The Design of Voice Output Communication Aids

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Introduction

Speech, Language and Communication Needs (SLCN) is an overarching term used to describe difficulties across one or more areas of communication (Enderby et al., 2009). Augmentative and Alternative Communication (AAC) describes a range of tools and techniques that support the communication of those with SLCN who have Complex Communication Needs (CCN). ISAAC, the international society for AAC, defines AAC as *"a set of tools and strategies that an individual uses to solve everyday communicative challenges"* (ISAAC, n.d.). AAC provides benefits across the lifespan including individuals with congenital conditions acquired at or near birth as well as those with conditions, including life limiting conditions, acquired later in life.

AAC can be broken down into unaided and aided AAC, the differentiation being where equipment or external supports are used (with aided AAC). Beyond this definitions become less clear. AAC is often categorised within the literature and practice as no, low, mid and high-tech (Beukelman & Light, 2020). With the evolution of the underlying technologies this categorisation has arguably become less relevant; as high technology equipment such as an iPad can be used for simple communicative tasks, such as single message production, that would have previously been categorised as low or mid tech. The use of graphic symbols to represent language are used in AAC as the main tool to support those who have not learnt alphabetic writing. Graphic symbols typically represent concepts or words rather than speech sounds and can be used receptively to support learning of language as well as expressively in an AAC system (Smith & Murray, 2016).

Communication aids are an aided AAC medium that can improve communication for those who otherwise experience difficulties with speaking. Voice output communication aids (VOCAs) provide speech output based on the user's input and typically use speech synthesis technology. The term VOCA is used in this commentary, but a variety of terms have been used in the literature and practice to describe these devices including powered communication aids and speech generating devices (SGDs). Those who use or may benefit from VOCAs have a wide range of underlying aetiologies (Baxter, Judge, et al. 2012). Table 1, based on the work of (Baxter, Judge, et al., 2012b) and Creer, Judge, et al. (2016), summarises the range of aetiologies that may lead to individuals using or potentially benefiting from VOCAs. Communication aids are an example of an Assistive Technology (AT), technology that *"enables and promotes the inclusion, participation and engagement of persons with disabilities"* (*Global Report on Assistive Technology*, 2022, p. xi).

Estimates for the prevalence of SLCN within the literature vary and predominately relate to children and young people rather than across the lifespan (Enderby et al., 2009): Lindsay & Strand (2016) conclude that 1.6% of the school age population have SLCN as their primary Special Educational Need classification; Norbury et al. (2016) assessed 9.9% of the school age population as having a language disorder; and the systematic review of prevalence studies by Law et al. (2000) provides a cautious estimate of children classified as having speech or language delay as being 5.95% of children up to the age of 7. Estimates of the prevalence of AAC and VOCA need or use in the literature are limited: Creer, Judge, et al. (2016) and Gross (2010) estimated the prevalence of AAC need as being 0.5% of the UK population; and Gross (2010) estimated that 0.05% of the UK population may benefit from the use of VOCAs.

Delivery of AAC and VOCAs varies, with different models of provision of AAC and AT in place across the world (*Global Report on Assistive Technology*, 2022). Service delivery of VOCAs is a key facilitator in

enabling effective VOCA use (Baxter, Judge, et al., 2012a). AAC design, development and distribution happens largely via a commercial market, and within the UK there are a number of companies who design, manufacture and distribute VOCA devices and software (*Communication Matters Suppliers Database*, n.d.). As well as accessing VOCAs via statutory services the market includes some degree of direct consumer purchase and purchase via voluntary sector organisations. VOCA provision, in common with other healthcare and healthcare technology delivery, thus involves intermediaries and non-consumer-market mechanisms between the VOCA developers, distributors, and end users.

As a clinical field AAC is multi-disciplinary and involves professions including Speech and Language Therapy/Pathology (SLT/P), Teaching, Occupational and Physio Therapy and Rehabilitation Engineering. The majority profession however is that of SLT/P and this is reflected in the AAC literature that tends to focus on optimising AAC outcomes for individuals in practice, something Kent-Walsh & Binger (2018) describe as implementation science.

The term 'those who use or may benefit from' is used in this commentary and included work in order to distinguish between use and need. This is an important distinction when considering VOCAs from a range of perspectives: from that of service provision, as not all who may benefit are served; from a social point of view, as how benefit is defined or realised may change with attitudes and culture; and from a technological and design point of view, as changing VOCA technology and improved VOCA design may allow more people to benefit from VOCAs.

This Thesis

VOCAs present a challenging design brief. Using technology to support face to face communication is a unique challenge that is further compounded by the fact that those accessing VOCAs may require alternative methods of control and/or representation of language. VOCAs are consequently often perceived as slow and ineffectual by those who use them. Design thus offers a considerable potential role in improving the outcomes of VOCA use.

This thesis collates a body of work related to the design of VOCAs. The work described investigated different aspects of VOCA design and this commentary explores how these aspects of design impact on the usability of VOCAs. Five publications by the author and a commentary (this document) are presented with the aim of demonstrating that the body of work is substantial, coherent, and impactful. The included publications were derived from a number of projects investigating and developing VOCAs and assistive technologies in which the author was involved. A Statement of Contributions to the work described in this commentary and the author's CV are also included in this submission (Appendix 1,2).

The publications presented as part of this thesis are referred to as Publication 1, 2, 3, 4, 5. In order to be clear about involvement of the author in projects and publications, where citations include the author of this thesis the citation has been amended to include the author, e.g. ((Baxter, Judge, et al., 2012b). The standard APA (7th Edition) convention is used for other citations. The bibliography retains the full authorship list and correct author order. This commentary also requires some discussion of personal involvement in work by the author and so in some sections of this commentary the first person written form is used.

Acknowledgements

I would like to thank all those who have encouraged me to complete this PhD and supported my journey in research and practice. Mark Hawley, as well as setting up the assistive technology team of which I am now a part, has been instrumental in providing me and others with the opportunity to research and advance assistive technology practice. Pam Enderby was key to initiating much of the project work described here as well as providing support and guidance. Janice Murray demonstrated faith and determination in achieving positive outcomes from research for those using AAC, including through the I-ASC project. Karen Sage doggedly and compassionately encouraged me to consider and then complete this PhD. Nicola Beaumont and others at Barnsley Hospital have supported my clinical academic role and the completion of this work. I am proud to work for the NHS and Barnsley Hospital NHS Foundation Trust.

Since accidentally falling into this career via a typewritten notice on a university pin board in the late 1990s I have been honoured to work with many fabulous people. Graham Race, Peter Swann and others at MERU were instrumental to my understanding, appreciation, and interest in design both in general and in terms of design for disability. There are too many other people who have been instrumental in my journey to list here, but hopefully these people know who they are. I consider many of the people with whom I have worked over the years to be friends as well as colleagues.

A number of people also kindly supported me in writing this commentary: Luc de Witte, Sue Mason, Amanda Hynan, Peter Cudd and Mark Hawley have all given direction and reviews; Kath Broomfield has steadfastly kept me from the many, many, potential distractions from writing and provided motivation and support through our regular writing sessions.

Finally, I would like to thank my family, friends, and those with whom I work, who have also supported me and kept me grounded in this endeavour.

This work is dedicated, with love, to Marie, Jess and Joe.

Context

As a PhD by publication this body of work was carried out over an extended period whilst working as a clinical academic. Throughout this period my clinical role has been in a specialised assistive technology team providing AAC and Environmental Control services and equipment. During this time I have also held honorary academic roles with the University of Sheffield (2008-Present) and with Manchester Metropolitan University (2016-2020). The overall context of this PhD should be considered as being in the English system of AAC delivery, although some of the projects linked to this body of work were UK wide.

In the following sections the clinical, research, methodological and personal reflexive context to this body of work is presented. Figure 2 and Table 3 summarise the research projects linked to this body of work.

Clinical Context

Prior to 2014 specialised services in England had been defined in National Specialised Services Definition Sets (National Specialised Commissioning Group, 2011) and responsibility for commissioning sat with local Primary Care Trusts or Strategic Health Authorities. Communication aid services had evolved in some areas through a combination of local initiatives, individual service development, and some specific initiatives such as the setting up of regional Communication Aid Centres in the 1990s (Leese et al., 1993) and the Communication Aids Project initiative between 2002 and 2006 (M. Clarke et al., 2007). There was, however, no requirement to commission communication aid services. Commissioning of these services had been frequently highlighted as inconsistent (Bush et al., 2007; Down, 2011; Royal College of Physicians & Institute of Physics and Engineering in Medicine, 2004). A key consideration identified as required to progress commissioning of these services was the lack of epidemiological data regarding the prevalence and incidence of need and use, and details of current service provision and standards. Research and activism, with the aim of securing effective commissioning of AAC services, was initiated in the 2000s by academic, public and voluntary sector organisations.

The current picture of AAC delivery in England, which has been in place since 2014, is represented in Figure 1. This system broadly consists of nationally commissioned specialised services providing specialised assessment and equipment, as well as locally commissioned services providing assessment and non-specialised equipment.
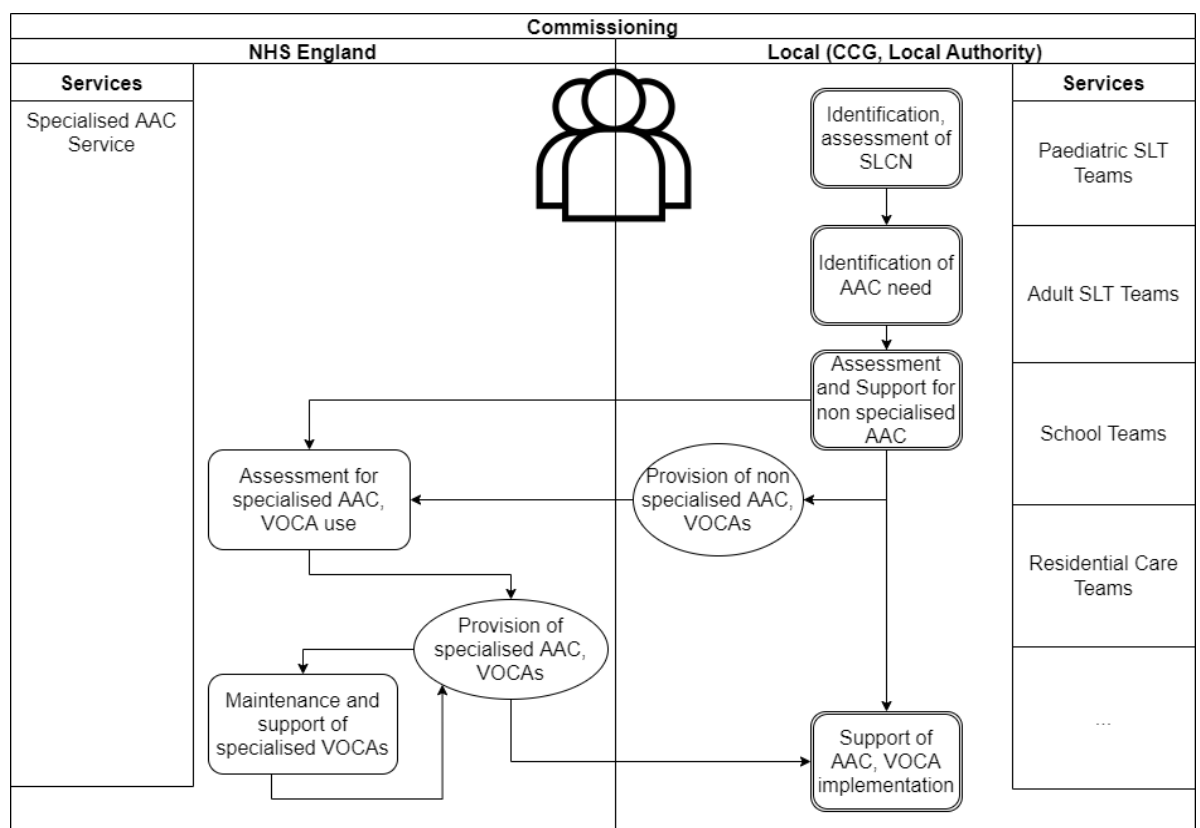

Figure 1: Representation of the current (2023) picture of AAC delivery in England.

