Design and Evaluation of a Wearable Assistive Technology for Children with ADHD

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Abstract

Attention Deficit Hyperactivity Disorder (ADHD), one of the most common neurodevelopmental disorders amongst children, is characterised by inattention and/or hyperactivity/impulsivity. Attention deficits lead to difficulties in sustaining attention and being easily distracted, interfering with development and functioning in children with ADHD. Environmental variables, such as sounds, colour schemes and lighting, may affect the performance of such children. There is little research on the effect of these variables and on assistive technologies for these children. Study 1 explored the experiences and attitudes of mothers of children with ADHD towards behavioural, environmental and technological interventions to help their children. Key findings were listening to readings of the Quran was found to calm children and help them concentrate more, suggesting that sound has a beneficial effect; Mothers were willing to have their children use assistive technologies. Focussing on sound, Studies 2 and 3 investigated the effect of white and pink noise on children with ADHD. Both noise types improved attention. Therefore, the ADHD Headmuffs, which incorporate white noise, were developed and their effectiveness in improving attention and reducing visual and auditory distractors in children with ADHD was investigated in Study 4. The ADHD Headmuffs both with and without white noise resulted in positive effects on children, but with an added benefit for white noise. Study 5 investigated children's satisfaction and acceptance of the ADHD Headmuffs. Children were satisfied and accepting of the Headmuffs but highlighted the need for customization. Study 6 evaluated the usability and acceptability of the ADHD Headmuffs with experts who reported that the Headmuffs are usable and acceptable and also highlighted further interesting issues. The key contribution of this thesis is an assistive technology, the ADHD Headmuffs, incorporating white or pink noise to improve attention and reduce visual and auditory distractors in children with ADHD.

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Glossary

ADHD - Attention Deficit Hyperactivity Disorder

ADHD-I - ADHD inattentive presentation

ADHD-H - ADHD hyperactive-impulsive presentation

ADHD-C - ADHD combined presentation

CEs - Commission errors

CPTs - Continuous Performance Tests

CV - Coefficient of Covariance

DSM - The Diagnostic and Statistical Manual of Mental Disorders

EF - Executive function

ER - Event rate

ICD - The International Statistical Classification of Diseases and Related Health Problems

ISI - Interstimulus interval

MAD - Median Absolute Deviation from the median

OEs - Omission errors

RTs - Reaction times

RTV - Reaction time variability

SD - Standard deviation

VAS - Visual Analogue Scale

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Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

Some of the work presented within this thesis has been submitted for publication:

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Chapter 1 - Introduction to Research and ADHD

According to the World Health Organization (WHO) (2016), around 20% of children worldwide have some sort of mental disorders. One group of these mental disorders is referred to as neurodevelopmental disorders (NDDs), a set of disorders that affect children in their early development and may persist into adulthood. NDDs are characterized by brain deficits that result in personal, academic, occupational and social functioning impairments (American Psychiatric Association, 2013).

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent NDDs amongst children. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association, 2013), ADHD is characterized by inattention and/or hyperactivity-impulsivity, which typically interfere with development and functioning.

Investigations of ADHD started in 1902 by the British paediatrician Sir George Still who described ADHD as "an abnormal defect of moral control in children" (Barkley, 2006). In 1932, the German physicians Kramer and Pollnow established the concept of the "hyperkinetic disease" that closely resembles the current definition of ADHD but focused more on the hyperactivity aspects (Lange et al., 2010). In 1980, the American Psychiatric Association published the third edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-3) in which more focus was given to the attention problems of the disorder and therefore, in this edition, the hyperkinetic disease was renamed as Attention Deficit Disorder (ADD) (with or without hyperactivity) (Barkley, 2006). Again, in the fourth edition of the DSM (DSM-4) in 1990, the disorder was renamed as ADHD, which has remained in DSM-5, the latest edition of the manual (American Psychiatric Association, 2013).

Being a parent of a child, I noticed that my child struggles with attention and impulsivity which became apparent when he was 3.5 years old. He was not paying attention to dangerous things and he was not following my instructions. He was restless and interrupting others when talking. The inattention and impulsivity problems have become more serious when he started school as educational tasks requires high attention. I started doing some research and I realised that these are the symptoms of ADHD. All existing solutions such as medications did not work with him. In addition, I did not find assistive technologies to help with his attention problems (see section 5.1) and this what inspired me to undertake this research.

1.1 ADHD: Definition, Sources of Problems and Impairments

ADHD is generally recognized by two main clusters of symptoms that are associated with several aspects of an individual's life. The first major symptom cluster is related to having problems with attention. This leads to difficulties in organizing tasks, sustaining attention and shifting attention between tasks, difficulties in following through instructions or finishing tasks and being forgetful in daily tasks as well as being easily distracted by auditory and visual distractors in the surrounding environment. The second major symptom cluster is hyperactive and impulsive behaviours including restlessness, talking too much and too fast, interrupting others, and difficulty staying seated and waiting turns (Roberts, et al., 2015). There are three severity levels of ADHD, mild, moderate or severe, depending on the symptoms and the resulting impairments. In addition, ADHD has three different presentations that are based on the predominant symptoms, including predominantly inattentive presentation (ADHD-I), predominantly hyperactive-impulsive presentation (ADHD-H) and combined presentation (ADHD-C) which combines both clusters of symptoms (for more details, see Chapter 2, section 2.2.1)

ADHD is considered an extremely heterogeneous disorder, one reason for that is the high rate of comorbid disorders. Common comorbidities that coexist with ADHD include Conduct Disorder (CD), anxiety, depression and Oppositional and Defiant Disorder (ODD) (Gnanavel et al., 2019). Research has suggested that more than 60% of children with ADHD have at least one comorbid disorder that typically persist into adulthood (Gillberg et al., 2004).

Research has also suggested that the main probable sources of problems in children with ADHD are problems in their executive function (EF) (see for more details, see Chapter 2, section 2.5). Executive function deficits include deficits in response inhibition, planning, executive processing speed, working memory (WM) and attention (Willcutt et al., 2005). At a neurochemical level, ADHD problems appear to be related to imbalance in certain neurotransmitters especially dopamine and norepinephrine, which are brain chemicals that contribute to behaviour control (Dervola et al., 2012).

Attention is not considered a standalone executive function (EF). Instead, it is an integral part of all EF and it is crucial for daily life functioning and activities. Studies of attention in children with ADHD have concentrated on four components of attention: orienting/alertness attention, selective/focused attention, divided attention, and vigilance/sustained attention. Amongst the four components, sustained attention has been found to be significantly underdeveloped in children with ADHD (for more details, see Chapter 2, section 2.5). Sustained attention is the ability to keep an active and prolonged state of alertness during a mental activity and is a basic requirement for information processing and cognitive development (Rapport et al., 2015). Deficits in sustained attention in children with ADHD become more severe when a child experiences distractors whether visual or auditory in the surrounding environment (for more details, see Chapter 2, section 2.3).

ADHD symptoms as well as deficits in EF negatively affect the daily life of children with ADHD and can result in educational impairments with varying presentations and severity levels. These also result in social impairments affecting their daily functioning (for more details, see Chapter 2, section 2.6).

1.2 Diagnosis of ADHD: DSM-5 and ICD-10

Large efforts have been dedicated over the years as to how to best diagnose mental disorders, including ADHD. This has resulted in the two well-known sets of diagnostic criteria, namely the Diagnostic and Statistical Manual of Mental Disorders (currently DSM-5) (American Psychiatric Association, 2013) and the International Statistical Classification of Diseases and Related Health Problems (ICD-10) (World Health Organization, 1993). The two sets of diagnostic criteria provide comprehensive sets of symptoms as well as guidance for how to best diagnose ADHD (for more details, see Chapter 2, section 2.2).

There have been several rating scales built upon the ADHD-related behaviours stated in DSM or ICD. These rating scales facilitate collecting subjective information from teachers, parents and others regarding symptoms and functioning of children which serve as a starting point of a child's assessment, although mental health clinicians have to confirm the final diagnosis (see Chapter 2, section 2.4.1).

1.3 Prevalence of ADHD amongst Children Globally, in KSA and the UK

Estimates of the overall worldwide prevalence of ADHD for children and adolescents aged 6-17 years old as well as the average percentages of the prevalence of the three ADHD presentations worldwide are shown in Table 1.1.

Table 1.1 Overall prevalence of ADHD and average percentages of the prevalence of the ADHD presentations worldwide, in the Kingdom of Saudi Arabia (KSA) and the UK

Region	ADHD	ADHD-I	ADHD-H	ADHD-C	Studies
Worldwide	5.29% - 7.10%	4.30%	2.90%	2.00%	Polanczyk et al. (2007, 2014); Willcutt, (2012)
KSA	3.40% - 13.50%	5.96%	5.38%	6.42%	Abu Taleb & Farheen (2013); Albatti et al. (2017); Al Hamed et al. (2008); Alqahtani, (2010) Al-Modayfer & Alatiq (2015); Jenahi et al. (2012); Homidi et al. (2013)
UK	0.08% - 2.23%	0.76%	0.16%	1.41%	Ford et al. (2003); Russell et al. (2014); Holden et al. (2013, 2018)

The ADHD-I presentation prevalence worldwide increases with age and this can be attributed to the fact that tasks demanding more attention increase as the child grows up. On the other hand, the ADHD-H presentation is more common in preschool children and decreases by age. The ADHD-C presentation is more common in pre-schoolers and elementary school children (Willcutt, 2012). In addition, age plays an important role in the overall prevalence of ADHD, with younger samples producing higher prevalence estimates compared to older samples (Polanczyk & Rohde, 2007). This may be partly because DSM criteria are mainly applicable for young children;

However, this might change with the adjustment of the age requirement in DSM-5 (Roberts et al., 2014).

Gender is also an important factor affecting the estimates of the prevalence worldwide as males are mostly reported to have the highest prevalence of ADHD in all three presentations. On average, the male to female ratio was about (2.30:1.00) in community samples of children with ADHD (Biederman et al., 2002; Willcut, 2012). However, Biederman et al. (2002) found that only one girl is referred to clinics for the treatment of ADHD for ten boys referred although girls and boys with ADHD have similar patterns of severity with ADHD. This can largely be attributed to the fact that clinical referrals for diagnosis of ADHD are often based on explicit behavioural problems and aggression reported mostly by teachers. Girls with ADHD were more likely to have the ADHD-I presentation and were less likely to have learning disabilities as comorbidity or disruptive behaviour problems including hyperactive and aggressive symptoms compared with boys with ADHD and this leads to the under-referral of girls with ADHD (Biederman et al., 2002; Biederman et al., 2004; Nøvik et al., 2006; Willcutt, 2012).

Reviewing the literature on the prevalence of ADHD in Saudi Arabia, the country where my research is conducted, no studies could be found that have investigated the prevalence throughout the country. However, some studies have been conducted to investigate the prevalence of this condition in particular cities in Saudi Arabia (Abu Taleb & Farheen, 2013; Albatti et al., 2017; Al Hamed et al., 2008; Alqahtani, 2010; Al-Modayfer & Alatiq, 2015; Jenahi et al.,2012; Homidi et al., 2013). The prevalence of ADHD in the various studies conducted in Saudi Arabia is shown in Table 1.1. The overall prevalence in Saudi Arabia is a little higher than the worldwide prevalence estimate. However, when compared to studies in other Arab countries, the prevalence rates in Saudi Arabia are quite similar. For instance, recent studies investigating ADHD prevalence in Qatar and UAE showed a prevalence of 9.40% and 14.90% respectively (Albatti et al., 2017). The reason for that may be because the Arab countries have similar social characteristics that affect the reporting and occurrence of the disorder (Polanczyk et al., 2014).

The average percentages of the prevalence of ADHD presentations in all the studies conducted in Saudi Arabia are shown in Table 1.1. The ADHD-I presentation prevalence in Saudi Arabia is a little higher than the worldwide prevalence of the same presentation whereas the ADHD-H and ADHD-C presentations register a much higher prevalence in Saudi Arabia compared to the worldwide prevalence for the two presentations. In addition, in all the studies reported, the male to female ratio for the prevalence of ADHD in Saudi Arabia was, on average (2.10:1.00), which is similar to the worldwide estimate mentioned above.

The prevalence of ADHD in the various studies conducted in the UK is presented in Table 1.1, above. The overall prevalence is much lower than the estimates of the prevalence of ADHD worldwide. It is also low in comparison with the estimated prevalence of ADHD in other European countries, which range from 3.00% to 5.00% as stated in the meta-analysis conducted by Polanczyk and Rohde (2007). One possible reason for the low UK estimates is the use of the ICD-10 diagnostic criteria that are stricter than the DSM criteria (Russell et al., 2014, for more details, see Chapter 2, sections 2.2.2 and 2.2.3). Malacrida (2004) suggested that the low UK estimates are also partly due to the under-diagnosis resulting from the concerns about the impact of ADHD diagnosis and the side effects of the use of ADHD stimulant drugs on children and their families.

The average percentages of the prevalence of the ADHD presentations in all the studies conducted in the UK are shown in Table 1.1, above. While the prevalence of all three presentations is lower than the worldwide prevalence of the same presentations, the ADHD-I and ADHD-H presentations register a much lower prevalence in the UK. In addition, in all the studies reported, the male to female ratio for the prevalence of ADHD was (4.7:1.0), which is much higher than the worldwide estimate mentioned above.

1.4 Effects of Environmental Variables on Children with ADHD

The focus of this programme of research is on the effects of environment variables, particularly sound on children with ADHD. Environmental variables may have an effect on the performance of children with ADHD and these include the presence of sounds, particular colours and lighting. This area of research has received little attention and there were limited studies that have investigated the effects of the environmental variables on children with ADHD (see Chapter 2, section 2.8). Looking at sound, it might be perceived as being detrimental to the attention of these children, because it might act as a distractor. However, a special kind of sound, called white noise, has been found to be beneficial for memory (Söderlund et al., 2007) and attention (Baijot et al., 2016; Söderlund et al., 2016) in children with ADHD and for memory (Söderlund et al., 2010) and attention (Helps et al., 2014) in children with attention problems but without a diagnosis of ADHD (for more details, see Chapter 2, section 2.8.1). Further work is required to investigate in more detail the effects of white noise and other kinds of sound, colours or lighting on the performance of children with ADHD.

1.5 Research Motivation and Aims

As discussed earlier, ADHD is one of the most prevalent neurodevelopmental disorders amongst children. ADHD symptoms particularly deficits in sustained attention and difficulties in resisting distractibility negatively affect the daily life of children with ADHD. These deficits result in serious impairments in educational and social functioning that without proper early intervention may persist into adulthood.

Early ADHD research focused on finding causes, establishing theories, methods for diagnosis and treatment plans for ADHD. This kind of research was following the well-known model used to deal with mental disorders, the medical model of disability (Paterson & Hughes, 2006). This model concerns finding the main reasons for the disability in addition to primarily finding ways to prevent and completely cure the disability and its related impairments. The medical model analyses the human body's functioning and works on fixing any function that does not conform to normative values (Fisher & Goodley, 2007). However, using the medical model is probably insufficient on its own for approaching the problems of ADHD considering that all efforts to permanently cure ADHD in children with ADHD through attention and working memory training have failed to yield successful enduring results (see Chapter 2, sections 2.5). In addition, using medication alone is not an appropriate long-term treatment for ADHD as medication shows results only while being used in addition to possibly having side effects (Brown, 2005). Furthermore, medications do not compensate for the skills that children with ADHD may not learn due to their impairments. Another analogy that would show the insufficiency of the medical model while approaching ADHD is with a person who is not able to walk as a result of

Multiple Sclerosis (MS). There is no cure for MS, and at the same time, we cannot insist that those with MS must keep on trying to walk and that practice will eventually make them walk. Instead, following the other well-known model to deal with a mental disorder, the social model of disability (Paterson & Hughes, 2006), we have made them a really good assistive technology, a wheelchair.

Therefore, we need to move beyond a purely medical model and follow the social model of disability in thinking about the needs of children with ADHD. The social model describes disability as a condition that is part of the individual variability of people and the fact that societies do not accommodate this variability. In this model, the uniqueness of individuals with a disability should be accepted and assistive technologies to help these individuals cope with their disability should be developed (Paterson & Hughes, 2006). Therefore, researchers should be addressing ADHD problems using the social model and should be developing assistive technologies to help those with ADHD deal with their disability until a complete cure for ADHD is discovered.

An assistive technology, according to the US Assistive Technology Act (2004), is a name given for "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities".

Another term used in the literature to describe assistive technologies is "technological interventions", which "refer to all interventions delivered using various electronic devices (e.g., video playing device, speech-generating device, tablet)" (Heng et al. 2021). Several studies used the term technological interventions to refer to any technological tool or service that provide support for mainstream people (e.g., classroom education as in Escueta et al. (2017) and obesity as in Kim & Song (2008)) as well as children and adults with disabilities (e.g., social skills for children with autism as in Goldsmith & LeBlanc (2004) and support parents of children with ADHD as in Pina et al. (2014)).

Both terms have been used very loosely and interchangeably in the literature. Thus, in this thesis, the term technological interventions is used when talking more generally and the term assistive technologies is used when talking specifically about technologies targeting children or adults with disabilities, such as the one that was developed in this programme of research, the ADHD Headmuffs.

In this context, there have been very few efforts to provide assistive technologies or technological interventions for children with ADHD in a number of areas in which children with ADHD need support (for more details, see Chapter 2, section 2.7). In particular, based on the literature review in Chapter 2, I concluded that there are very few studies on assistive technologies and technological interventions to improve the attention of children with ADHD and there is also a lack of technology for reducing distractors whether auditory or visual in such children (see Chapter 2, section 2.7).

As discussed in the previous section, environmental variables may affect the performance of children with ADHD. However, there is little research on the effects of these variables on these children. Consequently, research in this thesis aims to investigate the effects of one environmental variable, sound, on the attention of children with ADHD. It also aims to build an assistive technology that can be used to help improve attention using sound and would have the added benefit of reducing visual as well as auditory distractors in children with ADHD. The context in which this assistive technology would be used is in educational settings, particularly when performing tasks requiring attention. These include solving homework at home, attending a lesson in class and taking a test (for more details about these settings, see Chapter 8.2.3). These particular settings were chosen because attention is required when doing educational tasks and visual and auditory distractors are typically present in the surrounding environment and their effects on the attention of children with ADHD can be severe. The motivation to study these contexts of use of the assistive technology developed in this programme of research is described in more detail when the design of the assistive technology is explained in Chapter 6 (section 2.6).

1.6 Research Questions

To achieve the aims of this research stated above, this research is divided into three phases with two or more research questions in each phase as follows:

The first phase aimed at understanding the attitudes and experiences of parents of children with ADHD of the effects of environmental variables on the symptoms of ADHD of their children. This phase also investigated parents’ acceptance of using assistive technologies to improve the attention of their children. This phase addressed two research questions (see Study 1 – Chapter 3):

- RQ1: What are the experiences of parents of children with ADHD with behavioural interventions and environmental variables and interventions?
- RQ2: Would parents of children with ADHD accept using technological intervention and assistive technologies to help their children?

The second phase aimed to: a) validate findings from previous research about the effects of white noise and investigate the effect of pink noise on attention in children with ADHD and b) understand appropriate methods and tasks for measuring the effects of white and pink noise on the attention. This phase addressed three research questions:

- RQ3: Does white noise have a positive effect on the attention in children with ADHD? (see Study 2 – Chapter 4; and Study 3 – Chapter 5)
- RQ4: Does pink noise have a positive effect on the attention in children with ADHD? (see Study 3 – Chapter 5)
- RQ5: How can I best measure the effects of white and pink noise on attention? (see Study 2 – Chapter 4; and Study 3 – Chapter 5)

The third phase aimed to: a) design an assistive technology, the ADHD Headmuffs, incorporating sound, white or pink noise, b) apply the methods learned in Phase 2 to evaluate the effectiveness of the ADHD Headmuffs in improving the attention and reducing distractors in children with ADHD, c) develop methods for measuring the usability and acceptability of the ADHD Headmuffs and use these methods to evaluate the satisfaction and acceptability of children with ADHD with the ADHD Headmuffs and d) investigate experts' assessment of the usability and acceptability of the ADHD Headmuffs in particular settings of use. This phase addressed three research questions:

- RQ6: Will an assistive technology incorporating sound, particularly white noise or pink noise, be helpful for improving attention and reducing visual and auditory distractors in children with ADHD? (see Study 4 – Chapter 6)
- RQ7: Will children with ADHD be satisfied with and accept this assistive technology? (see Study 5 – Chapter 7)

- RQ8: How will experts evaluate the usability and acceptability of the assistive technology? (see Study 6 – Chapter 8)

1.7 Research Approach, Methods and Scope

This programme of research started with an exploratory qualitative study (Study1 - Chapter 3) based on semi-structured interviews with parents of children with ADHD. This study aimed to investigate whether the parents have noticed any positive or negative effects of environmental variables such as sounds, colour schemes and lighting on the symptoms of ADHD in their children. It also investigated the attitudes of parents toward using technological interventions and assistive technologies to help their children with ADHD. The data in this study was analysed using a qualitative method of analysis.

Following this exploratory study, an experimental study (Study 2 – Chapter 4) was conducted to validate findings from previous research about the effect of white noise on the attention in children with ADHD. The study also aimed to understand appropriate methods and tasks for measuring the effects of white and pink noise and for evaluating the effectiveness of the assistive technology in the two subsequent studies. This study used a within-participants design, with two conditions: White Noise and No Noise. It used a cognitive task, the visual Go/NoGo task as it provides objective measures of attention and impulsivity in children with ADHD (for more details about this task, see Chapter 2, section 2.4.2.2). The data in this study was analysed using quantitative methods of analysis.

The Go/NoGo task was used in this study as well as in the two subsequent studies for a number of reasons:

- The task is well established and it is still being used by researchers investigating many neurological disorders (Ballard, 2001; Homack & Riccio, 2006; Gordon & Caramazza, 1982; Metin et al., 2012).
- The task is one of the most commonly used tasks in ADHD research (Metin et al., 2012).

- It is free and non-invasive and provides objective measures of attention and impulsivity in individuals with ADHD (Baijot et al., 2016, Bezdjian et al., 2009; Metin et al., 2012; Tamm et al., 2012).
- It is language-independent, so it does not rely on knowing a specific language.
- Two previous studies by Baijot et al. (2016) and Helps et al. (2014) which investigated the effect of white noise on the performance of children with ADHD and children with attention problems, respectively, used the visual Go/NoGo task. Thus, using the Go/NoGo task in the studies of this programme of research means that the data collected in these studies can be compared with previous research.

The Go/NoGo task results in four measures: mission errors (OEs), which are errors resulting from failing to press the button for a Go stimulus, reaction times for correct Go trials (RTs), which measure the time between presenting the stimulus and the child's response, reaction time variability (RTV), which measures (in)stability in reaction times to a set of Go stimuli and commission errors (CEs), which are errors resulting from pressing the button when presented with a NoGo stimulus.

OEs, RTs, RTV were used throughout this thesis as indicators of deficits in sustained attention while CEs was used as an indicator of impulsivity (for why these are measures of these aspects, see section 2.4.2.1). Sustained attention was measured over a series of visual Go stimuli presented over a particular period of time. Nonetheless, I used the term "attention" as a short term for sustained attention in the studies using the Go/NoGo task in this program of research.

This study was followed by another experimental study (Study 3 – Chapter 5), which investigated the robustness of the effect of white noise on the attention in children with ADHD, using the visual Go/NoGo task with different task parameters to the task used in Study 2. The study also aimed to investigate the effect of pink noise on the attention in such children, and thus whether one kind of noise is better than the other. This study also used a within-participants design, with three conditions: White Noise, Pink Noise, and No Noise. The data in this study was analysed using quantitative methods of analysis.

Then, the assistive technology, the ADHD Headmuffs, were developed incorporating white noise with the aim of improving attention and reducing visual and auditory distractors in children with ADHD (for the design of the ADHD Headmuffs, see Chapter 6, section 6.2). Following the design of the ADHD Headmuffs, an experimental study (Study 4 – Chapter 6) was conducted to evaluate the effectiveness of the ADHD Headmuffs in improving attention and reducing distractors in children with ADHD in classroom-like settings. This study also used a within-participants design, with three conditions: Headmuffs with white noise, Headmuffs without noise, and Control. The same visual Go/NoGo task used in Study 3 was also used in Study 4 to assess the children's attention. The data in this study was analysed using quantitative methods of analysis.

This was followed by Study 5 (Chapter 7), which used semi-structured interviews and observations of children with ADHD. The aim was to measure the children's satisfaction levels and acceptance of the ADHD Headmuffs in relation to a number of proposed usability and acceptability aspects. The data in this study was analysed using quantitative and qualitative methods.

Finally, Study 6 (Chapter 8) was conducted with experts in HCI, assistive technologies and ADHD (for children). The aim was to investigate the experts' assessment of the usability and acceptability of the ADHD Headmuffs in particular settings of use. The data in this study was analysed using quantitative and qualitative methods.

The samples of participants used in Studies 1 and 6 in this programme of research are specified above. The sample of participants used in Studies 2, 3, 4 and 5 was children aged between 6 and 12 years old inclusive who are diagnosed with mild or moderate ADHD-I or ADHD-C; with IQ of more than 80; with no psychiatric comorbidities; with no sensory deficits and not taking any pharmacological treatments. This particular age group was chosen because children in this group resulted in higher prevalence estimates of both ADHD-I and ADHD-C compared to older or younger age groups (Polanczyk & Rohde, 2007; Willcutt, 2012). Also, children in this age group are at the beginning of their educational journey, in which they need high levels of attention to acquire the required knowledge and skills.

1.8 Contributions of the Programme of Research

The two major contributions of this programme of research are:

1. Confirming the positive effects of white noise and discovering the positive effects of pink noise on the attention of children with ADHD

2. The design, development and evaluation of an assistive technology, the ADHD Headmuffs, incorporating white or pink noise, to help improve attention and reduce visual and auditory distractors in children with ADHD. This resulted in the following sub contributions:

    - Measuring the effectiveness of the ADHD Headmuffs using objective measures of attention and impulsivity

    - Proposing a list of aspects for collecting children's satisfaction levels and acceptability with a wearable assistive technology and using them to measure the satisfaction and acceptability of the ADHD Headmuffs by children with ADHD

    - Proposing a set of appropriate aspects relevant to the usability and acceptability of the hardware aspects of a wearable assistive technology that would help guide the experts through the evaluation and using them to evaluate the usability and acceptability of the ADHD Headmuffs by experts in HCI, assistive technologies and ADHD (for children)

There are also other minor contributions for this programme of research which include:

1. Investigating the experiences and attitudes of Saudi parents (or at least mothers) of children with ADHD with the effects of the environmental variables and interventions on their children

2. Investigating the attitudes of Saudi parents (or at least mothers) of children with ADHD to using technological interventions and assistive technologies to help their children's ADHD

1.9 Ethical Statement

All the studies conducted in this programme of research were approved by the Physical Sciences Ethics Committee of the University of York. My supervisor, Professor Helen Petrie, has an enhanced DBS clearance to work with vulnerable groups including older people and children with special needs.

The studies followed the principles of ethical research with humans, including the ethical principles of "Do No Harm", "Informed Consent", and "Confidentiality":

Following the first principle, "Do No Harm", all the studies in this programme of research were designed in a way that would not expose the participants to any risks or put them in harmful situations. In particular, the volume of white and pink noise used in this research was at 77dB is safe for children and is in line with previous research on white noise with children (e.g., Baijot et al., 2016, Helps et al., 2014; Söderlund et al., 2007, 2010, 2016), in which the noise volume ranged from 65 to 85dB. According to the World Health Organization (WHO) (2015), sounds below 85dB are considered safe for individuals when used for a maximum of eight continuous hours. As for the safety of headphones, I could not find any research showing that headphones are harmful to children or adults and thus future research should look into this. For the ADHD Headmuffs, wearing them in real life might be stigmatizing and may increase the risk of bullying for children. However, I did not use the ADHD Headmuffs with children in real life in this programme of research and thus, careful considerations should be made in the future when deciding to use the ADHD Headmuffs in real settings such as classrooms. Finally, the participants were allowed to stop or withdraw from any study at any time without being questioned on why they stopped or withdraw.

For the second principle, "Confidentiality", the data collected in the studies of this programme of research was protected from unauthorised access through storing them in password-protected computers. In addition, the data was maintained in a totally anonymous manner and when reporting the results, a coding system was used to refer to participants results or thoughts.

Finally, following the third principle, "Informed Consent**",** all the participants were well-informed about the aims, anonymity and confidentiality of data, procedure and tasks of each study that they were invited to undertake. Study 1 was with parents of children with ADHD and the parents were briefed about its aims and their rights before the interview started, and they were requested to read and sign an informed consent form. Studies 2 to 5 were with children with ADHD. Information sheets about the studies were given to the parents and they were allowed to ask the researcher any questions they had and they were requested to read and sign an informed consent form. Children's verbal consents were also obtained at the beginning and during the studies. In Study 6, which was conducted online, experts were given information about the study at the beginning of the online meetings and they were allowed to ask the researcher any questions they had and they were asked to give their informed consent to continue with the meetings. This was followed by an online questionnaire in which a written information sheet was given and experts were requested to read and sign an informed consent form.

Chapter 2 - Literature Review

2.1 Introduction

This chapter presents relevant background information as well as research on technologies for children with ADHD. The chapter is divided as follows: section 2.2 gives a review for the two well-known diagnostic criteria for ADHD; section 2.3 presents the attention deficits and distractibility in children with ADHD; section 2.4 presents measures for assessing ADHD; section 2.5 shows executive function deficits in ADHD, section 2.6 presents the functional impairments in children with ADHD; section 2.7 gives a review of the technological interventions for children with ADHD; and finally, section 2.8 gives a review for the effect of the environmental variables on ADHD.

2.2 Primary Symptoms and Diagnosis of ADHD: DSM-5 and ICD-10

There have been great efforts in recent years to more accurately recognize and diagnose ADHD. The Diagnostic and Statistical Manual of Mental Disorders (DSM) from the American Psychiatric Association (APA) (2013) and the International Statistical Classification of Diseases and Related Health Problems (ICD) from the World Health Organization (1992) are the two best-known sets of diagnostic criteria for mental disorders, including ADHD. They both provide comprehensive sets of symptoms, as well as guidance for how to best diagnose ADHD. This section is divided into subsections as follows: section 2.1 gives a description of ADHD in DSM-5, section 2.2 gives a description of ADHD in ICD-10 and section 2.3 gives a comparison between DSM-5 and ICD-10.

2.2.1 Description of ADHD in DSM-5

DSM-5 is the most recent version of the Diagnostic and Statistical Manual of Mental Disorders, released by the American Psychiatric Association (2013) although DSM-IV is still in use (Wolraich 2016). DSM-5 is used in many countries as a tool for diagnosis and treatment recommendations of mental disorders, including ADHD. DSM-5 defines ADHD in terms of two core clusters of symptoms: inattention and hyperactivity/impulsivity. Each cluster of symptoms has a set of nine criteria, presented in Table 2.1, Criteria A1 and A2, below. In addition, to judge whether an individual meets the criteria for one of the core clusters of symptoms, the criteria B, C, D and E in Table 2.1 must also be met.

Table 2.1 DSM-5 diagnostic criteria for ADHD (Source: Roberts et al., 2015)

A. Either (1) or (2):

1) **Inattention:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with the developmental level and that negatively impact directly on social and academic/occupational activities:

   Note: For older adolescents and adults (age 17 and older), at least five symptoms are required. The symptoms are not solely a manifestation of oppositional behaviour, defiance, hostility, or failure to understand tasks instructions.

   (a) often fails to give close attention to details or makes careless mistakes in schoolwork, at work or during other activities (e.g., overlooked or missed details, work is inaccurate).
   (b) often have difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations or lengthy reading).
   (c) often does not seem to listen when spoken to directly (e.g., the mind seems to be elsewhere, even in the absence of any obvious distraction).
   (d) often does not follow through on instructions and fail to finish schoolwork, chores or duties in the workplace (e.g., starts tasks but quickly loses focus, and easily side-tracked).
   (e) often has difficulty organizing tasks and activities (e.g., difficulty managing sequential tasks, difficulty keeping materials and belongings in order; messy, disorganized with work, has poor time management, fails to meet deadlines).
   (f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adults, preparing reports, completing forms, reviewing lengthy papers).
   (g) often lose things necessary for tasks or activities (e.g., school materials, pencils, books; tools, wallets, keys, eyeglasses, mobile telephones).
   (h) is often easily distracted by extraneous stimuli (for older adolescents and adults, may include related thoughts).
   (i) is often forgetful in daily activities (e.g., doing chores, running errands; for older adolescents and adults, returning to class, paying bills, keeping appointments).

2) **Hyperactivity and impulsivity:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with the developmental level and that negatively impact directly on social and academic/occupational activities:

Note: For older adolescents and adults (age 17 and older), at least five symptoms are required. The symptoms are not solely a manifestation of oppositional behaviour, defiance, hostility, or failure to understand tasks instructions.

Hyperactivity

(a) often fidgets with hands or feet or squirms in the seat.
(b) often leave the seat in situations where remaining seated is expected (e.g., leaves her or his place in the classroom, in the office or other workplace, or in other situations that require remaining in place).
(c) often runs about or climbs excessively in situations in which it is inappropriate (Note: In adolescents and adults, may be limited to subjective feelings of restlessness).
(d) often unable to play or engage in leisure activities quietly.
(e) is often "on the go", acting as if "driven by a motor" (e.g., is unable or uncomfortable being still for an extended time, as in restaurants, meetings, etc; – may be experienced by others as being restless or difficult to keep up with).
(f) often talks excessively.

Impulsivity

(g) often blurts out an answer before questions have been completed (e.g., completes people sentences, cannot wait for turn in conversation).
(h) often has difficulty awaiting turn (e.g., while waiting in line).
(i) often interrupts or intrudes on others (e.g., butts into conversations, games, or activities, may start using other people's things without asking for or receiving permission; for adolescents and adults, may intruding into and take over what others are doing).

B. Several Hyperactive/impulsive or inattentive symptoms that caused impairment were prior to age 12 years.
C. Several impairments from the symptoms are present in two or more settings (e.g., at home, school, work; with friends or relatives; in other activities).
D. There is clear evidence that the symptoms interfere with, or reduce, the quality of social, academic, or occupational functioning.
E. The symptoms do not occur during a course of schizophrenia or another psychotic disorder and are not better accounted for by another mental disorder (e.g., mood disorder, anxiety disorder, dissociative disorder, or a personality disorder).

