels natural, like it is meant for the size of my palm, right?

R: Yes, so now I am going to put this here, this is a, as we can see this is a line where we have from zero to a hundred so I am going to ask you please that you could assign a score to every handle so I am going to give you in order to see and compare them can you please assign a score to the green, blue and the yellow one and the hundred is the better the value the highest value.

P: Ok.

R: So what would be the score from zero to hundred that you would give to the handles.

P: Ok, yellow is pretty much standard, its normal.

R: Ahh ok, 55.

P: The blue is, I would probably add a little bit more of 40.

R: Ahh ok.

P: And the green is somewhere in between.

R: Ahh ok so the yellow is 55, the green is 70 and the blue is.

P: Around 92.

R: Ok, for each handle can you please describe what you like and dislike about them?

P: Ahh ok, this is pretty much a standard handle, if I offer the same, about the same level of grip as I do this it would jiggle. This, that level of grip doesnt jiggle, it is only, you only hear that sound from me by rubbing against the back of my palm but this at that level it jiggles and for me to actually get a full grip I need to tighten my fist around which of course strains the palm, strains the joints of my hand and all that so ahhh in terms of what I like about it I like the fact that this is, you know like if you were wearing a perfectly fitted shoe, it just supports every bit of your foot, that it feels like that, this one feels too small and it makes walking too hard to use that and this feels ok but again it doesnt offer that fullness, you know, it is not like this one, it doesnt offer that fullness, it doesnt jiggle like the other one, this allows me to have a somewhat relax grip which still provides a firm hold on the handle.

R: Ok, for this one you already tell me the bad, the disadvantages and the advantages of this one, the good things?

P: Well, it is a handle, it provides, it is not like it is uncomfortable but with long time use you of course start feeling your hand is getting tired quickly, otherwise it is ok it is just a normal handle, it does the job, it is ok. I dont know if I am qualifying with the right adjectives now.

R: That is ok, for this one you already mentioned advantages and disadvantages, for the green one, advantages?

P: For the green one, it offers a little bit more support than that one, so for example it offers support here which that one doesnt, it is just that it doesnt, you know if this was a bit thicker in the middle there I think it would actually offer slightly better experience or about, slightly better than this one, because in this case while it offers support towards the back it doesnt push, imagine it doesnt push as much when I bear down on it, this one is beginning to push against my palm a little bit too hard at the back here but this is, this is like an in between that just turn out to be a little bit too small.

R: Now, I am going to mention factors that could influence in the selection of the best handle. I would like you to rate how important you think each of these factors are (out of 10):

	Participant importance rating
1. Comfort on hand	10
2. Comfort on wrist	10
3. Intuitive shape	8
4. Ease of maintaining grip	8
5. Support on hand/fingers	7
6. Stability in static posture	9
7. Stability in movement	10
8. Appealing to the user	5

R: Would you add any other factors that you consider as important?

R: Could you please assign a score from 0 to 10 to each factor per every handle? For this question, it is necessary to assign the value to the three handles before moving forward to the following aspect.

	FIRST OPTION Control	**SECOND OPTION** Personalised	**THIRD OPTION** Standard
1. Comfort on hand	6	8	5
2. Comfort on wrist	8	8	7
3. Intuitive shape	8	10	5
4. Ease of maintaining grip	8	10	5
5. Support on hand/fingers	8	10	5
6. Stability in static posture	5	5	5
7. Stability in movement	8	10	7
8. Appealing to the user	6	6	7

R: Now focusing on your favourite of these three, do you think that this handle could provide you a higher level of comfort, improve your freedom or assist you more than the commercial models that you have used previously? Why?
P: Yes. It provides more comfort than the current Fischer walking stick because, like the standard handle, it has a thin handgrip and it should be squeezed when it is gripped.

R: Going back to the original ratings, you rated the three experimental handles with the following values. Please could you now assign a score from 0 (zero) to 100 to your current walking stick handle? And explain the reasons of this value?

P: 55. It does not provide enough comfort.

R: Now I am going to tell you which one was your personalised walking stick.

R: Would you like to be added to the distribution list? This with the aim of sharing the results of the research.

P: Yes.

R: Thank you very much.