Research Context

The research context of this work emerged from my clinical practice in the 2000s. At this time I observed a disparity between mainstream technologies and assistive technologies and saw the challenges many who used assistive technology faced in effectively using this equipment in their day to day lives. I viewed the existing and nascent communication aids as technologically basic and limiting in an era of emergent smartphone technology and increasing computing power. My clinical practice at the time often highlighted a significant gap between the potential that individuals, family members, and carers perceived the technology as offering and the reality of use that they then experienced. It was clear that some could become proficient in using VOCAs, but my experience of working with individuals suggested that many would abandon or not take up VOCAs or would display unfulfilled communication potential. I perceived all these issues as being caused by inadequacy in technology and design and I was motivated by these experiences to investigate and improve the design of VOCAs.

Project work funded by the Devices For Dignity (D4D) Healthcare Technology Co-operative (Devices for Dignity, 2008) allowed me to investigate this perceived disparity between the potential and reality of use of VOCAs. I carried out this work in collaboration with Gillian Townend, an AAC specialist SLT, and this led to Publication 1 and subsequent work as part of D4D looking at the design of VOCAs (Judge et al. 2015; Mobasheri, Judge, et al., 2016).

The role of service delivery in VOCA design and provision emerged as a theme in the qualitative data collected in the D4D work and reported in Publication 1 and this motivated me to investigate further. I was also directly aware of disparities in AAC and AT service provision across the UK through personal experience of being employed in different services and through my former role as a trustee of Communication Matters (CM, the voluntary sector organisation representing those using and working with AAC in the UK). At this time CM contributed to securing an influential government report on SLCN by John Bercow MP (Bercow, 2007, 2008). In 2008/9 I was instrumental in securing funding from the Big Lottery Research Fund for project work that involved a range of methods to establish the need and use of AAC in the UK. Publication 4 was one output of this work as were two linked systematic literature reviews investigating barriers to VOCA use, which are now highly cited papers in the field (Baxter, Judge, et al., 2012a, 2012b). This work aimed to fill the epidemiological gap that had been highlighted as constraining the appropriate national commissioning of these services and provided baseline information about AAC provision in the UK (Creer, Judge, et al., 2016). Funding from the Department for Education also allowed further investigation focusing on local rather than specialised or regional services (Judge & Johnson, 2017). The outputs of this work included academic papers but also open data sets (Judge, 2013), published reports (Enderby, Judge, et al., 2013) and dissemination to those using AAC and their families, practitioners, commissioners and policy makers. This work supported the change of commissioning that occurred in 2014 and the subsequent development of specialised AAC services in England and the UK.

Another research priority that emerged from my clinical practice related to the design and provision of symbol VOCAs. I jointly initiated and secured, with Janice Murray from Manchester Metropolitan University (MMU), National Institute for Health Research (NIHR) Health Services Delivery Research funding for the I-ASC Project[1]. This project was led from MMU and aimed to investigate the decision making of all those involved in decisions relating to symbol VOCAs. The I-ASC project involved a

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[1] Identifying Appropriate Symbol Communication Aids for Children who are non-speaking: enhancing clinical decision making (I-ASC). NIHR HS&DR: 14/70/153

range of methods and linked studies and Publication 2 is one of the three literature review outputs of the project. The I-ASC project also involved qualitative enquiry (Lynch, Judge, et al., 2019; Murray, Judge, et al., 2019) and quantitative investigations through two linked stated preference experiments (Webb, Judge, et al., 2021; Webb, Lynch, Judge, et al., 2019; Webb, Meads, Judge, et al., 2019). As well as academic publications this work also involved wider dissemination to those using AAC and their families, practitioners, commissioners and policy makers. This dissemination involved events, presentations, reporting (Murray, Judge, et al., 2020), a website[2] and resources aimed at supporting those involved in decision making.

Access to assistive technology and VOCAs is a theme that emerges from several of the studies described here and is also a key area of interest. Access is the area of practice most strongly linked to the role of my profession as a Healthcare Scientist within AAC and Assistive Technology. The work included as Publication 3 is a chapter taken from a book whose remit is to train Clinical Engineers in assistive technology practice (Najafi & Cowan, 2018). My initial interest and exploration of switch access led to collaboration with David Colven (ACE Centre) to publish a definitive resource on switch access (Judge & Colven, 2006) and theoretical work considering the potential of modelling human-computer interaction in assistive technology (Judge, 2006). I have also carried out research and development work related to access and accessibility: between 2014 and 2018 in collaboration with a commercial partner I secured funding for and led two projects, the Small Business Research Initiative funded EMEGO projects. This work involved initially developing a proof of concept and then subsequently a prototype and production Electromyography (EMG) switch, following a user centred design methodology. This work resulted in an innovative EMG access method[3] being placed on the market.

User involvement in design was a key element of my contribution to much of the work described above and I developed an interest in this as a methodology. My foundations in user centred design were through involvement in projects aiming to understand users' perceptions of novel assistive technology devices: the SPECS (Judge et al., 2011) and VIVOCA (Hawley et al., 2013) projects developed innovative assistive technology based on recognition of dysarthric speech. My contribution in this work revolved around understanding the user's perceptions of this concept and technology and supporting users in contributing effectively to the design and evaluation of these technologies. The nature of these investigations involved applying design methodologies and using qualitative methods and this allowed me to consider how these methods could be best applied to the specific challenges of researching assistive technology as well as in involving those with communication difficulties. Subsequently I was involved in other work with this focus: work carried out with Imperial College and the Royal College of Art's Helix Centre investigated the use of AAC in intensive care units (Mobasheri, Judge, et al., 2016) and involved review, qualitative and ethnographic design methods to triangulate data around the design requirements of an ICU AAC system; I contributed to the development of the Sheffield Support Snood (Baxter, Judge, et al., 2016; Langley, Judge, et al. 2017; Reed, Judge, et al., 2015) in supporting user involvement and in understanding of the impact of the neck support on the use of other assistive technologies; and in the STAR project where participatory methods were used to consider the design of an app based therapy tool.

Having facilitated user involvement in design I also supported and investigated Public and Patient Involvement (PPI) in research and development and methods for facilitating this involvement. Publication 5

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reports PPI work which was jointly initiated and delivered as part of a collaboration with Steven Bloch (University College London) and Christopher McDermott (Sheffield Institute for Translational Neuroscience). PPI engagement carried out in the I-ASC project (in which I was co-investigator) has been recognised as exemplary in demonstrating meaningful PPI and involvement of those with SLCN (Jayes, Judge, et al., 2021) and the work by Katherine Broomfield in her NIHR funded PhD (in which I was clinical supervisor) has further developed creative PPI and engagement methods (Broomfield, Judge, et al., 2021).

Figure 2 summarises this research journey and the research context of the body of work presented in this Thesis.
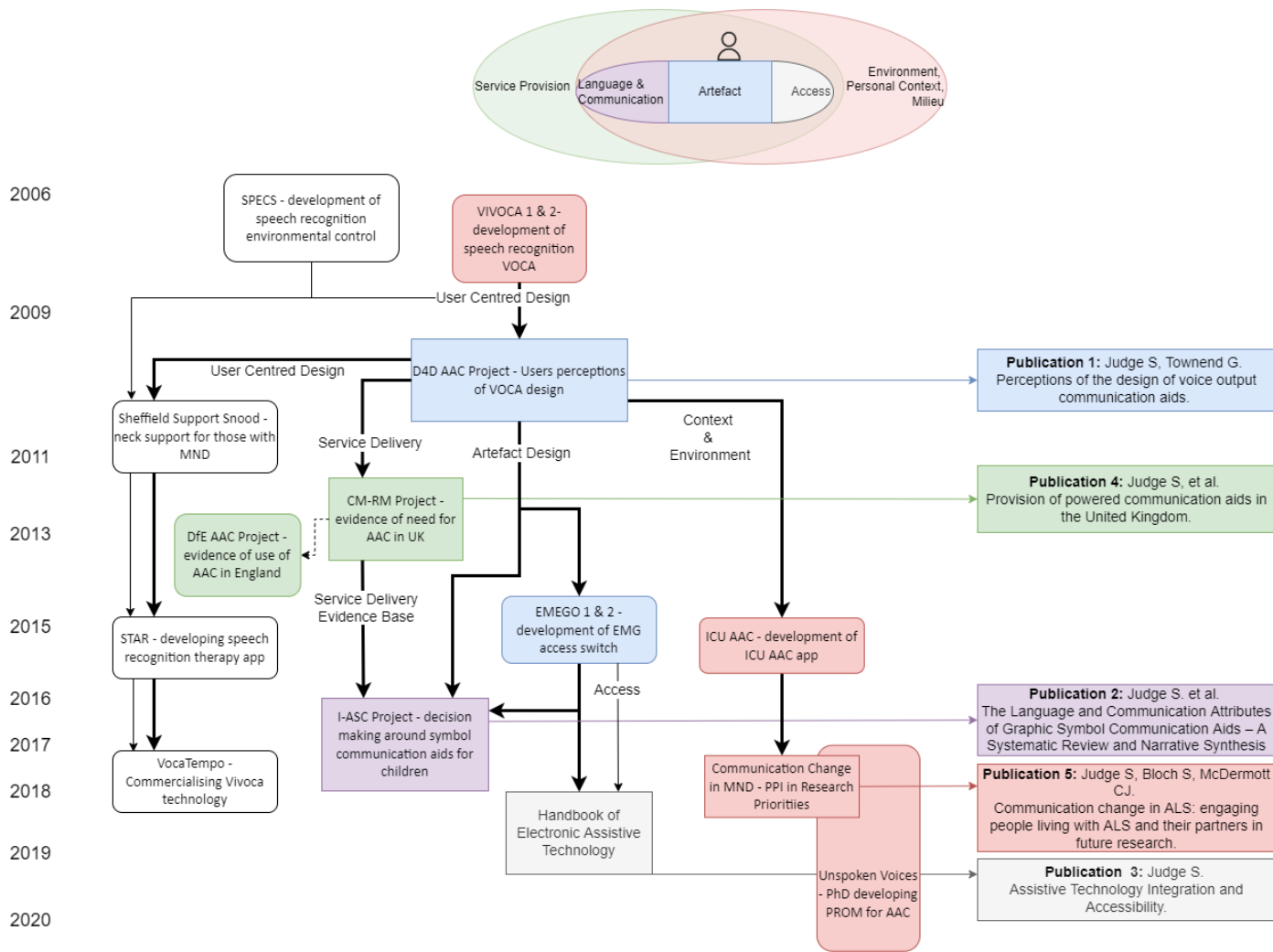
Figure 2 Simplified flow diagram of included papers, related projects (square boxes), other projects (rounded boxes) and key threads of interest.