Using DSM-5, ADHD is diagnosed as three different "presentations" (instead of three "subtypes" which was used in DSM-IV). The reason for this terminology is to emphasise that cases at different times may have more symptoms in one cluster than the other, without creating the notion of having three separate types (Roberts, et al., 2015).

The three presentations are based on the predominant symptoms that have persisted for the past six months:

- predominantly inattentive presentation (ADHD-PI) in which Criteria A1 (2.1, inattention) is met but Criteria A2 (2.1, hyperactivity-impulsivity) is not met.
- predominantly hyperactive-impulsive presentation (ADHD-PHI) in which Criteria A2 (hyperactivity-impulsivity) is met but Criteria A1 (inattention) is not met.
- combined presentation (ADHD-C) in which both Criteria A1 (inattention) and A2 (hyperactivity-impulsivity) are met.

In addition, the severity of symptoms must be specified during diagnosis. DSM-5 classifies severity as:

- **mild**, in which only few, if any, individual symptoms exceed those that are required to make the diagnosis and only minor impairments in social or occupational functioning are present
- **moderate**, in which symptoms lead to functioning impairments between more than 'mild' but less than 'severe'
- **severe**, in which many symptoms exceed those that are required to make the diagnosis, and/or there are significant impairments in social or occupational functioning present.

There are some limitations to the diagnosis of ADHD using the DSM-5 criteria. First, DSM-5 is dependent on symptoms in specific age groups in order to diagnose ADHD. However, it does not specify the number of symptoms required to diagnose pre-school children. In fact, this is problematic as pre-schoolers often express more hyperactive/impulsive behaviours that are typical development behaviours in their age and not necessarily a result of having ADHD (Roberts et al., 2015). Also, the accuracy of behaviour evaluation is dependent on the context. For instance, behaviour assessment of children by teachers in elementary school is more accurate than the assessment by teachers in middle and high schools. This is because, in elementary school, specific teachers spend more time with children in classrooms while in middle and high schools, teachers may only observe a student for 45 minutes each day (Wolraich, 2016). Furthermore, DSM requires a certain number of symptoms to "often" occur in a specific period of time. However, "often" occurrence is subjective to a teacher or parent who reports that specific inappropriate behaviours are present. There is also no clear standard criteria about whether the frequency of a given behaviour is considered normal or abnormal for a given age (Brown, 2005; Wolraich, 2016). In addition, DSM-5 ignores emotional dysregulation in the definition of ADHD (Barkley, 2016; Brown, 2005, 2009). However, since the first medical description of ADHD in 1775, symptoms of emotional dysregulation have been considered an important aspect in the theories and clinical descriptions of ADHD (Barkley, 2016). In fact, negative emotions including lower frustration tolerance, impatience, and getting angry quickly, and more general emotional expressions including being easily aroused are as frequent as the symptoms listed in the two symptoms clusters of ADHD (Barkley, 2016). Lastly, DSM-5 does not specify specific symptoms depending on gender. Although girls and boys with ADHD have similar patterns of severity with the problem, they express ADHD symptoms in varying degrees and presentations (Biederman et al. 2002).

2.2.2 Description of ADHD in ICD-10

ICD is a medical classification system that was released by the World Health Organization (WHO) in 1992 and the latest version (ICD-11) was released in 2018. Previous revisions of ICD referred to ADHD as hyperkinetic disorder (HKD), a term that is widely used in Europe and presented in European clinical guidelines (Taylor et al., 2004). Nonetheless, ICD-11 has moved from the term HKD to ADHD.

Since ICD-11 was put on official use recently on January 2021 (World Health Organization, 2021), the review below is about ICD-10 that has been used for a long time. ICD-10 defines HKD as a disorder of impaired attention and overactivity. The impaired attention is characterised by persistent difficulty in task involvement as well as moving between tasks without completion. Overactivity is manifest by fidgeting, too much talking, restlessness, and noisiness especially in cases, in which where calm is expected. ICD-10 also requires the symptoms to present for a long period of time before the age of six years. The impairments must also present in two or more settings such as home, classroom, or clinic. In addition, diagnosis of other disorders such as anxiety disorders, mood affective disorders, pervasive developmental disorders and schizophrenia must be carefully checked and excluded (World Health Organization, 1992).

ICD-10 also provides a list of symptoms that are specific for children with HKD including difficulty in social relationships, extravagance in dangerous situations, misbehaving and lack of adherence to social norms including intruding on and interrupting others, improperly answering questions, and not waiting in turn. In addition, ICD-10 is strict in the diagnosis in the sense that attention deficits should not be diagnosed unless these deficits are considered excessive for the age and IQ of the child. Similarly, overactivity must be considered by comparing a child's behaviour to the behaviour of other children of the same age and IQ in the same situation. Finally, overactivity in pre-school children should only be diagnosed when extreme levels are present. For adults, the diagnosis of HKD is based upon the same criteria. However, both attention and activity must be measured with reference to other typically developed individuals. To diagnose HKD, ICD-10 requires all three symptoms including inattention, hyperactivity and impulsiveness to be present at one time (World Health Organization 1993).

There are a number of limitations for ICD-10. For instance, ICD-10 only has one presentation for HKD that resembles the ADHD-C presentation in DSM-5 which may result in underdiagnosis of ADHD and thus lower incidence rates (Döpfner et al., 2008). ICD-10 also ignores emotional dysregulation in the definition of ADHD (Corbisiero et al., 2013). In addition, ICD-10 excludes those with comorbidities when diagnosing HKD, which again results in underdiagnosis of ADHD (World Health Organization, 1992). Lastly, ICD-10 does not specify specific symptoms depending on gender although boys and girls express ADHD symptoms in varying degrees and presentations as discussed above in section 2.2.1.

2.2.3 Comparison of DSM-5 and ICD-10

While both DSM-5 and IDC-10 require several impairments caused by ADHD symptoms to be present in two or more settings and that the symptoms interfere with social, academic, or occupational functioning, there are some differences between the two criteria. For instance, to diagnose HKD, ICD-10 requires all three symptoms including inattention, hyperactivity and impulsivity to be present at one time whereas the DSM-5 criteria give three different presentations of ADHD (see section 2.2.1, above). Nonetheless, according to Döpfner et al. (2008), ADHD-I, in all age groups, was found to be the most prevalent presentation, followed by ADHD-C and the ADHD-H presentations (Döpfner et al., 2008). In addition, DSM-5 accepts that children with ADHD may have comorbid disorders whereas ICD-10 excludes those with comorbidities when diagnosing HKD (see sections 2.2.1 and 2.2.2, above). This may result in underdiagnosis and thus lower incidence rates of ADHD when using ICD-10. Also, to diagnose ADHD, ICD-10 requires an onset of symptoms before the age of six years whereas DSM-5 requires an onset of symptoms at or prior to the age of 12 years. The requirement of ICD-10 of the symptoms to be present before the age of six years may result in underdiagnosis of ADHD in smaller children in particular as the inattention symptoms become clearer when the child gets older (Döpfner et al., 2008). Lastly, both DSM-5 and ICD-10 ignore emotional dysregulation despite its importance in the definitions and theories of ADHD as discussed above in section 2.2.1.

2.3 Attention Deficits and Distractibility in Children with ADHD

This programme of research focuses on two of the defining symptoms of the first cluster of symptoms of ADHD, which include deficits in attention and difficulties in resisting distractibility (see section 2.2.1). There are four types of attention with varying levels of deficits in children with ADHD and these types are described in more detail in section 2.5. In this section, distractibility in children with ADHD is discussed and a number of studies that have investigated the effect of distractors on the cognitive performance of children with ADHD is reviewed.

Distractibility, according to Ramsay (2015), is "a somewhat different form of inattention insofar as it represents punctuated attention or difficulties screening out interference" (p. 477). The sources of distractibility are often external environmental stimuli, which interrupt and divert attention away from the task on hand. Examples of external visual distractions in the context of the work in this thesis are someone passing by a window, someone entering the room or moving around the child and colourful pictures in a room. Examples of auditory distractors are someone talking or any distracting noises, which could be loud traffic, machinery or even footsteps. Nonetheless, distractibility can also result from internal distractions by internal thoughts such as remembering things, hunger, or an internal sense of restlessness (Ramsay, 2015). Internal distractibility is also referred to as mind-wandering and ADHD has been consistently linked with spontaneous mind wandering (Lanier et al., 2021). Some researchers have attributed the abnormal distractibility in children with ADHD to deficient control of the involuntary attention to any stimuli in the surrounding environment of children with ADHD (Cassuto & Berger, 2013; Gumenyuk et al., 2005).

The focus of this programme of research is on the external distractors. Therefore, a number of studies that have investigated the effect of visual, auditory and mixed distractors on the cognitive performance of children with ADHD is to be reviewed.

Cassuto and colleagues (2013) conducted a study with 345 children aged 7 to 12 years with ADHD using a task, MOXO, a continuous performance test that is similar to the Go/NoGo task which will be used in this programme of research (see section 2.4.2.2) with visual, auditory, and mixed distractors and no-distractor conditions and found that children with ADHD committed OEs in all distracting conditions compared to the no distractor condition. The study did not investigate the effects of distractors on RTs or RTV (for the explanation of these variables, see section 2.4.2).

Berger and Cassuto (2014) conducted another study using the same methodology with adolescents with ADHD aged 13 to 18 years. They found that adolescents with ADHD were negatively affected by all distracting conditions, but they made more OEs in pure visual or mixed distractor conditions compared to no distractor conditions or pure auditory distractor conditions. However, the study did not investigate the effects of distractors on RTs or RTV.

Gumenyuk and colleagues (2005) also conducted a study with 21 children: 11 with ADHD and 10 without ADHD aged 8 to 10 years using a visual discrimination task with an auditory distractor and no distractor conditions. They found that children with ADHD committed more OEs in the auditory distractor condition, and there was a trend to an increased RTs, but they did not investigate the effects of distractors on RTV.

A further study by Parsons and colleagues (2007) conducted a study with 20 children: 10 with ADHD and 10 without ADHD aged 8 to 12 years using virtual reality to present visual, auditory and mixed distractors in a Go/NoGo type task. They found that children with ADHD committed more OEs than children without ADHD during the distracting conditions, but no information was provided about whether OEs were higher in one distracting condition compared to the others. They also found no difference in RTs between the conditions, but they did not investigate the effect of distractors on RTV.

In addition, Adams and colleagues (2011) conducted a study with adults with ADHD using a Stroop Signal task (SST) to measure attention and a Delayed Oculomotor Response (DOR) task to measure distractibility in the presence of visual distractors. This study found higher RTV in the SST is linked to higher distractibility in the DOR task due to visual distractors.

Finally, Pelham and colleagues (2011) measured the classroom behaviour and performance of 41 children aged 7 to 13 years with ADHD under three conditions: video distraction, music distraction and no distraction. They found that the children had the worst performance in the video distraction condition, while their performance in the auditory distraction condition was very varied with some children performing better compared to the no distraction condition, but others performing worse.

As seen above, the visual, auditory or mixed distractors in the surrounding environment of children with ADHD affect their performance and thus lead to functional impairments. Therefore, modifications to the surrounding environment by lessening the distracting stimuli may be generally helpful for children with ADHD (Knouse, 2015; Pfiffner & DuPaul, 2015). Examples of existing modifications to the surrounding environment to reduce visual distractors include having a quiet room with blank walls, avoiding sitting a child with ADHD beside a classroom window or door and using cubicles or dividers (Barnett, 2017; Harris, 2006; Reiber and MacLaughlin, 2004). However, these modifications are context dependent and cannot be available whenever and wherever the child needs to perform a task requiring high attention. Thus, more work is required to provide an assistive technology that helps reduce the distracting stimuli and be available whenever it is needed.

2.4 Measures for Assessing ADHD

Psychologists and clinicians have used different measures to either assess ADHD or to check for the effectiveness of medication or interventions to address the impairments associated with ADHD. These measures include subjective and objective measures. Section 2.4.1 describes the subjective measures as well as their limitations, and Section 2.4.2 describes the objective measures, in particular the Continuous Performance Tests (CPTs) and the Go/NoGo task, which was used in a number of studies in this programme of research.

2.4.1 Subjective Measures of ADHD

Subjective measures of inattention, hyperactivity and impulsivity include questionnaires and/or surveys, interviews, and self-report methods. Self-report methods are very common techniques for measuring ADHD symptoms among adolescents and adults. Questionnaires and interviews with parents and teachers are the most suitable methods for measuring ADHD symptoms in children.

All of the methods above may include rating scales of ADHD symptoms that measure the frequency of ADHD-related behaviours as described in the DSM. These rating scales help in collecting information about symptoms and functioning of individuals who are more severe than their age and gender-matched peers. Using these rating scales can also reduce the time required to obtain information about children who may have ADHD, as well as make the information required understandable to these respondents. In fact, this is particularly important in eliciting information from teachers for whom direct contact with researchers and clinicians might be difficult.

As a requirement of the DSM-5, the information must be collected in several settings from parents, teachers, and others, and this is important for an accurate assessment of ADHD as well as treatment monitoring. Therefore, some rating scales provide different versions depending on the rater type. With that being said, rating scales do not provide a definite diagnosis of ADHD and it is important to have their results confirmed by professionally trained mental health clinicians (Kollins et al., 2011; Wolraich et al., 2011). Thus, rating scales results represents the start, not the end, of the clinical assessment.

There are many rating scales that are based on the behavioural symptoms of ADHD provided in DSM-IV or DSM-5 since ADHD symptoms have not changed between these versions (Wolraich, 2016). Examples of the most common rating scales for ADHD for children and adolescents are listed in Table 2.2.

Table 2.2 Most common rating scales based on DSM-IV

Reference	Name
Swanson, et al., (1982) as cited in Wolraich et al. (2007)	Swanson, Nolan, and Pelham-IV Questionnaire (SNAP-IV)
Achenbach & Edelbrock (1983) as cited in Wolraich et al. (2007)	Child Behaviour Checklist (CBCL)
DuPaul & Barkley, (1992)	Barkley Home and School Situations Questionnaire-Revised
Conners et al. (1998)	Conners Teacher and Parent Rating Scales
DuPaul et al. (1998)	ADHD-IV Parent and School Versions
Bagwell et al. (2001)	Disruptive Behaviour Disorder Rating Scale-IV
Wolraich et al. (2013)	Vanderbilt Parent and Teacher ADHD Rating Scales

While these measures might help identify some ADHD symptoms, they have some issues. Most existing questionnaires and interview measures have been found to have very low, if not negligible, correlations with each other (Monahan & Steadman, 1994 as cited in Bezdjian et al., 2009). In addition, questionnaires and interviews might be not effective for repeated use, such as measuring the long-term effect of an intervention or comparing the effectiveness of different interventions (Moeller et al., 2001). Furthermore, measures that rely on the viewpoints of parents or teachers are very subjective in the sense that they heavily depend on the person's norms and how the parents and teachers are educated about ADHD. For example, one person might see the extensive movement and running about of a child as hyperactivity while another person might see it as a normal thing for a child and part of their development.

Also, it may be very difficult to differentiate different and complex constructs, such as impulsivity and inattention using questionnaires and interviews (Bezdjian et al., 2009). For instance, DSM-IV items for ADHD are included in many of the questionnaires and interviews. In this version, there is an overlap between some items related to inattention, hyperactivity and impulsivity. Some of the items that are defined as inattention, such as 'often has difficulty in sustaining attention in tasks or play activities', or 'often does not follow through on instructions or fails to finish schoolwork, chores, or duties in the workplace', and some of the items that are defined as hyperactivity, such as 'often leaves seat in classroom or in other situations in which remaining seated is expected' are closely related to the general concept of impulsivity (Evenden, 1999). Therefore, the overall behaviour of an individual with ADHD may be a result of common factors in inattention, impulsivity and hyperactivity or it may also exist independently of each other (Evenden, 1999). To overcome the problems related to subjective measures, objective measures can be used, as described in the next section.

2.4.2 Objective Measures of ADHD

Objective measures of ADHD can be classified into two types: psychological measures, such as the Continuous Performance Tests (CPT), and physiological measures, such as electroencephalograph (EEG) and functional magnetic resonance imaging (fMRI). The difference between the two types is that the psychological measures help distinguish the three constructs of ADHD, the inattention, impulsivity and hyperactivity at the behavioural level (Bezdjian et al., 2009). In comparison, physiological measures work on the underlying neurophysiological processes or brain processes responsible for ADHD (Snyder & Hall, 2006).

Psychological measures may be good alternative methods to subjective measures of ADHD. This is because psychological measures are based on measuring the real behaviour of the child with ADHD (Homack & Riccio, 2006). In addition, psychological measures are effective for repeated use, such as measuring the long-term effect of an intervention or comparing the effectiveness of different interventions (Bezdjian et al., 2009). Furthermore, such measures have been successful in differentiating between different and complex constructs, such as impulsivity and inattention (Riccio et al., 2002).

2.4.2.1 Continuous Performance Tests (CPTs)

CPTs are a family of non-invasive computerized tests that have been used widely in the objective assessment of the evaluation of ADHD and other neurological disorders (Ballard, 2001; Homack & Riccio, 2006; Riccio et al., 2002). Examples of the most commonly used CPTs in ADHD research are the Go/NoGo task (see section 2.4.2.1) and the Conners test (Homack & Riccio, 2006).

The first CPT was developed by Rosvold and his colleagues in 1956 and since then CPTs have become one of the most common psychological measures to study vigilance or sustained attention as well as impulsivity (Riccio et al., 2002). In general, CPTs present two stimuli, target and non-target, to participants who are required to respond to the target stimulus and not respond to the non-target stimulus. Every stimulus is shown on the screen for a limited number of milliseconds (ms), called the *stimulus duration.* After that, a blank screen is shown for a period of time, called the *inter-stimulus interval* (ISI), before showing the next stimulus (Riccio et al., 2002). The response time to the presented stimulus starts from the appearance of the current stimulus and finishes just before the appearance of the next stimulus. The stimulus duration and the ISI specify the *event rate (ER),* which indicates the speed of presenting the stimuli (Tamm et al., 2012).

In the initial version of the CPT developed by Rosvold et al. (1956) (as cited in Riccio et al., 2002)., the target stimulus was a letter 'X' and the non-target stimulus was any letter other than 'X'. The stimuli were presented visually to participants one at a time, with a fixed stimulus duration of 920ms. However, there have been many variations in the components of CPTs as well as the populations they have been used with (Riccio et al., 2002). For instance, the stimulus in a CPT could be a letter as in the original version, a number (as in (Gordon, 1983, as cited in Riccio et al., 2002) and Wypych et al., 2019), a word (as in Earle-Boyer et al., 1991), or a picture of a person or an object (as in Anderson et al., 1969, as cited in Riccio et al., 2002 and Brophy et al. 2002). Other variations include presenting the stimuli in a visual form as in the initial CPT or in auditory form (as in Earle-Boyer et al., 1991 and Kaiser et al., 2006), or in both forms (as in (Sandford & Turner, 1995, as cited in Riccio et al., 2002)). In addition, CPTs have varied in the ratio of target to non-target stimuli, the stimulus duration, as well as the stimulus quality. CPTs have also varied in the ISI, including CPTs with a short interval, a long interval, or a variable interval (Riccio et al., 2002).

CPTs result in quantitative information about an individual's ability to sustain attention as well as impulsivity and this information includes (Riccio et al., 2002):

- *Omission errors (OEs),* errors resulting from missing a target stimulus.
- *Commission errors (CEs),* errors resulting from responding to a non-target stimulus.

- *Reaction times for correct target trials (RTs),* which measure the time between presenting the stimulus and the participant's response.
- *Reaction time variability (RTV),* which measures (in)stability in reaction times to a set of target stimuli.

Omission Errors (OEs)

Previous studies have shown that children with ADHD commit more OEs than typically developing children (Baijot et al., 2016; Helps et al., 2014; Schmidt et al., 2019). More OEs represent greater inattention in children with ADHD (Tamm et al., 2012, Schmidt et al., 2019). A number of studies of the validity of different CPTs in the literature found that the number of OEs was significantly correlated with behavioural ratings of inattention from teachers and caregivers (Bezdjian et al., 2009; Egeland et al., 2009; Klee & Garfinkel, 1983) and significantly correlated with other tasks measuring sustained attention (Klee & Garfinkel, 1983). Thus, OEs are considered a robust measure of (in)attention in children with ADHD. Nonetheless, to the best of my knowledge, little research has been conducted to investigate the neurological basis of OEs (Goetz et al., 2017).

Commission Errors (CEs)

Previous studies have shown that children with ADHD also commit more CEs than typically developing children (Baijot et al., 2016; Helps et al., 2014; Schmidt et al., 2019; Tamm et al., 2012). More CEs represent greater impulsivity in children with ADHD (Schmidt et al., 2019; Tamm et al., 2012). A number of studies of the validity of different CPTs in the literature found that the number of CEs was significantly correlated with behavioural ratings of impulsivity from teachers and caregivers (Bezdjian et al., 2009; Klee & Garfinkel, 1983). However, Halperin and colleagues (1991) found in their data that some CEs appear to reflect impulsivity in children while other CEs do not. Nonetheless, to the best of my knowledge, little research has been conducted to investigate the neurological basis of CEs in children with ADHD (Ding & Pang, 2021).

Reaction Times (RTs)

Previous research has mixed conclusions about RTs in children with ADHD. Some studies (Epstein et al., 2011b; Russell et al., 2006) found that children with ADHD are slower than typically developing children. According to a meta-analytic study by Kofler and colleagues (2013), children with ADHD had similar RTs to if not faster than typically developing children after controlling for RT variability (Kofler et al., 2013; Buzy et al., 2009). In addition, event rates (ERs) affect RTs in different ways. For instance, slow ERs result in under-activation and slow inattentive responding while fast ERs result in over-activation and thus impulsive fast responding (Metin et al., 2012). In addition, results from studies showed that fast ERs limit RTs and thus eliminate the differences in RTs between children with ADHD and typically developing children (Epstein et al., 2011b, Tamm et al., 2012).

As for the relation between RTs and ADHD symptoms, there is no consensus on whether RTs are linked to inattention or impulsivity. Bezdjian et al. (2009) and Halperin et al. (1991) suggested that higher CEs and faster RTs are indictors of impulsivity. This was based on a statistical inverse correlation between CEs and RTs. On the other hand, Cheyne et al. (2009) and Epstein et al. (2010) found based on a close observation of the patterns in their data that children with ADHD had had slower RTs just before and after OEs. The long RT prior to the OE may reflect the start of attentional disengagement (i.e., attentional lapses), whereas the OE may indicate complete attentional disengagement or mind wandering (Cheyne et al. 2009; Epstein et al. 2010). In this context, children with ADHD having longer RT on the trial just after an OE may reflect that the attentional disengagement extends beyond the OE (Epstein et al., 2010). Epstein et al. (2010) also found that Children with ADHD had long RT before successful inhibition that is not responding to a non-target stimulus. Long RTs prior to successful inhibition may reflect the beginnings of attentional disengagement as discussed above. Given that RTs are strongly correlated in trials nearer to one another, a long RT in one trial is very likely to result in a long RT or even a non-response in the next trial (Epstein et al., 2010). Another possible link between RTs and inattention is found in a study by Egeland and colleagues (2009) that showed that RTs significantly correlated with inattention ratings from both parents and teachers.

The majority of studies using different CPTs have used parametric analysis including, means to calculate RTs and ANOVAs (Kofler et al., 2013; Tamm et al., 2012). These studies appear to assume that their RT data meets the assumptions for parametric analysis without reporting analyses of whether their data meet the requirements for such analysis (Kofler et al., 2013; Tamm et al., 2012). However, RTs are typically non-normally distributed, with a positive skew and a tail of longer RTs, particularly for individuals with ADHD (see Figure 2.1, Castellanos et al., 2006; Kofler et al., 2013; Tamm et al., 2012).

Long outlying RTs might include real long but outlying responses or reflect complete lapses in attention as stated earlier (Kofler et al. 2013, Tamm et al. 2012). Thus, one may argue for replacing means of RTs with a more robust estimator, the median of RTs (as in Bezdjian, et al., 2009). Also, non-parametric tests, particularly rank-based tests, such as the Wilcoxon and Friedman tests are suggested to be more robust to problems with outlying data over their parametric counterparts such as ANOVAs (Cairns, 2019). In fact, Cairns (2019) stated that the Wilcoxon and Friedman rank-based tests appear to be very reliably robust in all practical situations.

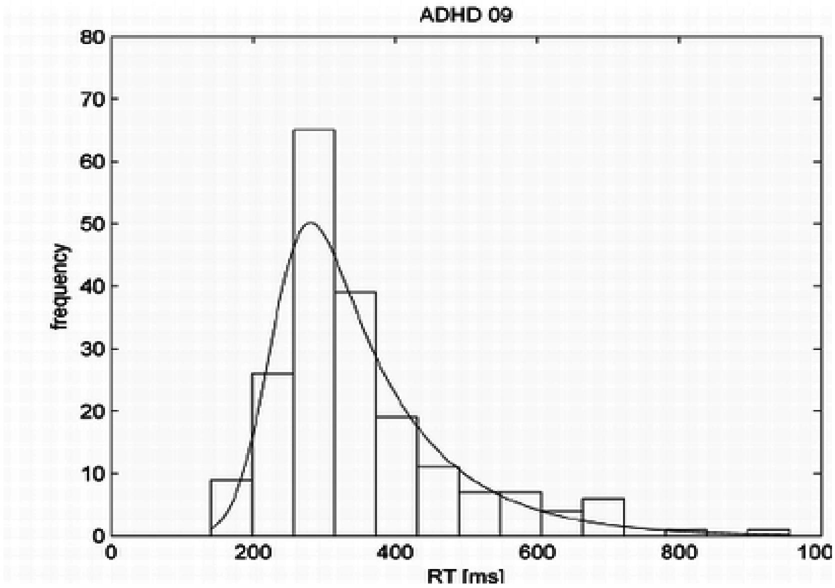


Figure 2.1 Example of RTs distribution with a positive skew for an individual with ADHD (Source: Gmehlin et al., 2014)

Reaction Time Variability (RTV)

Previous studies have shown that RTV is higher in children with ADHD compared to typically developing children, using different computerized tasks, including tasks assessing working memory, attention, inhibition and choice discrimination (Kofler et al., 2013; Tamm et al., 2012). The precise psychological explanation of what RTV in

ADHD reflects is constantly being debated amongst researchers (Tamm et al., 2012). However, previous studies have found that ADHD is not alone in this debate. In fact, high RTV has been documented in individuals with autism, schizophrenia, traumatic brain injury, and early-stage Alzheimer's dementia (Tamm et al., 2012). One common aspect among all these different populations is problems in attention. However, these problems seem to be significantly different across populations in the sense that different populations have different problems in attention, including selective attention, sustained attention, divided attention and combinations of these types (Tamm et al., 2012). In individuals with ADHD, increased RTV in a majority of studies has been linked to problems in sustained attention (Kofler et al., 2013; Tamm et al., 2012; Schmidt et al., 2019). Several studies also found that RTV correlated significantly with the behavioural ratings of inattention from parents and teachers (Bezdjian et al., 2009; Nigg, 1999; Wåhlstedt, 2009; Wåhlstedt et al., 2009). It was also found that RTV correlated significantly with OEs, the other indicator of inattention (Bezdjian et al., 2009).

RTV in ADHD research typically reflects periodic lapses in attention (i.e., problems in sustaining attention in tasks, that do not result in omission errors) (Epstein et al., 2010; Tamm et al., 2012). However, the precise patterns of these attentional lapses (i.e., fluctuations in RTs) over time have not been studied well in the literature and this could be partly attributed to the lack of adequate methods (Bluschke et al., 2021). In addition, the precise neurophysiological basis of RTV in ADHD has not been widely examined and continues to be debated (Tamm et al., 2012; Machida et al., 2019). In addition, despite the fact that RTV and OEs both seem to reflect inattention in children with ADHD, some studies have suggested that RTV has a different neurological basis from OEs (Goetz et al., 2017; Perri et al., 2017).

Similar to the effect of ERs on RTs, fast ERs are known to improve arousal and attention in children with ADHD and thus improve RTV (Tamm et al., 2012). One possible reason for that could be the state regulation dysfunction model. According to this model, fast ERs improve arousal and increase the activation state and thus attention in children with ADHD. The effect of the fast ERs on RTV in children with ADHD could also be explained methodologically, in the sense that fast ERs may limit RTs, and thus, lowers the differences or variability in RTs between trials (Epstein et al., 2011b). Alternatively, long ERs may result in under-arousal or under-activation and thus inattention and thus worsen RTV (Sonuga-Barke et al., 2010). One possible reason for that could be the delay aversion model of ADHD (Metin et al., 2012, 2014). This model suggests that individuals with ADHD do not cope well with a situation requiring delays or waiting (Sonuga-Barke & Halperin, 2010). As some tasks give participants with fixed and long delays (i.e., ISI), children with ADHD might find other interesting things to distract themselves from the task at hand and move their attention to stimuli irrelevant to the task (Hwang-Gu et al., 2019). Therefore, children with ADHD may perform inconsistently (i.e., increased RTV) in tasks with longer ISI (Metin et al. 2014). Similarly, rewards or motivational incentives such as giving children points for correct responses during the task are found to improve the RTV in children with ADHD (Adamo et al., 2019; Epstein et al., 2011a; Kofler et al., 2013).

There has been a controversy about the most suitable measures for measuring RTV. RTV has been calculated in the previous studies as the standard deviation (SD) of RTs or as the Coefficient of Variance (CV) of RTs (Elmaghrabi et al., 2020; Tamm et al., 2012; Vainieri et al., 2021). CV is calculated by dividing the standard deviation of RTs by the mean RT. In addition, some studies used more complicated methods to measure RTV, including Ex-Gaussian and Fast Fourier Transform (FFT) methods (Tamm et al., 2012). Nonetheless, RTs, as discussed above, are typically non-normally distributed. Thus, one may argue for replacing traditional SDs and CVs with more robust estimators, including interquartile ranges or Median Absolute Deviation from the median (MAD) (Cairns, 2019; Ospina & Marmolejo-Ramos, 2019).

2.4.2.2 The Go/NoGo Task

As discussed above, CPTs include a range of tasks that have been used widely as an objective assessment for evaluating ADHD and other neurological disorders. One of the well-known tasks in the family of CPTs which was used in a number of studies in this programme of research is the Go/NoGo task.

The Go/NoGo task has a very long history and was used by Gordon and Caramazza in 1982. The task has been used since then in several areas, such as bilingualism, visual-word recognition, masked priming, speech production and neuropsychology (Gomez, et al., 2007).

In ADHD research, the Go/NoGo task has been widely used as a tool to objectively assess and evaluate inattention and impulsivity in individuals with ADHD (Baijot et al., 2016, Bezdjian et al., 2009; Tamm et al., 2012). A meta-analytic study of research that has used the Go/NoGo task (Wright, et al., 2014), found that the majority of studies were on ADHD, while only a few studies were on other mental disorders.

As with all CPTs, a Go/NoGo task involves two stimuli, a Go stimulus and a NoGo stimulus. A participant must press a button on a keyboard or device as quickly and accurately as possible when a Go stimulus is presented on a computer screen and not press when a NoGo stimulus is presented. Go/NoGo tasks also vary in the type of stimuli used, the ratio of Go to NoGo stimuli, the stimulus durations, the Inter Stimulus Intervals (ISIs) and the Event Rates (ERs). ERs used in tasks could be fast, moderate or slow. However, there is no clear consensus on how to classify ERs into fast, moderate or long as it is relative to what is optimal to the task on hand. Therefore, ERs vary depending on the task and individual characteristics (Tamm et al., 2012). Table 2.3 presents five parameters for the Go/NoGo tasks and the ranges of values for these parameters according to two meta-analysis studies of the Go/NoGo tasks. The Go/NoGo task has the same dependent variables as discussed earlier for CPTs: OEs, CEs, RTs and RTV.

Table 2.3 The different parameters of the Go/NoGo task and their ranges of values

Parameter	**Study**	**Ranges of values**
Ratio of NoGo stimuli	Simmonds et al. (2008)	6.8% to 50%
Stimulus duration	Simmonds et al. (2008)	200ms to 1100ms
ISI	Simmonds et al. (2008)	800ms to 12000ms
Fast event rate	Metin et al. (2012)	1250ms and 2300ms
Slow event rate	Metin et al. (2012)	4250ms and 9000ms

There are no studies which have investigated the effect of the number of preceding Go or NoGo stimuli on the response of children to the next Go stimulus. There is also no clear consensus on the number of the Go or NoGo stimuli which should precede the NoGo stimuli. While Durston (2002) suggested that more commission errors were committed after five or more Go stimuli preceding a NoGo stimulus, Schulz et al.

(2009) found that commission errors were committed mostly when a NoGo stimulus was preceded by no, five or more Go stimuli.

The Cued Go/NoGo Task

There is a special kind of the Go/NoGo task, called a cued (i.e., a warned) Go/NoGo task. This task was used by one of the studies (Baijot et al., 2016) which inspired Study 2 and 3 in this programme of research. This task is the same as the typical Go/NoGo task described earlier but it has a cue or a warning stimulus, that is displayed just before displaying the intended Go or NoGo stimulus (Smith et al., 2004). The aim of the cue is to warn participants to be prepared for the next stimulus. The cued Go/NoGo task is used mainly in event-related potential (ERP) research. ERP is used to study the electrophysiological activity of brain components involved in performing a task (Smith et al., 2004, 2006). ERP data is collected by using the ElectroEncephaloGraphy (EEG) technique. EEG uses electrodes that are connected to specific places (i.e., sites) in the participant’s scalp, in order to register the underlying brain components' electrical waves (i.e., activities) (Smith et al., 2004, 2006). ERP data involves components (i.e., variables) that are related to response preparation, response initiation, response inhibition, sensory processing, context categorization, and context updating and stimulus discrimination. These components are calculated using a combination of data read from one or more specific sites. ERP data for a cued Go/NoGo task is typically calculated separately for the correct Go trials, NoGo trials and warning trials (Smith et al., 2006).

The Validity and Reliability of the Go/NoGo Task

Bezdjian and colleagues (2009) conducted a study with 1151 children with ADHD aged 9 to 10 years to investigate the validity of the Go/NoGo task in measuring inattention and impulsivity. The study collected behavioural data using the Go/NoGo task and questionnaire ratings of inattention and impulsivity from both teachers and caregivers. The four measures resulting from the Go/NoGo task were compared with inattention and hyperactivity-impulsivity ratings. The number of OEs was significantly correlated with inattention ratings from both teachers and caregivers and the number of CEs was significantly correlated with the hyperactivity-impulsivity ratings. RTs did not correlate with either of the symptom ratings but inversely correlated with the CEs. RTV correlated significantly with the inattention ratings and OEs.

As for the reliability of the Go/NoGo task, studies by Bezdjian et al. (2009) and Kindlon et al. (1995) conducted three-to-six-month test-retest studies. The results indicated that the measures of the Go/NoGo task were reliable and stable over time.

2.5 Executive Function Deficits in ADHD

Over the past decade, research has investigated the main causes of impairments in children with ADHD. Substantial evidence has accumulated showing that the behavioural and functional impairments in children with ADHD are functionally dependent on developmental deficits of executive function (EF), the person's cognitive management system (Brown, 2009; Rapport et al., 2015). The behavioural impairments, as described in section 2.1, are inattention, hyperactivity and impulsivity. The functional impairments include impairments in academic and social functioning.

ADHD is a highly heterogeneous neurocognitive disorder, with varying EF deficits to varying degrees (Kofler et al., 2019; Towey et al., 2019). Nonetheless, as stated earlier, children with ADHD have developmental deficits in EF mainly in working memory and related attentional components (Rapport et al., 2015).

Working Memory Deficits

The term working memory has developed gradually from the concept of short-term memory (STM), which refers to the temporary storage of information, to a combination of storage and manipulation (Baddeley, 2012). Working memory is defined as "a limited-capacity system that is responsible for the temporary storage, rehearsal, processing, updating, and manipulation of information held internally" (Rapport et al., 2015, p. 645). Working memory plays a vital role in guiding daily behaviour and is responsible for performing many complex tasks including, learning, comprehension, planning and reasoning. Working memory is composed of two main components, the working component and the memory component as shown in Figure 2.2.

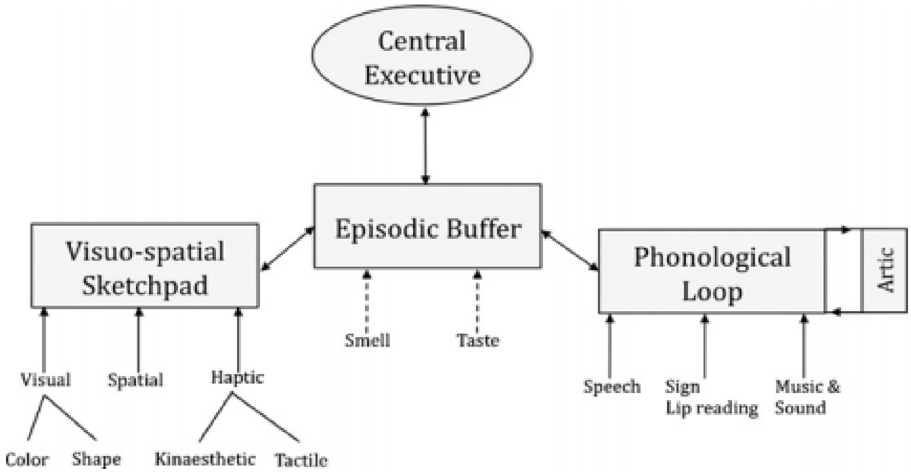


Figure 2.2 Baddeley's model of Working Memory (Baddeley, 2012)

The working component, the "central executive", is responsible for guiding behaviour through mental processing, updating, and reordering of the information held internally in the memory component. The central executive has a primary role in controlling and focusing attention (Baddeley, 2007, 2012). The memory component is also composed of three storage/rehearsal components, known as the phonological and the visuospatial components, and the episodic buffer. The phonological component is responsible for verbal information, including language-related information whether written or auditory. The visuospatial component is responsible for nonverbal (i.e., visual and spatial) information, including shape and location. The episodic buffer is a limited capacity storage binding both visuospatial and phonological information to form integrated episodes (Baddeley, 2012).

Research has suggested that children with ADHD have deficits the most in the working component of working memory (i.e., the central executive), which is thought to be causally and functionally related to their problems of inattention, hyperactivity and impulsivity (Kofler et al., 2010; Rapport et al., 2015). Also, the working component is involved in many important academic and intellectual tasks such as reading, mathematics, listening comprehension, learning and reasoning (Rapport et al., 2015). In contrast, children with ADHD have medium deficits in the memory components, the phonological and visuospatial components, which are found to be minimally related, if not completely unrelated, to the main symptoms of ADHD and their functional impairments. Also, the memory component has a limited association with learning outcomes (Rapport et al., 2015). The episodic buffer is thought to be intact in children with ADHD and is unrelated to ADHD core symptoms (Kofler et al., 2017).

Two meta-analysis studies by Melby-Lervåg and Hulme (2013) and Rapport et al. (2015) investigated the effectiveness of working memory training for children with ADHD. Both meta-analysis studies stated that all available working memory training targets only the phonological and visuospatial components of working memory. Also, both meta-analysis studies suggested that training programmes resulted in medium short-term improvements in working memory skills. However, there was limited evidence that these improvements were maintained. More importantly, there was no convincing evidence that the improvements obtained could be generalized to other untrained skills (Melby-Lervåg & Hulme, 2013; Rapport et al., 2015).

Attention Deficits

Attention is considered as an essential part of EF. It has often been suggested that limitations in the attentional resources lead to working memory and other EF deficits. However, locating and identifying the particular attentional components impaired in those with ADHD has been particularly challenging (Rapport et al., 2015). Attention is not a unitary construct, and studies of attention in children with ADHD often concentrate on four attentional components: orienting/alertness attention, selective/focused attention, divided attention, and vigilance/sustained attention.

Orienting/alertness attention is “the ability to enhance one’s activation level following a stimulus of high priority” (Rapport et al., 2015, p. 646). This aspect of attention has been suggested to be intact in children with ADHD (Rapport et al., 2013, 2015). Selective/focused attention is defined as “the ability to facilitate the processing of one source of environmental information while preventing the processing of others” (Rapport et al., 2015, p. 646). Studies have shown mixed results, in which children with ADHD have shown better, similar and worse selective attention measures compared to typically developed children (Rapport et al., 2013, 2015). Divided attention refers to “the ability to attend and respond to multiple tasks or multiple tasks demands simultaneously” (Rapport et al., 2015, p. 646). Studies have shown similar results to the selective attention in the sense that there was no definitive conclusion about divided attention measures in children with ADHD (Rapport et al., 2013, 2015). Finally, vigilance/sustained attention is "the ability to maintain a tonic state of alertness during prolonged and sustained mental activity" (Rapport et al., 2015, p. 646). Sustained attention in children with ADHD involves deficits to varying degrees in visual and/or auditory attention (Lin et al., 2021). Studies have shown that children with ADHD have significantly underdeveloped vigilance/sustained attention (Rapport et al., 2013, 2015).

Since this programme of research is focused on the attention of children with ADHD, this review includes both the studies that conducted attention training for children with ADHD along with results from two meta-analysis studies about the effectiveness of these training studies. A summary of the studies conducted to investigate the effectiveness of attention training in children with ADHD is presented in Table 2.4.

Table 2.4 Summary of attention training studies

Reference	**Sample**	**Computerized?**	**Program**	**Attention type**
Kerns et al. (1999)	T(n) = 7, M = 9.39 C(n) = 7, M = 9.35	Yes	Pay Attention!	Sustained, Selective, Divided
Semrud et al. (1999)	T(n) = 21, M = 10 C_{ADHD}(n)=12, C(n)=21, M = 10	No	APT	Sustained
Tucha et al. (2011)	T(n) = 16, M = 10.7 C(n) = 16, M = 10.7	Yes	AixTent	Sustained, Selective, Divided
Lange et al. (2012)	T(n) = 16, M = 10.8 C(n) = 16, M = 10.8	Yes	AixTent	All
Tamm et al. (2013)	T(n)=54, M = 9.3 C(n)=51, M = 9.3	No	Pay Attention!	Sustained, Selective, Divided

Note: T(n) is the number of participants in the treatment group, C(n) is the number of participants in the control group), M is the mean age

One of the earliest studies (Kerns et al., 1999) conducted attention training on two groups of children with ADHD: a treatment group and a control group. The treatment group received game-like tests, called Pay Attention! for training and measuring attention components including sustained, selective and divided attention. The control group played several computerised video games with no specific aim in mind. Children in both the treatment and control groups received sixteen individualized training sessions, for thirty-minute sessions over eight weeks. To measure the effectiveness of the training, all children were examined before and after training using IQ tests, attention tests, academic efficiency tests and ADHD symptoms scales both at home and school. The study showed that the treatment group improved in both sustained and selective attention compared to the control group. It also showed that there was an improvement in academic efficiency, planning and in teachers' ratings of inattentive–impulsive behaviours in the classroom (i.e., far transfer effects for the training). However, there were no pre and post-tests to measure the efficacy of the training of the divided attention despite that the divided attention was included in the training. In addition, there was a lack of a longer-term follow-up to measure the lasting effect of the training. The number of children who participated in the study is small. Besides that, some children were on stimulant medications during the study that are known to improve attention as suggested by Epstein et al. (2011a) and the study did not investigate the differential effects of medication on a child's performance.

Semrud et al. (1999) also conducted a study on a treatment group with ADHD who received full attention training, and two control groups: one group of children with ADHD who did not complete the training and one group of children without ADHD who did nothing. The study used visual and auditory attention tasks from the Attention Process Training (APT) developed in earlier research to train both sustained visual and auditory attention and selective attention. Children of treatment groups were grouped by age into four to five children and received sixteen minutes training sessions, twice a week over eighteen consecutive weeks. All children completed pre and post-tests using a test of visual and auditory attention different from the APT tests used during training of the treatment group. The study showed that children with ADHD showed significant improvement in sustained visual and auditory attention after the training. The post-test scores for the trained ADHD group were similar to the post-test scores for the control group without ADHD and significantly better than the post-test scores for the control group with ADHD. This study has the same limitations as in the previous study of including some children who were on stimulant medications and not measuring the long-term effect of the training. Another limitation is having a control group who performed nothing.

Tucha et al. (2011) conducted attention training on a treatment group of children with ADHD and a control group of children without ADHD. The study used computerized tests called AixTent for training attention components including selective, vigilance, divided attention. Children in the treatment group received eight individualized training sessions for one hour over four weeks. Children in the control group did not receive any training. To measure the effectiveness of the training, children with ADHD were examined before and after training using six computerized tests of attention while children without ADHD were examined only once. The study showed that after training, children with ADHD had improvements in vigilance and selective attention similar to the measures for the control group but minimal improvements in divided attention. Also, the study showed that the training resulted in improvement in an untrained function, flexibility which was defined in the study as the ability to shift the focus of attention. However, this study has the same limitations as in the previous studies above of including some children who were on stimulant medications, and not measuring the long-term effect of the training. Another limitation is having a control group who did not receive any training.

Lange et al. (2012) conducted attention training on a treatment group of children with ADHD and a control group of children without ADHD. The study used computerized tests for training attention components including selective, vigilance, divided attention that were the same as those used by Tucha et al. (2011). Children in the treatment group received eight individualized training sessions for one hour over four weeks. Control children did not receive any training. To measure the effectiveness of the training, children with ADHD were examined before and after training using computerized tests of attention that were the same as those used by Tucha et al. (2011) while children without ADHD were examined only once. The study showed that children with ADHD had improvements in vigilance and divided attention but no significant effect in selective attention. However, even though the results reported in the study showed that the trained group achieved similar results in the divided attention to the control group, the improvement in the vigilance attention in the trained group is much lower than the measures for the control group. As with the previous studies, this study had a number of limitations including, not measuring the long-term effect of training, not giving the control group any training and having all children on medications.

Lastly, Tamm et al. (2013) conducted a training program for attention training on a treatment group and a control group of children with ADHD. The study used Pay Attention! as used previously by Kerns et al. (1999) for training attention components including sustained, selective and divided attention. Children in the treatment group received sixteen individualized training sessions for thirty minutes over eight weeks. Children in the control group did not receive any training. To measure the effectiveness of the training, children in both groups were examined before and after training using rating scales completed by parents, teachers, children and clinicians for ADHD symptoms and executive functioning. All children also performed several objective neuropsychological tests for measuring executive functioning. To measure the three trained components of attention of the treatment group, children were examined before and after training using the Test of Everyday Attention for Children (TEA-Ch) (Manly et al., 2001). The study showed that all three components of attention including, sustained, divided and selective attention improved after training. In addition, the results showed that parents reported fewer ADHD symptoms, and better executive functioning for the intervention group compared to the control group. Clinicians also reported fewer ADHD symptoms and fewer impairments. Children reported improvement in their ability in planning and to both focus and shift attention. Teachers did not report any significant improvements in the ADHD symptoms and executive functioning. Neuropsychological tests for measuring executive functioning for children were not statistically significant. The study lacks a control group of children without ADHD to compare the results of the training against their measures. As with the previous studies, the long-term effect of training was not measured.

To investigate the effectiveness of the attention training programs described earlier, two meta-analysis studies were conducted (Rapport et al., 2013, 2015[1]). The two studies were based on four categories of effects including, *immediate near transfer effects, long-term near transfer effects, immediate far transfer effects and long-term far transfer effects.* Table 2.5 summarises the results of the attention training studies as reported in the studies based on the four categories of effects.

[1] The same corpus of papers was used in the two meta-analysis studies

Table 2.5 Summary of results of attention training studies

Reference	Immediate near transfer	Long term near transfer	Immediate far transfer	Long term far transfer
Kerns et al. (1999)	Yes	No	Academic efficiency, planning, ADHD symptoms	No
Semrud et al. (1999)	Yes	No	No	No
Tucha et al. (2011)	Yes	No	No	No
Lange et al. (2012)	Yes	No	No	No
Tamm et al. (2013)	Yes	No	ADHD symptoms, Executive functioning	ADHD symptoms, Executive functioning

The immediate near transfer effects measures whether the training programme results in immediate improvement in tasks that measure the same exact attentional component targeted in the training but were not used in the training. According to the two meta-analysis studies, none of the studies targeting attention found significant immediate near transfer effects (Rapport et al. 2013, 2015).

The long-term near transfer effects measure whether the training results of a particular attentional component were maintained over a longer period of time after the training programme is completed. The same tasks used during the training could be used to measure the long-term near transfer effect. However, it is crucial to also use other tasks not used in the training to demonstrate that the underlying attention component has improved and to eliminate task-specific practice effects. According to the meta-analysis, none of the studies targeting attention measured long-term near transfer effects (Rapport et al. 2013, 2015).

The immediate far transfer effects measures whether the training programme results in immediate improvements in behavioural, cognitive, and functional outcomes that were partially relying on the trained attentional components. Only two studies (Kerns et al. 1999; Tamm et al., 2013) of attention training reported immediate far transfer effects. However, according to the meta-analysis, the reported far transfer effects are not significant and were based on unblinded ratings (Rapport et al., 2013, 2015). Because the parents and teachers usually knew that the children had received attention training, they would tend to rate their attention as improved, an example of the expectancy effect (Rosnow & Rosenthal, 1997, 2005).

The long-term far transfer effects measures whether the behavioural, cognitive, and functional outcomes obtained from the training were maintained over a longer period of time after the training programme. Only one study of attention training reported long-term far transfer effects (Tamm et al., 2013). Again, according to the meta-analysis, the reported far transfer effects were due to expectancy effects as discussed above (Rapport et al., 2013, 2015).

All in all, the meta-analysis revealed that attention training programmes were not reliably linked to any improvement in the trained attentional components. In addition, no improvement in the cognitive or academic functioning, as measurements of the far transfer effects, were found (Rapport et al., 2013, 2015).

Executive functions deficits in ADHD: another approach

Another way of describing deficits of executive functions in children with ADHD which will be useful in this programme of research is proposed by Brown (2005, 2009), a clinical psychologist specializing in ADHD and related problems. According to Brown's expanded model of the complex cognitive functions impaired in ADHD, there are six areas of EFs that are critical for all children to deal with tasks of daily life and which are impaired in children with ADHD. These six areas are activation, focus, effort, emotion, memory and action. Each of these is described in some more detail below.

The first function is *activation*, which is required to "organizing tasks and materials, estimating time, prioritizing tasks, and getting started on work tasks" (Brown, 2005, p. 38). Children with ADHD often show procrastination. They often leave tasks classified as important until the last minute especially if these tasks are not interesting for them (Brown, 2005, 2009). Children with ADHD often struggle with following routines such as morning and bedtime routines (Sonne et al., 2016; Weisberg et al., 2014; Zuckerman et al., 2015).

The second area is *focus*, which involves “focusing, sustaining focus, and shifting focus to tasks.” (Brown, 2005, p. 38). Children with ADHD typically lack efficient focusing in the sense that they find it hard to focus on something unless it was very attractive to them. They also find it hard to keep focused and to move the focus from one task to another as they easily get distracted not only by things around them but also by their own thoughts. Therefore, they find difficulties in mathematics and reading, which require sustaining focus and moving focus between tasks (Brown, 2009).

The third area is *effort*, which involves “regulating alertness, sustaining effort, and processing speed” (Brown, 2005, p. 38). Children with ADHD often find it hard to sustain effort over longer periods of time and to complete tasks on time, particularly tasks requiring large efforts such as expository writing. In addition, many children with ADHD experience continuous difficulty in regulating sleep and alertness. They often find it hard to sleep unless they are extremely tired, as they cannot turn their thoughts off. When they finally fall asleep, they usually find it hard to get up in the morning (Brown, 2009).

The fourth area is *emotion*, which involves “managing frustration, and modulating emotions” (Brown, 2005, p. 38). Many children with ADHD have difficulty in managing frustration, desire, worry, anger, disappointment, and other emotions. Children with ADHD usually find it hard to control their emotions and let these emotions overwhelm them and take over their thinking. As a result, it may become impossible for children with ADHD to pay attention and focus on anything other than their emotions (Brown, 2009).

The fifth area is *memory*, particularly “using working memory and accessing recall” (Brown, 2005, p. 38). Children with ADHD often have an exceptional memory for things that happened a long time ago if these things were interesting. With a lack of interest, they may have difficulty remembering what they have just read or heard, what they wanted to say or where they put things. They may also find it difficult to hold information in working memory, particularly when doing several tasks simultaneously (Brown, 2009).

The sixth and final area is *action*, including “monitoring and regulating self-action” (Brown, 2005, p. 38). Many children with ADHD have problems regulating and controlling their actions. They typically cannot control or plan what they are going to say or do and they often jump too quickly to incorrect conclusions. Also, they often have problems in regulating their actions in terms of slowing or speeding up appropriately, depending on the task on hand. They also have difficulty noticing when other people are offended by what they have just said or done and struggle to modify their behaviour accordingly (Brown, 2005).

2.6 Functional Impairments in Children with ADHD

ADHD symptoms as well as deficits in EF negatively affect the daily life of children with ADHD and result in impairments in educational and social functioning (Dupaul & Langberg, 2015).

The majority of children with ADHD have educational impairments with varying presentations and severity levels. According to a meta-analysis by Frazier et al. (2007), the most significant educational impairment in children with ADHD is in writing, followed by reading, followed by mathematics and then spelling. In addition, children with ADHD often have difficulties in efficiently completing classwork, homework and tests. More specifically, most children with ADHD when given tests or worksheets to solve independently over a specific period of time, often solve fewer problems and solve them less accurately compared to their typically developed peers (Dupaul & Langberg, 2015). In addition, EFs deficits in children with ADHD manifest themselves academically as losing or misplacing homework, disorganized school desks and bags, and not recording school assignments correctly, if at all (Dupaul & Langberg, 2015). In addition, children with ADHD are at high risk of detention, expulsion and grade repetition, as well as low rates of high school and postsecondary education (Loe & Feldman, 2007).

In addition, it was estimated that 52% to 82% of children with ADHD have significant social impairments affecting their daily functioning (Kofler et al., 2011). Children with ADHD do not usually indicate that they experience social problems; however, parents, teachers, and peers report that children with ADHD have peer relation difficulties (Kofler et al., 2011; McQuade & Hoza, 2015). For instance, it has been found that children with ADHD, within only 30 minutes of interaction with their peers, usually get criticized and rejected (Kofler et al., 2011). In fact, when children with ADHD make friendships, these friendships are lower in quality and are less stable over time (McQuade & Hoza, 2015). It was also reported that children with ADHD are less liked, less cooperative, less competent, more disruptive, and have poorer overall social skills in comparison with their typically developed peers (Kofler et al., 2011). This may be because children with ADHD have difficulties encoding social cues, interpreting social situations and making appropriate social interactions. In fact, it has been suggested that children with ADHD may find it hard to understand emotions in others' faces and spoken languages (McQuade & Hoza, 2015).

2.7 Technological Interventions and Assistive Technologies for Children with ADHD

In recent years, the interest of researchers in technological interventions to assist children with ADHD has increased. In this section, a review of these interventions is provided. The interventions are divided into a number of specific areas: attention, emotional regulation, support for parents and other carers, including supporting both parents and children in creating good routines. A summary of these interventions is shown in Table 2.8. Systems to support the diagnosis of ADHD (e.g., Gilboa et al., 2011; Park et al., 2009; Yeh et al., 2012), are not included, as I am interested in the support for children, their parents and carers once they have been diagnosed.

2.7.1 Technological Interventions to Support Daily Routines

According to DSM-5, one of the symptoms for children with ADHD is that they have difficulties organizing tasks and often fail to follow instructions (see section 2.2.1). In daily life, these difficulties may appear in following and completing bedtime and morning routines. Reviewing the literature for interventions targeting such routines, two studies were found, MOBERO (Sonne et al., 2016) and TangiPlan (Weisberg et al., 2014; Zuckerman et al., 2015).

MOBERO (Sonne et al., 2016) was a smartphone system that has two modules one for parents and one for their children with ADHD. Both modules were designed to assist children with ADHD and their families in: establishing healthy morning and bedtime routines for their child, improving the child's sleeping habits, assisting the child to become independent, and lowering the family’s frustration levels. The system also included a Daily Assessment Application (DAA), a digital diary for parents, with prompts to remind parents to complete it and to evaluate the quality of their child’s sleep.

The main evaluation of MOBERO involved a two-week baseline period followed by a two-week intervention period. Eleven families, including 4 girls and 9 boys with ADHD, aged 6 - 12 years old were involved. Before starting the baseline phase, all families completed the ADHD Rating Scale-IV and the Children’s Sleep Habit Questionnaire. During the intervention period, parents were asked to use MOBERO in their everyday morning and bedtime routines along with the DAA. At the end of the intervention period, semi-structured interviews were conducted with the parents about their experience of using MOBERO and they were asked to complete the two questionnaires again. The results showed that the system resulted in higher child independence, and lower parent frustration levels during morning and evening routines. The results also showed that MOBERO resulted in a 20.1% reduction in inattention symptoms, with no effect on the hyperactivity/impulsivity symptoms and an 8.3% improvement in the child’s sleep habits.

These results were based on a short intervention period of only two weeks with a relatively low number of participants. Also, the study does not provide information about the severity of ADHD symptoms initially shown by the children in the study, particularly their sleep patterns, which would be important when assessing the effectiveness of the intervention. In addition, the system’s components were changed during the intervention phase which is considered unscientific as it makes it impossible to draw a unified conclusion from the results.

TangiPlan (Weisberg et al., 2014; Zuckerman et al., 2015) was a prototype of a tangible assistive technology intended to improve morning routines for children with ADHD. It consisted of six tangible objects, which represented tasks that needed to be completed during a child's morning routine and a tablet computer application for planning tasks and matching them with the objects. The objects served as physical reminders to perform their corresponding tasks.

An initial evaluation of the prototype was conducted with two families, with one family having one boy aged 13 years and one family having a girl, aged 13.5 years. The first family used the prototype for two weeks and the second family for four weeks. On the first and last day of the evaluation, both children and parents answered questionnaires about their satisfaction with the current morning routine, the level of parental involvement during the morning routine. Also, on the last day of the evaluation short semi-structured interviews with the children and their parents were conducted to capture their experiences in using the system (Zuckerman et al., 2015). The results showed that, before using TangiPlan, both mothers and children gave, on average, a rating of three out of five for the morning routine satisfaction and a rating of four out of five for the parental involvement during morning routines. After using TangiPlan, the study results showed that, on average, the satisfaction rating of both mothers and children increased to approximately four out of five; the parents' involvement rate decreased to approximately two out of five (Zuckerman et al., 2015).

Although this was a real-world evaluation, it is hard to draw solid conclusions about the value of the system given the short evaluation period of only two weeks as well as only including two children with ADHD in the evaluation. Also, no information was provided about the severity of ADHD in the children. In addition, the results may be open to reactivity and social desirability effects (Lazar et al., 2017) as only self-reported measures were used, but it is nonetheless an interesting initial evaluation. Unfortunately, no further reports on this assistive technology could be found in the literature.

2.7.2 Technological Interventions to Regulate Emotions

Emotional dysregulation has been suggested to be one of the core components in ADHD (see section 2.2.1). Reviewing the literature for interventions targeting emotional regulation in children with ADHD, two studies were found, BlurtLine (Smit & Bakker, 2015) and Chillfish (Sonne & Jensen, 2016a, 2016b).

BlurtLine (Smit & Bakker, 2015) was a prototype involving an interactive belt that contains a vibration motor to detect any movement, resulting from impulsive breathing (i.e., blurting) in the part of the body where the belt is placed. The aim was to help children with ADHD to control their impulsive speaking during class time.

The main evaluation of the prototype was conducted for one morning class with one boy with ADHD aged eight years old. During the evaluation period, a webcam was installed in the classroom and directed at the child to stream a video to another room where the researchers were located. After the evaluation period, the child, his parents and teachers were interviewed to assess their experience of using BlurtLine. The child indicated that he was satisfied with wearing the belt and that BlurtLine made him aware of his blurting behaviour and helped him find the best way to participate in conversation during class. However, the child indicated that he received false-positive signals when he did not feel that he was blurting and thus he completed talking. One of the child's teachers stated that he did not notice any changes in the child's behaviour. However, another teacher stated that the child acted differently compared to usual but that this might be due to the presence of the camera in the classroom. His parents, on the other hand, did not notice any changes in their child's behaviour.

Although this is a real-world intervention, the evaluation included only one child for a very short period of time, i.e., one morning, making it hard to assess the prototype efficacy. Unfortunately, further studies with more extensive evaluations of BlurtLine could not be found. In addition, the study results were obtained from interviews with the child, parents and teachers which resulted in only subjective results. Therefore, more objective and precise measures are required. Lastly, the study needed to have a control condition, against which the child's behaviour when wearing Blurtline could be compared to.

Chillfish (Sonne & Jensen, 2016a, 2016b) was a prototype of a 2D computer game and a LEGO fish controller which was used to play the game that aimed to provide calming experiences similar to regular breathing exercises for children with ADHD after an emotional outburst or prior to sleeping.

The main evaluation of the prototype was conducted with 12 children with ADHD aged 8-13 years old; however, only three children completed the study before the electronic parts inside the prototype stopped working (Sonne & Jensen, 2016b). The study used a within participants design, having children play PacMan game, perform a breathing exercise or play Chillfish, play PacMan game again, and then perform a breathing exercise or play Chillfish. PacMan game was used to simulate of a stressful situation. While playing the game, the child worn a heart rate belt and Electrodermal

Activity (EDA) sensors were placed in the inside part of the hand to measure their stress levels. The results from plotting the heart rate variability (HRV) data, collected by the heart rate belt, of the children suggested that playing ChillFish lowered stress similar to calming breathing exercises. The study also highlighted the challenges of evaluating hardware prototypes with children.

The main limitation of this study is that only three children completed the evaluation, making it impossible to conduct a valid statistical analysis from the study. In addition, the study was conducted in only one session for only one day.

2.7.3 Technological Interventions to Support Parenting

Families of children with ADHD usually deal with a number of challenges. These challenges include the continuous stress from regular daily life in addition to the stress resulting from coping with their child's issues. Reviewing the literature for interventions providing strategies for parents of children with ADHD, only one study was found, Parent Guardian (Pina et al., 2014).

Parent Guardian (Pina et al., 2014) was a prototype for an assistive technology that aimed at detecting high-stress levels in parents of children with ADHD and provided in situ strategies to better deal with these stresses. It consisted of four main components, a smartphone, a peripheral screen, an Electrodermal Activity (EDA) sensor, and cloud storage. The wristband EDA was used as a stress indicator while the cloud storage was used for further analysis of the prototype usage data. The smart phone as well as the screen were used to display the intended strategies in the form of images and texts providing information on how to cope with the detected stress.

The prototype evaluation was conducted with ten families, involving 8 mothers and 2 fathers, average age 38.4 years, with each family having at least one child with ADHD, aged between 6 to 18 years. The evaluation consisted of two phases, each lasting 7 days. The first phase aimed to make families familiar with the system. During the second phase, the intervention was used fully and strategies were sent once data about stressful situations were detected by the sensor. By the end of this phase, interviews with parents were conducted to explore their experiences of using the prototype. Parents were also asked to complete a questionnaire rating the overall experience with the prototype. The results showed that, on average, parents rated the effectiveness of

Parent Guardian in helping them cope with stressful situations as 5.1 (where 1= no at all, 7=extremely). Similarly, parents, on average, rated the usefulness of the coping strategies as 5.1.

Although this is a real-world evaluation, it was conducted for a short period of time, only 7 days. Also, the EDA wristband produced false positives in some times and missed some stressful situations in other times. Parents stated that when the coping strategies were presented at the peak of their stress levels, it was hard for them to recover. Thus, it is very important for such an intervention to have an accurate and early stress detection property. In addition, the results may be open to reactivity and social desirability effects (Lazar, et al., 2017) as only self-reported measures were used, but it is nonetheless an interesting initial evaluation.

2.7.4 Technological Interventions to Improve Attention

Attention, as stated earlier (2.2.1), is one of the core symptoms of ADHD and attention training has failed to yield improvements in children with ADHD. Therefore, the literature was reviewed for technological interventions to improve attention, apart from training, targeting children with ADHD, one commercial product was found, TimeTimer (TimeTimers, n.d.) and one study was found, CASTT (Sonne et al., 2015).

TimeTimer (TimeTimers, n.d.) is a commercial product that comes in different versions such as a wristband, a mobile app and a physical device. They all aim to assist the child in remaining focused on a task by visually showing the remaining time on a task. In addition to assisting people with ADHD, the website also claims that the system is beneficial for others such as those with Autism Spectrum Disorder (ASD). However, no studies were found that investigated the benefits of TimeTimer with children with ADHD.

CASTT (Sonne et al., 2015) was a prototype that aimed to help children with ADHD in regaining attention in a schoolwork context. The prototype collected children's physical and physiological activities using eight sensors, a heart rate belt and an EEG headset. The sensors collected body excessive movement indicating the loss of interest and thus inattention. This data along with the researcher's subjective assessment of the children's attention level were used to provide real-time assistance for children. In the evaluation of CASTT, when the children were found to be inattentive, researchers manually trigger the assistive technology represented in an app in the mobile phone given to the children but prior to that the children receive vibration notification for checking the mobile phone. The app contained quizzes for the child to solve and then after solving the questions correctly, children were asked to go back to their schoolwork.

The main evaluation of CASTT was conducted with only one child with ADHD for a duration of 1.5 hours during a mathematics class; no information about the age or gender of the child was provided. The results showed that the child immediately responded to one notification from the prototype and answered the quiz questions. None of the other children in the class noticed the vibration notifications or the use of the mobile by the child. When the intervention was triggered and the child had completed the quiz, the child returned to an attention state similar to the one that the child had when the class first started. The study assumed that at the beginning of the class the child should have full attention and as the time of the class passes, the child started losing their attention.

The main limitation of this prototype is that the evaluation included only one child with ADHD for a very short period of time. In addition, the prototype included many wearable sensors to be worn every day during school time. There were also issues with using devices designed for adults, which were too big for the children. In addition, there were issues with collecting enough data from the sensors which are typical of children with ADHD in the classroom situation. The study only reported visual results of the sensors data and no further information about the heart rate belt or the EEG data. In addition, no further evaluation of the prototype with more children could be found. Another major issue with this study is that it is not clear in the study how CASTT is supposed to help with regaining attention. As discussed earlier in sections 2.3 and 2.5, children with ADHD have deficits in sustained attention and increased distractibility and CASTT seems to divert the attention of the child to a different task.

2.7.5 Conclusions on the Proposed Technological Interventions to Help Children with ADHD, their Parents and Carers

A summary of the work that has been conducted to assist children with ADHD is provided in Table 2.6, below.

Table 2.6 Summary of the technological interventions to support children with ADHD, their parents and carers

Intervention	**Category**	**Specific purpose**	**Targeted audience**
MOBERO (Sonne et al., 2016)	Routines	Bedtime and morning routines	Children and parents
TangiPlan (Weisberg et al., 2014; Zuckerman et al., 2015)	Routines	Morning routines	Children
BlurtLine (Smit & Bakker, 2015)	Emotion regulation	Impulsive speaking	Children
ChillFish (Sonne & Jensen, 2016a, 2016b)	Emotion regulation	Emotional outbursts	Children
Parent Guardian (Pina et al., 2014)	Parenting	Stressful situations	Parents
TimeTimer (TimeTimers, n.d.)	Attention	Remaining focused	Children and adults
CASTT (Sonne et al., 2015)	Attention	Regaining attention	Children

It is clear that the technological interventions for helping children with ADHD with bedtime and morning routines, MOBERO (Sonne et al., 2016) and TangiPlan (Weisberg et al., 2014; Zuckerman et al., 2015), achieved promising results. However, there are issues related to the evaluation studies conducted, particularly the short intervention periods, the relatively low number of participants and the lack of information about the severity of ADHD symptoms of the children, making it hard to draw solid conclusions about their effectiveness.