Methodology

This manuscript differs from a traditional PhD dissertation in that an overall methodological approach was not pre-planned. The methods chosen for each of the related projects were, however, pre-planned (see Table 3), often in collaboration with others (see Appendix 2). The overall methodological approach of this body of work can be described as phenomenological, based on a pragmatic research philosophy, and using predominately qualitative and observational methods. Some studies involved interventions (involving users in the design of devices and then providing the devices for the user to trial and evaluate) and were classified as interventional from the point of view of ethical review, however the method of understanding the effect of this intervention was through observation and qualitative feedback.

Exceptions to this are the study presented in Publication 1 where survey methods were used to gain quantitative data around preferences, and the two experiments carried out in the I-ASC project that provided quantitative stated preference data from participants.

For each project linked to this body of work a conceptual framework was constructed prior to carrying out each study through review of the literature and described in the research protocols. The exception to this was in the ICU AAC work where the Means Reasons and Opportunities model (Money, 1997) was used as the sole explicit theoretical frame.

Balandin and Goldbart (2011) and Kent-Walsh and Binger (2018) describe an evolution in methodologies within the AAC field, from descriptive and experimental designs reporting quantitative results and single case experiments, to a wider methodological base including a growth in qualitative methodology. It is generally accepted that it is challenging to meaningfully design and carry out research to investigate the effectiveness of AAC interventions (Light, 1999; Smith, 2016) and the strength and quality of research within the AAC field can be considered relatively weak (Baxter, Judge, et al., 2012b).

Publication 2 is included in this commentary as a systematic review. Given the context of the research evidence base within the field, systematic reviews need to be carefully constructed and considered in order to be of value. The reviewing method chosen in the systematic review reported in Publication 2 was designed to provide a pragmatic and clinically relevant result from a weak and thin interventional evidence base. The methods chosen in Baxter, Judge, et al., 2012a, 2012b and Broomfield, Judge, et al., 2022 allowed for the review and synthesis of studies reporting qualitative data, an area of research methodology that is still developing (Lucas et al., 2007).

One methodological contribution throughout this work was in ensuring that participants with SLCN could engage in qualitative methods, PPI, and research delivery. One of the outputs of the work described in Publication 1 included resources that could be used to support involvement of those with SLCN and these resources have been subsequently used in clinical practice (Judge et al., 2018). Publication 5 also provides an example of the involvement of participants with SLCN in PPI.

Other authors have considered wider methods and methodologies in discussing ways to strengthen the AAC evidence base including case studies (Murray et al., 2013), service evaluation (Publication 5; Judge and Hayton, 2022), and quality improvement and implementation science (Kent-Walsh & Binger, 2018). The service delivery elements of this work, such as that reported in Publication 4, can be considered to be participatory action research or applied policy research: with myself as a clinician participating in the system that I wished to study and change; with the research directly and contemporaneously informing service commissioning and delivery; and with the work embedded in community based action including voluntary sector organisations such as Communication Matters and the Foundation for Assistive Technology.

Reflexivity

In writing this thesis I have examined the beliefs, judgements, and practices I held whilst carrying out this research. I have a specific perspective that is important to recognise in this work: I am a practitioner (specifically a Healthcare Scientist) working with people who use AAC and I have no direct lived experience of AAC use. I have a vested interest in the status quo model of service delivery remaining,

i.e. that of practitioners (who do not use AAC) owning the expertise, financial, social and organisational capital necessary to provide AAC to those who might need it.

My early practice was working with designers at MERU designing, producing, and providing both custom and commercial assistive devices to the children living with disabilities with whom we worked. This practice was formative in terms of my epistemological and disability advocacy perspectives. My work at MERU was situated in a culture of the social model of disability and we applied design as an explicit reaction to this. This practice rejected the Medical Model focus on impairments and ways in which devices could address 'functional deficiencies'.

My background and training as an engineer is that of having a positivist epistemological approach (Creswell & Poth, 2016). Carrying out research with those who use assistive technology and VOCAs has required me to appreciate a more constructivist approach to research. I have moved from looking to establish significant quantitative results relating to performance in use of VOCAs and other AT to accepting the need to situate the use of assistive technology in its specific context, to investigate the experience of use of this technology, and to then use this and participatory methods to improve design.

Much of the qualitative research I have conducted was carried out from a post-positivist standpoint in that I have sought to understand the lived experience of individuals in order to provide applicable knowledge. The consideration of rigour in qualitative research is a topic of discussion, including in the AAC literature (Balandin & Goldbart, 2011), and my background and standpoint leads me to value rigour and repeatability. It is pleasing to note that work to which I contributed (Mobasheri, Judge, et al., 2016) was cited in Kent-Walsh and Binger's review of AAC methodology as having a robust qualitative method (Kent-Walsh & Binger, 2018).

My professional background, as a Healthcare Scientist working in the field of Clinical Engineering, also clearly has an impact on my approach to this topic and my research. I work in a research and practice field where the predominant profession is of SLT/P with a smaller cohort of engineers and designers. This can be contrasted with an AAC industry formed predominantly of engineers with a smaller cohort of SLT/P advisors or colleagues. My practice has been at relatively tertiary services and thus my experience of those with SLCN using AAC, VOCAs, and other AT, is skewed towards the population accessing these services as well as those (effectively self-selecting) users more active in the AAC and AT communities. Table 1 is sorted in order of the prevalence of individuals on the caseload of the service in which I work in order to illustrate this context.

In this commentary I use the term Voice Output Communication Aids (VOCAs) and I feel this reflects my perception of the role of these devices: in providing 'voice' (and its associations with identity) rather than speech per se (and its associations with articulate sounds); of there being an input and output; of the aim being primarily to support communication; and the devices being an aid and augmenting rather than replacing the other communication methods that an individual will undoubtedly have. This focus does not however discount or devalue the use of VOCAs when they are used for non-voiced communication and indeed the integration of VOCAs, access methods, and other assistive and mainstream technologies, is an area of specific interest and described in Publication 3.

Included Publications

Five publications are included in this PhD by Publication. In the following sections each publication is presented and its relevance to the design of VOCAs and the wider impact of the work noted.

Artefact Design (Publication 1)

VOCAs are physical objects used by individuals to support their expressive and receptive communication and as such VOCAs are designed. The design of VOCAs has been criticised, in common with other assistive products designed for those with disabilities. The design of VOCAs will impact on the capability and motivation of users to use a device, the perceptions of the user by those around them, and the ability of others to support the user in use of it. Without involvement in their design from those who use these devices, designers are likely to produce VOCAs that do not meet the real needs of those living with SLCN.

The study presented in this publication was a mixed method study investigating the perceptions of the design of VOCAs by those who use or could use them (Judge & Townend, 2013). This study involved interviews with 18 participants who used VOCAs, questionnaire responses from 43 people who used, had previously used, or reported considering using VOCAs, and 68 AAC professionals. The study is thus one of the most extensive investigations into users' perceptions of VOCA design. As a mixed method study the results from the qualitative Framework Analysis of interviews and free text responses were triangulated with the descriptive statistics of the survey responses, to which a statistical test was applied to test for associations between 'importance' and 'availability'.

This work contributed a robust and clear, ecologically strong, picture of what users want from the design of VOCAs and demonstrated the need to involve those using VOCAs in their design. The findings highlighted factors that users prioritised in terms of artefact design; with those factors emerging most strongly relating to robustness and reliability rather than highly technical or innovative features. Although the study aims focused on artefact design themes also strongly emerged that related to service provision and the interaction between the device and an individual's context and environment. This work demonstrated that the design of VOCAs can not be considered in isolation from the individual's personal context or environment and the wider picture in which the individual and VOCA are placed.

This work contributed methodologically to the understanding of involvement of people with SLCN in qualitative research, and also in being a relatively large mixed methods AAC study. Within the AAC literature qualitative survey studies appear relatively frequently but mixed methods studies and larger qualitative studies are not common. The resources used in this study were subsequently published as a resource for practitioners to support conversations with individuals about AAC choices (Judge et al., 2018).

The findings of this work subsequently informed the other projects and studies reported in this thesis and were presented at conferences to clinicians, researchers, and industry representatives in the field as well as privately to companies developing VOCAs. This dissemination focused on the need for robust and reliable VOCAs as a key design consideration, and that consideration of the context and environment of use of VOCAs by individuals should inform design and practice. It is difficult to measure direct impact of this dissemination but it is pleasing to note that AAC companies are now advertising devices based on robustness (*Grid Pad 10s Tough Cover - Thinksmartbox.Com*, 2022).

Publication 1.pdf

Publication 1: Judge, S., & Townend, G. (2013).

[Perceptions of the design of voice output communication aids.](#)

International Journal of Language & Communication Disorders, 48(4), 366–381.

Interaction Design: Language System (Publication 2)

VOCAs exist to support individuals in communicating with others and to this end they must provide a means of representation of language that the user must interact with in some way. As such VOCAs have language and communication attributes that are designed into the VOCA software. The provision of vocabulary and language packages is a key design feature of VOCAs. Despite language and communication attributes being a key area of discussion and decision making in practice they have been neglected as a primary focus of study; developments in language and communication attributes have arguably been driven more by technological constraints rather than explicit design choices.

The systematic review presented explores how the empirical research literature can inform VOCA design and practice when considering language and communication characteristics of graphic symbol communication aids (Judge, Randall, et al., 2019). This work was part of the I-ASC project whose overall aim was to study and improve the decision making process relating to the choice of symbol communication aids for children. The aim of this systematic review was to establish what was already known in the literature, from studies with those who use AAC, about the language and communication characteristics of communication aids. This information was then included alongside other forms of evidence in resources, aimed at supporting decision making by practitioners and design decisions that VOCA developers make, related to language and communication attributes.

This review involved screening 1899 papers, assessing 19 using a quality appraisal tool, and thematically analysing the data extracted from the remaining eight papers. Whilst quality appraisal is a standard tool of literature review its application in the AAC field, where the literature includes a variety of experimental and descriptive methods, is infrequent (Kent-Walsh & Binger, 2018). The appraisal tool used was chosen to allow for appraisal and comparison across a range of study methods (Crowe et al., 2011; Crowe & Sheppard, 2011). The synthesis step was also chosen specifically to cope with the anticipated variation in type of study. Both these choices reflected the aim of attempting to draw useful conclusions from the review rather than producing a conclusive lack of evidence statement that a more rigid methodological approach may have produced.

The review identified a small number of attributes reported as investigated in the literature but also highlighted the weak foundation of evidence on which consideration of the impact of these attributes is based. The findings of this review contribute to the understanding of the decision making picture to which practitioners are faced on a daily basis, and also the challenge that VOCA designers have in developing language representation and interaction methods for VOCAs.

Publication 2.pdf

Publication 2: Judge, S., Randall, N., Goldbart, J., Lynch, Y., Moulam, L., Meredith, S., & Murray, J. (2019).

The Language and Communication Attributes of Graphic Symbol Communication Aids – A Systematic Review and Narrative Synthesis.

Disability and Rehabilitation: Assistive Technology, 15(6), 652–662.

Interaction Design: Access (Publication 3)

VOCAs, as with any computer, are useless without an interaction method. For those with physical disabilities interaction with technology often involves access equipment and techniques that are not those originally envisaged by the system designers (i.e. alternative access methods). Access is thus a key aspect of VOCA and assistive technology design.

The book chapter presented aims to support the training of new clinicians, technologists, developers, engineers and others in assistive technology. The training of new assistive technology practitioners is key to providing effective support to those using VOCAs (Norrie et al., 2021). Access, HCI and Accessibility are core areas of practice in which these professionals, working in trans- and inter-disciplinary teams, can contribute. This chapter is included in this body of work to highlight the importance of access in any model of VOCA design. This chapter is also included in order to demonstrate the impact and role that Healthcare Scientists, Practitioners, and Technologists have in this area of AAC and AT practice.