For technologies targeting emotional regulation, the evaluations of these technologies had the same issues as the technologies for routines. In addition, emotional dysregulation is a problem that is apparent with children with ADHD for the whole day. ChillFish (Sonne & Jensen, 2016a, 2016b), as one intervention for emotional regulation, required having a computer to run the calming game. However, the children need to have the intervention when the problem occurs and not just when playing the game. Similarly, Blurtline (Smit & Bakker, 2015) required wearing a heart rate belt that children may forget to wear all the time and may feel uncomfortable wearing for a long time as well. Thus, for emotional regulation particularly, assistive technologies with minimal hardware are required.

For the technology to help with parenting, Parent Guardian (Pina et al., 2014), it was really promising but it also requires a longer evaluation period, as well as a way to check how parents were really using the technology.

For interventions for improving attention, TimeTimer (TimeTimers, n.d.) was not evaluated with children with ADHD and CASTT (Sonne et al., 2015) had issues with the design of the prototype and the evaluation. One problem with CASTT is that it was not clear in the study how CASTT would automatically detect inattention. In addition, the study did not state the rationale or the theoretical reasons for how solving a quiz in the middle of doing classwork would help regain attention. In addition, the technology required wearing many sensors every day during school time, which is impractical for daily use. Lastly, as with the other technologies discussed earlier, the number of participants in the evaluation as well the intervention period needs to be extended to get robust results.

All in all, it can be seen that little research has been conducted on technological interventions and assistive technologies for helping children with ADHD with bedtime and morning routines, emotion regulation, attention and parenting. Furthermore, the studies reviewed have a number of issues that need to be addressed before robust conclusions about their effectiveness can be made. First, the existing studies on technological interventions were all preliminary studies conducted for very short periods of time and no further studies were conducted after the initial studies. None of the studies investigated the long-term effect of using the interventions or technologies on the performance of the children, which is very important when evaluating the usability and acceptability. Also, there are other areas of deficits in children with ADHD that research needs to work on such as dealing with the distractibility of children with ADHD due to auditory and visual stimuli.

Lastly, only one study, TangiPlan (Zuckerman et al., 2015), investigated the satisfaction of children with the technology. Blurtline (Smit & Bakker, 2015) also checked the satisfaction of the child involved in the study by asking him one question about if he was satisfied with wearing the technology or not. The remaining studies reviewed did not conduct any investigation of the satisfaction and acceptability of the technologies with the children. Both satisfaction and acceptability are of high importance for the successful adoption of the technologies, especially if these technologies are meant to be used in public settings such as in schools. It is also important to investigate the acceptability of the technological interventions to parents and teachers of children with ADHD, especially the technologies meant to be used in public settings.

2.8 Environmental Variables and ADHD

A number of environmental variables have been investigated in previous research to see whether these have effects on children with ADHD. These include the presence of sounds, particular colours and lighting in the environment.

For instance, the effect of a variety of colour schemes on the performance of children with ADHD has been investigated in a number of studies (e.g., Banaschewski et al., 2006; Imhof, 2004; Roessner et al., 2008; Silva & Frère, 2011). Nonetheless, no studies were found that investigated the effect of lighting on children with ADHD and only one study, by Amor et al. (2015), investigated the effect of lighting on adults with ADHD. The research about the effect of colours and lighting on children with ADHD is beyond the scope of this thesis and thus will not be reviewed in detail. In the section below, a number of studies that have investigated the effect of sound on children with ADHD are reviewed in detail.

2.8.1 Effects of Sound on Children with ADHD

There have been a number of studies investigating the effect of using background white noise and pink noise on the performance of children with ADHD. Before introducing these studies, it is important to understand the nature of white and pink noise.

White and Pink Noise

White noise is defined as a random signal with equal amounts of energy per frequency and this gives it a constant power spectral density (Foley, 2014), as depicted in Figure 2.3. The term white noise was derived from the concept of white light, which contains all light frequencies in equal proportions. White noise is intended to be similar in that it contains all sound frequencies that human ears can hear and recognize. It is heard as a hissing sound, similar to the “sh” sound in "ash". *Pink noise*, on the other hand, has random frequencies in equal energy per octave, and every octave has double the size of the previous one (see Figure 2.4). Pink noise has a lower intensity for higher frequencies making it smoother and deeper compared to white noise (Kuo, 2018).

White noise and pink noise have many applications in scientific and technical disciplines, such as electrical engineering (Chichilnisky, 2001), computing (Petrie & Connelly, 2000) and in the treatment of tinnitus (Jastreboff, 2000). In addition, white noise has been shown to be beneficial in the work environment (Loewen & Suedfeld, 1992). Another use for white noise is to help with sleep for children (Forquer & Johnson, 2005) and with insomnia for adults (Smith & Neubauer, 2003).

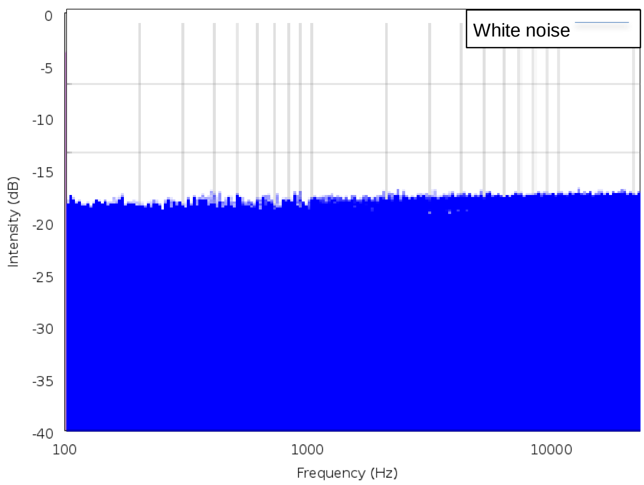


Figure 2.3 White noise spectrum (Source: Wasserma & Segool, 2013)

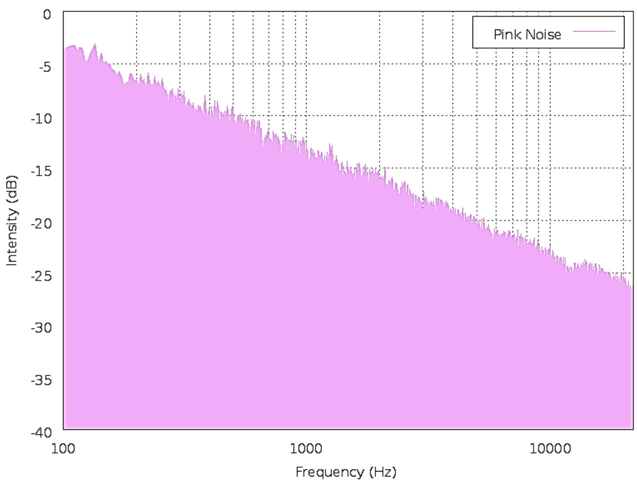


Figure 2.4 Pink noise spectrum (Source: Wasserma & Segool, 2013)

Studies using White and Pink Noise

For the current research, the use of white noise is to improve the attention of children with ADHD. There have been a number of studies investigating the effect of using background white noise on the attention of children with ADHD while performing cognitive tasks which are reviewed below.

Söderlund and colleagues (2007) conducted a study on the effect of white noise on the cognitive performance of children with ADHD. The study was conducted with 21 children with ADHD and 21 children without ADHD, aged 9.4 to 13.7 years. The study used a memory recall task in which the children heard a series of 12 sentences each involving a concrete object (e.g., a ball) and were given an example of the object. After hearing the sentences, the children had to recall as many sentences as possible. Trials were conducted with white noise (81dB) and without white noise. There was a positive effect of white noise on the performance of children with ADHD, whereas white noise disrupted the performance of the children without ADHD. One limitation of this study is that it involved children with ADHD who were on medication that is known to improve attention. Medication is considered a confounding variable in these kinds of studies and thus its interaction with the task should be investigated. The study also used only one task to measure the children's performance. This makes it very hard to draw solid conclusions about the results of the study and thus the results need to be confirmed in future studies using different tasks.

A more recent study by Baijot et al. (2016) confirmed the positive effect of using white noise on the performance of children with ADHD using a different task. The study was conducted with two groups of children, aged 8 to 12 years, a group of 13 children with ADHD and 17 children without ADHD. The children performed a visual cued Go/NoGo task (for more information about the task, see section 2.4.2.2) with white noise (at 77 dB) and without white noise. The aim of using this particular Go/NoGo task in this study was to investigate the effect of white noise at neurophysiological levels. Without white noise, the children with ADHD made significantly more omission errors (OEs) (indicators of inattention) compared to children without ADHD. With white noise, the children without ADHD made more OEs compared to the no noise condition and the difference between children with ADHD and children without ADHD in OEs was not significant. It is worth noting that the study did not provide information about whether there was a significant difference in OEs for children with ADHD between the white noise and no white noise conditions. Finally, the results showed that white noise had no effect on the number of commission errors (CEs) (indicating impulsivity) nor on the response time variability (RTV) (the other indicator of inattention) of children with ADHD (for more information about these measures, see section 2.4.2.1). This study has a number of limitations. First, the study used parametric analysis but did not check for the normality of the data, particularly for reaction times that are typically non-normally distributed. Although the results of this study are promising, these results need to be confirmed in future studies using different tasks. Alternatively, future studies could look into using the Go/NoGo task with different parameters, as changing the task parameters is known to affect some of the resulting variables (for more information, see section 2.4.2.1).

Söderlund and colleagues (2016) conducted a further study with 20 children with ADHD and 20 typically developing children with a mean age of 12.9 years (no age range was given). The children performed three cognitive tasks, memory recall, Spanboard and 2-back tasks, in two conditions, 80dB white noise and no noise. The memory recall task was the same as the task in Söderlund et al. (2007). The Spanboard task involved showing children dots on a 4×4 grid on a computer screen and then hiding the dots and asking children to use the mouse to show the dots again in the correct locations. The 2-back task involved presenting a sequence of 30 words and asking children to indicate whether the current word matches one of the two words presented earlier. Children with ADHD performed all the tasks twice, once while medicated and once while not medicated. The results showed that white noise improved the performance of children with ADHD in all tasks apart from the 2-back test; there was no significant effect for medication. In addition, the combination of white noise and medication did not add further improvement to the performance of children with ADHD. In fact, in the word recall task, medication removed the positive effect of white noise as compared to the no noise condition and being off medication. Typically developing children’s performance did not differ significantly in noise versus no noise conditions in any of the tasks. This study had the same limitation as in the study by Baijot et al. (2016) of using parametric analysis without reporting the results for the normality of the data.

In addition, there have been a number of studies investigating the effect of using background white noise for children with attention deficits, but who do not have a diagnosis of ADHD while performing cognitive tasks. These are usually children who are rated by their teachers as having poor attention in class.

A study by Söderlund et al. (2010) with 51 children, comprised 10 children with attention problems and 41 without attention problems. The children with attention problems were identified by their teachers' ratings of their attention. The study used the same memory recall task as in Söderlund et al., (2007), performed with noise (at 78dB) and without noise. The results showed that the performance of children with attention problems improved in the noise condition compared to no noise. On the other hand, the children without attention problems performed worse in the noise condition compared to no noise. One limitation of this study ass in the previous studies is in the use of parametric analysis.

A study by Helps et al. (2014) was conducted with 90 children, aged 8 to 10 years, with different attentiveness levels as rated by their teachers, including 25 super-attentive children, 29 normal-attentive children and 36 sub-attentive children. The study used two non-executive function (EF) verbal tasks, a word recall task and a word recognition task and two EF tasks, a Spanboard task and a Go/NoGo task. The word recall task was the same as the task in Söderlund et al. (2007) explained above while the word recognition tasks involved presenting children with words and asking them to recognize words, they heard earlier in the word recall task. The Spanboard task was the same as the task in Söderlund et al. (2016) explained above. EF tasks were performed under three different levels of white noise, 65dB, 75dB and 85dB while non-EF tasks were performed under three lower white noise levels, 65dB, 70dB and 75dB. This was important because words in the non-executive function tasks were not audible when louder WN levels were used. The results showed that moderate white noise worsened the performance of super-attentive children in both task types but improved performance of sub-attentive children only in executive function tasks. More specifically, for executive function tasks, the study showed that white noise exposure at low level (65 dB) was not sufficient to remove the difference in OEs between the three groups but moderate (75 dB) and high (85 dB) levels of white noise successfully removed the differences in OEs between the groups included in the study. The normal-attentive children were not affected by white noise in either task types. Switching from a moderate level of white noise to a high level had little impact on performance for any group. One limitation of this study is the lack of a control condition of no noise against which the performance of children in different noise levels could be compared.

The white noise benefit on attention found in the studies mentioned above is in accordance with theories about ADHD, namely the moderate brain arousal model, the optimal stimulation theory (Zentall & Zentall, 1983) and the state regulation deficit model of ADHD (Sonuga-Barke et al., 2010) derived from the cognitive energetic theory (Sergeant, 2005). These theories suggest that adding extra-task stimulation, i.e., white noise in the studies above, improves executive functioning in terms of attention in children with ADHD.

The Moderate Brain Arousal Model (MBA) is a neurocomputational model which explains the link between attention and white noise benefits. The model states that brains of individuals with ADHD have low levels of internal neural noise resulting from an impaired dopaminergic system and need more external environmental noise or stimulation to work at optimal brain arousal levels compared to typically developing children (Sikström & Söderlund, 2007). The model suggests that the white noise benefit results from a phenomenon called stochastic resonance (SR), also called noise-improved signalling. SR suggests that adding a specific amount of white noise may result in a better-quality signal transmitted into the brain, and improve the signal-to-noise ratio, and thus better performance in many tasks (Söderlund et al., 2007). The MBA model also suggests that white noise either regulates dopamine transmission or substitutes its effects on neural transmission. Dopamine has a strong effect on cognition and attention (Söderlund et al., 2016).

The optimal stimulation theory (OST) suggests that, for every organism, reaching the optimal level of cognitive performance requires an optimal level of arousal. The theory hypothesizes that children with ADHD have under-arousal and thus they have lower levels of cognitive performance under typical conditions (Zentall & Zentall, 1983). According to the theory, the hyperactive and impulsive behaviours and inattentiveness of children with ADHD act as self-stimulating efforts in an attempt to improve their arousal level and consequently their performance. Zentall and Zentall (1983) argued that adding extra task stimulation could improve the arousal level of children with

ADHD, and this would result in a cognitive functioning comparable to that of the typically developing children.

Another possible explanation for the white noise benefit for attention might be explained by the vigilance regulation model (VRM) (Hegerl et al., 2010), which hypotheses that those with ADHD have irregular vigilance due to under-arousal. This is also in accordance with the state regulation deficit model of ADHD (Sonuga-Barke et al., 2010) derived from the cognitive energetic theory of information processing (Sergeant, 2005).

The state regulation deficit model (SRD) suggests that individuals with ADHD have problems in controlling and maintaining their energetic state, specifically arousal level, especially in non-interesting tasks. Arousal is the starting point for executing any cognitive task and is affected by internal factors, such as stress or lack of sleep and external factors, such as extra environmental stimulation, such as white noise. Arousal was manipulated in many studies using different event rates (for more details about event rates, see section 2.4.2.1). Faster event rates were found to improve arousal while slower event rates were found to result in under arousal. In addition, in-task rewards or incentives resulted in a better arousal level (Sergeant, 2005).

As for using pink noise with children with ADHD, only one study was found that investigated the effect of pink noise (at 80 dB) on the impulsive choice of children with ADHD (Metin et al., 2016). The study was conducted with 25 children with ADHD and 28 children without ADHD, aged 8 to 10 years. The study involved two simple tasks measuring impulsive choice, with children choosing between smaller sooner (SS) or larger later (LL) rewards. It is known that children with ADHD prefer SS to LL rewards compared to children without ADHD. In the first task, at the start of each trial, the children were presented with two coins on the computer screen (5 cents and 10 cents). Children were told that if they chose 5 cents, the reward will be earned after 2 seconds, and if they chose LL (10 cents), the reward will be earned after 30 seconds. The next trial starts after the reward for the previous trial was earned. Both the total amount of rewards earned so far and the number of remaining trials was shown on the screen. The task consisted of a total of 40 trials, with 20 trials with pink noise and 20 trials without noise. The dependent variable was the percentage of LL choices. The second task is the same as the first task except for the time after which the LL reward is earned. The time is not fixed but dynamically calculated depending on the child performance during the task. The noise was delivered at 80dB. The study results showed that children with ADHD make more impulsive choices than children without ADHD. The results also showed that pink noise has no effect on the impulsive behaviour in children with ADHD as measured by LL.

It is important to note that this study is not comparable to what I am doing in this programme of research since it was about a different concept of impulsivity. That study investigated the effect of pink noise on the impulsive choice of two kinds of rewards whereas my research investigated the effect of white/pink noise on impulsive responding (i.e., failure to inhibit responding when supposed to do so). In addition, it was surprising that the study by Metin et al. (2016) only investigated the effect of pink noise on the impulsive choice in children with ADHD, when previous studies investigating the effect of white noise showed that white noise has positive effects on attention but not on impulsivity. Therefore, one would have expected the researchers to mainly investigate the effect of pink noise on attention.

In conclusion, only a few studies above have investigated the effect of white noise on the attention of children with ADHD, which is the focus of this programme of research and none checked the effect of pink noise on the attention. Some studies also lacked a control condition of no noise against which the performance of children would be compared. In addition, the studies have some issues with the normality of the data and the use of parametric analysis. Although the studies used a range of cognitive tasks which is good, changing the parameters of these tasks could affect the performance of the children. Therefore, the positive effect of white noise needs to be investigated further using different parameters of the tasks and different noise levels. In addition, it would be interesting to see if pink noise has an effect on the attention of children with ADHD.

2.9 Conclusions to the Literature Review

This literature review covered a number of topics about ADHD in children including primary symptoms and diagnosis of ADHD, attention deficits and distractibility, measures for assessing ADHD, executive function deficits, technological interventions to support children with ADHD and the effect of environmental variables on ADHD.

The literature review identified a number of interesting gaps in the research on assistive technologies for children with ADHD. First, it showed that very few assistive technologies to improve attention have been developed. This literature review also showed that there is a lack of technologies to reduce distractors in children with ADHD.

Another gap highlighted in this literature review was that there were only a small number of studies that found a positive effect of using white noise on the attention of children with ADHD using a variety of cognitive tasks, but these studies have some issues with the normality of the data and using parametric analysis. The literature review also highlighted the fact that cognitive tasks, particularly the Go/NoGo task, are very useful and produce objective measures of the attention and impulsivity of children with ADHD. Nonetheless, changing the parameters of the tasks may affect the results and thus, the results on the effect of white noise need to be confirmed using tasks with different parameters and using non-parametric analysis when needed.

Additionally, pink noise is one variation to white noise which may be more pleasant to listen to than white noise, which may also potentially have a positive effect on the attention of children with ADHD. However, one gap that was identified in this literature review is that only one study was found that investigated the effect of pink noise, but this was on the impulsivity of children with ADHD, not their attention. Thus, the effect of pink noise on the attention of children with ADHD should be investigated.

Based on these gaps, I was inspired in this programme of research to investigate the effect of sound, particularly white and pink noise. I was also inspired to incorporate the white and pink noise into an assistive technology to improve attention and reduce distractors in children with ADHD and to evaluate the effectiveness of the assistive technology using the Go/NoGo task. I needed to find a way of delivering white and pink noise to children with ADHD and also a way of reducing visual distractors, and headphones augmented by “wings” (to reduce visual distractors) seemed an interesting possibility (for more detail on the motivation of the design of the assistive technology, see Chapter 6, section 6.2).

Chapter 3 - Study 1: Experiences and Attitudes of Parents of Children with ADHD towards Behavioural and Technological Interventions and Environmental Variables and Interventions

3.1 Introduction

As explained in Chapter 2, (section 2.2.1), children with ADHD have deficiencies in attention, hyperactivity and impulsivity. There have been many efforts to deal with these symptoms, including attention and working memory training, lowering hyperactivity, supporting parents as well as the children themselves. These efforts include some technological interventions and assistive technologies to address issues such as attention training (see Chapter 2, section 2.5), emotional regulation and support for parents and other carers including developing good routines (see Chapter 2, section 2.7).

One area of interest, which has only received a very limited amount of research, is the effect of the environmental variables such as sounds, colour schemes and lighting on children with ADHD (see Chapter 2, section 2.8). There may be both positive and negative effects of these environmental variables on attention, hyperactivity and impulsivity in children with ADHD. Reviewing the literature, no studies were found that investigated whether parents of children with ADHD have noticed any effects of these environmental variables on their children. In addition, no studies were found that investigated the attitudes of parents toward using technological interventions and assistive technologies to help their children with ADHD.

The aim of this study was to bridge these gaps in the research and to investigate whether Saudi parents of children with ADHD have noticed any effects of environmental variables on their children. The study also investigated parents' attitudes to using technological interventions and assistive technologies to help their children's ADHD. Finally, the study investigated parents' use and attitudes towards behavioural interventions, that is non-technological strategies and techniques, that parents may use to help their children's ADHD. Behavioural interventions are typically interventions aiming at increasing wanted behaviours and decreasing unwanted behaviours. These include Behavioural Parent Training (BPT), classroom behaviour management and cognitive behaviour interventions that target executive function challenges and many more (Daley et al., 2017; Sonuga-Barke et al., 2013). These are usually undertaken in several sessions over time through training practitioners, teachers, parents or children themselves or both (Sonuga-Barke et al., 2013).

3.2 Method

3.2.1 Participants

A number of methods were used to recruit participants as it proved difficult to find a sufficient sample of participants. The Saudi ADHD Society facilitated the connection with some mothers of children with ADHD. In addition, Twitter was used in recruiting further participants. This was by posting a tweet inviting parents of children with ADHD to participate in this study and asking well-known ADHD professionals to retweet this tweet. A snowball sampling method (Atkinson & Flint, 2001) was also used by asking participants at the end of their interview if they knew other parents of children with ADHD who would be interested in being in the study and this resulted in the recruitment of the largest number of participants. The original aim had been to recruit parents, both mothers and fathers, of children with ADHD, but all the parents who volunteered were mothers.

15 mothers of children with ADHD living in Riyadh, Saudi Arabia took part in the study. Two mothers had two children with ADHD while the remaining mothers had one child with ADHD and at least one typically developed child. The children with ADHD were 2 girls and 15 boys aged from 5 to 12 years, with a mean age of 7.2 years. All the children had ADHD-C except for two children who had ADHD-I. The mothers were aged from 28 to 40 years, with a mean age of 31.3 years. 14 mothers had Bachelor's degrees and one mother had secondary level education. All mothers spoke Arabic as their native language and the interviews were conducted in Arabic.

3.2.2 Design

This study recruited only Saudi parents and this was because Boujarwah et al. (2011) noted that disabilities and assistive interventions for people with disabilities need to be understood in the context of the surrounding culture. Thus, as the rest of the research was going to be conducted in Saudi Arabia, this study investigated the knowledge and attitudes of Saudi mothers and how their children might be helped with technology.

The study used semi-structured interviews to investigate parents' experiences of the effects of environmental variables on their children's ADHD and their attitudes towards technological interventions and assistive technologies to help their children. The study also investigated parents' use and attitudes towards behavioural interventions, that is non-technological strategies and techniques, that parents may use to help their children's ADHD. It was decided to include an investigation of behavioural interventions as they are the most commonly used type of interventions for children with ADHD (Daley et al., 2017). Thus, behavioural interventions would provide a good start for the discussion with parents. In addition, discussion of behavioural interventions may provide ideas for the development of new technological interventions or assistive technologies in the future.

Semi-structured interviews were chosen over other kinds of interviews such as fully structured or unstructured interviews for a number of reasons. First, semi-structured interviews consist of a set of pre-planned questions that guides the interviews but they are also flexible and allow for adding more probing questions to encourage further discussion (Sharp, et al., 2019). Semi-structured interviews also allow for exploring topics in more depth and breadth (Lazar, et al., 2017).

3.2.3 Materials

Each interview consisted of five sections (for the full interview guide, see Appendix A.2):

1. Introduction – This was aimed to give introductory information about the researcher, the aim of the study, what would happen to the data collected, confidentiality agreement and asks if they mind being recorded, if appropriate. When the parents gave their consent, they were presented with the next sections.

2. Demographics – This was aimed to ask parents some warm-up questions about their age, educational level, children's gender, age and specific ADHD diagnosis.

3. Understanding parents' experiences and attitudes towards behavioural interventions – This section contained the following questions that parents were asked:

- Do you have experience with behavioural interventions, that are non-technological strategies, therapies and techniques, to improve the attention in your child and/or decrease the hyperactivity and impulsivity? If yes:
    - What are these interventions?
    - How did you know about these interventions?
    - How did you apply these interventions?
    - What effects have you noticed on your child from using these interventions?

4. Understanding parents' experiences and attitudes towards environmental variables and interventions: This section contained the following questions that parents were asked:

- Do you have experience with environmental variables and interventions related to sounds, colour schemes or lighting to improve the attention in your child and/or decrease the hyperactivity and impulsivity? If yes:
    - What are these interventions?
    - How did you know about these interventions?
    - How did you apply these interventions?
    - What effects have you noticed on your child from using these interventions?

5. Understanding parents' experiences and attitudes towards technological interventions and assistive technologies: This section contained the following questions asked to parents:

- Would you adopt and use technological interventions and assistive technologies that would help improve your child's attention? If no: can you explain why you would not use them?

3.2.4 Pilot Study

A pilot study was conducted to check for the clarity of the wording of the interview questions. It was conducted with two mothers of children with ADHD. No issues were found. The two mothers who participated in the pilot study did not participate in the main study.

3.2.5 Procedure

Interviews were conducted individually with mothers of children with ADHD. The interviews were either face-to-face or by phone depending on the participants' preference. At the beginning of the interview, information about the researcher, the aim of the study, what would happen to the data collected and confidentiality agreement were explained to the participant. Mothers were asked if they mind being recorded and they were given the information sheet and then completed an informed consent form (see Appendix A.1). In the case of mothers who preferred the interviews to be by phone, the informed consent forms were sent to them by email and they read and signed the forms prior to the interviews. Then, the researcher started asking the mothers the interview questions and asked probing questions when necessary to encourage further discussion (for the interview guide, see Appendix A.2). All interviews were tape-recorded for later, detailed analysis. At the end of the interview, the researcher asked mothers if they had anything else to say, debriefed them and thanked them for their participation. On average, interviews lasted 40 minutes.

3.2.6 Data analysis

Interviews were transcribed verbatim in Arabic. Useful quotes were translated into English by one author and reviewed by the other author. Data from the interviews were analysed using one of the thematic analysis approaches, the inductive (data-driven) approach (Braun & Clarke, 2006). Thematic analysis was the most appropriate method for the analysis of the data in this study in comparison to other methods of analysis such as Grounded Theory and content analysis for a number of reasons. In this study, I had specific focused questions thus I did not need such an open approach as the grounded theory which typically involves an open research aim and open research questions and focuses on theory development from the data (Lazar et al., 2017). Content analysis, on the other hand, concerns reducing large amounts of data and coding is typically based on previous research (Flick, 2014). The inductive approach of thematic analysis was used because there was little or no existing literature or theories on the topics of this study (Braun & Clarke, 2006).

The analysis started with the researchers familiarising themselves with the data, developing codes followed by developing themes from the codes (Clarke & Braun., 2014). The analysis was carried out by two independent researchers, the researchers then worked together until they reached an agreement on the themes.

3.3 Results and Discussion

The themes which emerged from the thematic analysis on the different interventions were "awareness of the intervention", "source of information about the intervention", "actions and persistence in action in relation to the intervention", and "positive and negative effects of the intervention".

3.3.1 Experiences with Behavioural Interventions for Children with ADHD

Behavioural interventions that are non-technological strategies therapies and techniques, mentioned by the mothers of children with ADHD to improve the attention and reduce hyperactivity/impulsivity in their children as well as deal with other problems resulting from ADHD.

On their "awareness of behavioural interventions", all 15 mothers reported that they are aware and currently use behavioural interventions for helping their children to try to improve their attention and/or lower their hyperactivity and impulsivity. Examples of mothers' responses about interventions targeting attention included:

> *I play LEGO with my little girl as this helps improve her attention. (P6)*
>
> *To improve my child's attention, I use brain exercises such as puzzles and games … I also use other exercises to improve his attention by inserting beads into thin thread and reverse counting. (P7)*
>
> *I use some exercises to increase my child's attention such as brain exercises, exercises for optical motor synergy, and walking on a straight line. (P8)*

I use pictures to reinforce verbal instructions. (P13)

Examples of mothers' responses about interventions targeting hyperactivity and impulsivity included:

The best thing to control his hyperactivity is swimming. I fill a little plastic swimming pool with warm water because he hates cold water and I leave him play for as long as he wants. Also, playing with sand is the best technique for calming children with ADHD. I brought sand to my house so he plays with it even though I live in an apartment. (P1)

To calm my child and decrease his hyperactivity, I use a technique where I set my child on a chair and put my hands with some pressure over his thighs so he does not move. At the same time, I set a timer and do not allow my child to stand up until the time is up. (P7)

One mother mentioned techniques for dealing with problems her daughter has such as anger and aggressiveness:

To reduce aggressiveness, I hold her hand and talk to her very calmly without getting angry or raising my voice. When she is very angry, I just simply stop talking to her and leave her inside the room until he calms down and this helped a lot. (P4)

The awareness of all mothers with behavioural interventions is in line with the study by Daley et al. (2017) which suggested that behavioural interventions are the most commonly used type of interventions for children with ADHD.

On the theme of "sources of information about behavioural interventions", all 15 mothers reported that they found out about interventions from ADHD professionals:

I learned these techniques from the occupational therapist at the ADHD centre. (P2)

All the exercises I use were recommended by the specialists in the ADHD training centre that I take my child to every week. (P3)

However, two mothers reported that after learning some interventions from ADHD professionals, they also came up with their own interventions. For example, the mother (P1) who discussed swimming and playing with sand also noted:

No professional told me about these techniques, I invented them and these really work and his hyperactivity is much less. (P1)

Another mother noted:

To calm my child, I have got some ideas that I made myself and they do really work. I make my child help with cleaning, cooking, and tidying up the house. This consumes his excessive energy and also helps improve his attention. (P9)

On the theme of "actions and persistence in action with behavioural interventions", all but one of the mothers reported that they had been trying to use the interventions with their children regularly:

At the beginning, my child resisted and hated the techniques I used with him to improve his attention. But as I used them with him regularly every day, he became used to them. In fact, we enjoy playing attention games every day. (P1)

I use the calming techniques every day in different combinations so that he becomes familiar with these interventions and they become like habits for him. (P9)

However, one mother reported that she could not apply the interventions with her child regularly. She said:

My child hated doing the exercises at home as this reminds him of doing the exercises at the ADHD training centre, which he does not really enjoy. (P5)

On the theme of "positive and negative effects of behavioural interventions", all the 14 mothers who reported regularly using behavioural interventions said that they have seen positive effects in their children. Again, the mother who discussed swimming and playing with sand (P1) noted:

These really work and his hyperactivity is much less. (P1)

The mother who uses brain exercises such as puzzles, games and reverse counting with beads (P7) to improve the attention of her child noted:

These techniques improved my child's attention a lot. (P7)

The mother who uses pictures to reinforce verbal instructions noted:

This technique helped my child follow my instructions easily. (P13)

The positive effects of using behavioural interventions found by the mothers are consistent with a number of systematic reviews and meta-analytical studies that suggested that behavioural interventions are valuable for children with ADHD (Charach et al., 2013; Corcoran & Dattalo, 2006; Fabiano et al., 2009).

However, the mother who tried exercises that had been demonstrated at the ADHD training centre (P5), reported that she did not see either positive or negative effects for techniques she used to improve her child's attention. She said:

> *So, I did not particularly see positive effects in him. (P5)*

From the results above, it is clear that all mothers are aware of behavioural interventions and all but one have been using them regularly. All mothers also reported that they had learnt about the interventions they used from ADHD professionals. However, two mothers have also developed their own interventions. All mothers but one also reported that these interventions have positive effects on their children.

3.3.2 Experiences with Environmental Interventions and Variables for Children with ADHD

Environmental interventions and variables include those related to sounds, colour schemes, and lighting to help children with ADHD in improving their attention and decreasing their hyperactivity and impulsivity. The following sections describe whether parents of children with ADHD experienced effects of environmental variables and interventions related to sound, colour schemes and light.

On "awareness of interventions and variables related to sound", the most common response voiced by mothers about sounds that had an effect on their children was that of listening to the Quran being read to them by either the child's parents or via recordings. All mothers stated that having their children listen to the Quran helped them in terms of calming their children and improving their concentration:

> *The most beneficial sound for my child is the Quran. My child likes the voice of one reader called AlOfasi and once my child hears his voice, he immediately becomes calmer and concentrates. (P5)*
>
> *Listening to the reading of the Quran makes my child happy, relaxed and improves his concentration. (P9)*
>
> *It is only the Quran, especially the tranquillity verses that calm my child. (P15)*

On the other hand, when mothers were asked whether they knew about or used any other types of sounds to help their children apart from the Quran, 14 mothers (93%) indicated that they had never heard about or tried any other helpful sounds. One representative response is:

> *I have never tried or heard about sounds helpful for children with ADHD. (P11)*

Amongst these 14 mothers, three mothers added that they never been interested in using sounds, as their children are sensitive to sounds in general and sounds distract them:

> *I never knew or tried sounds with my child as he is highly sensitive to sounds and hates loud sounds. (P3)*
>
> *I never think of using sounds with my child. Sounds distract him easily even his sisters' sounds distract him. (P7)*
>
> *My child is always scared and sensitive to sounds so I never thought of using sounds with him. (P13)*

However, one mother stated that she used specific music with specific frequency with her child:

> *I use music with frequency 528 [Hertz] and it has made a huge improvement in my child in terms of consciousness and attention. (P14)*

As noted above, one main sound used by mothers to help their children was reading from the Quran. The main source of information for mothers that the Quran is helpful for their children is that all Muslims believe in the calming effects of the Quran on humans. For instance, one mother said:

> *As you know, we, all Muslims, believe in how Quran results in rest and tranquillity. (P6)*

The mother (P14) who used the music with a specific frequency and found it helpful for her child, explained that she learnt about this idea from a doctor in Kuwait:

> *I saw a tweet by a doctor in Kuwait, about the music he developed that is very promising for my child. I was so interested in this topic, so after few days, I travelled to him and bought the CD. I saw tremendous improvements in my child. (P14)*

On the theme of "actions and persistence of action with using interventions related to sound", all mothers reported that they have their children listen to Quran every day at different times during the day and particularly before bedtime. One mother stated that she was persistent with having her child listen to Quran every day as part of the bedtime routine, she said:

One of our bedtime routines when my child lies on his bed is to have him listen to his favourite Quran reader and sometimes I read Quran for him by myself. (P9)

The mother who uses music said:

I used to put headphones for my child and made him listen to this music every day. I used the music for two months straight in the settings recommended by the doctor to get the best results. (P14)

With respect to using the Quran as sound to calm their children and improve their concentration, all mothers reported positive effects for their children as noted above in responses from mothers P5, P9 and P15. Mothers P4 and P5 also noted:

My child falls asleep after a few seconds of listening to the Quran by her favourite reader. (P4)

It is only the Quran, especially the tranquillity verses that calm my child. (P15)

As noted above, one mother (P5) mentioned that the voice of a particular reader (AlOfasi[2]) has a considerable effect on her child and that her child is not calmed by other readers. Also as noted above, the mother (P14) who used music with a specific frequency reported tremendous improvement in her child in terms of attention and cognitive capacity in general.