This book chapter describes integration of access methods. Integration would traditionally be defined as operating multiple devices from a single access method, however this chapter contributes to the understanding of access and accessibility by highlighting how integration of access links with (technology) accessibility. Assistive technologies have, previously, been the way that alternative physical access to technology has been mediated, but this construct is being challenged more by 'baked-in' accessibility options in operating systems that support alternative physical access methods. There is a complex interaction between assistive and accessibility design considerations; for example switch scanning is now part of the Android and Mac OS operating systems, but Google and Apple do not make switches and the exact nature of the scanning methods varies between operating systems.

This chapter contributes to the shift in understanding of VOCA and other assistive technology access methods: to extend the conceptualisation of assistive technology access to include accessibility. This aligns with the need highlighted by others to train software engineers in assistive technology and accessibility (Waller, 2019a). This chapter also highlights the complexity in design relating to how the user, with their access method, interacts with the VOCA software and operating system; and that VOCA developers are increasingly both constrained and enabled by operating systems' accessibility architecture.

Publication 3.pdf

Publication 3: Judge, S. 2019.
[Assistive Technology Integration and Accessibility.](#)
In D. Cowan & L. Najafi (Eds.), Handbook of Electronic Assistive Technology (pp. 289–310). Academic Press.

Service Delivery (Publication 4)

As a technology VOCAs are dependent on a system of service delivery for all aspects of their use and lifecycle. Service delivery of VOCAs emerged as a key consideration that could not be separated from the other aspects of device design in the work reported in Publication 1. The explanatory model of data collected in the I-ASC project (Murray, Judge, et al., 2019) also highlights service provision as one of the competing considerations in decision making around VOCA choice. It is thus suggested that the context of service delivery should be a factor considered in VOCA design. As an example consider the utility of an otherwise well designed device that breaks down and cannot be fixed, or a device that is considered too complex to setup by those with responsibility for assessing and providing equipment.

Delivery of VOCAs is via a highly distorted market, much of this delivery in the UK is within the NHS which in itself is a distorted market where there is a lack of effective ability *for "patients to drive change by consumer choice"* (Bevan & Ven, 2010, p. 347). VOCA use is not indicated by any specific etiological markers and little was known about the incidence and prevalence of use or need of this intervention. Prior to the work reported in this paper UK AAC service provision was poorly understood and this hampered commissioning and service design, and provision of VOCAs.

The paper presented here focused on understanding service delivery and the population using VOCAs (Judge, Enderby, et al., 2017). The aim of this work was to inform changes in commissioning and design of services; and to inform VOCA designers and companies of the current and potential market for VOCAs, the characteristics of those who make up this market, and the nature of the service delivery system used to provide these devices. The study involved obtaining robust survey data from 98 services that provided AAC across the UK and using these data to provide quantitative estimates of VOCA need and use.

There is little epidemiological work within the AAC literature and this paper contributed data from a robust observational epidemiological method. These data could be compared and combined with linked work using a literature based epidemiological method (Creer, Judge, et al., 2016). The major contribution of this work was to provide population level estimates of AAC use: the study highlighted a large variation in estimated levels of use of VOCAs (defined in this work as powered communication aids) with a mean value of 0.0155% observed as compared to a 0.05% level of estimated need. Data recording and reporting within services was weak as only 28% of responses were retrieved from database extracts.

These data had significant impact and directly informed campaigning, commissioning and eventually structural changes in national AAC service commissioning (NHS England, 2015). These data provide a comparative, baseline, indication of use for any future studies looking at the impact of the 2014 commissioning changes or otherwise investigating the epidemiology of AAC and VOCA use. These data also provided VOCA developers and suppliers with a better understanding of the services to which they were selling VOCAs and the population of individuals using them, and thus directly informed design decisions.

Publication 4.pdf

Publication 4: Judge, S., Enderby, P., Creer, S., & John, A. (2017). Provision of powered communication aids in the United Kingdom. Augmentative and Alternative Communication, 33(3), 181–187.

Personal Context and Environment (Publication 5)

Communication is an interaction that involves partners and takes place in a society and culture. Effective communication is highly dependent on all of these to be successful. The outcome of AAC mediated communication might be seen to be transactional, but a wider view places the individual using AAC within their environment and context and in having dialogue, telling narrative stories, and building social closeness and belonging. The design of VOCAs should encompass these desired outcomes and take into account the environment and context in which the communication is occurring.

The paper presented describes the outcomes of PPI work with people living with Motor Neurone Disease (MND) in identifying research priorities relating to VOCAs (Judge, Bloch, et al., 2019). Similarly to the work presented in Publication 1 the initial hypothesis when initiating this work was that potential VOCA features such as voice banking would be identified as research priorities. While aspects of preparedness for communication change relating to technology were identified as research priorities, wider research priorities relating to the role of life/communication partners were also strongly identified.

This paper is included within this thesis as a further example demonstrating that VOCA design cannot be viewed in isolation from other factors of environment and personal context. This work highlighted the importance of considering factors such as the impact of an individual's communication change on a life partner, the individual's willingness to anticipate change and prepare and a partner's support of this, and different attitudes by those living with MND and their partners to adapting to communication change including through use of AAC.

Focus groups are a commonly used part of qualitative research methodology but infrequently reported in research or PPI with those with SLCN. One of the aims of this work was to trial the use of focus groups as an involvement method for those living with MND with varying levels of speech involvement. The focus groups were conducted successfully and demonstrated the potential of this as an effective method for this cohort, and in addition the focus group discussion in itself appeared to provide some benefit to participants.

A growing movement asserts that research priorities should be set by those with lived experience. Other authors have carried out work to identify research priorities of those who use AAC and others have investigated perceptions of AAC use for those living with MND but this work was the first to explicitly identify research priorities of those living with MND regarding VOCAs and communication. Rather than providing a list of new technologies to design this work suggests that VOCA designers should focus on how VOCAs can support those living with MND in anticipating and preparing for communication change (at differing rates and with differing attitudes to change), adapting to changes throughout the disease course, and in designing VOCAs that better include and support the partner in the communication process.

Publication 5.pdf

Publication 5: Judge, S., Bloch, S., & McDermott, C. J. (2019). Communication change in ALS: Engaging people living with ALS and their partners in future research. Disability and Rehabilitation: Assistive Technology, 14(7), 675–681.

Commentary

Design is commonly thought of as being concerned with the physical appearance of a device but it is now well accepted that design and design thinking can be more widely applied to consideration of interactions with an artefact as well as with systems, society and the lived environment (Norman, 2014, 2016). Design within the context of healthcare is an established field and discipline (Chamberlain & Craig, 2017).

Design is a mechanism for being able to think about artefacts and products such as VOCAs and how they meet the needs of their users more broadly. The effectiveness of meeting the needs of users is encompassed in the concept of usability. Norman, in his seminal book The Design of Everyday Things (DoET) considers usability of products and analyses how objects *afford* certain actions that a user might, if they perceive and understand these affordances, carry out in order to be able to achieve an objective (Norman, 1998). What is usable to one individual (e.g. the designer of a product, or someone like them) may not be usable to others and so all products will be accessible to some degree to a cohort of users and inaccessible to others.

Usability is defined in the ISO standard (ISO 9241) as the *"extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO, 2018). Usability thus draws focus onto consideration of the specified users and the goals these users wish to achieve. To investigate how usable a product such as a VOCA is we need to be able to understand who it is being designed for and what they are intending on doing with it. A consideration of usability also requires a designer to consider what effectiveness, efficiency and satisfaction mean in the context of the product and how these might be defined and measured. Whilst these might seem self-explanatory and simple to conceptualise for many products, and maybe even for VOCAs, this commentary will unpack these considerations when considering VOCA design and present the challenge and opportunity that considering the design, and consequently the usability, of VOCAs presents.

Human-Computer Interaction (HCI) encompasses the study and design of methods with which an end user interacts with a computer to achieve a goal. This cross disciplinary field of study and practice has evolved since the formative work of Card et al. (1986) to encompass wider fields such as user experience and interaction design. HCI has a strong theoretical foundation and models based on this theory of human interaction and processing are used to predict performance of users in interactions.

It is now well recognised that early and meaningful involvement of individuals in the design of products and services intended for them is important. Norman also espoused in DoET the concept of user-centred design in focusing on the needs of the user (Norman, 1998), and later evolved this thinking to incorporate wider considerations including how behaviour and emotional connection with products affects their use and usability (Norman, 2004). Many areas of investigation, under the umbrella of human centred design, have emerged looking at how user focus and/or involvement in design can most effectively produce better designed products. Sanders & Stappers (2008) summarise the current landscape of human centred design research illustrating this as a two dimensional landscape with one axis representing user involvement (user as subject to user as partner) and the other axis methodology (led by research to led by design). Sanders & Stappers (2008) also describe a human centred design method as involving a growing emphasis on the front end of 'pre-design' with the goal of understanding what should be designed and gaining, through involvement, an understanding of users and their contexts of use. The Design Council's

Double Diamond is possibly the most well recognised design methodology in the literature and practice. The recent evolution of this design methodology includes a greater emphasis on co-creation, collaboration, and engagement, as well as the core aspects of iteration of design (Design Council, 2019). Whilst human centred design is recognised by many as beneficial in practice it is far from ubiquitous; Sanders & Stappers argue that it has taken time for participatory design to have an impact because it *"has been seen as academic endeavour with little or no relevance for the competitive marketplace"* (Sanders & Stappers, 2008, p. 10).

This commentary considers how usability, human-computer interaction and human centred design, relate to Voice Output Communication Aids, examining these concepts from the perspective of the aspects of VOCA design investigated in the included publications.

Context of VOCA Design

The challenge of designing VOCAs was identified early in the emergence of AAC as a field (Newell, 1987) and the challenge continues to this day: Light et al. critiqued VOCA design and highlighted *"that traditional AAC technologies may not be optimally designed to meet the needs of all of these individuals"* (Light et al., 2019, p. 4); Waller suggested the need for a *"paradigm shift in the design of AAC technologies"* (Waller, 2019b, p. 159)*;* while Pullin identified the potential role of designers from a range of disciplines in AAC (Pullin, 2009) and subsequently discussed the need to consider AAC from the perspective of interdisciplinary design (Pullin et al., 2017).

Since their first use in the 1970/80s VOCAs have transformed in many ways, supported by the ongoing developments of consumer electronics and software. As Light et al. state *"The development of the first AAC technologies more than 30 years ago primarily reflected what was technologically possible at the time combined with the ingenuity and creativity of clinicians and manufacturers"* (Light et al., 2019, p. 4)*.* Early VOCAs were based on microcontrollers or computers running dedicated software, often with separate electronic systems for speech synthesis, and with physical keyboards with text or graphic symbols displayed on the keys (Low & Beukelman, 1988; Vanderheiden, 2002). These technological constraints required that the language packages of initial VOCAs using graphic symbol representations were pre-loaded into the devices. The constraint of a fixed keyboard also required that the keyboard overlay was designed to contain all the information required by the user to be able to decode the intended output. Graphic symbol systems developed at the time achieved this through encoding multiple meanings into symbols (Baker, 1982; Tenny, 2016). The link between the symbol, language package and the communication aid in these systems was thus deeply intertwined.