It is clear from the mothers' responses that all the mothers agreed that using the Quran helped calm and improve the concentration of their children. In addition, one mother reported using music to improve her child's attention and consciousness. To get good results from both the Quran and the music, mothers reported that they needed to make their children listen to them regularly. With respect to any other kinds of sounds, 14 out of the 15 mothers reported that they had never been aware or used sounds that would be helpful for their children.

On the theme of "awareness of interventions related to colour", mothers' responses were divided into four categories. First, seven mothers reported that they never tried using colours as an intervention for their children or noticed any effect of colour on

[2] A sample of this reader can be heard at: https://www.youtube.com/watch?v=XRWSiiSuvbg

their children. When these mothers were asked whether they had heard of this type of intervention, they stated that they never heard of them.

Three mothers provided the second category of responses. It is similar to the first category in the sense that mothers had not tried using specific colours or noticed any effect of colour on their children, but these mothers noticed that their children prefer some colours to others, but that they did not have any particular effect on their children:

> *My child likes red in everything, in her shoes, dress, bed sheets, but I did not notice any difference with this colour or any other colour. (P4)*

> *My boy likes everything blue, his classes, bag, everything but I did not notice any effect for this colour and other colours on him. (P13)*

The third category includes responses from two mothers who knew or had heard that there are colours that have an effect on children with ADHD but who had not seen any effect of these colours on their children. For instance, one mother said:

> *My child's teacher told to me to use cool colours and avoid warm colours in order to calm my child down. I followed her advice but I did not see any difference in my child. (P3)*

Another mother said that she had studied the colour palette and colour effects on individuals in general during her Bachelor's degree and she thought these ideas are applicable to everyone, including children with ADHD. She tried using colours that she thought would be helpful to her child but noted:

> *I tried to make him wear cool tone clothes and painted the dining room green but I did not see any difference in him. I am not really interested in this topic, as I do not think it will have that huge an impact on my child. (P13)*

The last category of responses came from three mothers and includes mothers who had never heard about any effect of colours on children with ADHD but when asked reported that they had noticed positive or negative effects of some colours on their children based on their own observations:

> *I noticed that red, yellow and bright colours make my boy more hyperactive while white and dark blue make him less hyperactive. (P10)*

> *My child likes everything blue, his bed sheet, his toys, and I can tell that he is comfortable and calm when he is surrounded by the colour blue. (P12)*

> *I noticed that orange, red, and yellow coloured things increase my child hyperactivity and make him stressed. (P14)*

As noted, most of the mothers knew nothing about the possible effect of colours on children with ADHD. However, in the third category, two mothers reported that they knew from a number of different sources that colours have an effect on children with ADHD. For instance, mother P3 said that her child's teacher was the source of her awareness about the possible effects of cool and warm colours on her child. The other mother (P13) had studied the effects of colour as part of her Bachelor's degree.

Mothers in the fourth category, who noticed an effect of colours on their children, all reported that although they did not know and had not been told that colours have an effect on their children, their own observations lead them to see the effect of colours on their children's attitude.

Starting with the two mothers who reported that they knew that some colours have an effect on their children, it does not seem that these mothers take appropriate or persistent actions in relation to colours. For instance, the mother (P3) who reported that her child's teacher told her to use cool colours and avoid warm colours in order to calm her child down said:

> *I followed the teacher's advice and made my child wear cool colours but I did not see any difference in my child. (P3)*

In this case, the mother only applied the teacher's advice with respect to clothing and not for the entire environment surrounding the child, particularly where the child spent most of his time. The other mother (P13) did not take appropriate action in the sense that she used her previous knowledge about the effect of colour on people in general, which is not necessarily applicable to children with ADHD.

As reported above, only three mothers reported observing an effect of colours on their children. All three found that warm colours increased hyperactivity in their children and cool colours made their children less hyperactive. One mother (P10) reported that red, yellow and bright colours made her son more hyperactive while white and dark blue made him less hyperactive. Similarly, mother (P12) reported that blue made her son calmer and mother (P14) reported that warm colours like orange, red and yellow made her child more hyperactive.

It is clear that none of the mothers interviewed had full awareness about how different colour schemes might affect their children whether positively or negatively. As a result, none of the mothers took determined actions that might lead to positive results in terms of improving their children's attention and lowering their hyperactivity and impulsivity by manipulating the colour environment.

Nine mothers reported that they were not aware of possible effects of lighting on their children and that they had never noticed a positive or a negative effect on their children of different lighting intensity or colours:

> *I did not notice any effect for different lighting. (P11)*

On the other hand, six mothers responded that by their own observation of their children, they had noticed positive or negative effects for some lighting conditions. Examples for the responses of four mothers who reported noticing negative effects for some lighting conditions on their children:

> *I noticed by observing my child's behaviour that yellow and bright lighting annoys my child. (P3)*
>
> *I noticed that my child hates darkness and bright lights but never noticed a difference with different light colours. (P6)*
>
> *He hates bright lights but I did not notice a difference with my child with respect to different lightings' colours. (P9)*
>
> *I noticed that dim lighting distracts my child but I did not notice any difference with my child with respect to different lighting colours. (P12)*

Only one mother reported that she had noticed a positive effect for specific lighting on her children:

> *When I dim the lighting, my child's hyperactivity becomes less but I did not notice any effect for the lighting colour. (P8)*

Another mother noticed both positive and negative effects:

> *I noticed that bright lights improved my child's attention whereas dim lights distract him. But I did not notice any effect for different lighting colours. (P7)*

As noted above, 9 mothers reported that they did not see any effect for the different lighting conditions on their children. For the remaining six mothers, their own observations of their children's behaviour under a variety of lighting conditions were the source of information about the positive or negative effects.

Mothers who reported positive effects for different lighting conditions on their children's behaviour said that they tried to constantly provide those conditions. For instance, one mother who reported noticing that dim lighting lowers her child's hyperactivity said:

> *I try my best to make the lighting in my house not too bright because dim lights are best for lowering his hyperactivity. (P8)*

Another mother who noticed that bright lighting helped improve her child's attention said:

> *I always make sure to have bright lightings in the room when my child needs to do tasks that require attention such as doing his homework. (P7)*

Mothers who reported noticing negative effects for different lighting conditions also said that they consistently tried to avoid these conditions. For instance, one mother who noticed that yellow and bright lighting annoys her child said:

> *…so I always do my best to avoid yellow and bright lighting as they annoy my child." (P3)*
>
> *Another mother who responded that her child hates darkness and bright lighting said:*
>
> *… I always make sure to have very dim light in his room while sleeping and avoid bright lighting as much as possible. (P6)*

Four mothers reported noticing negative effects of some lighting conditions on their children. For instance, three mothers (P3, P6, P9) reported a negative effect of bright lighting on her child. One mother (P6) reported a negative effect of darkness and one mother (P3) reported a negative effect of yellow lightings. Finally, one mother (P12) reported the negative effects of dim lighting on her child. On the other hand, one mother reported a positive effect of dim light on her child. And finally, one mother noticed both positive and negative effects.

As noted above, nine mothers were not aware of the effect of different lighting conditions on their children. However, six mothers noticed, by their own observations, that the degree of the light brightness and colour affect their children either negatively or positively. All these mothers took consistent actions with either adopting the lighting condition that led to positive effects or avoiding the lighting conditions that led to negative effects.

3.3.3 Using Technological Interventions and Assistive technologies for Children with ADHD

13 mothers responded positively to the idea of using technological interventions or assistive technologies if they are helpful for their children:

> *I have heard of many assistive technologies for children with ADHD such as BrainGame, which is computerized training software for children with ADHD. They use it in the centre that I take my child to. I will definitely use assistive technologies if they are beneficial for my child. (P5)*

Amongst the 13 mothers who agreed on the use of technological interventions or assistive technologies for helping their children, four mothers added a condition of their children's acceptance to using these technologies:

> *I will definitely use assistive technologies if my child likes them. (P15)*

Two mothers rejected the idea of using technological interventions or assistive technologies. They believed that technology, in general, leads to ADHD and worsens the symptoms of children with ADHD:

> *I have heard about many assistive technologies such as programs and games for children with ADHD, but I will not use them for my child at all because I believe technology in general worsens my child's state, even if technologies are not the main source for ADHD.* ***.*** *(P9)*

> *No, I will not use [technological interventions/assistive technologies], because TV and electronics, such as iPhone and iPad in general lead to ADHD. (P5)*

3.4 Conclusions

This study aimed to investigate the experiences of parents of children with ADHD with interventions to help their children. I was particularly interested in experiences with technological interventions, assistive technologies, and environmental variables and interventions involving sound, colour schemes and lighting, but for the sake of opening discussions with the parents, completeness and for possible ideas for future technologies, I also included behavioural interventions. All interventions were analysed, regardless of whether they are supported by scientific evidence. I had hoped to recruit both mothers and fathers to participate in the study, however, mainly due to Saudi attitudes to parenting, I was only able to recruit mothers.

The most interesting result was the fact that all the mothers stated that having their child listen to a reading of the Quran helped the children become calm and concentrate more. It is important to understand that the Quran is read as a text but not in a typical speaking or reading aloud cadence. Although different readers have different individual styles and voices (and are thus not as rule governed as Gregorian chant or Jewish cantillation), there is a melodic and rhythmic quality to the reading. Therefore, Quran, music or melodies might be distracting when listened to while doing tasks requiring attention as the listener might unintentionally pay attention to them rather than the task on hand. In comparison, white noise, as explained in Chapter 2 (section 2.8), is without melody or rhythm and there is a possible link here with the research by Söderlund and colleagues (2007, 2016) and Bajiot and colleagues (2016) on the benefits of white noise for children with ADHD. They found that the presence of white noise improved the cognitive performance of children with ADHD. The results of this study and those of Söderlund and colleagues (2007, 2016) and Bajiot and colleagues (2016) have inspired me to explore the use of sound in an assistive technology to help children with ADHD perform better. Therefore, it was decided to conduct experimental studies investigating the effect of using specific kinds of sounds including white and pink noise (see Chapter 2, section 2.8) on the attention and impulsivity of children with ADHD.

In addition, this study has given insights into the experiences of Saudi mothers towards using technological interventions or assistive technologies for helping their children. Only a small minority of mothers were against these kinds of interventions. It would be interesting to compare these results with attitudes of Saudi fathers and attitudes of parents in other countries.

Overall, this study has contributed to my understanding of the possibilities of assistive technologies for children with ADHD. The study found that mothers are open to using assistive technologies for their children, which in addition to the fact that there are very few assistive technologies described in the literature support the need for more assistive technologies to assist children with ADHD. The study also found that almost all mothers have noticed beneficial effects of sound, particularly reading of the Quran, although I decided to explore the effect of white noise in the next study rather than a text-based sound source, for the reasons explained above. Finally, experiences of mothers with the effects of colour and lighting in the environment on their children were much more mixed, so I decided not to investigate these effects.

Chapter 4 - Study 2: The Effect of White Noise on Attention of Children with ADHD Using a Go/NoGo Task

4.1 Introduction

The first study (see Chapter 3, section 3.1) in this programme of research was an exploratory study that investigated whether parents of children with ADHD have noticed any effects of environmental variables such as sounds, colours schemes and lighting on their children. The results showed that interventions and their possible beneficial effects related to sounds, colours and lights are not well known to the majority of Saudi mothers. This was not surprising, as the effects of environmental variables on children with ADHD have not yet been well investigated (see Chapter 2, section 2.8). However, the most interesting result was the fact that all the Saudi mothers stated that having their child listen to a reading of the Quran helped the child calm and concentrate more. The Quran has a melodic and rhythmic quality to the reading. Although white noise is without melody or rhythm, there is a possible link here with the research which has shown the benefits of white noise for children with ADHD.

For instance, white noise has been shown to have a positive effect on memory (Söderlund, et al., 2007) and attention (Baijot et al., 2016; Söderlund, et al., 2016) in children with ADHD, and on memory (Söderlund et al., 2010) and attention (Helps et al., 2014) in children with attention problems although they do not have a diagnosis of ADHD. In addition, not only does white noise have positive effects on children with attention problems, it also has positive effects on adults with attention problems (Flodin et al., 2012; Söderlund et al., 2009). Previous studies did not find an effect of white noise on impulsivity. Therefore, in this study, I predicted to have a positive effect of white noise on attention but no effect on impulsivity of children with ADHD.

So, building an assistive technology that incorporates white noise could be beneficial for children with ADHD. However, since there are only a few studies that investigated the effect of white noise on the performance of children with ADHD, it was sensible to investigate further whether white noise has a positive effect on the performance of children with ADHD and how best to measure this effect before developing the assistive technology.

A visual Go/NoGo task was used in this study to provide objective measures of attention and impulsivity in children with ADHD (for more details, see Chapter 2, section 2.4.2.1). A typical Go/NoGo task results in four operational variables that measure inattention and impulsivity, these are omission errors (OEs), commission errors (CEs), reaction times for correct Go trials (RTs), and reaction time variability (RTV).

Previous studies (Schmidt et al., 2019; Tamm et al., 2012) showed that children with ADHD make more OEs and CEs than typically developing children. More OEs represent greater inattention in children with ADHD, while more CEs represent greater impulsivity in children with ADHD (Schmidt et al., 2019; Tamm et al., 2012) (for more details, see Chapter 2, section 2.4.2.1). Previous research also found that white noise lowered OEs and thus improved attention in children with ADHD (Baijot et al., 2016) and children with attention problems (Helps et al., 2014). However, white noise has no effect on CEs and thus has no effect on impulsivity in children with ADHD (Baijot et al., 2016). Therefore, it was predicted that in this study a White Noise condition will result in fewer OEs for children with ADHD compared to a No Noise condition, whereas there will be no difference in CEs between these conditions.

As for RTs, previous research has shown mixed results about RTs in children with ADHD. Some studies (Epstein et al., 2011b; Russell et al., 2006) have shown that children with ADHD have slower RTs than typically developing children while a study by Buzy et al. (2009) found that children with ADHD had faster RTs than typically developing children after controlling for RT variability. However, according to a meta-analytic study by Kofler et al. (2013), children with ADHD had similar RTs to typically developing children after controlling for RT variability. In addition, the event rates (ERs) at which tasks are presented (for more details, see Chapter 2, section 2.4.2.1) affect RTs in different ways. For instance, according to the State Regulation Deficit (SRD) model of ADHD, slow ERs, relative to what is optimal for the task, result in under-activation in brain networks and thus inattentive responding, which results in slow RTs. On the other hand, fast ERs, relative to what is optimal to the task, result in over-activation in brain networks and thus impulsive responding, which results in fast RTs (Metin et al., 2012). Moreover, results from studies have shown that fast ERs limit the range of RTs and thus eliminate possible differences in RTs between children with ADHD and typically developing children (Epstein et al., 2011b; Tamm et al. 2012). As for the relation between RTs and ADHD symptoms, Bezdjian et al. (2009) and Halperin et al. (1991) suggested that faster RTs are indictors of impulsivity. This was based on an inverse correlation between CEs and RTs, which is common sense. On the other hand, Epstein et al. (2010) found, based on close observation of the patterns in their data, that children with ADHD had significantly slower RTs in trials just before OEs and in trials just before a successful inhibition (i.e., non-response in the NoGo condition). These patterns may reflect the start of attentional disengagement (i.e., attentional lapses) that consequently lead to not responding (i.e., OEs or successful inhibition) (for more details, see Chapter 2, section 2.4.2.1). Egeland and colleagues (2009) also linked RTs to inattention after finding that RTs significantly correlated with inattention ratings from both parents and teachers. Finally, only one study, by Baijot et al. (2016), which investigated the effect of white noise on RTs, found no effect for white noise on RTs.

In this current study, it was chosen to tentatively link RTs to inattention in children with ADHD as and Epstein et al. (2010) found in their study. This was because the findings by Epstein et al. (2010) were based on the close observation of the patterns in their data and this was also support by the Egeland et al. (2009) study as discussed above. In addition, in this study, a faster ER than that used by Baijot et al. (2016) (for explanation, see Chapter 2, section 2.8.1) was chosen, so there is no study on which to base a hypothesis about the effect of white noise on RTs in children with ADHD in this situation. Therefore, since RTs may reflect inattention in the same way that OEs do, it was predicted that in this study a White Noise condition will reduce RTs for children with ADHD compared to a No Noise condition.

As for RTV, there has been a controversy about the most suitable methods for measuring RTV (for more details, see Chapter 2, section 2.4.2.1). Previous studies showed that RTV is higher in children with ADHD compared to typically developing children and that higher RTV represents higher inattention in children with ADHD (Kofler et al., 2013; Schmidt et al., 2019; Tamm et al., 2012). Similar to the effect of

ERs on RTs, fast ERs are known to improve arousal and attention in children with ADHD and thus decrease RTV. In comparison, long ERs have been shown to result in under-arousal and inattention in children with ADHD and thus increase RTV (for more details, see Chapter 2, section 2.4.2.1). Finally, only one study by Baijot et al. (2016), which investigated the effect of white noise on RTV, found no effect for white noise on RTV in children with ADHD.

In this study, a faster ER than Baijot et al. (2016) (for explanation, see Chapter 2, section 2.8.1) is used, so there is no study on which to base a hypothesis about the effect of white noise on RTV in children with ADHD in this situation. However, since RTV reflects inattention in the same way that OEs do, it was predicted that in this study a White Noise condition will reduce RTV for children with ADHD compared to a No Noise condition.

It is important to note that the design of this study was based on a number of previous studies, but with some key differences. These include studies that used white noise and the Go/NoGo task to measure the performance of children with ADHD, such as Baijot et al. (2016) and studies of children with attention problems without a diagnosis of ADHD such as Help et al. (2014). The key difference is that these previous studies compared children with ADHD with a control group of normally developing children whereas this current study compares different noise conditions for children with ADHD. The differences also include the Go/NoGo task components, such as stimulus duration, ISI and ER. Another important difference is in the data analysis, including issues with statistics (for more details, see Chapter 2, sections 2.4.2.1 and 2.8.1). In addition, I addressed problems with the analysis of the data, which are not normally distributed, which does not seem to have been considered by previous research.

This study aimed to investigate the effect of white noise on the attention and impulsivity in children with ADHD. The study used a within-participants design, having children with ADHD undertake a visual Go/NoGo task with and without the presence of white noise.

The hypotheses tested in the study are as follows:

1. White noise will improve attention in children with ADHD. This leads to three more specific hypotheses:

1a: The White Noise condition will reduce the number of OEs in comparison to the No Noise condition

1b: The White Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition

1c: The White Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition.

2. White noise will not affect impulsivity in children with ADHD. This leads to a further hypothesis:

2a: There will be no significant difference in the number of CEs between the two noise conditions

3. The ongoing experience with the Go/NoGo task has no effect on attention of children with ADHD. This leads to three more specific hypotheses:

3a: The number of OEs will not be significantly different in a sequence of blocks of the Go/NoGo task

3b: RTs (as measured by mean and median) will not be significantly different in a sequence of blocks of the Go/NoGo task

3c: RTV (as measured by SD, CV and MAD) will not be significantly different in a sequence of blocks of the Go/NoGo task

As it was predicted in this study that white noise will not have an effect on impulsivity, a hypothesis about the effect of the ongoing experience with the Go/NoGo task on CEs in children with ADHD was not included.

4.2 Method

4.2.1 Participants

The children with ADHD who were recruited to participate in the study had been assessed using the DSM-V (American Psychiatric Association, 2013) criteria for ADHD by a paediatric neurologist or neuropsychologist at local centres and hospitals in Saudi Arabia, namely the AlTamayouz Centre for Intellectual and Learning Disabilities in Children and the Department of Developmental and Behavioural Disorders in Children, at King Abdullah Hospital for Children (KAHC). Some children with ADHD were also recruited through messages posted on Twitter. To get the message to relevant parents, I posted a tweet with a request for participation in this study in my Twitter account and asked well-known ADHD professionals to share this tweet in their accounts.

The inclusion criteria for participation in the study were:

- Diagnosed with ADHD-I or ADHD-C (see Chapter 2, section 2.2.1)
- Aged between 6 and 12 years old inclusive
- IQ of more than 80, based on reports prepared by local hospitals or provided by parents
- No psychiatric comorbidities
- No sensory deficits
- Not taking any pharmacological treatments that could affect behavioural performance other than methylphenidate. Methylphenidate is normally used to improve attention. If taking methylphenidate, this was stopped 24 hours prior to the experimental session because this period is sufficient to ensure full wash-out (Greenhill & Ford, 2002)

A pool of 62 children with ADHD was available through both the AlTamayouz Centre and KAHC, but many of these children failed to meet all the inclusion criteria (e.g., they often have comorbidities). In addition, three children started the study, but became bored and requested to withdraw before the end of the study.

Therefore, 16 children with ADHD participated in the whole study and their data were included in the analysis, 9 girls, aged 8 to 12 years (mean age = 9.4 years, SD = 1.42), 7 boys aged 8 to 12 years (mean age = 8.56 years, SD = 0.73). 10 children were diagnosed with ADHD-C type and 6 children were diagnosed with ADHD-I type. 5 children were diagnosed with ADHD prior to the age of 4 years while 11 children were diagnosed with ADHD between the age of 5 and 7 years (for full information for all the participants, see Appendix B.3).

4.2.2 Design

A within-participants study design was used. Children performed a visual Go/NoGo task. The decision to use the visual Go/NoGo task in this study was based on a number of reasons explained in Chapter 1 (section 1.7).

In the Go/NoGo task children had to press a button as fast and as accurate as possible if they saw an aeroplane (i.e., a Go stimulus) on a computer screen, but not press the button if they saw a bomb (i.e., a NoGo stimulus) (see Figure 4.1, for full details about the Go/NoGo task, see Chapter 2, section 2.4.2.2). These particular stimuli were chosen in this study because previous studies, such as a study by Brophy et al. (2002) and a study by Rubia et al. (2001), involving both boys and girls with ADHD used these stimuli in their Go/NoGo task. The stimulus duration was 200ms while the inter-stimulus interval (ISI) was 1400ms, thus the event rate (ER) was 1600 milliseconds (ms), which is considered a fast ER (for more details, see section 4.2.3). The stimulus duration and the ISI were fixed for every Go and No/Go stimulus regardless of whether the child had made a correct response or not. The study involved one block of 20 stimuli for practice, and the main part of the study consisted of four blocks of 60 stimuli alternating between the White Noise and No Noise conditions. All blocks contained 45 Go stimuli (75%) and 15 NoGo stimuli (25%). This particular ratio was used because many studies using a Go/NoGo task with children with ADHD have used this ratio (for more details, see section 4.2.3). The order and spacing of the Go and NoGo stimuli were fixed for all children to avoid the effect of randomness of presenting the Go and NoGo stimuli on the performance of the children. Each NoGo stimulus was proceeded by no, five or more Go stimuli as suggested by previous studies (for more details, see Chapter 2, section 2.4.2.2).

The design of the four alternate blocks with white noise and no noise was used to investigate whether the ongoing experience with the Go/NoGo task has an effect on the attention of children with ADHD.

The study involved one independent variable that had two conditions: White Noise, and No Noise. There were four dependent variables, which were:

- Omission errors (OEs), which are errors resulting from failing to press the button for a Go stimulus
- Commission errors (CEs), which are errors resulting from pressing the button when presented with a NoGo stimulus
- Reaction times for correct Go trials (RTs), which measure the time between presenting the stimulus and the child's response
- Reaction time variability (RTV), which measures (in)stability in reaction times to a set of Go stimuli

As discussed in section 4.1, higher OEs and RTVs are indications of inattention, particularly vigilance or sustained attention while higher CEs are an indication of impulsivity. As for RTs, previous research showed mixed results about the effect of ADHD on children's RTs.

As stated earlier, the aim of this study was to investigate if white noise has a real effect on the attention and impulsivity of children with ADHD and not that white noise is just blocking auditory distractors. Therefore, to obtain meaningful results, the influence of external factors was minimized such that the experiment was conducted in a quiet room with white walls that was also free of visual distractors.

In this study, giving rewards or incentives during the task was avoided, as this improves arousal and performance in children with ADHD and rewards are not available all the time in real life (see Adamo et al., 2019; Epstein et al., 2011a; Kofler et al., 2013).

In addition, the most recent and relevant guidelines on how to conduct usability evaluations with children at school proposed by Sim et al. (2016) have been used when conducting this study. Although this study was not conducted in a school, the guidelines were relevant as this study was conducted in empty rooms at the centres as stated in section 4.2.1.

4.2.3 Experimental Task

The study used the visual Go/NoGo task, a well-known experimental task, which is one example of the Continuous Performance Tests (CPTs) used widely as an objective assessment for evaluating ADHD and other neurological disorders (for more details, see Chapter 2, section 2.4.2.1).

A typical visual Go/NoGo task involves two visual stimuli, a Go stimulus and a NoGo stimulus. The child must press a button on a keyboard or device as quickly and as accurately as possible when a Go stimulus is presented on a computer screen and not press when a NoGo stimulus is presented. The stimulus is shown on the screen for a limited number of milliseconds (ms) and this time is called the *stimulus duration.* After that, a blank screen is shown for a period of time, called the *inter-stimulus interval* (ISI), before showing the next stimulus. The timing of the stimulus starts from its appearance on screen until the appearance of the next stimulus (See Figure 4.2). The stimulus duration and the ISI together make up what is called the *event rate* (ER), which indicates the speed of presenting the stimuli (Tamm et al., 2012). Studies varied in the stimulus duration (typically between 200ms and 1100ms) and the inter-stimulus interval (typically between 800ms and 12000ms), and thus in the event rate (Simmonds et al., 2008).

ERs used in tasks could be too fast, moderate or too slow. However, there is no clear consensus on how to classify ERs into fast, moderate or slow as it is relative to what is optimal to the task at hand. Therefore, ERs vary depending on the task and individual characteristics. A meta-analytic study by Metin et al. (2012) suggested that for a Go/NoGo task, ERs between 1250ms and 2300ms are considered fast ERs.

The percentages of the Go stimuli to the NoGo stimuli in a task have also varied in previous studies. However, again there is no clear consensus on how to choose the ratio of Go stimuli to NoGo stimuli in a task. According to a meta-analytic study by Simmonds et al. (2008), studies varied in the proportion of NoGo trials and ranges from 6.8% to 50%. Several studies used a Go/NoGo task with 75% Go stimuli and 25% NoGo stimuli with individuals with ADHD (Durston et al., 2003; Hwang et al., 2019; Schulz et al., 2012; Solanto et al., 2009; Wiersema et al., 2005) and with individuals without a diagnosis of ADHD (Harper et al., 2014; Helps et al., 2014; Nieuwenhuis et al., 2004)

My version of the Go/NoGo task was programmed using Psytoolkit[3] (Stoet, 2010, 2017). The first screen is an instruction screen (see Figure 4.1, Panel 1), which was explained verbally to the child by myself. I informed the child that they must press the keyboard spacebar as fast and as accurate as possible once they see an aeroplane and not to press when they see a bomb. Then, I pressed the spacebar to move to the stimulus screen. As stated earlier, there are two stimuli, a Go stimulus (a picture of an aeroplane) and a NoGo stimulus (a picture of a bomb) (see Figure 4.1, Panel 2). The child must

[3] https://www.psytoolkit.org/

press the keyboard spacebar as fast as possible when a Go stimulus is displayed and not press when a NoGo stimulus is presented.

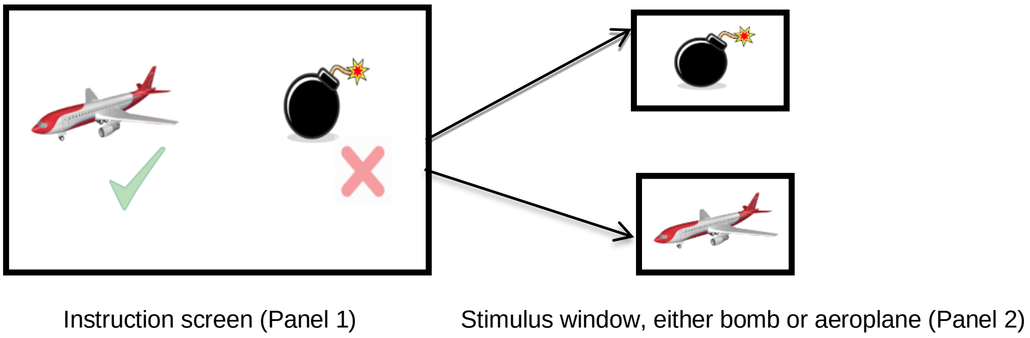


Figure 4.1 Illustration of the Go/NoGo content

The stimulus is shown on the screen for 200ms. After that, a black screen is shown for 1400ms. Thus, the time that is allowed for the child to respond to the presented stimulus and after which the next stimulus is presented is 1600ms. The ER used is considered a fast ER as described earlier in this section (see Figure 4.2). The stimulus duration and the ISI are fixed for every Go and No/Go stimulus regardless of whether the child makes a correct response or not. This means that if a child successfully responded to a Go stimulus within the 1600ms, the next stimulus would not appear until the 1600ms interval finishes. Similarly, if a child mistakenly responded to a NoGo stimulus within the 1600ms, the next stimulus would not appear until the 1600ms interval finishes.

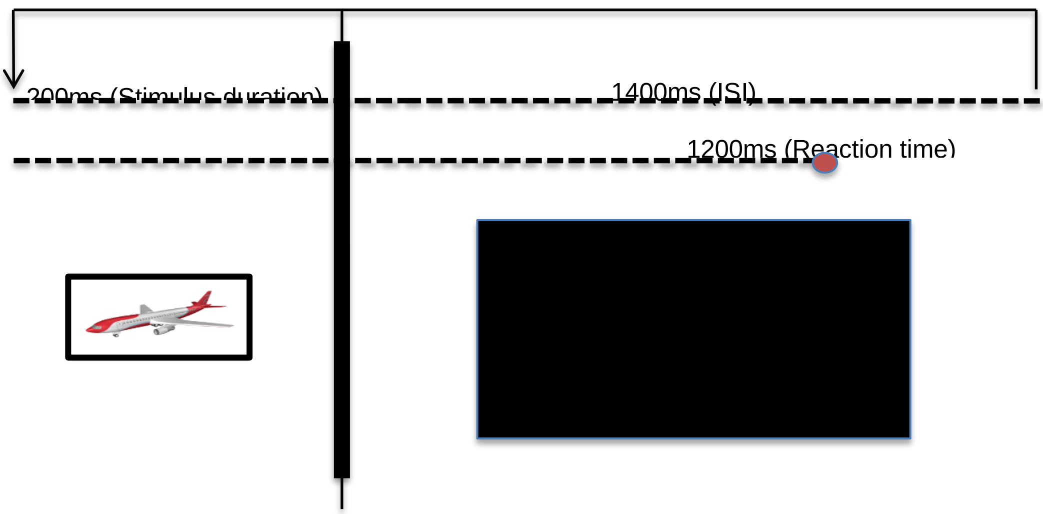


Figure 4.2 Example of one Go/NoGo trial, showing a Go stimulus, stimuli duration, ISI and reaction time

The study involved one block of 20 stimuli for practice, these were not analysed. There is no clear consensus on the required number of stimuli in an experimental block. However, it is recommended that the number of stimuli be more than 50 (Metin et al., 2012). The main part of this study consisted of four blocks of 60 stimuli each (slightly above this recommended minimum), meaning that there were 120 stimuli in the White Noise condition and 120 stimuli in the No Noise condition. Each block contained 45 Go stimuli (75%) and 15 NoGo stimuli (25%), meaning that there were 90 Go stimuli and 30 NoGo stimuli in each noise condition. This percentage was chosen as it was used by several studies using a Go/NoGo task with individuals with ADHD and with individuals without a diagnosis of ADHD as mentioned earlier.

4.2.4 Equipment and Materials

A MacBook Pro running IOS Sierra with a 15-inch screen was used for the experiment. White noise was delivered at 77dB, which also fits into the range of white noise levels of 75 to 85dB, the range found by a number of studies to be beneficial for the attention of children with ADHD (for more details, see section 2.8.1). The white noise was delivered, using Buddy Headphones play model no. 72692BP-PLAY-GLACIER and an iPhone X. Both the headphones and the iPhone were used in the testing procedure below.

To ensure that the headphones delivered the chosen dB accurately, a testing procedure was devised (illustrated in Figure 4.3). This procedure used a foam dummy head, headphones, and a sound level meter (Brand: BAFX, Model number: BAFX3608).