Display technology developments, in concert with increasing processor power, facilitated the portable computer epoch and provided a new set of technological constraints and opportunities for VOCA designers. This second generation of VOCAs were based on early tablet computers, had display screens, were less likely to have hardware keyboards, and in some cases to some degree exposed the underlying operating system. This change in how VOCAs were designed precipitated discussions within clinical practice (Millar et al., 1999; Romich, 1999) and the research literature (Dudek et al., 2005; Hochstein et al., 2003) about the benefits of dynamic or static systems for different clinical groups or situations. These devices are some of the first examples of the use of on-screen keyboards, a now ubiquitous concept and application. Screen based VOCAs provided the potential for the key symbol to change based on the user's input and thus removed the constraint for the key/symbol to encode all the information. Single meaning

graphic symbol representation sets could be more easily included and displayed in their full extent, by allowing navigation through pages of symbols on the screen (the computer equivalent to turning pages in a paper communication book). Rather than pre-loading vocabulary packages into devices the increased computing power and memory allowed for AAC software to support self-creation and editing of vocabulary items. For many this process is still known as programming, a semantic legacy of the more involved, low level, process previously required to edit vocabularies.

With the emergence of smartphones and tablets, such as iPads, AAC software and the underlying operating system of these devices was further exposed and made available in VOCAs. Incremental technological changes such as internet connectivity, capacitive (rather than resistive) screens, processing power and battery life combined with mainstream design and adoption to create a new technological category – and one that the AAC field and industry rapidly mobilised to attempt to take advantage of. The increasing accessibility of app development resulted in the creation of many more AAC apps (McNaughton & Light, 2013), however it can be seen that frequently these AAC apps were launched with no structured or substantial vocabularies and many did not become established in practice.

Challenge of VOCA Design

Those using VOCAs often experience them as slow, ineffective at communication, and challenging to access (Broomfield et al., 2022; Publication 1). One response to this challenge is to develop and investigate interventions that aim to improve individuals' use of VOCAs. Considering VOCA design in a user, rather than a technology or intervention centred way, also clearly offers scope to improve the experience of those using VOCAs.

The study and investigation of VOCA design seems little considered in the AAC literature. Studies may describe potential implications for design but these are often not then considered from the perspective of design. Johnson et al. (2006), for example, described the results of a survey of SLT/Ps on the success of use of AAC and identified system characteristics and poor fit as factors but did not discuss, consider, or investigate, how changes to VOCA design might address these perceived limitations on AAC success. Light et al. posit in their discussion paper that *"research is required to examine the cognitive, linguistic, social, sensory perceptual, and motor demands that are imposed on the end-users"* (Light et al., 2019, p. 5). Whilst seemingly supporting a focus on VOCA design this statement itself could be perceived as highlighting a reluctance to discuss VOCA use in terms of design, with emphasis being placed on the adoption and implementation of the device by the user rather on the design of the VOCA or specific VOCA attributes that may maximise outcomes.

Many studies reported in the AAC literature note implications for the design of VOCAs as a finding. Evaluating specific design choices and compromises and the impact and effect of specific VOCA design choices on AAC outcomes is, however, infrequently an explicit topic of studies in the AAC literature. For example in a study of older adults' story telling Stuart suggested implications for design but these suggestions were untested (Stuart, 2000). Newell (1987) proposed design strategies and highlights the interdisciplinary nature of successful VOCA design but interestingly did not mention designers; similarly, in discussing opportunities for the field and AAC technology development, Light et al. noted the lack of *"researchers, engineers, and technical developers"* (Light et al., 2019, p. 3) but not designers. Blackstone et al. identified the role of design but limited it to the need to *"use ergonomics in the design and development of AAC technologies and instructional strategies"* (Blackstone et al., 2007, p. 191); and whilst Light et al

discussed VOCA design by comparison with mainstream toy design, this work looked only at what are essentially aesthetic aspects of design (Light et al., 2004).

Some authors have carried out work to establish design considerations relating to VOCAs, for example Light et al worked with children who did not use AAC to identifying design ideas that might be applied to AAC design for those who do use AAC (Light et al., 2007), and Pullin used artefacts to provoke and challenge ways of thinking about VOCA design (Pullin, 2009, 2013). There is also a significant literature exploring the design and development of novel VOCAs, for example: Waller et al. considered how VOCAs might be designed to better support narrative (Waller & Newell, 1997) and developed VOCAs to investigate this (Black et al., 2010; Waller, 2019b); Mobasheri, Judge, et al. (2016) and MacAulay et al. (2002) considered design of AAC and VOCAs in the context of ICU; and Hawley et al. (2013) considered the design of voice input VOCAs and developed systems to investigate the design of this novel interaction method.

VOCA design has changed since the introduction of the first communication aids and it is often cited that the AAC field is rapidly changing technologically (Baxter, Judge, et al., 2012a; Lund et al., 2017; McNaughton & Light, 2013) with the implication being that design of VOCAs is rapidly changing. This perception of rapid change warrants inspection from the perspective of VOCA design and particularly from the perspective of the design factors considered important by those who use VOCAs as highlighted in Publication 1. For example, Publication 1 highlighted that factors such as robustness were critical to end users; examining this by comparison between a 1980s Lightwriter and 2020s iPad being used as a VOCA it is clear that robustness may not have improved.

Human Centred VOCA Design

Toby Churchill, the creator of one of the formative text-based VOCAs, was himself someone who used AAC and this VOCA was clearly early evidence of the impact of user led design. It is not clear however that human centred design is established as a recognised method in VOCA design or what involvement users have. As an example, despite an editorial forum note in the AAC journal concluding that *"concerted research and development is required to design a whole new generation of AAC technologies reflecting principles of user-centred design utilising the tenets of human-computer interface research"* (Light & McNaughton, 2013, p. 306), the AAC journal has a total of five articles mentioning user or human centred/centered design.

One reason for the scarcity of genuine human centred VOCA design may be the challenges, and perceptions of challenges, relating to engagement with those with communication difficulties (Nind, 2008). Waller et al. asserted that effective user centred design would be improved through the training of those who use AAC in the principles of user centred design and carried out workshops to achieve this (Prior et al., 2011; Waller et al., 2005). Barring a few exceptions, however, this demonstration of supporting end users of AAC to have meaningful, rather than tokenistic, involvement in the design process has not subsequently resulted in an increased uptake or reporting of this method in the literature.

Arguably the most basic form of involvement in design involves asking users/customers/consumers what they think about the artefacts that they are using. Prior to Publication 1 little work had previously been carried out with those who use VOCAs to understand their experiences of design. O'Keefe, Brown, and Schuller (2009) also carried out (around the same time) a survey based ranking exercise, including 19 participants who use VOCAs in establishing a prioritised list of VOCA features from a pre-conceived list of

209 items. Comparing the findings from this study to those in Publication 1 highlights similarities: the top three features rated by those using VOCAs in the O'Keefe et al. study also related to robustness and reliability. Both studies also highlighted some differences between the stated priorities of those using VOCAs and others involved in their support. Overall, these studies provide a picture of the stated preferences of end users, and so provide a strong initial basis on which VOCA designers could review designs and design decisions.

This type of stated preference study contributes to human centred design, but can not be considered participatory design. It is not clear that those developing VOCAs systematically involve end users in the design process. Other authors have highlighted the importance of human centred and participatory design in the design of VOCAs (Tönsing et al., 2022a) and there is well established discussion of the role of participatory design methods in assistive technology (Harris, 2017; Newell et al., 2011; Poulson & Richardson, 1998). The literature discussing participatory design within the AAC field appears largely absent in practice and research however; in reviewing the literature related to design of symbol communication aids Tönsing et al. (2022) conclude that the application of human centred design approaches is still limited, and that the role of stakeholders in the design process tended to be informative rather than collaborative.

The population of those who use AAC is acknowledged as hard to reach and engage with (Nind, 2008) and a key aspect of the involvement of those who used AAC in the study reported in Publication 1 and 5 as well as work in the I-ASC project (linked to Publication 2) was aiming to make this involvement as meaningful as possible and also to ensure appropriate authorship. It has been clearly shown in this and other work that 'hard to reach' should not mean impossible to reach or engage with. If these two points are linked is not clear, i.e. if the perceived challenge of involving those with SLCN is linked to the limited uptake of human centred participatory design approaches, and the picture is likely more complex than this. The work included here does however demonstrate the potential to include those who use VOCAs in design processes as well as demonstrating the value in doing so.

Human-Computer Interaction with VOCAs

It might be assumed that the field and practice of HCI and related disciplines such as Interaction Design would have a significant impact on VOCA use and design. Higginbotham et al. (2007) suggested that Norman's DoET book influenced those researching and manufacturing VOCAs, however there is little direct evidence of this in the empirical literature. Ibrahim et al. explicitly considered VOCA design from an HCI perspective in carrying out a qualitative video study of children in a special school setting and suggested that *"to date this research has not 'talked back' to interaction designers tasked with designing AAC and new technologies for children"* (Ibrahim et al., 2018, p. 1). Publications within the HCI and Computer Science literature sometimes cover AAC topics and occasionally novel interaction or rate enhancement techniques are developed and published (e.g. Bonaker et al., 2022; Fiannaca et al., 2017; Mackenzie & Felzer, 2010; Wills & Mackay, 2006) but there seems little linkage of this work into AAC practice.

HCI has a strong theoretical basis that appears absent in the consideration of VOCA design. Higginbotham and Caves (2002) address this through presenting a model of (VOCA) device mediated communication performance in conversation. This model integrates HCI models such as GOMS (Card et al., 1986) and provides a theoretical perspective that Higginbotham and Caves proposed could lead to conversational analysis techniques that would highlight VOCA usability issues and potential design

improvements.   Newell et al. (1992) contested the nomothetic approach of one of the small number of AAC modelling studies in the literature (Horstmann & Levine, 1990) that applied models based on the performance of those without physical disabilities to those with physical disabilities. Whilst not discounting the potential usefulness of modelling to illuminate VOCA design this response highlights the challenge of ensuring modelling has ecological validity and also highlights the lack of available data on which AAC user specific models might be built.

Usability of VOCAs

The hypothesis of this work is that VOCA design requires specific consideration in terms of usability. Schemas or heuristics used in other HCI or technology design can not be unthinkingly transferred to VOCA design. VOCAs have a unique set of users with unique interaction constraints, aiming to achieve a set of goals (face to face communication) addressed in no other area of technological design.

Successful VOCA use is influenced by a range of factors. The systematic review by Baxter et al. provides an insight into the barriers to VOCA use, highlighting a range of factors: *" ease of use of the device; reliability; availability of technical support; voice/language of the device; decision-making process; time taken to generate a message; family perceptions and support; communication partner responses; service provision; and knowledge and skills of staff"* (Baxter, Judge, et al., 2012a, p. 115). Using VOCAs for communication is an additional demand on an individual and an additional skill that the individual needs to learn (Light, 2003; Murray et al., 2016). VOCAs are used in conversations and so the communication partner also plays a key role in a VOCA being used successfully (Bloch & Wilkinson, 2011; Smith & Connolly, 2008). Lynch, Judge, et al. (2019) and Murray, Judge, et al. (2019) also identified many factors that funnel and influence decision making around VOCA choice and use: identifying competing considerations (access & communication aid attributes and individual characteristics), as well as cultural and contextual influences (ways of working, transitions, available resources, and team knowledge and skill).

The challenge of communication using a VOCA is not the same as the challenge of other ICT communication such as email or text messaging. Higginbotham & Caves (2002) highlight a number of the unique conversational challenges that those using VOCAs face, whilst Clarke & Wilkinson (2005) present data from Conversation Analysis of a peer interaction. Clarke and Wilkinson highlight VOCA turns that can be vulnerable to problematic understanding in conversation, suggesting that VOCA usability can be evaluated against a reduction in these problematic turns. The body of work presented here also highlights two usability considerations that set apart VOCA design from the design of other HCI systems: the need to use alternative methods to access and control communication; and the need to design communication software with language and communication attributes that support expressive and often receptive language.

Usability requires an understanding of the user, the specified goals, what constitutes effectiveness, efficiency and satisfaction, and the specified context of use. Tönsing et al. (2022) reviewed published AAC system designs against human centred design principles from ISO 9241 (Part 210, 2019); at the core of these principles is an understanding of the human, task, and context and these are now examined in the context of VOCA design and this body of work.

Publication 4 and related work contributed to a better understanding of the aetiologies of those who use VOCAs and highlighted the diversity of conditions that may lead to the need for AAC use. However, an aetiological description of those who may use AAC is not necessarily useful from the perspective of design. As well as varying aetiologies, there is variation in presentation both within and across aetiologies. Considering SLCN from the perspective of possible use cases of a VOCA highlights the diversity of possible users of a VOCA:

- Dysarthric or anarthric speech are the predominate SLCN symptoms that indicate the potential for use of a VOCA. Anarthria refers to the absence of speech sounds. Dysarthria refers to difficulty in making speech sounds (Enderby, 1980) that can lead to difficulties with intelligibility (the ability for others to understand speech) and understandability (the ability of others to make meaning from speech (Bloch & Wilkinson, 2009)).
- Challenges with learning, understanding, or using language can also be experienced by those who may benefit from VOCAs. For example, some children born with Cerebral Palsy need additional support in learning written language, some adults who have had a Stroke may have word finding difficulties that affect their ability to use language expressively (Beukelman & Light, 2020).
- As a dialogue with others, communication is fundamentally affected by an individual's ability to speak or process language. Individuals with SLCN do not experience universally supportive communication partners or environments and so, unless social contact is reduced to those who can act as effective communication partners, those with SLCN will likely experience problematic communication and have to adapt their communication according to the situation (Smith & Connolly, 2008).
Using a VOCA in communication affects the rate of speech production as well as other factors including message length, grammatical complexity and expression of identity. All these factors can impact on the effectiveness of communication and perceptions of competence, informativeness, and value by those communicating with someone using a VOCA (Hoag et al., 1994, 2004).

It is important to note that whilst the SLCN symptoms are listed separately above they are often experienced in combination, and often in combination with challenges in other aspects of life. Difficulty with learning and processing information can impact on the acquisition of the skill of VOCA use (Smith & Murray, 2016), while associated physical disabilities can impact on the ability to access technology using conventional input/output devices and thus require the establishment of alternative methods of control of VOCAs.

Speech is something that speaking children learn through the intensive exposure to spoken language in their environment in the first few years of life, and the trial and error of babble and early speech and language development. Whilst children with Complex Communication Needs will still be exposed to spoken language, difficulties with speaking mean that their experience of learning expressive communication is significantly and materially different. Those who acquire communication difficulties in later life will have experience of speech; the process of loss of this speech, itself a traumatic event, results in the need to learn a method of communication with which they are not familiar. Many of those who use VOCAs will have associated physical disabilities that mean that they are unable to use, or have challenges

with, standard technology interfaces (in terms of a VOCA a standard interface would be a physical or on-screen keyboard and/or a physical or touchscreen cursor). Even those using a VOCA without any physical difficulties are required to learn to use their fingers to control a keyboard to communicate, something tangibly different in many ways to the evolutionarily programmed method of using one's mouth. This requirement to learn specific, additional, skills to control a VOCA and communicate is termed an operational skill by Light and McNaughton (2014).

Control of a VOCA is an operational skill that people who use speech for communication do not need to consider and a specific design consideration related to the specific needs of those using AAC that is fore-fronted in AAC and assistive technology design. Access methods capture the intentional movements of a user and translate these into signals that the VOCA/computer can use in order to control the AAC software and thus production of speech. Switch access to AAC and technology is a significant area of access consideration in use of VOCAs and other assistive technologies (Judge & Colven, 2006). Access methods to date have largely been considered as a standalone and assistive product and have based on physical interfaces, i.e. requiring physical actuation, and requiring specific separate assistive software to operate. Publication 3 challenges the conceptualisation of access methods as assistive and highlights that increasingly access is being implemented as an element of (operating system) accessibility. It is likely that access will evolve to include increased use of sensors and machine learning and Table 2 provides a taxonomy of current and innovative access methods.

Higginbotham et al. provide a conceptual framework for considering AAC access and note that *"AAC access entails a complicated interrelationship between the features of the AAC technology, the individual's physical (motor, sensory, perceptual) ability, cognitive/linguistic skills, and device users and their communication partners' abilities to interact and communicate"* (Higginbotham et al., 2007, p. 243). The I-ASC model of AAC decision making, based on data from practitioners making AAC decisions, suggests that access considerations often drive decisions about VOCA recommendations, suggesting that access may be prioritised over other 'competing considerations' such as the language attributes of a VOCA (Murray, Judge, et al., 2019). Despite this Tönsing et al. (2022) highlight that, in reviewing published studies of VOCA design, few studies explicitly considered the impact of alternative access methods on the VOCA design.

Task

The task those using a VOCA are attempting to achieve may, on first inspection, seem clear and easy to define; the term Voice Output Communication Aid suggests an input of written language, producing an output from the aid of 'voice', leading to an outcome of communication. The task of VOCA use is however more complex in many respects.

It may be assumed that individuals who use VOCAs do not communicate via speech or other methods and this view also appears to some extent in the AAC literature (Beukelman et al., 2007; Pennington, 2008). The Total Communication approach challenges these assumptions and values the range of different communication methods and approaches that an individual may have, and which may vary according to the communication partner, environment, context, or other factors. The vast majority of those, if not all, who use VOCAs will use a variety of means of communication including speech, gesture, and partner support in conversational interactions (Z. Clarke, Judge, et al., 2023; Murphy et al., 1996; Smith, 1994; Smith & Connolly, 2008). Thus the task of VOCA design should, it is argued, not be to provide

the totality of communication for an individual (to replace communication that would otherwise be verbal) but to support communication interactions.

Those who use VOCAs do so to achieve better outcomes, but describing the outcomes of VOCA use is more challenging than it might seem. As well as outcomes relating to communication, individuals value wider outcomes such as participation, inclusion, education, or employment. Ripat et al. (2019) and Broomfield, Judge, et al. (2022) investigated the perspectives of those using AAC on the meaning of, and outcomes from, VOCAs. Outcomes relating to the use of the VOCA itself were identified (e.g. 'It's an inefficient voice' , 'It's my voice' (Ripat et al., 2019)) but outcomes also included the impact of using a VOCA on areas such as social participation, empowerment and closeness (e.g. 'Enhanced interactions', 'More than a voice' (Broomfield et al., 2022)). Smith and Murray (2011) used the metaphor of a parachute jump to describe the goals and outcomes of use of a VOCA and include the lack of a rip-cord to highlight that experiences of using a VOCA may, without the right support, sometimes result in failure.

Learning language is also often an explicit or implicit aim of AAC and VOCA use (Light, 1997). How the aim of language learning integrates with these other goals or outcomes is part of open debate in AAC practice and literature. For example, some authors advocate that learning of literacy should be a universal aim and that literacy will ultimately provide a more effective communication method than other graphic symbol based options. A VOCA orientated around learning of language (e.g. one with vocabulary arranged semantically) may be less usable for communication than a VOCA with vocabulary arranged to support communication (e.g. arranged pragmatically). Participants involved in supporting those using symbol based VOCAs in the study by Judge et al. (2022) described some vocabulary packages as being literacy based, or promoting literacy, and other packages as evidence based in other ways. However it is clear from the review in Publication 2 that there is a lack of empirical research investigating the effect that VOCA attributes have on language learning or communication. This potential conflict between the two vying tasks task of language learning and communication is played out in the design of VOCAs.

The role of face to face communication in society has changed over this period and other communication media such as text messaging, email, social media, and gaming are now equally, if not more, important to those with SLCN (Blackstone et al., 2007; Hynan et al., 2014, 2015). As highlighted in Publication 3 accessibility of operating systems allows those who would have been considered as AT and VOCA users to use the accessibility architecture of operating systems to achieve a range of goals, many of which would be classified as AAC. Those using these accessibility features may not identify as AAC or AT users and are likely to have an experience that is materially different to others. The scope of what a VOCA is has also thus become much broader and voice output may represent only one of a range of communication goals from the use of a VOCA, access, or accessibility tools.

To be able to measure the effect of a design change on the effectiveness of achieving a task with a VOCA requires outcome measurement. There are no established Patient Reported Outcome Measures that investigate AAC outcomes (Broomfield, Judge, et al., 2019) and a limited range of outcome measures are reported in studies in the literature. Outcome measures used in studies tend to focus on measures of efficacy and didactic exchange such as information carrying words, number of turns, and type of turns (Calculator, 1999; Lund & Light, 2006) and what are effectively information theory measures such as letter/word/utterance rates, bits per character and error rates (Mackenzie & Felzer, 2010; Roark et al., 2015; Todman, 2000). Abandonment, or non-use, of VOCAs is a measure that is frequently cited in the literature (Johnson et al., 2006; Lasker & Bedrosian, 2001) but one that assumes that VOCA use is an

outcome in its own right and does not in itself support any depth of understanding of individuals' desired or achieved outcomes. Light (1989, 2003) and subsequently Light and McNaughton (2014) introduced the concept of communicative competence; although not a formal outcome measure, this model is widely cited in the literature when considering outcomes. Communication competence focuses on the individual (as having competence in different ways) and this is in common with other frameworks that are sometimes referred to in reference to outcome measurement such as Blackstone and Berg's Social Networks Communication Inventory (Blackstone & Berg, 2004), and the Means, Reasons and Opportunities model (Money, 1997). The use of these as measures is thus arguably conceptually inappropriate when considering outcomes of VOCA design choices. The Therapy Outcome Measure (TOM) includes an AAC specific measure based on the International Classification of Functioning, Disability and Health framework; the TOM AAC measure (Enderby, 2013) is administered by the therapist providing an AAC intervention, and is sensitive to the overall intervention, but is also not designed to measure changes in VOCA design.

Measures of storytelling, narrative, partner engagement, and social closeness etc. that might be sensitive to the impact of VOCA use on wider outcomes, appear to be largely absent. These different perspectives on the outcomes of VOCAs as an intervention reflect not just the nuanced role of this technology in individuals' lives but also the challenge of clinical practice, research, and also design. How does a VOCA designer know they have done a good job?

Another aspect of the uniqueness of the AAC task being achieved by VOCAs relates to the need to represent language on the device, and specifically the need to represent language and allow those who are not literate to access it. Since the inception of the AAC field development of AAC language packages has been intertwined with VOCA hardware development. The initial constraints of overlay displays on VOCAs drove the creation of the supportive environments required for children and young people to learn these systems successfully and many expert AAC users emerged; however the threshold of learning required to master these systems also meant that for many these systems were inaccessible. Display based systems provided the ability to lower the cognitive demands for learning and using these VOCAs; however introducing a range of AAC languages into environments reduced the ability to create favourable language learning environments. Finally, the ability to create vocabulary packages from scratch created an explosion of available vocabularies, and it may be that this explains a large portion of actual complexity referred to when practitioners and others discuss the complexity of VOCA choices and developments. Publication 2 highlights the lack of empirical research evidence supporting design or practice decisions relating to language and communication attributes of VOCAs. VOCA designers do not have a strong empirical literature on which they can make judgements around what features a VOCA should have. How does a designer evaluate whether the language and communication attributes that they have designed into their system are usable?