Panel 1 Panel 2 Panel 3

Figure 4.3 Setup for measuring the dB for the headphones

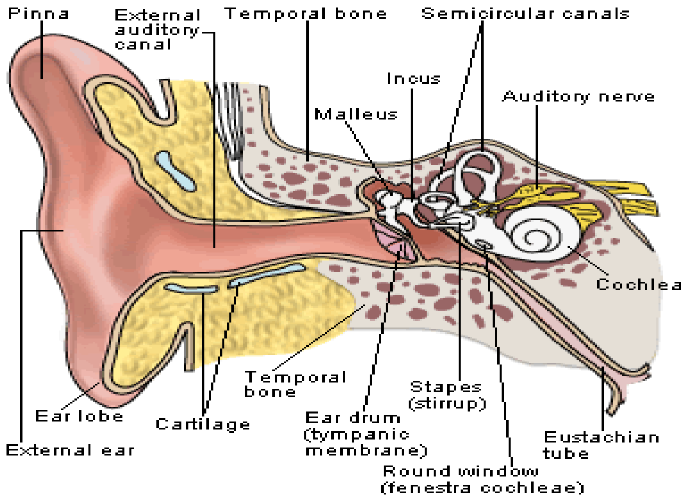


Figure 4.4 Anatomy of human ears, showing the ear canal, the external ear and the eardrum (Source: Tracey, 2000)

Looking at the anatomy of the ear, the ear canal that connects the external ear (pinna) to the eardrum is responsible for transmitting the sound waves to the middle and inner ear (see Figure 4.4). The length of the ear canal in children 12 months and older is similar to the length of the ear canal in adults, which is on average approximately 2.5 cm (Keefe et al., 1993). Therefore, the first step in the testing procedure was to make a hole of 2.5cm in length and 0.7cm in diameter imitating the ear canal in children in the dummy head (see Figure 4.3, Panel 1). Second, the headphones were placed over the ears of the dummy head, while playing white noise (see Figure 4.3, Panel 2). The sound meter was placed inside the dummy head, approximately where the eardrum is located (see Figure 4.3, Panel 3). Then, white noise was delivered through an iPhone X and the volume was adjusted several times until the reading of the dB meter was 77dB. The same headphones and white noise volume were used with children during the experiments.

Prior to the experiment, a questionnaire (for the full questionnaire, see Appendix B.1) with screening questions was given to parents of children with ADHD to ensure that their child met the inclusion criteria. The main points of the questionnaire included:

- The ADHD type that the child was diagnosed with
- The age at which the child was diagnosed with ADHD
- The child’s age
- The child’s IQ

- Whether the child has any psychiatric comorbidities
- Whether the child has any sensory deficits
- Whether the child is taking any pharmacological treatments other than methylphenidate

Two questions were asked to the parents and children at the end of the experiment:

- For parents: Would you use white noise to help improve your child's attention when performing a task requiring high attention?
- For children: Do you believe white noise helped you concentrate more?

4.2.5 Pilot Study

A pilot study was conducted to check for any problems with the study, particularly any technical problems with the version of the Go/NoGo task to be used in this study. It was conducted with two children with ADHD, recruited through the AlTamayouz Centre for Intellectual and Learning Disabilities in Riyadh, Saudi Arabia. The sizes of the Go/No stimuli were found to be too small, which was mentioned spontaneously by the children. Thus, the sizes of Go/No stimuli were made bigger. The dimensions of the Go/No stimuli before the pilot study were (200mm x 118mm) while the dimensions of the Go/No stimuli before the pilot study were (299mm x 177mm). No other issues were found. The two children who participated in the pilot study were not included in the main study.

4.2.6 Procedure

As stated earlier, I followed the guidelines for conducting evaluations with children proposed by Sim and colleagues (2016). These involve guidelines for the planning of the evaluation, the introduction of the evaluation session, during the evaluation session, and finishing up.

The sessions were conducted in the two centres specified in section 4.2.1. Prior to the sessions, I met with the ADHD specialists at the centres and explained the nature of the study and the inclusion criteria for children to participate. I then asked the specialists in the two centres to examine the test rooms to ensure that the rooms were suitable for the study. The rooms contained a table and chairs, so they were free of any potential visual and auditory distractors, had good lighting and a moderate temperature and had electricity sockets available. Also, I ensured that the setup of the two rooms was identical so that all children experienced the same experimental environment.

For children recruited through the two centres mentioned above, the children were chosen after confirming with the specialists that they met the inclusion criteria since the specialists have up to date information about the children. Then, the specialists contacted the parents of the eligible children and told them briefly about the nature of the study and then obtained their verbal consents to allow me to contact them. I then contacted the parents of the eligible children and arranged for a convenient time and day to come to the centre to conduct the experiment.

As for the children recruited through Twitter, I sent an email to the parent containing brief information about the study, some screening questions to ensure that the child met the inclusion criteria for the study and asked for supporting documents for some questions (for the questionnaire, see Appendix B.1). I then contacted the parents of the eligible children and arranged for a convenient time and day to come to one of the centres to conduct the experiment.

The study was conducted in a quiet room in which the normal background noise level was about 48 - 52dB. The room had plain white walls to eliminate any distractors for the children during the experiment and it contained only a table and four chairs. The child, I, a specialist in ADHD, and the child's parent were all present in the room. To start, I explained verbally to the child's parent the nature of the study in more details. I then showed the parent the Go/NoGo task on the computer along with a demonstration of the white noise, so that the parent could establish for themselves that the task would be appropriate for their child. Parents then had the chance to ask questions about the research and when they were completely comfortable with their child's participation in the study, they read the information sheet and completed the informed consent form (see Appendix B.2). After that, I asked the parent and the ADHD specialist if they would wait outside the room, to eliminate any distractions for the child during the study. If leaving the room was not acceptable for any reason, the parent was asked to sit on a chair behind the child and remain silent and not to talk or give instructions to the child during the study.

Prior to the study, I conducted some small talk with the children about their age, brothers and sisters they may have, and their favourite hobby, to help them feel comfortable with me. Then, I had a script about the study to introduce to the children, so that all the children would be given the same information. The script contained information about the purpose of the study, the children's role, what would happen to the collected data, the confidentiality agreement and that the child could withdraw from the study any time if they wish to. The children also got to ask any questions they might have, so they felt comfortable participating in the study.

Then when I had obtained the verbal consent of the child, I asked the child to sit in front of the computer screen in a way that allowed their dominant hand to be comfortably placed on the computer keyboard. The distance between the centre of the screen and the eyes of the child was approximately 120cm. After that, I explained to the child the Go/NoGo task and that they need to press a button as quickly and accurately as possible if they saw an aeroplane but not press the button if they saw a bomb. Then, I helped the child put on the headphones, to ensure they were correctly positioned. After that, the practice block of 20 stimuli was presented to the child to ensure that they fully understood the task and what they should do. If performance during the practice session was poorer than 60% correct trials, the same practice block was presented again until performance reached at least 60% correct trials. During the experiment, if a child seemed to be distressed, upset or annoyed, or explicitly asked to withdraw from the study, the study was stopped immediately.

After finishing the practice phase, the child undertook the four experimental blocks of 60 stimuli each. The child received alternate blocks with white noise and no noise. The order of the blocks was counterbalanced, with half the children starting with white noise and half without white noise. The aim was to balance for practice and fatigue effects. The child was given five-minute rests between blocks. During the pilot study, it was found that five minutes was enough for the child to have a rest and be ready to start the next block.

When the experimental session was completed, I asked the child a question about their experience. I also asked the parents a question about their opinion of the effect of white noise on their child (see section 4.2.4). Finally, I thanked the child and the parent for participating in the study and the child was given a gift of a toy such as LEGO or building blocks.

4.2.7 Data Analysis

To ensure reliable and valid estimates of the dependent variables, corrections to some trials were made. If a trial has a reaction time (RT) of less than 100ms, the time was not included in analyses. This is because the physical time to press a button, the non-decision portion of a simple RT is approximately 100ms (Epstein et al., 2011a). 4% of correct Go trials were removed in this way.

The following measures were calculated for each child for each block and for the white noise and no noise conditions:

- Number of OEs, this is the total number of misses of Go trials
- Number of CEs, this is the total number of times a child presses in NoGo trials.
- Reaction time (RT) measures were calculated in two ways (see Chapter 2, section 2.4.2.1):
    - The mean RT as calculated by the majority of previous studies such as the study by Baijot et al. (2016).
    - The median RT.
- Reaction time variability (RTV) for the correct Go trials was calculated in several ways in order to be able to compare with previous studies (for more details, see section 4.1):
    - The standard deviation of the reaction times (SD) as used by previous studies (Tamm et al., 2012)
    - The Coefficient of Covariance (CV) as used by previous studies (Tamm et al., 2012):

$$CV = SD(RTs) / mean(RTs)$$

    - The Median Absolute Deviation from the median of reaction times (MAD) (Howell, 2005):

$$MAD = median(|RT_i - \underline{median}(RTs)|)$$

Previous studies using different tasks, including the Go/NoGo task (Baijot et al., 2016, Durston et al., 2003, Epstein et al., 2002) appear to assume that their RT data meet the assumptions for parametric analysis, without reporting analyses of whether their data do meet the requirements for such analysis. However, RTs are typically non-normally distributed, with a positive skew and a tail of longer RTs (for more details, see Chapter 2, section 2.4.2.1).

The normality of the data in this study was evaluated by checking diagrams, including histograms and QQ plots, along with statistical tests including the Shapiro-Wilk and Kolmogorov–Smirnov tests. RT data in this study were non-normally distributed (see Appendix B.4) and thus, did not meet the requirements for parametric analysis. Also, the other measures calculated in this study, including mean RTs, median RTs, SDs, CVs, MADs, OEs and CEs are non-normally distributed in some or all blocks. Therefore, in addition to the parametric measures, which were calculated to allow comparison with previous studies, non-parametric measures of RTs (i.e., median RTs) and RT variability (i.e., MAD) were calculated.

To check for the effect of noise regardless of the blocks, two-sample related measures Wilcoxon signed-rank tests were conducted on all variables (OEs, CEs, mean RTs, median RTs, SDs, CVs, MADs). Then, the block effect was only checked for variables for which white noise had a significant effect. The block effect was checked using four-related samples Friedman tests. All tests were two-tailed with a significance level of 0.05.

The effect size ‘r’ for Wilcoxon signed-rank tests can be calculated as:

$$r = Z/\sqrt{N}$$

in which Z is the z-score and N is the total number of observations (Rosenthal, 1991, as cited in Field, 2017). The interpretation of the effect size was based on the widely used Cohen’s benchmark (Cohen, 1988, 1992, as cited in Field, 2017): a large effect ($r \geq 0.50$), a medium to large effect ($r \geq 0.30$) and a small to medium effect ($r \geq 0.10$). It is important to note that an effect size needs to be interpreted with respect to the context of the research domain (Cairns, 2019; Field, 2017). Cairns (2019) argued that small effects in some contexts such as in safety critical systems is very meaningful and of practical significance. Similarly, small effects in contexts in which finding effects are hard due to difficulties in precisely measuring them are meaningful (Cairns, 2019). Therefore, small improvements in attention can be useful for children with ADHD considering the diverse nature of children with ADHD, even those with the same form of ADHD and the very high variability in these children's data.

4.3 Results

Table 4.1 provides an overview of the results and whether the hypotheses outlined above were supported. The next sections provide details of the statistical analyses of each hypothesis.

Table 4.1 An overview of the results and whether the study hypotheses were supported

Hypothesis		**Results**
1a: The White Noise condition will reduce the number of OEs in comparison to the No Noise condition		Strong support
1b: The White Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition	Mean	No support
	Median	No support
1c: The White Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition	SD	Strong support
	CV	Strong support
	MAD	No support
2a: There will be no significant difference in the number of CEs between the two noise conditions		Strong support
3a: The number of OEs will not be significantly different in a sequence of blocks of the Go/NoGo task		Strong support
3b: RTs will not be significantly different in a sequence of blocks of the Go/NoGo task		N/A
3c: RTV will not be significantly different in a sequence of blocks of the Go/NoGo task		Strong support

Note: N/A = Not Applicable, Strong support = a significant p value, Weak support = a trend for a significant p value, no support = a non-significant p value.

4.3.1 Omission Errors (OEs)

The results of the mean and median numbers of OEs, standard deviations and semi-interquartile ranges during the White Noise and No Noise conditions are presented in Figure 4.5.

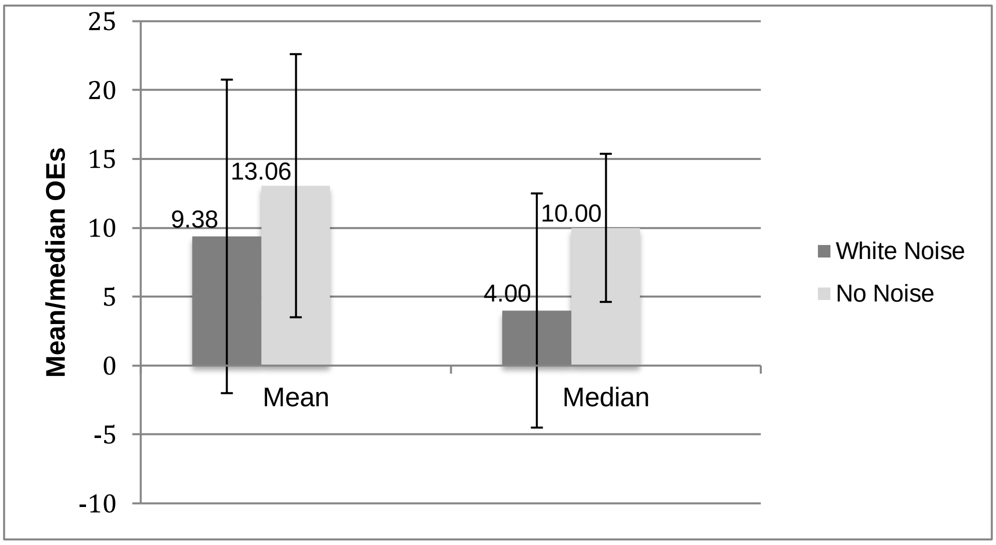


Figure 4.5 Mean, standard deviation, median and semi-interquartile range of omission errors (OEs) during White Noise and No Noise conditions

A Wilcoxon signed-rank test was conducted on the OEs and found a significant effect for noise condition, with a medium to large effect size, $Z = -2.27$, $p = .023$, $r = -0.40$. As can be seen in Figure 4.5, the number of OEs was significantly less in the White Noise condition (*Mdn* = 4.00, *SIQR* = 8.50) compared to the No Noise condition (*Mdn* = 10.75, *SIQR* = 5.38). So, the OEs rate, based on the median number of OEs, goes from 11.11% in the No Noise condition to 4.44% in the White Noise condition, a decrease of about 6.67%. On the other hand, the OEs rate, based on the mean number of OEs, goes from 14.51% in the No Noise condition to 10.42% in the White Noise condition, a decrease of about 4.00%.

To investigate the block effect, a four sample Friedman test was conducted on the OEs, and a trend for an effect for block was found, with a low to medium effect size, $Q = 6.94$, $p = .074$, $r = 0.15$. A follow up Wilcoxon signed-rank test OEs for the first and second blocks regardless of the noise condition was conducted, and found no significant effect, $Z = -0.65$, $p = .515$, $r = -0.15$.

Thus, the results support hypothesis (1a) (see section 4.1 for the study hypotheses) that the OEs in the White Noise condition are significantly fewer than in the No Noise condition and supports the idea that attention of children with ADHD is better in the White Noise condition. In addition, the results support hypothesis (3a) that the OEs are not significantly different in a sequence of blocks of the Go/NoGo task and thus, supports the idea that the ongoing experience with the Go/NoGo task has no effect on attention of children with ADHD.

4.3.2 Reaction Times (RTs)

The results of the means and medians, standard deviations and semi-interquartile ranges of the mean and median RTs for correct Go trials during the White Noise and No Noise conditions are presented in Table 4.2.

Table 4.2 Means, standard deviations, medians and semi-interquartile ranges for the mean and median RTs for correct Go trials

Measure	White Noise		No Noise	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
Mean RTs (ms)	538.46 (137.70)	486.63 (111.52)	559.02 (130.32)	522.30 (70.80)
Median RTs (ms)	496.93 (120.51)	455.50 (193.88)	503.53 (127.88)	464.00 (54.13)

The effect of white noise condition on RTs was investigated using two measurements of RTs, median RTs and mean RTs for correct Go trials, as was used by previous studies (see section 4.2.7 for more details).

A Wilcoxon signed-rank test was conducted on the median RTs for the correct Go trials. This found no effect for noise condition, $Z = -0.511$, $p = .609$, $r = -0.09$. This means that there was no significant difference between the mean RTs in the two conditions. Since there was no significant effect of noise condition on the median RTs, the block effect was not checked.

A Wilcoxon signed-rank test was conducted on the mean RTs for the correct Go trials. This found no significant effect for noise condition, $Z = -1.241$, $p = .215$, $r = -0.22$. This means that there was no significant difference between the mean RTs in the two conditions. Since there was no significant effect of noise condition on the mean RTs, the block effect was not checked.

Thus, the results on the median RTs and the mean RTs do not support hypothesis (1b) (see section 4.1 for the study hypotheses) that the mean and median RTs in the White Noise condition are significantly lower than the mean and median RTs in the no noise condition and do not support the hypothesis that attention of children with ADHD is different in the two conditions.

4.3.3 RT Variability (RTV)

The results of the means, medians and standard deviations and semi-interquartile ranges of the three measures of RTV (SD, CV and the MAD) during the White Noise and No Noise conditions are presented in Table 4.3.

Table 4.3 Means, standard deviations, medians and semi-interquartile ranges and for the SDs, CVs and MADs of RTs

Measure	White Noise		No Noise	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
SD	208.87 (102.56)	186.05 (93.62)	244.52 (100.51)	246.60 (72.60)
CV	0.37 (.10)	0.38 (.10)	0.43 (0.11)	0.46 (0.10)
MAD	122.69 (81.32)	84.75 (57.50)	134.69 (93.08)	107.50 (35.25)

The effect of noise condition on RTV was investigated using three measurements of RTV, which are SD, CV (that were used by previous studies) and MAD (for more details on how to calculate these measures, see section 4.2.7).

A Wilcoxon signed-rank test was conducted on SDs of RTs and found a significant effect for noise condition, with a medium to large effect size, $Z = -2.69$, $p = .007$, $r = -0.48$. As shown in Table 4.2, on this measure, RTV was significantly lower in the White Noise condition (*Mdn* = 186.05, *SD* = 93.62) compared to the No Noise condition (*Mdn* = 246.60, *SIQR* = 72.60), a decrease of 24.55% (14.58% using the mean).

To investigate the block effect, a four-sample Friedman test was conducted on the SDs, and a trend for an effect for block was found, with a low to medium effect size, $Q = 6.53$, $p = .089$, $r = 0.14$. A follow- up Wilcoxon signed-rank test on SDs for the first and second blocks regardless of the noise condition was conducted, and found no significant effect, $Z = -1.03$, $p = .301$, $r = -0.23$.

A Wilcoxon signed-rank test on CVs of RTs found that there is a significant effect for noise condition, with a large effect size, $Z = -3.15$, $p = .002$, $r = -0.56$. As can be seen in Table 4.2, on this measure, RTV was significantly lower in the White Noise condition (*Mdn* = .38, *SIQR* = .10) compared to the No Noise condition (*Mdn* = .46, *SIQR* = .110), a decrease of 17.39% (13.95% using the mean).

To investigate the block effect, a four-sample Friedman test was conducted on the CVs, but no effect for block was found, $Q = 4.13$, $p = .248$, $r = 0.09$.

Finally, a Wilcoxon signed-rank test on MADs of RTs found that there was no effect for noise condition, $Z = -1.14$, $p = .255$, $r = -0.20$. This means that RT variability, as measured by MAD was not affected by noise condition. Since there was no significant effect of noise condition on MAD, the block effect was not checked.

Thus, the results on MAD do not support hypothesis (1c) (see section 4.1 for the study hypotheses) that RTV in the White Noise condition is significantly lower than RTV in the No Noise condition. However, the results on SD and CV support the hypothesis that RTV in the White Noise condition is significantly lower than RTV in the No Noise condition and supports the hypotheses that attention of children with ADHD is different in the two conditions. In addition, the results support hypothesis (3c) that RTV is not significantly different in a sequence of blocks of the Go/NoGo task and thus, supports the idea that the ongoing experience with the Go/NoGo task has no effect on attention of children with ADHD.

4.3.2 Commission Errors (CEs)

The results of the mean and median number of CEs, standard deviations and semi-interquartile ranges during the White Noise and No Noise conditions are presented in Figure 4.6.

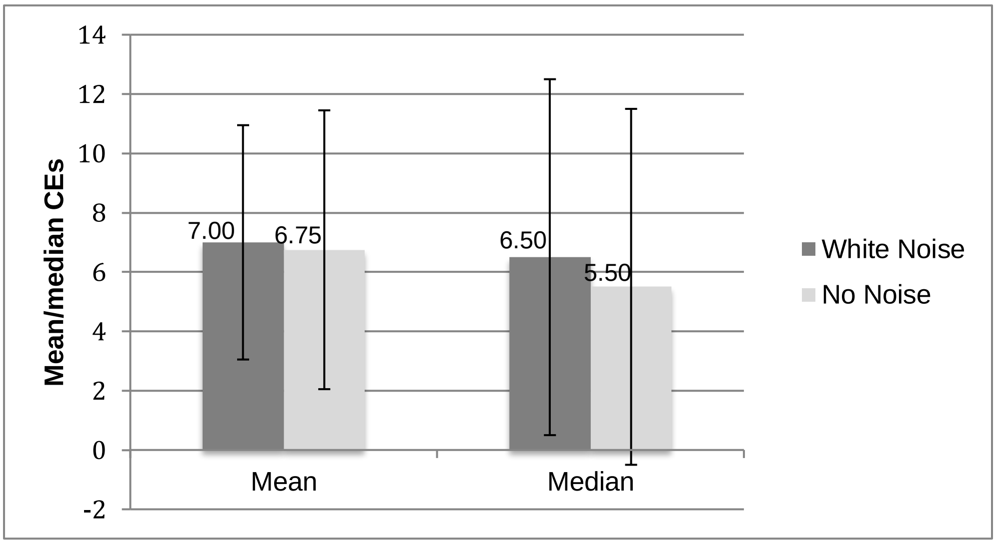


Figure 4.6 Mean, standard deviation, median and interquartile range of commission errors (CEs) during White Noise and No Noise conditions

A Wilcoxon signed-rank test was conducted on the CEs, but found no significant effect for noise condition, Z = -0.20, p = .841, r = 0.04. This means that White Noise condition did not affect CEs. Since there was not a significant effect of White Noise on CEs, the block effect was not checked.

Thus, the results on CEs support hypothesis (2a) (see section 4.1 for the study hypotheses) that White Noise condition will have no effect on CEs. This means that the impulsivity of children with ADHD did not improve during the White Noise condition.

4.3.5 Reactions of Parents and Children to Using White Noise

All parents were asked whether they would use white noise to help their children concentrate, especially in tasks requiring more attention. 15 (93%) parents stated that they would definitely use white noise as long as it helps to improve their children’s attention. The children were asked whether they believed white noise helped them concentrate more. 14 (87%) children reported that white noise improved their attention.

4.4 Discussion and Conclusions

This study investigated whether there is an effect of white noise on the attention and impulsivity of children with ADHD as measured by their performance on a visual Go/NoGo task.

The study collected objective measures of cognitive performance using a Go/NoGo task with 16 children with ADHD. Similar studies involving children with ADHD such as Baijot et al. (2016), Söderlund et al. (2007, 1016) and children with attention problems without a diagnosis of ADHD such as Helps et al. (2014) and Söderlund et al. (2010) have participants ranging from 13 to 20 children, somewhat small sample sizes due to the strict inclusion criteria and the fact that comorbidities are very common in children with ADHD (Gillberg et al., 2004). Thus, the number of children in this study is comparable to previous studies.

As discussed above (section 4.1), the design of this study was based on a number of previous studies, but with some key differences and this will be taken into consideration when comparing the results of this study with the previous studies. These include studies that used white noise and the Go/NoGo task to measure the performance of children with ADHD, such as Baijot et al. (2016) and studies of children with attention problems without a diagnosis of ADHD such as Helps et al. (2014) (for more details, see section 4.1).

The results of this study supported the first hypothesis, that white noise will improve attention in children with ADHD and showed that white noise (at 77 dB) improved the attention in children with ADHD as measured by OEs and RTV (as measured by SD and CV). A detailed discussion of the results of each sub hypotheses is provided below.

Hypothesis (1a) (see section 4.1) was supported, as there were significantly fewer OEs in the White Noise condition compared to the No Noise condition. The OEs rate goes from a median of 11.11% in the No Noise condition to a median of 4.44% in the White Noise condition, a decrease of about 6.67%. If one uses the less representative measure of mean rate, the decrease is only about 4.00%, from 14.51% in No Noise to 10.42% in White Noise. This result agrees with results from Helps et al. (2014) and Baijot et al. (2016). Helps et al. (2014) do not provide results on the magnitude of the decrease for children with ADHD, but the decrease was significant. In the Baijot et al. (2016) study, the decrease was not significant but from the graph (Figure 2), the decrease in mean OE rate appears to be approximately 5%, from 15% OEs for children with ADHD in the No Noise condition to 10% in the White Noise condition. This is similar in magnitude to the results of this study but not in the location on the scale perhaps due to differences in task parameters between this current study and the Baijot et al. (2017) study. However, it is interesting that when one calculates the decrease with non-parametric statistics compared to parametric statistics, it is larger and my result was a significant difference. Perhaps the results from Baijot et al. (2016) would have been significant if they had used non-parametric statistics. However, all three studies (mine; Baijot et al., 2016; Helps et al., 2014) do suggest that white noise makes a difference to the attention of children with ADHD as measured by OEs.

Hypothesis (1b) (see section 4.1) was not supported for the two measures of RTs, as there was no significant difference in mean and median RTs between the White Noise and the No Noise conditions. These results agree with results from Baijot et al. (2016) who also found no effect of white noise on mean RTs even when using a long event rate as compared to the short event rate used in this current study. It is important to note that failing to detect a significant effect for white noise on RTs may mean that white noise truly has no effect on attention in children with ADHD as indicated by RTs. But it may also mean that RTs are not an appropriate measure for attention in children with ADHD. This result might also be because of the small number of children and therefore, this should be examined further in future research with a larger number of children. Other possible reasons for not detecting an effect for white noise on RTs will be discussed later in this section.

Hypothesis (1c) (see section 4.1) was supported, on two of the three measures of RTV (SDs and CVs), with RT variability being significantly lower in the White Noise condition, a decrease of about 14%. This is a significant difference and is approximately twice the magnitude of the difference in the OEs, the other indicator of attention. On the third measure (MAD), the hypothesis was not supported, as using this measure of RTV was not significantly less in the White Noise condition compared to the No Noise condition. In contrast to the results found on SDs and CVs in this study, Baijot et al. (2016) did not find a significant difference between White Noise and No Noise on the two measures. This raises doubts about the validity of the measures (SDs and CVs) used to measure RTV in previous studies since these measures are typically used to summarize normally distributed data and RTs are very typically not normally distributed as discussed in section 4.2.7.

As discussed earlier, OEs, RTs and RTV all reflect inattention in children with ADHD. However, the positive effect of white noise in this study seems to be limited to attention as indicated by OEs, and RTV (as measured by SDs and CVs) but not by RTs or RTV (as measured by MAD). This could be due to a combination of different reasons considering that there are still no robust measures for RTs or RTV (for more details, see Chapter 2, section 2.4.2.1). First of all, the characteristics of the Go/NoGo task used in this study, particularly the fast event rate (ER), might have an effect on the results obtained. The fast ER in the Go/NoGo task is known to improve arousal and thus the performance in children with ADHD (Tamm et al., 2012). Weak arousal was suggested by Halperin and colleagues (2006, 2008) to be one reason for the RT variability in children with ADHD. Therefore, the fast ER might have resulted in improving the children's attention and thus lowering RTs and RTV to a point at which white noise was not sufficient enough to make further improvements to RTs and RTV. Another possible explanation for the effect of the fast ER on RTs and RTV is that fast ERs limit RTs and thus, minimises the differences between the two conditions, the white noise and no noise. However, after investigating the results further (see section 4.3.3, Table 4.1), RTs were not thought to be limited since SDs (SD for median RTs in White Noise = 120.51, (SIQR = 193.88); SD for median RTs in No Noise = 127.88, (SIQR = 54.13)) were high, so the limitation of RTs argument is not valid here. In addition, RTs and RTV may have a different neurological basis in comparison to OEs (Goetz et al., 2017; Perri et al., 2017). Therefore, white noise might not have a strong effect on the neurocognitive processes underlying RTs or RT variability.

In this context, it has been suggested that children with ADHD have impairments in balancing the speed-accuracy trade-off in decision making (Mulder et al., 2010). This suggestion was accurate and obvious in the No Noise condition in which children might have opted for making fast choices rather than making accurate choices especially with the fast event presentation rate used in this study. However, contrary to this suggestion, white noise in this study made children make both more accurate and faster choices.

The results also supported the second hypothesis, that white noise has no effect on impulsivity in children with ADHD. In particular, hypothesis (2a) (see section 4.1) was supported, with no significant difference in CEs between the White Noise and the No Noise conditions. This result supports that of Baijot et al. (2016) who also found no significant difference between the CEs in the White Noise and No Noise conditions. It is important to note that one needs to treat failure to reject the null hypothesis (i.e., failing to detect an effect of white noise on CEs) with caution. First, it is possible that the white noise does not affect impulsivity in children with ADHD, so a finding of no difference in CEs between the two conditions is appropriate. However, there are many other reasons for retaining the null hypothesis. It may be that CEs are not a good measure of impulsivity in children with ADHD in spite of the findings from previous research about the established relation between CEs and impulsivity (for more details, see Chapter2, section 2.4.2.1). It may also be that the Go/NoGo task does not tap into impulsivity sufficiently or that the magnitude of the difference in impulsivity in the white noise/no noise comparison is not large enough to show a significant effect. This is the problem of the "fallacy of the null hypothesis" (Harris 2008; Rozeboom, 1960).

In addition, the results supported the third hypothesis that the ongoing experience with the Go/NoGo task has no effect on the attention of children with ADHD. In particular, hypothesises (3a and 3c) (see section 4.1) were supported, with no significant difference in OEs and RTV in a sequence of blocks of the Go/NoGo task. This is in line with the results from Baijot et al. (2017) who found no block effect on the performance of children with ADHD.

The white noise benefit on attention found in this study and the previous studies is in accordance with current theories of the underlying aetiology of ADHD, namely the moderate brain arousal model, the optimal stimulation theory (Zentall & Zentall, 1983), and the state regulation deficit model of ADHD (Sonuga-Barke et al., 2010) derived from the cognitive energetic theory (Sergeant, 2005). The theories suggest that adding extra-task stimulation, i.e., white noise in this study, improves arousal and thus attention in children with ADHD (for more details, see section 2.8.1).

Finally, the majority of parents of children with ADHD in this study were happy to use white noise with their children and the majority of children also believed that white noise helped improve their attention. These results are encouraging and show that the use of white noise is accepted by both parents and children with ADHD.

In conclusion, the results of this study help to show the effect of white noise (at 77dB) on the attention of children with ADHD as measured by the Go/NoGo task, which confirms findings from previous research by Baijot et al., (2016) which also used the Go/NoGo task. While these results are useful, it is important to note that this study only used one level of white noise and one set of parameters for the Go/NoGo task to investigate the effect of white noise on children with ADHD. A more thorough investigation would investigate different levels of white noise, different kinds of noise, different parameters of the Go/NoGo task, which may affect the results of the study as well as other tasks that help measure attention. Therefore, I decided to run the next study, which is Study 3 of this programme of research (see Chapter 5) but this time with different parameters of the Go/NoGo task, to further confirm the positive effects of white noise found in this study and to investigate the effect of pink noise on the attention of children with ADHD.

Chapter 5 - Study 3: The Effect of White and Pink Noise on Attention of Children with ADHD Using a Go/NoGo Task

5.1 Introduction

As discussed in Chapter 2 (section 2.8.1), white noise has been shown to have a positive effect on the performance children and adults with ADHD using a number of cognitive tasks.

Study 2 (see Chapter 4) in this programme of research was aiming to investigate the robustness of the effect of white noise found in the previous studies on attention of children with ADHD using a Go/NoGo task. The results showed a significant positive effect of white noise on attention but not on impulsivity of children with ADHD. However, the positive effect of white noise on attention was only limited to some measures of attention, including omission errors (OEs) and reaction time variability (RTV) (as measured by SD and CV) but not to reactions times (RTs) or RTV (as measured by MAD) (for more details, see Chapter 4, section 4.4).

Since Study 2 (see Chapter 4) used one level of white noise and one set of parameters for the Go/NoGo task to investigate the effect of white noise on children with ADHD, a more thorough investigation is important. This include investigating the effect of different levels of white noise, different kinds of noise using different parameters of the Go/NoGo task and other tasks that help measure attention. Therefore, it was decided to conduct another study, Study 3 of this programme of research, in which the effect of white noise as well as pink noise was investigated using different parameters of the Go/NoGo task.

Pink noise was chosen because it is similar to white noise but has a lower intensity in the higher frequencies making it smoother and deeper compared to white noise (see Chapter 2 Section 2.8.1). This means that some children may find it more pleasant as background noise. Also, if pink noise was beneficial to the attention of children with ADHD, this gives the children the option to choose another noise to help them concentrate when doing tasks requiring high attention. In addition, the effect of pink noise on attention and impulsivity of children with ADHD has not been investigated extensively in previous research. In fact, only one study by Metin et al. (2016) was found that investigated the effect of pink noise on the impulsive choices of children with ADHD to two kinds of rewards, which is not the impulsivity measured in this thesis, and found no effect for pink noise (for more details, see Chapter 2, section 2.8.1). That study did not investigate the effect of pink noise on attention of children with ADHD which is the focus here.

As discussed earlier, previous studies as well as Study 2 in this programme of research found an effect of white noise on attention and no effect on impulsivity. Therefore, since pink noise is similar to white noise, one would expect a positive effect of pink noise on attention but no effect on impulsivity of children with ADHD.

This study used a visual Go/NoGo task which produces a number of objective measures of attention and impulsivity. The Go/NoGo task used in this study is similar to the task used in Study 2 but with some variations in the parameters (for more details, see section 5.2.3). The main variation is that the event rate (ER) used in the task in this study is longer than the ER used in Study 2.

A typical Go/NoGo task results in four operational variables that measure inattention and impulsivity. These are omission errors (OEs), commission errors (CEs), mean/median reaction times for correct Go trials (RTs), and reaction time variability (RTV).

As discussed in Chapter 4 (section 4.1), previous research showed that children with ADHD make more OEs and CEs than typically developing children. Higher OEs represent greater inattention in children with ADHD while higher CEs represent greater impulsivity in children with ADHD. Study 2 in this programme of research and the study by Baijot et al. (2016) found that white noise lowered OEs and thus, improved attention in children with ADHD. Also, a study by Helps et al. (2014) found that white noise lowered OEs and thus improved attention in children with attention problems but without a diagnosis of ADHD. However, both Study 2 and the Baijot et al. (2016) study found that white noise has no effect on CEs and thus impulsivity in children with ADHD. Therefore, in this study, it was predicted that a White Noise condition will result in fewer OEs for children with ADHD compared to a No Noise condition whereas there will be no difference in CEs between these conditions.

As for pink noise, no study was found that investigated the effect of pink noise on attention and impulsivity in children with ADHD using a Go/NoGo task. Therefore, there is no study on which to directly base a hypothesis about the effect of pink noise on OEs and CEs in children with ADHD in this situation. However, since pink noise is similar to white noise with some variations, I predicted that in this study a Pink Noise condition will result in fewer OEs for children with ADHD compared to a No Noise condition whereas there will be no difference in CEs between these conditions. Similarly, as there is no previous research on the effect of pink noise on attention, and it is similar to white noise, therefore, I predicted that both White Noise and Pink Noise conditions will have a comparable effect on OEs.

As discussed in Chapter 4 (section 4.1), previous research has shown mixed results about whether children with ADHD are faster, slower or similar in RTs to typically developing children. In addition, some researchers have linked higher RTs to inattention while others have linked lower RTs to hyperactivity. Furthermore, the ER at which tasks are presented affects RTs in different ways. For instance, faster ERs result in faster RTs while slower ERs result in slower RTs in children with ADHD. However, only one study by Baijot et al. (2016), which investigated the effect of white noise on RTs, found no effect for white noise on RTs in children with ADHD.

As in Study 2 (see Chapter 4, section 4.1), in this current study I chose to tentatively link RTs to inattention in children with ADHD. In addition, this present study used a slow ER similar to the ER used in Baijot et al. (2016). However, Baijot et al. (2016) used a visual cued Go/NoGo task whereas this present study used a visual Go/NoGo task without a cue (for explanation, see Chapter 2, section 2.4.2.2), so there is no study on which to directly base a hypothesis about the effect of white noise on RTs in children with ADHD in this situation. Therefore, since RTs may reflect inattention in the same way that OEs do, I predicted that in this study a White Noise condition will reduce RTs for children with ADHD compared to a No Noise condition.

As for pink noise, again, no study was found that investigated the effect of pink noise on attention and impulsivity in children with ADHD using a Go/NoGo task, so there is no study on which to directly base a hypothesis about the effect of pink noise on RTs in children with ADHD on this task. Since pink noise is similar to white noise, I predicted that in this study a Pink Noise condition will reduce RTs for children with ADHD compared to a No Noise condition. Similarly, as there is no previous research on the effect of pink noise on attention, and it is similar to white noise, therefore, I predicted that both White Noise and Pink Noise conditions will have a comparable effect on RTs.

As for RTV and as discussed in Chapter 4 (section 4.1), there has been a controversy about the most suitable method for measuring RTV. Previous research showed that RTV is higher in children with ADHD compared to typically developing children and that higher RTV represents greater inattention in children with ADHD. Similar to the effect of ERs on RTs, fast ERs are known to improve attention in children with ADHD and thus decrease RTV and long ERs have been shown to result in inattention in children with ADHD and thus increase RTV. However, only one study by Baijot et al. (2016), which investigated the effect of white noise on RTV, found no effect for white noise on RTV in children with ADHD.

As discussed earlier, the present study used a slower ER similar to the ER used in the study by Baijot et al. (2016). However, Baijot et al. (2016) used a visual cued Go/NoGo task whereas this present study used a visual Go/NoGo task but without a cue (for explanation, see Chapter 2, section 2.4.2.2), so there is no study on which to directly base a hypothesis about the effect of white noise on RTV in children with ADHD on this task. However, since RTV reflects inattention in the same way that OEs do, I predicted that in this study a White Noise condition will reduce RTV for children with ADHD compared to a No Noise condition.

As for pink noise, no study was found that investigated the effect of pink on attention in children with ADHD using a Go/NoGo task, so there is no study on which to directly base a hypothesis about the effect of pink noise on RTV in children with ADHD in this situation. Since pink noise is similar to white noise with some variations, I predicted that in this study a Pink Noise condition will reduce RTV for children with ADHD compared to a No Noise condition. Similarly, as there is no previous research on the effect of pink noise on attention, and it is similar to white noise, therefore, I predicted that both White Noise and Pink Noise conditions will have a comparable effect on RTV.

As discussed above, the design of this study was based on a number of previous studies, but with some key differences (for more details about the differences see, Chapter 4, section 4.1). The previous studies include ones that used white noise and the Go/NoGo task to measure the performance of children with ADHD, such as Baijot et al. (2016) and studies of children with attention problems without a diagnosis of ADHD such as Helps et al. (2014) (for more details about the studies, see Chapter 2, section 2.8.1).

The present study aimed to investigate the effect of white noise and pink noise on the attention and impulsivity in children with ADHD. It also investigated whether one of these noise types has a better effect than the other on the attention of such children and whether children performed better in their preferred noise condition compared to their not preferred noise. The study used a within-participants design, having children with ADHD undertake a visual Go/NoGo task with white noise, with pink noise and without the presence of noise.

The hypotheses tested in the study are as follows:

1. Both white and pink noise will improve attention in children with ADHD. This leads to six more specific hypotheses:

> 1a: The White Noise condition will reduce the number of OEs in comparison to the No Noise condition
>
> 1b: The White Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition
>
> 1c: The White Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition.
>
> 1d: The Pink Noise condition will reduce the number of OEs in comparison to the No Noise condition
>
> 1e: The Pink Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition
>
> 1f: The Pink Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition

2. There will be no difference between the effectiveness of white and pink noise in improving the attention of children with ADHD. This leads to three more specific hypotheses:

> 2a: There will be no significant difference in the number of OEs between the White Noise and Pink Noise conditions
>
> 2b: There will be no significant difference in RTs (as measured by mean and median) between the White Noise and Pink Noise conditions
>
> 2c: There will be no significant difference in the RTV (as measured by SD, CV and MAD) between the White Noise and Pink Noise conditions

3. White and pink noise will not affect impulsivity in children with ADHD. This leads to two more specific hypotheses:

> 3a: There will be no significant difference in the number of CEs between the White Noise and the No Noise conditions
>
> 3b: There will be no significant difference in the number of CEs between the Pink Noise and the No Noise conditions

As it was predicted in this study that white noise and pink noise will not have an effect on impulsivity, a hypothesis about the difference in CEs between the White Noise and Pink Noise conditions was not included.

4. The preferred noise, whether white or pink noise, will improve the attention more than the not preferred noise in children with ADHD. This leads to three more specific hypotheses:

> 4a: The preferred noise condition will reduce the number of OEs in comparison to the not preferred noise condition
>
> 4b: The preferred noise condition will reduce RTs (as measured by mean and median) in comparison to the not preferred noise condition
>
> 4c: The preferred noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the not preferred noise condition

5.2 Method

5.2.1 Participants

The children with ADHD who participated in the study were recruited in the same ways and using the same inclusion criteria as in Study 2 (see Chapter 4, section 4.2.1)

A pool of 42 children with ADHD was available through both the AlTamayouz Centre and KAHC, but many of these children failed to meet all the inclusion criteria (e.g., they had comorbidities). In addition, one child started the study, but became bored and requested to withdraw before the end of the study.

Therefore, 15 children with ADHD participated in the whole study and their data were included in the analysis. This included 10 girls, aged 8 to 12 years, (mean age = 8.5 years, SD = 1.23) and 5 boys, aged 8 to 12 years (mean age = 9.2 years, SD = 1.02). 9 children were diagnosed with ADHD-C type and 6 children were diagnosed with ADHD-I type. 6 children were diagnosed with ADHD prior to the age of 4 years while 9 children were diagnosed with ADHD between the age of 5 and 7 years (for full information for all the participants, see Appendix C.2). None of the participants who were part of Study 2 participated in this study.

5.2.2 Design

A within-participants study design was used. The children performed a visual Go/NoGo task, in which children had to press a button as fast and as accurate as possible if they saw an aeroplane (i.e., the Go stimuli) on a computer screen, but not press the button if they saw a bomb (i.e., the NoGo stimuli) as in Study 2 (see Chapter 4, section 4.2.2). The stimulus duration was 150ms while the inter-stimulus interval (ISI) was 2500ms, thus the event rate (ER) was 2650ms, which is a slower ER compared to that used in Study 2 (for more details, see Chapter 4, section 4.2.3). The stimulus duration and the ISI were fixed for all Go and No/Go stimuli regardless of whether the child had made a correct response or not. The study involved one block of 20 stimuli for practice, while the main part of the study consisted of three blocks of 70 stimuli each. All blocks contained 35 Go stimuli (50%) and 35 NoGo stimuli (50%).

It is important to note that this study used the same stimulus duration, ISI, number of stimuli and ratio as in the study by Baijot et al. (2016) that investigated the effect of white noise on children with ADHD using a Go/NoGo task and inspired this study and Study 2 (for more details, see Chapter 4, section 4.2.3). This was because Study 2 used a different ratio and number of stimuli and most importantly a shorter event rate compared to the study by Baijot et al. (2016) but found significant positive effect on the attention of children with ADHD as opposed to the non-significant effect of white noise on the attention of such children found by Baijot et al. (2016) (for more details, see Chapter 2, section 2.8.2). Therefore, it was sensible to replicate the task used in Baijot et al. (2016) except for not using the cue since I am not aiming to measure the physiological activity of the brain while performing the task (for more details about the cued Go/NoGo task, see Chapter 2, section 2.4.2.2).

This study involved one independent variable with three conditions: Pink Noise, White Noise, and No Noise. The study also involved the same dependent variables as used in Study 2 (see Chapter 4, section 4.2.2), namely omission errors (OEs), commission errors (CEs), reaction times for correct Go trials (RTs), reaction time variability (RTV).

As discussed earlier in Study 2, the aim of this study was to investigate if white and pink noise has a real effect on the attention and impulsivity of children with ADHD and not that white or pink noise is just blocking auditory distractors. Therefore, to obtain meaningful results, the influence of external factors was minimised such that the experiment was conducted in a quiet room with white walls that was also free of visual distractors.

In addition, as there was no practice/fatigue effect (i.e., no block effect) in Study 2 (see Chapter 4, section 5.3), I did not investigate that in this Study. In addition, in this study, no rewards or incentives were given during the task, as these improve arousal and performance in children with ADHD and rewards are not available all the time in real life (Adamo et al., 2019; Epstein et al., 2011a; Kofler et al., 2013).

Lastly, as in Study 2 (see Chapter 4, section 4.2.2), the most recent and relevant guidelines on how to conduct usability evaluations with children proposed by Sim et al. (2016) have been used when conducting this study.

5.2.3 Experimental Task

The study used a visual Go/NoGo task similar to the task used in Study 2 with some variations (for more details about this task, see Chapter 4, section 4.2.3). The difference between the task used in Study 2 and this task is in the ratio of the Go to NoGo stimuli, stimulus duration and ISI, and thus the ER. This study is also different from Study 2 in the ratio of Go to NoGo stimuli.

The stimulus is shown on the screen for 150ms (stimulus duration). After that, a black screen is shown for 2500ms (ISI) as in Baijot et al. (2016). Thus, the time that is allowed for the child to respond to the presented stimulus and after which the next stimulus is presented is 2650ms (see Figure 5.1). This means that in the task for this study, a slower ER was used compared to the ER used in study 2. The stimulus duration and the ISI are fixed for all Go and No/Go stimuli regardless of making a correct response or not. This means that if a child successfully responded to a Go stimulus within the 2650ms, the next stimulus will not appear until the 2650ms interval finishes. Similarly, if a child mistakenly responded to a NoGo stimulus within the 2650ms, the next stimulus will not appear until the 2650ms interval finishes.

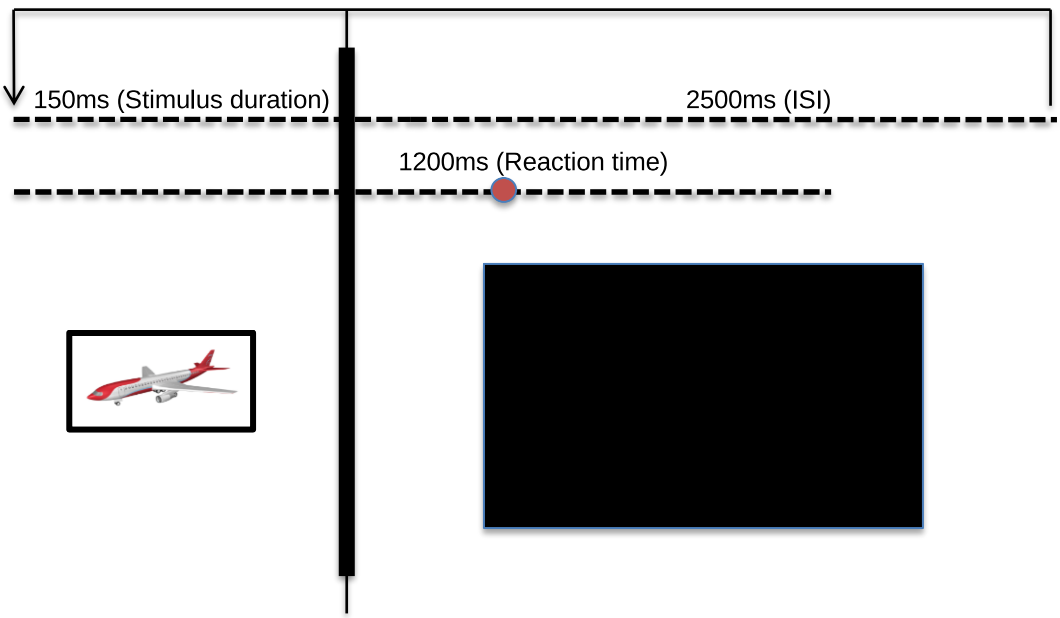


Figure 5.1 Example of one Go/NoGo trial, showing a Go stimulus, stimuli duration, ISI and reaction time

As explained in Chapter 2 (section 2.4.2.1), fast ERs are known to improve arousal and attention in children with ADHD and thus decrease RTs and RTV. On the other hand, slow ERs may result in under-arousal and inattention and thus increase RTs and RTV. Therefore, a slow ER of 2650ms was used in this study as compared to the faster ER of 1600ms used in Study 2 to investigate whether the benefits of white noise on children with ADHD observed in Study 2 still hold with a slower ER. Also, since the ER used in this study much closer to the ER of used in Baijot et al. (2016) than the ER used in Study 2, this allows for a better comparison with the results from Baijot et al. (2016).

The study involved one block of 20 stimuli for practice, this was not analysed. The main part of the study consisted of 3 blocks of 70 stimuli each. All blocks contained 35 Go stimuli (50%) and 35 NoGo stimuli (50%). The percentage of 50% Go stimuli was chosen because it was used in Baijot et al. (2016) and other previous studies (see Chapter 2, section 2.4.2.2).

5.2.4 Equipment and Materials

A MacBook Pro running IOS Sierra with a 15-inch screen was used for the experiment. Pink and white noise were delivered at 77dB, as in Study 2, using Buddy Headphones play model no. 72692BP-PLAY-GLACIER and an iPhone X. Both the headphones and the iPhone were used in the testing procedure.

To ensure that the headphones delivered the chosen dB accurately, I used the same testing procedure as explained in Study 2 (see Chapter 4, section 4.3.4).

Prior to the experiment, the same questionnaire (for the full questionnaire, see Appendix B.1) with screening questions used in Study 2 was given to parents of children with ADHD to ensure that their child met the inclusion criteria.

Two questions were asked to the parents and children at the end of the experiment:

- For parents: Would you use white noise or pink noise to help improve your child's attention when performing a task requiring high attention?
- For children:
    - Do you believe white noise and pink noise helped you concentrate more?
    - Do you prefer white noise or pink noise?

5.2.5 Pilot Study

A pilot study was conducted to check for any problems with the experimental set-up to be used in this study. It was conducted with two children with ADHD, recruited through the AlTamayouz Centre for Intellectual and Learning Disabilities in Riyadh, Saudi Arabia. No issues were found. The two children who participated in the pilot study were not included in the main study.

5.2.6 Procedure

As in Study 2 (Chapter 4), I followed the guidelines for conducting evaluations with children proposed by Sim et al. (2016). These involve guidelines for the planning of the evaluation, the introduction of the evaluation session, during the evaluation session, and finishing up.

The sessions were conducted in either of the two centres specified in Chapter 4 (section 4.2.1) depending on which was preferred and closest in location to the parents. Prior to the sessions, I met with the ADHD specialists at the centres and explained the nature of the study and the inclusion criteria for children to participate. The same rooms used for the evaluation of children in Study 2 were also used in this study. The same procedure for recruiting children and contacting their parents that was used in Study 2 (Chapter 4, section 4.2.6) was used in this study as well.

As in Study 2 (see Chapter 4, section 4.2.6), the child, I, a specialist in ADHD, and the child's parent all met in the test room. To start, I explained verbally to the child's parent the nature of the study in more detail. Then, I showed the parent the Go/NoGo task on the computer along with a demonstration of the white and pink noise, so that the parent could establish for themselves that the task would be appropriate for their child. Parents then had the chance to ask questions about the research and when they were completely comfortable with their child's participation in the study, they completed the informed consent form (see Appendix C.1). After that, I asked the parent and the ADHD specialist if they would wait outside the room, to eliminate any distractions they might create for the child during the study. If leaving the room was not acceptable for any reason, the parent was asked to set on a chair behind the child and remain silent and not to talk or give instructions to the child during the study.

Prior to the study, I followed the same procedure of introducing myself and the study nature and content to the children using the script as in Study 2. The children were encouraged to ask any questions they may have had, so they felt comfortable participating in the study.

As in Study 2, I asked the child to sit in front of the computer screen, explained to them the Go/NoGo task, helped them put the headphones and presented the practice block to them (for more details, see chapter 4, section 4.2.6).

After finishing the practice phase, the child undertook the three experimental blocks of 70 stimuli each. The three blocks were performed under three conditions, with Pink Noise, with White Noise, and with No Noise. The order of the blocks was counterbalanced in a circular manner as shown in Table. 5.1. The aim was to balance for practice and fatigue effects (Baijot et al., 2016) although no such effects were found in Study 2. The child was given five-minute rests between blocks.

Table 5.1 Counterbalancing the order of the conditions for Study 3

Child	Order
C1	1: pink noise, 2: white noise, 3: no noise
C2	2: white noise, 3: no noise, 1: pink noise
C3	3: no noise, 2: pink noise, 1: white noise
C4	1: pink noise, 2: white noise, 3: no noise

When the experimental phase was completed, I asked the child about their experience. I also asked the parent about their opinion of white and pink noise on their child (see section 5.2.4). Finally, I thanked the child and the parent for participating in the study and the child was given a gift of a toy such as LEGO or building blocks.

5.2.7 Data Analysis

As in Study 2 (see Chapter 4, section 4.2.7), to ensure reliable and valid estimates of the dependent variables, corrections to some trials were made. 0.07% of correct Go trials were removed in this way.

The number of OEs and CEs, RTs and RTV were calculated for every child for each block separately as in Study 2 (for how these measures were calculated, see Chapter 4, section 4.2.7).

The normality of the data in this study was evaluated as in Study 2. RT data in this study were non-normally distributed and thus, do not meet the requirements for parametric analysis. Also, the other measures calculated in this study, including mean RTs, median RTs, SDs, CVs, MADs, OEs and CEs were non-normally distributed in some or all blocks.

To compare all three noise conditions (White Noise, Pink Noise and No Noise), a series of three-group related samples Friedman tests were conducted on the dependent variables (OEs, CEs, mean RTs, median RTs, SDs, CVs, MADs). All tests were two-tailed with a significance level of 0.05.

In addition, to test the specific hypotheses set out in section 5.1, Wilcoxon signed-rank tests were conducted on the different combinations of conditions on all dependent variables. It could be argued that Bonferroni adjustment on the probability level to be used in interpreting the Wilcoxon tests. This is because when making multiple comparisons, it is more likely that a result would be found to be significant when it is actually not significant (a Type I error) (Cairns, 2019). The adjusted significance level after the Bonferroni adjustment is 0.017 (.05/3). However, as I was making planned comparisons, it can also be argued that the standard p value of 0.05 is still valid (Cairns, 2019). Both probability levels were considered. All tests were two-tailed.

Finally, to check whether the performance of children was better in their preferred noise condition, children were divided into two groups, those who preferred white noise and those who preferred pink noise. Then, Wilcoxon signed-rank tests were conducted on all dependent variables for the two noise conditions, the preferred noise and not preferred noise conditions, for the two groups.

The effect size 'r' was calculated for Wilcoxon signed-rank tests using the same formula as in Study 2 (see Chapter 4, section 4.2.7). The effect size 'W' for the Friedman test was calculated as the Kendall's Coefficient of Concordance as suggested by Tomczak & Tomczak (2014). The interpretation of the effect size 'r' and 'W' was based on the same Cohen's benchmark used in Study 2 (see Chapter 4, section 4.2.7).

5.3 Results

Table 5.2 provides an overview of the results and whether the hypotheses outlined above were supported. The next sections provide details of the statistical analyses of each hypothesis.

Table 5.2 An overview of the results and whether the study hypotheses were supported

Conditions	Hypothesis		Result
White Noise vs No Noise	1a: The White Noise condition will reduce the number of OEs in comparison to the No Noise condition		Strong support
	1b: The White Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition	Mean	Strong support
		Median	Strong support
	1c: The White Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition	SD	Strong support
		CV	Weak support
		MAD	Strong support
	3a: There will be no significant difference in the number of CEs between the White Noise and the No Noise conditions		Strong support
Pink Noise vs No Noise	1d: The Pink Noise condition will reduce the number of OEs in comparison to the No Noise condition		Strong support
	1e: The Pink Noise condition will reduce RTs (as measured by mean and median) in comparison to the No Noise condition	Mean	Weak support
		Median	Weak support
	1f: The Pink Noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the No Noise condition	SD	No support
		CV	No support
		MAD	No support
	3b: There will be no significant difference in the number of CEs between the Pink Noise and the No Noise conditions		Strong support
White Noise vs Pink Noise	2a: There will be no significant difference in the number of OEs between the White Noise and Pink Noise conditions		Strong support
	2b: There will be no significant difference in RTs (as measured by mean and median) between the White Noise and Pink Noise conditions	Mean	Strong support
		Median	Strong support
	2c: There will be no significant difference in the RTV (as measured by SD, CV and MAD) between the White Noise and Pink Noise conditions	SD	Strong support
		CV	Strong support
		MAD	Strong support
Preferred noise vs not preferred noise	4a: The preferred noise condition will reduce the number of OEs in comparison to the not preferred noise condition		Weak support
	4b: The preferred noise condition will reduce RTs (as measured by mean and median) in comparison to the not preferred noise condition	Mean	Weak support
		Median	No support
	4c: The preferred noise condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the not preferred noise condition	SD	No support
		CV	No support
		MAD	No support

Note: Strong support = a significant p value, Weak support = a trend for a significant p value, no support = a non-significant p value.

5.3.1 Omission Errors (OEs)

The results of the mean and median numbers of OEs, and standard deviations/interquartile ranges, during the White Noise, Pink Noise and No Noise conditions are presented in Figure 5.2. In addition, a summary of the statistical tests comparing the OEs in the different noise conditions is presented in Table 5.3.

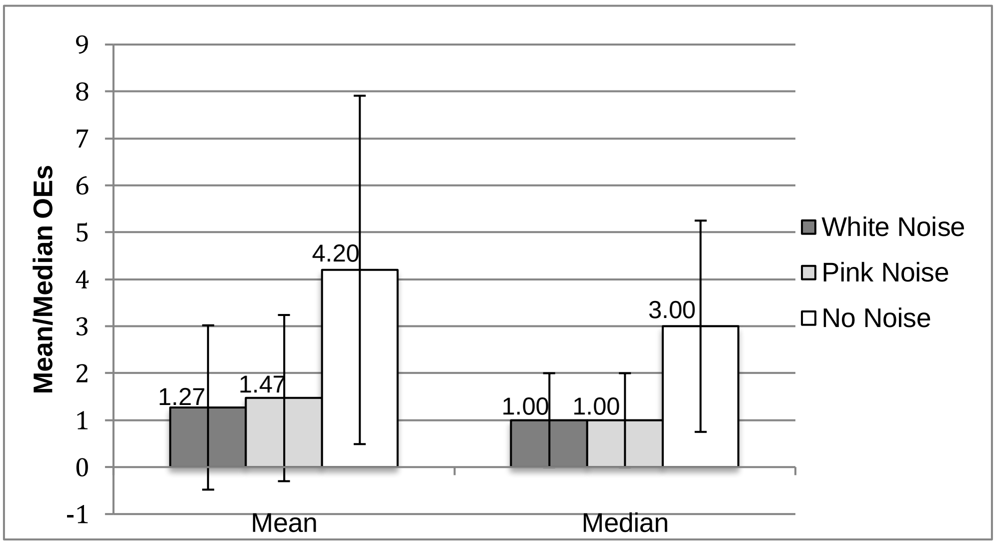


Figure 5.2 Mean, standard deviation, median and semi-interquartile range of omission errors (OEs) during White Noise, Pink Noise and No Noise conditions

Table 5.3 Tests of OEs between noise conditions

Comparison	Test	Observed value	p value	Effect size
White vs Pink vs No Noise	Friedman	Q = 9.64	0.008 (++)	W = 0.32
White vs No Noise	Wilcoxon	Z = -2.67	0.008 (++)	r = -0.49
Pink vs No Noise	Wilcoxon	Z = -2.95	0.003 (++)	r = -0.54
Pink vs White Noise	Wilcoxon	Z = -0.41	0.68	r = -0.08

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

White Noise vs Pink Noise vs No Noise

A repeated measures Friedman test showed a significant difference between the three conditions, with a medium to large effect size.

White Noise vs No Noise

A follow-up Wilcoxon test showed a significant difference in OEs between White Noise and No Noise, with a medium to large effect size. As can be seen in Figure 5.2, the number of OEs was less in the White Noise condition (*Mdn* = 1.00, *SIQR* = 1.00) compared to the No Noise condition (*Mdn* = 3.00, *SIQR* = 2.25). Using the means, the OE rate goes from 12.00% in the No Noise condition to 3.63% in the White Noise condition, a decrease of about 8.00%. Using the medians, the rate goes from a median of 8.57% in the No Noise condition to a median of 2.85% in the White Noise condition, a decrease of approximately 6.00%.

This supports hypothesis (1a) (for the study hypotheses, see section 5.1) that the OEs in the White Noise condition are significantly fewer than in the No Noise condition and supports the hypothesis that attention of children with ADHD is better in the White Noise condition.

Pink Noise vs No Noise

A Wilcoxon test showed a significant difference in OEs between Pink Noise and No Noise, with a large effect size. As can be seen in Figure 5.2, the number of OEs was less in the White Noise condition (*Mdn* = 1.00, *SIQR* = 1.00) compared to the No Noise condition (*Mdn* = 3.00, *SIQR* = 2.25). Using the means, the OE rate goes from 12.00% in the No Noise condition to 4.20% in the Pink Noise condition, a decrease of approximately 8.00%. Using the medians, the OE rate goes from 8.57% in the No Noise condition to 2.86% in the Pink Noise condition, a decrease of approximately 6.00%.

This supports hypothesis (1d) that the OEs in the Pink Noise condition are significantly fewer than in the No Noise condition and supports the hypothesis that attention of children with ADHD is better in the Pink Noise condition.

Pink Noise vs White Noise

The two Wilcoxon tests showed that there is no significant difference in OEs between White Noise and Pink Noise. This supports hypothesis (2a) that the OEs in the White Noise condition are not different from the Pink Noise condition and supports the hypothesis that the attention of children with ADHD are not different in the two noise conditions.

5.3.2 Reaction Times (RTs)

The results of the means and medians, standard deviations and semi-interquartile ranges of Mean and Median RTs for correct Go trials during the White Noise, Pink Noise and No Noise conditions are presented in Table 5.4. In addition, a summary of the statistical tests comparing the mean/median RTs in the different noise conditions is presented in Table 5.5.

Table 5.4 Means, standard deviations, medians and semi-interquartile ranges for the mean and median RTs for correct Go trials

Measure	White Noise		Pink Noise		No Noise	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
Mean RTs (ms)	565.92 (118.35)	528.11 (90.52)	577.89 (141.67)	546.29 (84.52)	654.04 (197.89)	655.89 (121.47)
Median RTs (ms)	535.70 (120.36)	514.00 (99.50)	531.60 (114.62)	515.00 (72.50)	599.87 (193.21)	574.50 (78.00)

Note: N/A = Not Applicable.

Table 5.5 Tests of mean/Median RTs between noise conditions

Measure	Comparison	Test	Observed value	p value	Effect size
Median RTs	White vs Pink vs No Noise	Friedman	Q = 3.73	0.16	W = 0.12
	White vs No Noise	Wilcoxon	Z = -.2.22	0.027 (+)	r = -0.41
	Pink vs No Noise	Wilcoxon	Z = -1.76	0.078	r = -0.32
	Pink vs White Noise	Wilcoxon	Z = 0.00	1.000	r = 0.00
Mean RTs	White vs Pink vs No Noise	Friedman	Q = 4.80	0.091	W = 0.16
	White vs No Noise	Wilcoxon	Z = -2.50	0.012 (++)	r = -0.46
	Pink vs No Noise	Wilcoxon	Z = -1.76	0.078	r = -0.32
	Pink vs White Noise	Wilcoxon	Z = -0.23	0.820	r = -0.04

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

White Noise vs Pink Noise vs No Noise

A repeated measures Friedman test was conducted on the median RTs showed that there is no significant overall difference between the three conditions. A repeated measures Friedman test was conducted on the mean RTs showed that there is a trend for a significant overall difference between the three conditions, with a small to medium effect size.

However, as I had specific a priori hypotheses about differences between the conditions, even though an overall significant effect was not found, I conducted tests on the specific comparisons.

White Noise vs No Noise

A Wilcoxon signed-rank test was conducted between the median RTs for the White Noise and No Noise conditions for the correct Go trials. This found a significant effect between the conditions without the Bonferroni adjustment, but a trend with the adjustment, with a medium to large effect size. As can be seen in Table 5.4, the median RTs was less in the White Noise condition (*Mdn* = 514.00, *SIQR* = 99.50) compared to the No Noise condition (*Mdn* = 574.50, *SIQR* = 78.00), a decrease of approximately 11.00% (11.00% also with the mean)

A Wilcoxon signed-rank test was also conducted between the mean RTs for the White Noise and the No Noise conditions for the correct Go trials. This found a significant effect both with and without the Bonferroni adjustment for the two noise conditions with a medium to large effect size. As can be seen in Table 5.2, the mean RTs was less in the White Noise condition (*Mdn* = 528.11, *SIQR* = 90.52) compared to the No Noise condition (*Mdn* = 655.89, *SIQR* = 121.47), a decrease of approximately 19.00% (14.00% with the mean).

Thus, the results on the median and mean RTs support hypotheses (1b) (with the caveat that there was only a trend on median RTs if the Bonferroni adjustment is made, critical probability level for a trend with Bonferroni adjustment would be 0.033) that the mean and median RTs in the White Noise condition are lower than the mean and median RTs in the No Noise condition. This means that these results support the hypothesis that the attention of children with ADHD is better in the White Noise condition.

Pink Noise vs No Noise

A Wilcoxon signed-rank test was conducted between the median RTs for the Pink Noise and No Noise conditions for the correct Go trials. This found a statistical trend for an effect between the two conditions (without Bonferroni adjustment, not significant with Bonferroni adjustment), with a medium to large effect size. As can be seen in Table 5.4, the median RTs tended to be less in the Pink Noise condition (*Mdn* = 515.00, *SIQR* = 72.50) compared to the No Noise condition (*Mdn* = 574.50, *SIQR* == 78.00), a decrease of approximately 10.00% (8.00% with the mean).

A Wilcoxon signed-rank test was also conducted on the mean RTs for the Pink Noise and No Noise conditions for the correct Go trials. This found a statistical trend for an effect between the two conditions (without Bonferroni adjustment, not significant with Bonferroni adjustment), with a medium to large effect size. As can be seen in Table 5.4, the mean RTs tended to be less in the Pink Noise condition (*Mdn* = 546.29, *SIQR* = 84.52) compared to the No Noise condition (*Mdn* = 655.89, *SIQR* = 121.47), a decrease of approximately 16.00% (12.00 with the mean).

Thus, the results on the median and mean RTs provide weak support for hypothesis (1e) (with the caveat that there was no effect on median and mean RTs if the Bonferroni adjustment was made) that the mean and median RTs in the Pink Noise condition are lower than the mean and median RTs in the No Noise condition. This means that these results provide weak support for the hypothesis that attention of children with ADHD is better in the Pink Noise condition.

Pink Noise vs White Noise

Two Wilcoxon signed-rank tests were also conducted between the median RTs for the Pink and White Noise condition and found no significant effect.

Two Wilcoxon signed-rank tests were also conducted between the mean RTs for the Pink and White Noise condition and found no significant effect.

Thus, the results on the median and mean RTs support hypotheses (2b) that the mean and median RTs are not different between the two noise conditions and support the hypothesis that attention of children with ADHD is not different in the two noise conditions.

5.3.3 RT Variability (RTV)

The results of the means and medians, standard deviations and semi-interquartile ranges of the three measures of RTV (SD, CV and the MAD) during the White Noise, Pink Noise and No Noise conditions are presented in Table 5.6. In addition, a summary of the statistical tests comparing the SD, CV and MAD of RTs in the different noise conditions is presented in Table 5.7.

Table 5.6 Means, standard deviations, medians and semi-interquartile ranges for the SDs, CVs and MADs of RTs

Measure	White Noise		Pink Noise		No noise	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
SD	176.43 (53.71)	172.83 (51.94)	212.56 (148.72)	176.93 (46.80)	266.44 (141.35)	278.83 (99.70)
CV	0.32 (0.09)	0.29 (0.08)	0.35 (0.16)	0.30 (0.06)	0.40 (0.15)	0.37 (0.13)
MAD	87.90 (22.08)	91.50 (15.5)	93.70 (38.76)	86.50 (9.75)	130.47 (93.86)	100.00 (44.50)

Note: N/A = Not Applicable.