Publication 2 also highlights that the usability of AAC systems used in practice has not been studied empirically. Judge et al. (2022) demonstrated the importance of the vocabulary packages in the decision making of practitioners and those around children and young people using graphic symbol AAC; however the literature review of Tönsing et al. (2022) on studies of graphic symbol AAC system design highlighted the limited consideration of vocabulary organisation and selection in these published studies.

Context

The findings reported in Publications 1, 4, and 5 highlight the importance of considering the environment in VOCA design. The interaction between VOCA use, the physical and social environment (milieu), and the impact of service provision, is now well established in the AAC literature but mostly considered from the perspective of AAC implementation rather than VOCA design.

Publication 1 and 5 suggest that considering how to design for the milieu should be a key construct in VOCA design. These findings are echoed by the work from Ripat et al. who identify in their theme 'It is more than a voice' that social participation is at the very heart of reasons for communication. Ripat et al also highlight the need to consider personal context in identifying that the meaning assigned by participants to VOCA use was *"found to be unique to the individual and extended far beyond a means to generate digitized speech"* (Ripat et al., 2019, p. 77). In extending Clarke's communication theory, and arguing that VOCA use should be considered from the perspective of device-mediated communication, Higginbotham and Caves (2002) highlight the potential role for VOCAs in improving 'conversational performance'. This challenge is one that has been recognised since the inception of the field. Waller and Newell highlighted in 1997 the need to consider VOCA design from a conversational point of view (Waller & Newell, 1997) and in reflection in 2019 Waller highlighted that design of VOCAs to *"simulate the co-construction of conversation"* was still an open design challenge (Waller, 2019b). AAC companies have responded to these challenges in a limited way, for example in 'partner windows' which have recently featured in some VOCAs (but which were originally conceived of in the early VOCA designed by Toby Churchill), and in the use of animated emoticons.

Environments that are geared to support specific language systems overcome some of the barriers to using VOCAs for some individuals (Lynch, Judge, et al., 2019). Within the UK many school settings have tended to support a single graphic symbol language representation system (Meek & Moffatt, 1998). Tenny (2016) suggests advantages of speed for symbolic (word based) systems over text based ones for a population of 'non cognitively impaired' individuals, however this analysis needs consideration in terms of the contemporaneous AAC context: educational reforms in the 1990s and 2000s in the UK reduced the number of 'non cognitively impaired' children in SEN schools, and this is likely to have made communication environments supporting these symbol systems more challenging to maintain. This evolution in communication environments for children using AAC is one example of the impact of the environment on the use of VOCAs and this may be linked to VOCA design evolving to move from more defined language packages to the more idiosyncratic vocabulary packages seemingly preferred by clinicians (Webb, Judge, et al., 2019).

From the perspective of VOCA design a device that requires the entire environment around the individual to adapt may be considered as poorly designed; although considering this from a social model of disability or ableism perspective might posit that the environment, rather than the individual, should adapt. The VOCA, and design of VOCAs, thus sits squarely at the intersection of these perspectives and as an artefact potentially offers a method of mediating between them.

Publication 4 highlights the role of NHS services as one of the external influences on VOCA provision in the UK. The AAC market in most cases involves mediators (AAC practitioners working within services providing AAC) and these mediators distort the market by introducing actors between the producer and the consumer. Practitioners working in services personalise systems to meet individual needs (Judge et al., 2022; Thistle & Wilkinson, 2015) and this process should be considered in terms of design,

although it is likely that both practitioners and VOCA designers do not recognise this as such (Fuzesi, 2019). Equally, given the nature of the market, VOCA designers may explicitly or implicitly design features to suit the needs of practitioners rather than end users, something that the inclusion of 'cultural and contextual influences' in the I-ASC model of AAC decisions suggests (Lynch, Judge, et al., 2019). Publication 1 and O'Keefe et al. (2009) however suggest that AAC professionals sometimes have differing priorities to those using VOCAs when considering VOCA features. Viewing these findings as a whole challenges the conceptualisation of a VOCA as only having one user and also that of there being only one designer. Those around the individual using a VOCA can act as users of the device and also designers of the device in some situations.

Considering the environment, milieu, personal context, and service delivery mechanisms from the standpoint of design presents exciting challenges. How might VOCAs be designed to confront this challenge directly; in supporting conversational interactions, but also generating environments that are supportive, supporting communication partners to develop effective communication partner skills, or re-considering the involvement of practitioners in the design of VOCAs for individuals. VOCA design offers the chance to change the experience of communication of those using and supporting the use of these devices.

Towards a Model for VOCA Design

This commentary presents a body of work derived from a range of different investigations and studies carried out by the author relating to aspects of VOCA design and considers how usability, human-computer interaction and human centred design, relate to Voice Output Communication Aids. Figure 3 represents and proposes this work as a model of VOCA design. It is proposed that this model provides an initial, grounded, and ecologically strong frame on which VOCA designers can consider the design of VOCAs, or that others could use when evaluating these designs.

It is further suggested that success in VOCA design could be measured in how effectively a device addresses the components of the proposed model. In addition to traditional heuristics, a VOCA-based heuristic evaluation process based on this model would consider a design and evaluate:

- if the VOCA addresses specific needs of the individual (human) and their SLCN (e.g. designing for an individual who has some understandable speech);
- if the specific task that the VOCA aims to address and the outcomes it aims to achieve are clear (e.g. communicative support in narrative conversation with unfamiliar partners in order to build social closeness) ;
- how the VOCA will be accessed, considering the specificity of the individual and task (e.g. how speech recognition will be used to access certain communication functions, how word predictions will be displayed for an individual using switch scanning);
- how the language system within the VOCA is designed to support these tasks and goals/outcomes (e.g. how narrative content can be accessed to support story telling);
- how the personal context of the VOCA user's environment is considered (e.g. by making the VOCA robust and droppable);
- how the VOCA would be used within the milieu (e.g. making it easily supportable);
- how the VOCA would be delivered to the end user by a service (e.g. ensuring it can be maintained by a service or easily backed up by the user);

- how the VOCA is designed to be used as an artefact (e.g. that it is something desirable, acceptable that a user feels an affinity with).
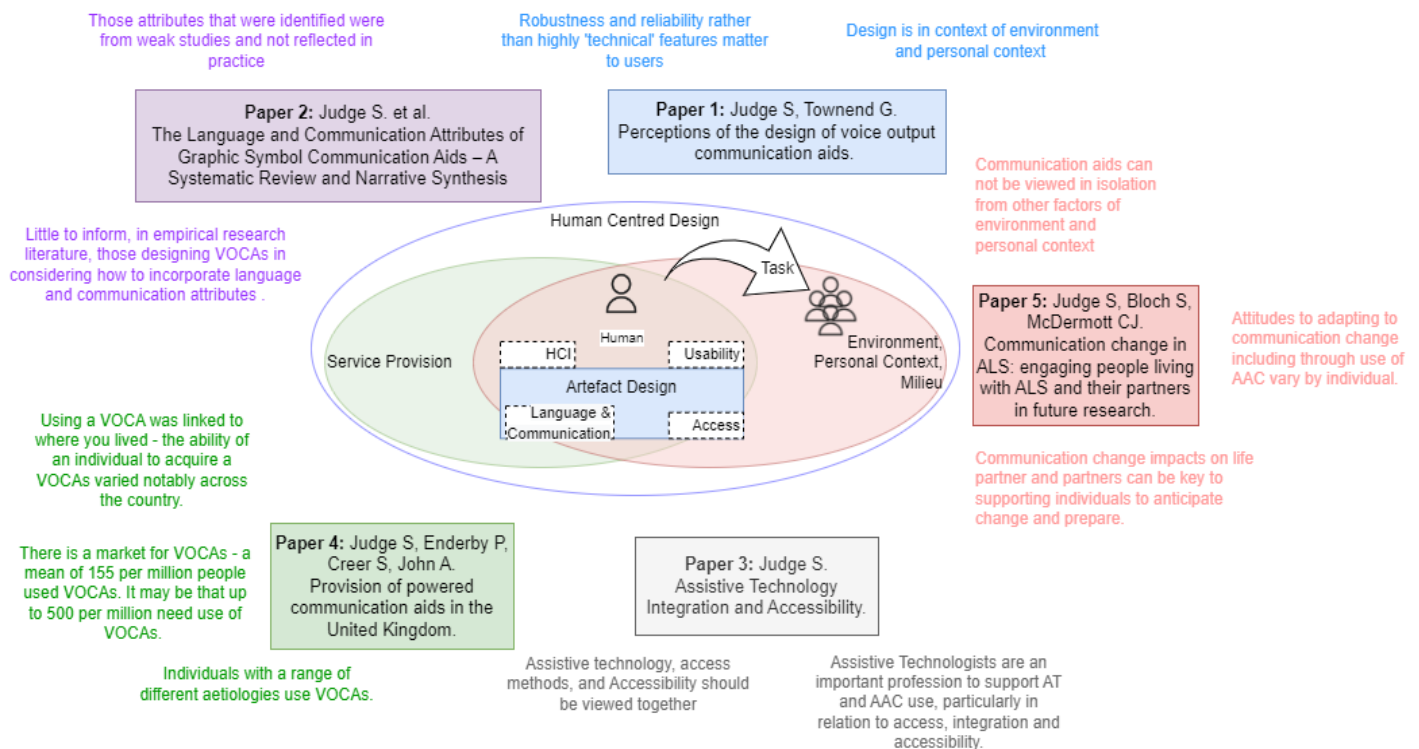

Figure 3: A Model of VOCA Design overlaid with the publications included (boxes) and key findings (floating text).

The publications and commentary that constitute this thesis are presented as a coherent and significant body of work describing design considerations relating to Voice Output Communication Aids. Publication 1 highlights the need, as expressed by those using VOCAs, to focus on VOCA design. The other work presented here then highlights the challenge and complexity of this design process: Publication 2 highlights the lack of empirical evidence about the effect of key VOCA considerations, such as language and communication characteristics, on which designers could inform design choices; Publication 3 illustrates the complex and evolving relationship between access and accessibility within which designers must work; Publication 4 demonstrates the heterogeneity of the potential users for whom a VOCA designer must design; and Publication 1, 4 & 5 forefront the need to situate the design of a VOCA in the personal and social environment of the end user.

This thesis has considered why it is an appropriate endeavour to consider VOCAs from the perspective of design, why the proposed model can be considered a foundation for future investigations, and points to some of the possible routes to future investigation. This commentary has asserted that:

- VOCAs have not been well considered from the perspective of design in the AAC literature and that many aspects of VOCA design have, to date, been driven not by explicit design processes or choices but by contemporaneous technological developments;
- that the role of milieu and the environment, including service provision, on VOCA adoption and implementation is now well understood but has not yet been significantly translated into VOCA designs;

- and that although human centred participatory design methods are well recognised these are not systematically deployed in the design of VOCAs.

Implications for future VOCA design

This body of work highlights that VOCAs have not been well considered from the perspective of design and that many aspects of VOCA design have been driven by technological rather than user-centred developments. This work highlights that human centred design with those with Complex Communication Needs is valuable and positive and proposes that these human centred, participatory, design methods are adopted more systematically across VOCA design, research and development.

Truly involving the users or potential users of these systems will produce design that varies significantly from the current design of VOCAs, which replicates the paper-based systems from which it evolved. Reconsidering the design processes involved in VOCA design will, in the long term, lead to VOCAs that can be (shown to be) more effective in meeting the communication goals and outcomes that users desire.

This work highlights that there is much work to do in improving the experience of those who use VOCAs through better design. The model presented can be used as a heuristic checklist by those currently designing VOCAs in order to evaluate and iterate their designs. There is also a clear need to gather empirical research evidence, with the population of those using VOCAs, to establish the effect of VOCA design features – starting with those currently used and debated in practice.

It is undoubtable that new technologies will emerge that have AAC applications and further drive change in the AAC field, for example Sennott et al. (2019) provide some examples of the potential role of artificial intelligence technology within AAC. This thesis does not argue that technological push per se should be resisted, it has clearly conveyed many benefits to those with CCN, but that (human centred) design is used in order to consider the role of these technologies in future VOCAs.

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Glossary of Terms

Abbreviation	Term
AAC	Augmentative and Alternative Communication
CCG	Clinical Commissioning Group
CCN	Complex Communication Needs
CM	Communication Matters
CP	Cerebral Palsy
EMG	Electromyography
GOMS	Goals Operators Methods Model
HCI	Human-Computer Interaction
HSDR	Health Services Delivery and Research
HTC	Healthcare Technology Co-operative
ICU	Intensive Care Unit
ISAAC	International Society for Augmentative and Alternative Communication
MND	Motor Neurone Disease
MP	Member of Parliament
MRO	Means, Reasons and Opportunities
NHS	National Health Service
NIHR	National Institute of Health Research
NSSDS	National Specialised Services Definition Sets
PPI	Patient and Public Involvement
PROM	Patient Reported Outcome Measure
RcSLT	Royal College of Speech and Language Therapists
SBRI	Small Business Research Initiative
SEN	Special Educational Need
SGD	Speech Generating Device
SLCN	Speech, Language and Communication Needs
SLT/P	Speech and Language Therapy/Pathology, Therapist/Pathologist
UCD	User Centred Design
VOCA	Voice Output Communication Aid

Tables

Table 1: Aetiology of VOCA users

Condition (ICD 10 Code – Service Ranking Data)	Caseload Prevalence, Barnsley AT Team AAC Service Rank (Barnsley AT Team Service)[4]	Mean VOCA caseload per service. Rank (Judge et al., 2017)	Potential AAC Need. Rank (per 100,000) (Creer et al., 2016)	Prevalence of Condition Rank (per 100,000) (Creer et al., 2016)
Other	1	1		
Cerebral palsy	2	2	6 (24)	=6 (200)
Autistic spectrum disorder	3	8	3 (100)	3 (1000)
Motor neurone disease	4	3	9 (5.5)	=12 (8)
Learning disabilities	5	4[5]	4 (70.5)	4 (469.9)
Stroke	6	5	5 (61.4)	2 (1024)
Developmental Delay	7	9		
Multiple sclerosis	8	6	13 (0.4)	7 (150)
Rett syndrome	9	-	=16 (0.2)	15 (0.4)
Head/brain injury	10	10[6]	7 (12)	5 (300)
Locked-in syndrome	11	-	=14 (0.3)	14 (2)
Parkinson's disease	12	11	2 (120)	=6 (200)
Muscular dystrophy	13	12	=14 (0.3)	10 (12.5)
Cleft palate and craniofacial malformations	14	14		
Huntington's disease	15	-	11 (2.1)	13 (7)
Alzheimer's/dementia	-	15[7]	1 (123)	1 (1230)
Profound and multiple learning disabilities (PMLD)	-	7	8 (9.2)	8 (36.7)
Prader–Willi	-	-	10 (4.6)	11 (10)
Williams syndrome	-	-	12 (2)	9 (13)
Myasthenia gravis	-	-	=16 (0.2)	=12 (8)
Head and neck cancer	-	13		

[4] Table ordered by caseload prevalence of Barnsley AT Team Service.
[5] Other Learning Disabilities in Judge et al. 2017
[6] Head injury in Judge et al. 2017
[7] Dementia in Judge et al. 2017

Table 2: Access Method Taxonomy[8]

Underlying Technology	Method	Category	Implementation	Notes
Electro Mechanical (Discrete)	Switches	Switches	Switch	Typically using Micro switch (snap action switch) actuators.
		Switch Arrays	(Switched) Joystick	Used for directional scanning or joystick-mouse. Implemented as joystick, but also keyboard (i.e. arrow keys)
			Keyboard	
Electro Mechanical (Continuous)	Pointing Devices	Mice	Mouse	
			Roller Balls	(upside down mice)
		Joysticks	Joystick mouse	Continuous -i.e. displacement is related to mouse speed.
Electrical Sensing	InfraRed	Proximity / Gate	IR proximity switch	Only implemented as gate/switch. E.g. blink or twitch switch. Auto or manual re-calibration.
	Capacitive	Proximity / Gate	Capacitive proximity switch	Only implemented as gate/switch. Signal threshold for switch.
		2D detection	Touch Screen	Now predominate touchscreen implementation in tablets/screens etc.
	Sonar	Proximity / Gate	Sonar proximity Instrument	Only implemented as musical instrument (proximity/continuous) e.g. Sound Beam
	Accelerometer (MEMS)	Switch	Accelerometer switch	Implemented as switch. E.g. head or foot switch. Signal threshold for switch.
		Joystick	Accelerometer Joystick	Implemented as Joystick mouse, e.g. head mounted.
	Resistive	Switches	Resistive Switch	Implemented as discrete 'plate' switches.
		2D detection	Touchscreen	Implemented largely in historical systems.
Video movement sensing	Eye Gaze Technology (Camera, IR spectrum)	Eye Gaze Detection	Eye Gaze Cursor Control	Driven by the GOGAIN project in the early 2000s (Bates et al., 2007).

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[8] This table describes, in overview, access methods – i.e. the method an individual uses to create a signal in which to interact with the technology. Access techniques include other aspects of signal processing and those relating to switching are described in Judge & Colven (2006).

Underlying Technology	Method	Category	Implementation	Notes
		Blink Detection	Blink select	Implemented as mouse click adjunct to eye gaze. Not implemented independently as switch access method, but possible to configure as such.
	Camera (Visible spectrum) movement detection	2D directional sensing	Camera Mouse	
			Camera Joystick	
		2D Camera movement detection	Camera Switches	Machine learning of movements implementations. Eyebrows, mouth, other e.g. *Project Activate* (2021)
	Depth camera movement detection	3D directional/movement sensing		Not implemented.
	Scene detection			Implemented as an AT (e.g. Microsoft Lens), not as part of access method.
Audio sensing	Level detection		Sound Switch	Signal threshold (manual) for switch.
	Automatic Speech Recognition	Speaker dependent	Command based speech recognition.	Discrete recognition. Sicare system. Dragon dictate historical systems. Dysarthric speech recognition (Hawley et al., 2013).
		Speaker independent	Continuous speech recognition	Dysarthric speech recognition implemented in research systems.
	Speaker Identification			Not implemented
Electrophysiological sensing	EMG	EMG	EMG switch	The use of Electromyography (EMG) and some other sensing technologies to detect muscle activation (Judge, Nasr, et al., 2017; Tai et al., 2008) Dry and 'wet' electrode systems. Manual threshold set.
		EOG (Electrooculogram)	Eye Gaze Cursor Control	Not implemented. Historical 'EagleEyes' system
	MMG (Mechanomyogram)	Force Sensing Resistors/Piezo/Accelerometers etc.	MMG Switch	Not implemented. For a summary see Esposito et al. (2018).
	(EEG) electroencephalogram	Scalp/intracortical/ECog etc.	BCI	Implemented in research systems. For a summary of methods see Shih et al. (2012).

Table 3: Summary of the context of this body of work

Project	Methods	Methodological Considerations	Theory/Conceptual Framework(s)	Model Domain	Other Outputs
SPECS - development of speech recognition environmental control	Qualitative - Interviews User Involvement in Design	User Centred Design Methods / Qualitative investigation for those with communication disabilities Qualitative analysis	HAAT, MPT User Centred Design	Interaction - Access	Pre-market dedicated device developed.
D4D AAC Project - Users perceptions of VOCA design	Qualitative - Interviews Surveying / Mixed Methods	Qualitative investigation for those with communication disabilities Descriptive statistics Qualitative analysis	HAAT, MPT Means-Reasons-Opportunities Usability for AT (Arathnat) Light - Communication Competence	Overall Model; Environment and Context	Involvement tool - Talking Mat type resource for AAC.... Industry engagement Open Dataset
VIVOCA 1 & 2- development of speech recognition VOCA	Qualitative - Interviews User Involvement in Design	User Centred Design Methods / Qualitative investigation for those with communication disabilities Qualitative analysis	User Centred Design Communication Networks Models of communication - Barnlund, Tarone, Clarke Multi-modal AAC / Total Communication	Interaction - Language & Access; Environment and Context	App on market
CM-RM Project - evidence of need for AAC in UK	Systematic Literature Reviewing Quantitative - Surveying	Epidemiology Participatory Action Research Applied Policy Research Descriptive statistics Qualitative analysis	Evidence Based Practice	Service Design	Policy Open Dataset
DfE AAC Project - evidence of use of AAC in England	Quantitative – Surveying, Descriptive Statistics	Epidemiology Participatory Action Research Applied Policy Research Descriptive statistics	Evidence Based Practice	Service Design	Open Dataset
I-ASC Project - decision making around symbol communication aids for children	Systematic Lit Review, Quality Appraisal Qualitative - Interviews Stated Preference (Quantitative)	Ethnography Qualitative investigation for those with communication disabilities PPI involvement in research for those using AAC	Evidence Based Practice Decision support Aided Language development	Interaction - Language; Environment and Context	Explanatory model Practitioner and Family Resources (website).

Project	Methods	Methodological Considerations	Theory/Conceptual Framework(s)	Model Domain	Other Outputs
	Experiments - Discrete choice & Best-Worst Scaling	Quantitative methods in AAC research Systematic review & quality appraisal across study types.			
EMEGO 1 & 2 - development of EMG access switch	User Involvement in Design	User Centred Design Methods / Qualitative investigation for those with communication disabilities	User Centred Design Health Economic Evaluation Technology Readiness	Interaction - Access	Device on market
ICU AAC - development of ICU AAC app	Systematic Lit Review Qualitative Investigation Ethnographic design User involvement in design	Design Ethnography User centred Design Methods	Means, Reasons, Opportunities (Money) Technology acceptance models Behaviour change theory	Environment and Context	App on market
Sheffield Support Snood - development of neck support for those with MND	User involvement in design	Participatory Design Methods Qualitative investigation for those with physical and/or communication difficulties	User Centred Design	Interaction - Access	Device on market
Unspoken Voices - PhD developing PROM for AAC	Qualitative Evidence Synthesis Qualitative Analysis	Qualitative investigation for those with communication disabilities PPI involvement in research Qualitative analysis (longitudinal)	Patient Reported Outcome Measurement Dialogic analysis of qualitative data.	Environment and Context	
STAR - developing speech recognition therapy app	User involvement in design	User Centred Design Methods / Qualitative investigation for those with communication disabilities	User Centred Design Behaviour change theory		App on market
MND AAC Service Evaluation	PPI	PPI involvement in research for those using AAC	Service evaluation Research priority setting	Environment and Context	

Appendices

Appendix 1: CV

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Appendix 2: Statement of Contributions

Statement of
Contributions - SJ -