Table 5.7 Tests of SD, CV and MAD of RTs between noise conditions

Measure	Comparison	Test	Observed value	p value	Effect size
SD	White vs Pink vs No Noise	Friedman	Q = 5.73	0.057 (+)	W = 0.19
	White vs No Noise	Wilcoxon	Z = -2.50	0.012 (++)	r = -0.46
	Pink vs No Noise	Wilcoxon	Z = -1.36	0.173	r = -0.25
	Pink vs White Noise	Wilcoxon	Z = -.34	0.733	r = -0.06
CV	White vs Pink vs No Noise	Friedman	Q = 2.53	0.282	W = 0.08
	White vs No Noise	Wilcoxon	Z = -1.93	0.053	r = -0.35
	Pink vs No Noise	Wilcoxon	Z = -1.14	0.256	r = - 0.21
	Pink vs White Noise	Wilcoxon	Z = -0.89	0.394	r = -0.16
MAD	White vs Pink vs No Noise	Friedman	Q = 3.70	0.158	W = 0.12
	White vs No Noise	Wilcoxon	Z = -2.05	0.041 (+)	r = -0.37
	Pink vs No Noise	Wilcoxon	Z = -1.65	0.100	r = - 0.30
	Pink vs White Noise	Wilcoxon	Z = -0.47	0.638	r = -0.09

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

White Noise vs Pink Noise vs No Noise

A repeated measures Friedman test was conducted on the SDs of RTs and found a statistical trend for a difference in SDs between the three noise conditions, with a small to medium effect size. A repeated measures Friedman test was also conducted on the CVs of RTs and found no significant difference in CVs between the three noise conditions. Another repeated measures Friedman test was conducted on the MADs of RTs and found no significant difference in MADs between the three noise conditions.

However, as I had specific a priori hypotheses about differences between the conditions, even though an overall significant effect was not found, I conducted tests on the specific comparisons.

White vs No Noise

A Wilcoxon signed-rank test was conducted between the SDs of RTs for the White Noise and No Noise conditions for the correct Go trials. This found a significant difference between the two conditions, with a medium to large effect size. As shown in Table 5.6, on this measure, RTV was lower in the White Noise condition (*Mdn* = 172.83, *SIQR* = 51.94) compared to the No Noise condition (*Mdn* = 278.83, *SIQR* = 99.70), a decrease of approximately 38.00% (34.00% using the mean).

A Wilcoxon signed-rank test was also conducted between the CVs of RTs for the White Noise and No Noise conditions for the correct Go trials. This found a statistical trend for an effect between the two conditions (without Bonferroni adjustment, not significant with Bonferroni adjustment), with a medium to large effect size. As can be seen in Table 5.6, on this measure, RTV tended to be less in the White Noise condition (*Mdn* = .29, *SIQR* = .08) compared to the No Noise condition (*Mdn* = .37, *SIQR* = .13), a decrease of approximately 22.00% (20.00% using the mean).

Finally, a Wilcoxon signed-rank test was conducted between the MADs of RTs for the White Noise and No Noise conditions for the correct Go trials. This found a significant difference between the two conditions, with a medium to large effect size. As can be seen in Table 5.6, RTV was lower in the White Noise condition (*Mdn* = 91.50, *SIQR* = 15.50) compared to the No Noise condition (*Mdn* = 100.00, *SIQR* = 44.50), a decrease of about 9.00% (33.00% using the mean).

Thus, the results on SD and MAD support hypothesis (1c) that RTV in the White noise condition is significantly lower than RTV in the No Noise condition and supports the hypothesis that attention of children with ADHD is better in the White Noise condition. The results on CV provide weak support for hypothesis (1c) (with the caveat that there was no effect on CV if the Bonferroni adjustment was made) that RTV in the White Noise condition is lower than RTV in the No Noise condition and thus provide weak support for the hypotheses that attention of children with ADHD is better in the White Noise condition.

Pink Noise vs No Noise

A Wilcoxon signed-rank test was conducted between the SDs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

A Wilcoxon signed-rank test was conducted between the CVs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

Finally, a Wilcoxon signed-rank test was conducted between the MADs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

Thus, the results on the SDs, CVs and MADs of RTs do not support hypothesis (1f) that RTV in the Pink Noise condition is lower than RTV in the No Noise condition and do not support the hypothesis that the attention of children with ADHD is better in the Pink Noise condition.

Pink Noise vs White Noise

Two Wilcoxon signed-rank tests were also conducted between the SDs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

Two Wilcoxon signed-rank tests were also conducted between the CVs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

Finally, two Wilcoxon signed-rank tests were also conducted between the MADs of RTs for the Pink Noise and No Noise conditions for the correct Go trials and found no significant effect.

Thus, the results on the SDs, CVs and MADs of RTs support hypothesis (2c) that RTV is not different between the two noise conditions and supports the hypothesis that attention of children with ADHD is not different in the two noise conditions.

5.3.4 Commission Errors (CEs)

The results of the mean and median number of CEs, and standard deviations/interquartile ranges, during the White Noise, Pink Noise and No Noise conditions are presented in Figure 5.3. In addition, a summary of the statistical tests comparing the CEs in the different noise conditions is presented in Table 5.8.

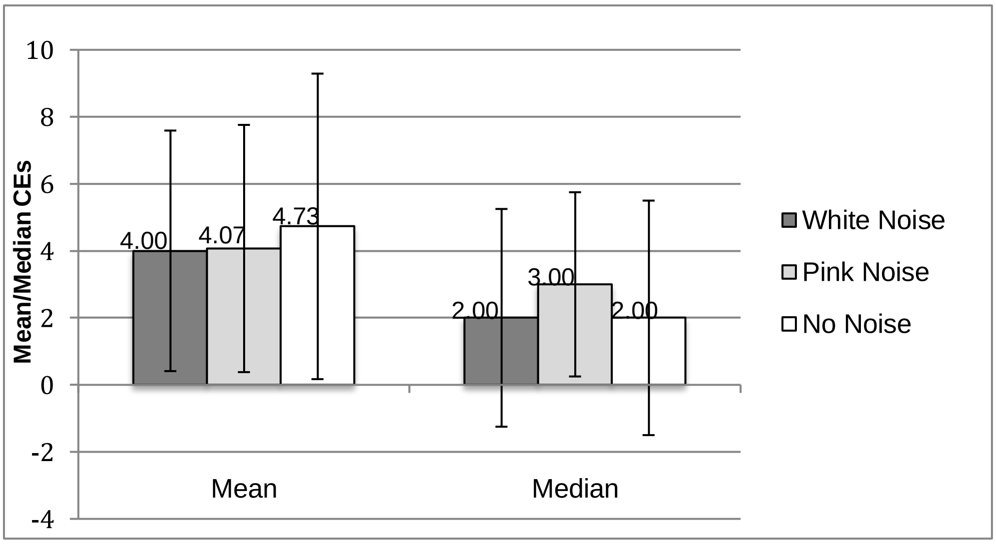


Figure 5.3 Mean, standard deviation, median and semi-interquartile range of commission errors (CEs) during White Noise, Pink Noise and No Noise conditions

Table 5.8 Tests of CEs between noise conditions

Comparison	Test	Observed value	p value	Effect size
White vs Pink vs No Noise	Friedman	*Q* = .49	0.783	W = 0.02
White vs No Noise	Wilcoxon	*Z* = -0.20	0.843	r = -0.04
Pink vs No Noise	Wilcoxon	*Z* = -0.21	0.838	r = -0.04

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

White Noise vs Pink Noise vs No Noise

A repeated measures Friedman test showed that there was no significant difference between the three conditions. However, as I had specific a priori hypotheses about differences between the conditions, even though an overall significant effect was not found, I conducted tests on the specific comparisons.

White Noise vs No Noise

A Wilcoxon test showed that there is no significant difference in CEs between White Noise and No Noise. This supports hypothesis (3a) that the CEs in the White Noise condition are not different from the No Noise condition and supports the hypothesis that impulsivity of children with ADHD is not different in the two noise conditions.

Pink Noise vs No Noise

A Wilcoxon test showed that there is no significant difference in CEs between Pink Noise and No Noise. This supports hypothesis (3b) that the CEs in the Pink Noise condition are not different from the No Noise condition and supports the hypothesis that impulsivity of children with ADHD is not different in the two noise conditions.

5.3.5 Reactions of Parents and Children to Using White and Pink Noise

All parents were asked whether they would use white or pink noise to help their children concentrate, especially in tasks requiring more attention. All parents stated that they would definitely use white or pink noise as long as it helps to improve their children's attention. The children were asked whether they believed white noise or pink noise helped them concentrate more. 14 (93%) children reported that they believed white or pink noise improved their attention. The children were also asked whether they preferred white noise or pink noise. 7 (46%) children reported that they preferred pink noise while 8 (53%) children reported that they preferred white noise, thus there was no clear preference for one or the other type of noise.

Table 5.9 The results of tests, medians, semi-interquartile ranges of OEs, mean and median RTs, SDs, CVs and MADs of RTs during White Noise, Pink Noise for children who either preferred White or Pink Noise

Preferred noise	Measure	White Noise Median (SIQR)	Pink Noise Median (SIQR)	Observed value	p value
White Noise	OEs	0.50 (0.88)	1.50 (1.38)	Z = -1.47	.143
	Mean RTs	542.56 (98.80)	579.82(157.89)	Z = -1.68	.093
	Median RTs	481.50 (81.10)	543.75 (92.88)	Z = -1.41	.159
	SD	173.48 (67.00)	181.59(166.44)	Z = -1.26	.208
	CV	0.27 (0.10)	0.33 (0.17)	Z = -1.19	.233
	MAD	87.50 (21.13)	89.75 (30.57)	Z = - 1.26	.208
Pink Noise	OEs	1.00 (1.00)	0.00 (1.00)	Z = -0.92	.357
	Mean RTs	528.11(104.79)	546.29 (97.99)	Z = -1.52	.128
	Median RTs	523.00 (85.50)	515.00(118.00)	Z = -1.52	.128
	SD	172.83 (16.34)	164.16 (32.08)	Z = -1.35	.176
	CV	.29 (.05)	.28 (.06)	Z = -0.25	.799
	MAD	91.50 (0.08)	86.00 (18.00)	Z = -1.15	.249

To investigate whether children performed better in their preferred noise condition, Wilcoxon sign-ranked tests were conducted on OEs, mean RTs, Median RTs, SDs, CVs, and MADs of RTs for whichever was their preferred and not preferred noise condition. The medians, semi-interquartile ranges, Wilcoxon sign-ranked tests during the White Noise and Pink Noise conditions for children in their preferred noise are presented in Table 5.9, above.

Children may seem to have better performance in terms of the number of OEs, mean RTs, median RTs, SDs, CVs and MADs of RTs in their preferred type of noise. However, there were no significant differences between whichever was their preferred and not preferred noise condition for all variables except for a trend for an effect for the mean RTs in the white noise group, with a medium to large effect size, Z = -1.68, P = 0.093, r = 0.42. The mean RTs tends to be less in the preferred noise condition (i.e., White Noise condition) (Mdn = 542.56, $SIQR$ = 98.80) compared to the not preferred noise condition (i.e., Pink Noise condition) (Mdn = 579.82, $SIQR$ = 157.89).

All in all, the results on mean RTs also provide weak support for hypothesis (4b) that RTs tend to be lower in the preferred noise condition, in particular when the preferred noise condition is White Noise. Thus, the results mean RTs provide weak support for the hypothesis that the attention of children with ADHD is better in the preferred noise condition.

However, the results on OEs, median RTs, SD, CVs and MADs of RTs do not support hypothesis (4c), that SDs, CVs and MADs of RTs are significantly lower in the preferred noise condition. Thus, these results do not support the hypothesis that the attention of children with ADHD is better in the preferred noise condition.

5.4 Discussion and Conclusions

This study investigated whether there is an effect of white and pink noise on the attention and impulsivity of children with ADHD as measured by their performance on a Go/NoGo task. It also investigated whether one of the two noise types has a better effect than the other on the attention of such children and whether children performed better in their preferred noise condition.

The study collected objective measures of cognitive performance using a Go/NoGo task with 15 children with ADHD. As stated in Chapter 4 (section 4.4), similar studies such as Baijot et al. (2016), Söderlund et al. (2007, 1016) and children with attention problems without a diagnosis of ADHD such as Helps et al. (2014) and Söderlund et al. (2010) have included between 13 to 20 children. The small numbers are due to the strict inclusion criteria and the fact that having comorbidities is very common in children with ADHD (Gillberg et al., 2004). Thus, the number of children in this study is comparable to previous studies.

Overall, the results of this study supported the first hypothesis, that both white and pink noise will improve attention in children with ADHD. The results showed that white noise (at 77dB) improved the attention in children with ADHD on all measures of attention and that pink noise (at 77dB) improved the attention as measured by OEs and mean and median RTs in such children. A detailed discussion of the results of each sub hypotheses is provided below.

Hypothesis (1a) (see section 5.1) was supported, as there were significantly fewer OEs in the White Noise compared to the No Noise. The median OEs rate decreased by 6% while the mean OEs rate decreased by about 8%. This result agrees with the results from Study 2 (Chapter 4) in this programme of research, and also the studies by Helps et al. (2014) and Baijot et al. (2016). Helps et al. (2014) do not provide results on the magnitude of the decrease in OEs for children with ADHD but stated that the decrease was significant. In Study 2, the median OEs rate decreased by about 7% while the mean OEs rate decreased by about 4%. This is similar in magnitude but not in the location on the scale to the results obtained from Study 2. In Baijot et al. (2016), the decrease was not significant but from the graph (Figure 2), the mean OE rate appears to decrease by about 5%. This is very similar in both magnitude and location on the scale to the results obtained from this study. Perhaps the results from Baijot et al. (2016) would have been significant if they had used non-parametric statistics for their analysis. However, all four studies (Studies 2 and 3 in this programme of research, Baijot et al., 2016; Helps et al., 2014) do suggest that white noise makes a difference to the attention of children with ADHD as measured by OEs.

Hypothesis (1b) was supported, with mean and median RTs being significantly lower in the White Noise condition, a decrease of about 11% for the median RTs and 13% for the mean RTs. This is a significant difference and the difference in the median RTs is approximately twice the difference in the median rate of OEs, the other indicator of inattention. In contrast to the results found on the mean and median RTs in this study, Baijot et al. (2016) did not find a significant difference between White Noise and No Noise on these two measures. This may be because Baijot et al. (2016) used only the mean RTs and that the mean is typically used to summarize normally distributed data and RTs are very typically not normally distributed as discussed in section 5.2.7. Also, Baijot et al. (2016) used a cued Go/NoGo task compared to the task used in this study (see Chapter 2, section 2.4.2.2 for more details). In the cued Go/NoGo task, a warning stimulus is shown just before displaying the next Go or NoGo stimulus. This may have resulted in improving the children's attention in the sense that it helped them make faster responses to a point at which white noise was not sufficient enough to make further improvements to RTs. In addition, Study 2 (see Chapter 4, section 4.4) did not find a significant difference between White Noise and No Noise on these two measures, the mean and median RTs. This could be due to using a fast ER in Study 2, which is known to improve arousal and thus the attention in children with ADHD (Tamm et al., 2012). Similar to the potential effect of the cue on RTs as discussed above, the fast ER may have resulted in improving the children's attention in that it helped them make faster responses to a point at which white noise was not sufficient enough to make further improvements to RTs. However, the results obtained in this study suggest that white noise makes a difference to the attention of children with ADHD as measured by the mean and median RTs.

Hypothesis (1c) was supported on two of the three measures of RTV (SD and MAD), with RTV being significantly lower in the White Noise condition, a decrease of about 33%. This is a significant difference and is approximately five times the difference in the median rate of OEs and is approximately twice the difference in the median RTs. In addition, on the third measure (CV), the hypothesis was weakly supported and RTV in the White Noise condition tended to be lower than RTV in the No Noise condition, a decrease of about 23%. In contrast to the results found on SDs and CVs in this study, Baijot et al. (2016) did not find a significant difference between White Noise and No Noise on the two measures, even though that study used very similar ER to this study. This raises doubts about the validity of the measures (SD and CV) used to measure RTV in previous studies since these measures are typically used to summarize normally distributed data and RTs are very typically not normally distributed as discussed in section 5.2.7. However, the results obtained in this study and Study 2 suggest that white noise makes a difference to the attention of children with ADHD as measured by RTV.

Hypothesis (1d) was supported, as there were significantly fewer OEs in the Pink Noise condition compared to the No Noise condition. The median OEs rate goes decreased by about 6% while the mean OEs rate decreased by about 8%. These results are very similar to the results obtained from White Noise in this study, which are also comparable to the results by Baijot et al. (2016) and the results from Study 2 as discussed earlier in this section. This suggests that pink noise makes a difference to the attention of children with ADHD as measured by OEs.

Hypothesis (1e) was weakly supported as the mean and median RTs in the Pink Noise condition tended to be lower than the mean and median RTs in the No Noise condition, a decrease of about 12% for the mean RTs and 11% for the median RTs. This is a significant difference and the difference in the median RTs is approximately twice the difference in the median rate of OEs, the other indicator of attention. In addition, the decrease in the mean and median RTs that resulted from pink noise in this study is very comparable to the decrease in the mean and median RTs that resulted from white noise. This suggests that pink noise makes a difference to the attention of children with ADHD as measured by mean and median RTs.

Hypothesis (1f) was not supported on all three measures of RTV (SD, CV and MAD). This means that RTV was not affected by the Pink Noise condition. This is contrary to the improvement in the RTV that resulted from white noise as discussed earlier in this section. It is unclear why pink noise had a comparable effect to white noise on attention as indicated by OEs and RTs but not on RTV. It is also unclear why and how pink noise has successfully affected RTs and made children with ADHD respond faster in the Pink Noise condition but it did not affect RTV in the sense that it did not make children with ADHD make stable responding.

The results also supported the second hypothesis, that there will be no significant difference between the effectiveness of white and pink noise in improving the attention of children with ADHD on all measures of attention. This means that hypothesis (2a) was supported, with no significant difference in OEs between the two conditions. Hypothesis (2b) was also supported, with no significant difference in mean/median RTs between the two conditions. Hypothesis (2c) was also supported, with no significant difference in RTV between the two conditions.

It is important to note that one needs to treat failure to reject the null hypothesis (i.e., failing to detect a difference in OEs, RTs or RTV between the White Noise and the Pink Noise conditions) with caution. First, it is possible that both white noise and pink noise have a comparable effect on the attention of children with ADHD, so the findings of no difference in OEs, RTs, and RTV between the white noise and pink noise conditions are appropriate. However, there are many other reasons for retaining the null hypothesis. It may be that the Go/NoGo task is not sufficient enough to show the difference between the two noise conditions considering also the small number of children in this study. It may be also that the magnitude of the difference in attention in the white noise/pink noise comparison is not large enough to show a significant effect. It might also be that the level of noise (i.e., noise dB) chosen has affected the results. This is the problem of the “fallacy of the null hypothesis” (Harris, 2008; Rozeboom, 1960).

In addition, the results supported the third hypothesis, that both white and pink noise have no effect on impulsivity in children with ADHD and showed that both pink noise and white noise have no effect on CEs. A detailed discussion of the results of each sub hypotheses is provided below.

Hypothesis (3a) was supported, as there was no significant difference in CEs between the White Noise and the No Noise conditions. This result supports that of Baijot et al. (2016) and Study 2 in this programme of research that also found no significant difference between the CEs in the White Noise and No Noise conditions.

Hypothesis (3b) was supported, as there was no significant difference in CEs between the Pink Noise and the No Noise conditions. As discussed in section 5.1, there is no study that investigated the effect of pink noise on the impulsivity of children with ADHD using a Go/NoGo task or any other similar task. However, this result supports that of Baijot et al. (2016) and Study 2, although the two studies were based on white noise, that also found no significant difference between the CEs in the White Noise and No Noise conditions.

As discussed earlier, it is important to note that one needs to treat failure to reject the null hypothesis with caution. First, it is possible that the white noise and pink noise do not affect impulsivity in children with ADHD, so the findings of no difference in CEs between the White Noise/No Noise conditions and Pink Noise/No Noise conditions are appropriate. However, there are many other reasons for retaining the null hypothesis in this case. It may be that CEs are not a good measure of impulsivity in children with ADHD in spite of the findings from previous research about the established relation between CEs and impulsivity (for more details, see Chapter2, section 2.4.2.1). It may also be that the Go/NoGo task does not tap into impulsivity sufficiently or that the magnitude of the differences in impulsivity in the white noise/no noise comparison and pink noise/no noise comparisons are not large enough to show a significant effect.

As discussed in Chapter 4 (section 4.4), the white noise and pink noise benefits on attention found in this study and the previous studies are in accordance with current theories of the underlying aetiology of ADHD, namely the moderate brain arousal model, the optimal stimulation theory (Zentall & Zentall, 1983), and the state regulation deficit model of ADHD (Sonuga-Barke et al., 2010) derived from the cognitive energetic theory (Sergeant, 2005). The theories suggest that adding extra-task stimulation, i.e., white and pink noise in this study, improves arousal and thus attention in children with ADHD (for more details, see Chapter 2, section 2.8.1).

Currently, white noise may seem better than pink noise as white noise resulted in improvement in all indicators of attention. However, as stated in section 5.3.5, some children preferred white noise while others preferred pink noise but there was no significant difference between the White and Pink Noise conditions for the two groups, except for the improvement in mean RTs for the white noise group. This might be because of the small number of children and therefore, this should be examined further in future research with a bigger number of children. This might also be because of the noise level used particularly for pink noise, considering that the effect of pink noise on the attention and impulsivity of children with ADHD was never investigated in the literature. Thus, the effect of different levels of pink noise should be investigated in future research. However, as for now, parents and children can choose whatever noise they prefer.

In conclusion, Study 2 (Chapter 4) and Study 3 (Chapter 5) in this programme of research have shown that white and pink noise are both beneficial to the attention of children with ADHD. The findings of these studies are useful for the design of an assistive technology to help improve attention and reduce distractors in children with ADHD by allowing the children to use the noise they prefer to concentrate more when performing specific educational tasks. In the next study of this programme of research, the assistive technology will be developed and evaluated with such a sample of children.

Chapter 6 – ADHD Headmuffs: an Assistive Technology to Improve Attention and Reduce Distractions for Children with ADHD

6.1 Introduction

As described in Chapter 2 (section 2.2.2), two of the defining symptoms of the first cluster of symptoms of ADHD include deficits in attention and difficulties in resisting distractibility. The deficits in attention in children with ADHD involve deficits with varying degrees in visual or auditory attention (Lin et al., 2021). The abnormal distractibility is thought to be due to deficiency in controlling involuntary attention to any stimuli in the environment surrounding children with ADHD (Cassuto & Berger, 2013; Gumenyuk et al., 2005). This can be very detrimental for daily life functioning and result in academic, occupational and social impairments (see chapter 2, section 2.6).

In addition, the deficits in attention and increased distractibility in children with ADHD mean that these children are easily distracted by extraneous stimuli. These distracting stimuli might be auditory or visual or mixed auditory-visual, such as ambient sounds in a classroom, a car driving by an open window, or a person walking in and out of the room (Adams et al., 2009). Research has shown that while both visual and auditory distractors affect the attention of children with ADHD (Adams et al., 2009; Berger & Cassuto, 2014; Cassuto & Berger, 2013; Gumenyuk et al., 2005; Parsons et al., 2007; Pelham et al., 2011), visual and mixed visual-auditory distractors have a stronger negative effect than auditory distractors (Adams et al., 2009; Pelham et al., 2011).

Studies 2 and 3 in this programme of research and previous studies (Baijot et al., 2016; Söderlund et al., 2016) have shown that the attention of children with ADHD is improved using white noise (Studies 2 and 3) and pink noise (Study 3).

Therefore, an assistive technology that incorporates white or pink noise should help improve attention in children with ADHD. Another possible benefit for the assistive technology is that it can potentially help reduce visual and auditory distractors in the environment surrounding children with ADHD. Such an assistive technology, the ADHD Headmuffs, are presented in section 6.2. The evaluation of the ADHD Headmuffs with a sample of children with ADHD is presented in section 6.3.

6.2 The ADHD Headmuffs: an Assistive Technology for Improving attention and Reducing Distractors in Children with ADHD

The ADHD Headmuffs are designed to improve attention in children with ADHD by playing white or pink noise through headphones, which may positively enhance attention and reduce auditory distractors. The ADHD Headmuffs also reduce visual distractors from the surrounding environment by incorporating "wings" to the sides of the head (see Figure 6.1, below). The context in which the ADHD Headmuffs are to be used is when performing educational tasks, including doing homework at home, attending a lesson in class or when taking a test (for more details about the scenarios of use in these particular contexts, see Chapter 8, section 8.3.2). This educational context, both at a school and at home, emerged from my own experience of parenting a child with ADHD and his educational challenges as well as from discussion with parents and their children with ADHD which occurred in the course of the previous studies.

Figure 6.1 The ADHD Headmuffs worn by a 9-year-old child – side view during a writing task

The prototype of the ADHD Headmuffs is shown in Figure 6.1 and involves two main parts, the headphones and the wings. The headphones are off-the-shelf, but the wings are tailor-made for the ADHD Headmuffs. The headphones play three important roles. First, they are used to play the white/pink noise, which helps improve the attention of children with ADHD and mask some auditory distractors as well (for more details, see Chapter 5, section 5.4). The use of the headphones for this purpose was inspired by the previous studies which used headphones to present children with white and pink noise (see Chapter 2, section 2.8.2.2). Second, the headphones help hold the wings comfortably on the child's head and they can potentially reduce visual distractors. Third, noise-cancellation headphones even without white/pink noise also help eliminate auditory distractors but in the current prototype of the ADHD Headmuffs, regular headphones were used.

As described in Chapter 2 (section 2.3), external visual distractors in the context of undertaking educational tasks (described above) include someone passing by a window, someone entering the room or moving around the child and colourful pictures on the walls of the room. A quiet room with blank walls, cubicles and dividers are often used to reduce the visual and auditory distractors in the environment surrounding children with ADHD (see Chapter 2, section 2.3). These are very useful solutions but from my own experience, they are context dependent and may not be available whenever and wherever the child needs to perform an educational task requiring attention. For instance, while parents of a child with ADHD might be able to have a quiet room with reduced visual distractors at home, this may not be the case when the child goes to a mainstream school, library, or even a relative's house and has to do an educational task that requires attention. Another interesting motivation for the design of the ADHD Headmuffs was that while I was researching the literature for tools or technologies to help with concentration and I saw a picture for a prototype of a wearable product developed by Panasonic, which includes a band that wraps around the back of the head (see Figure 6.2). This product was meant to be used by adults, and not those with ADHD, in open workplaces to help workers focus more. But as far as I am aware, it has not been evaluated with neurotypical individuals or those with ADHD. This inspired me to design the wings and augment them to the headphones, which mimics the experience of having a cubicle or dividers to reduce visual distractors but the wings are available whenever and wherever needed.

The wings were designed so that they can be moved up and down and can also be adjusted by bending inward at the front to provide optimal reduction of visual distractors. The design of the ADHD Headmuffs went through a number of iterations.

First, a paper prototype of the wings was made (see Figure 6.3) and the measurements were adjusted several times to fit an average 9-year-old child's head. Then, an AutoCAD model for the internal armature[4] of the wings was made using the final measurements from the paper prototype.

Figure 6.2 A prototype of a wearable product developed by Panasonic (Source: https://panasonic.net/)

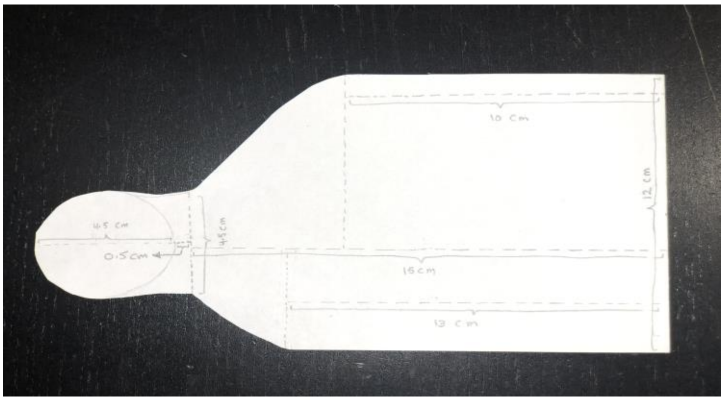


Figure 6.3 The paper prototype of one of the wings of the ADHD Headmuffs showing the measurements

The internal armature of the wings was then printed using a 3D printer and the components were attached to each other using aluminium wires, making the internal armature flexible, allowing considerable adjustment (see Figure 6.4). The wearer can adjust the angle of the wings to optimise the obstruction of visual distractors (see Figure 6.5). The idea for the flexible internal armature came from practice in stop motion animation, where aluminium armature wire is used in rigging character models

[4] The wings were developed with the help of Andrew Lewis, who has strong practical skills in metal working and 3D printing

to hold them in place during the animation process (Shaw, 2008). Finally, the wings were covered with several layers of soft fabric that could in the future be decorated and personalized to a child's taste (see Figure. 6.5). The choice of fabrics came after a discussion about possible factors such as the comfort for the wearer and the durability of the wings. Several inner layers of fabric cover the internal armature to protect the wearer from the sharp edges and a corduroy fabric was used for the outer layer, as it is soft but durable. Finally, a non-reflective black fabric was used on the inner surface to minimise any distractions. The stitching was also done in such a way as to minimize the visibility of stitches and folds to the wearer, which might create visual distractions. It was more complicated to stitch together this way, but the overall effect was cleaner.

Figure 6.4 The internal armature of the wings of the ADHD Headmuffs showing the wiring

Panel 1 (inner surface)

Panel 2 (outer surface)

Figure 6.5 The wings of the ADHD Headmuffs showing them covered with soft black material

6.3 Study 4: Evaluation of the ADHD Headmuffs

6.3.1 Introduction

In developing an assistive technology, it is very important to evaluate its usability. According to the ISO 9241standard on Ergonomics of Human System Interaction (Part 11, 2018), usability is defined as:

> *"The extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."*

Effectiveness refers to the "accuracy and completeness with which users achieve specified goals"; efficiency refers to the "resources [involving time, human effort, costs and materials] used in relation to the results achieved"; and satisfaction refers to the "extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations." (ISO 9241-11, 2018). There are several methods for evaluating usability, which include evaluations conducted by experts and evaluations with users or potential users (Petrie & Bevan, 2009). Evaluations can be done locally or remotely depending on the type of evaluation being conducted and the users involved (Petrie et al., 2006).

This study investigated the effectiveness of the ADHD Headmuffs designed to improve attention for children with ADHD by playing white noise and reducing visual and auditory distractors. The study also investigated whether the ADHD Headmuffs with no noise (i.e., the wings and their reduction of visual distractors) have a positive effect on the attention of children with ADHD. In addition, the study investigated whether the ADHD Headmuffs with white noise have a better effect on the attention of such children than the ADHD Headmuffs with no noise. The study used a within-participants design, having children undertake a visual Go/NoGo task with three conditions: Headmuffs and white noise (Headmuffs/WN), Headmuffs and no white noise (Headmuffs/NN) and no Headmuffs and no white noise (Control).

The Go/NoGo task used in this study is the same as the task used in Study 3 (for more details, see Chapter 5, section 5.2). A typical Go/NoGo task results in the three operational variables that measure attention: omission Errors (OEs), reaction times for correct Go trials (RTs), and reaction time variability (RTV).

As discussed in Chapter 4 (section 4.1), previous studies showed that children with ADHD make more OEs than typically developing children, which reflects greater inattention in children with ADHD. Studies 2 and 3 (Chapters 3 and 4) in this programme of research and the Baijot et al. study (2016) found that white noise lowered OEs and thus improved attention in children with ADHD. Also, a study by Helps et al. (2014) found that white noise lowered OEs and thus improved attention in children with attention problems but without a diagnosis of ADHD.

Therefore, it was predicted that in this study using the ADHD Headmuffs with white noise will result in fewer OEs compared to a Control condition. Also, as the ADHD Headmuffs may help in reducing visual distractors, it was predicted that using the ADHD Headmuffs with no noise will result in fewer OEs compared to a Control condition. Finally, based on my arguments above about the established positive effect of white noise on the number of OEs in children with ADHD and the potential effect of the ADHD Headmuffs in reducing visual distractors, it was predicted that using the ADHD Headmuffs and white noise would result in fewer OEs for children with ADHD compared to the ADHD Headmuffs without white noise.

As discussed in Chapter 4 (section 4.1), previous research has shown that children with ADHD have slower, the same or even faster RTs compared to typically developing children. Some researchers linked higher RTs to inattention while others linked lower RTs to hyperactivity. Furthermore, the event rate (ER) at which tasks are presented affects RTs in different ways with faster ERs result in faster RTs while slower ERs result in slower RTs in children with ADHD (for more details, see Chapter 4, section 4.1).

As in Studies 2 and 3, in this current study, I chose to tentatively link RTs to inattention in children with ADHD. Since this study used the same Go/NoGo task as in Study 3, which showed that white noise significantly reduced RTs compared to a no noise condition, it was predicted that using the ADHD Headmuffs and white noise would reduce RTs compared to a Control condition. Also, as the ADHD Headmuffs may help in reducing visual distractors, it was predicted that using the ADHD Headmuffs with no noise would reduce RTs compared to a Control condition. Finally, based on my arguments above about the established positive effect of white noise on RTs in children with ADHD and the potential effect of the ADHD Headmuffs in reducing visual distractors, it was predicted that using the ADHD Headmuffs and white noise will reduce RTs for children with ADHD compared to the ADHD Headmuffs with no noise condition.

As discussed in Chapter 4 (section 4.1), there has been a controversy about the most suitable method for measuring RTV. Previous studies showed that RTV is higher in children with ADHD compared to typically developing children and that higher RTV represents greater inattention in children with ADHD. Similar to the effect of ER on RTs, fast ERs are known to improve arousal and attention in children with ADHD and thus decrease RTV, while long ERs have been shown to result in under-arousal and inattention in children with ADHD and thus increase RTV.

As discussed earlier, since this study used the same Go/NoGo task as in Study 3, which showed that white noise significantly reduced RTV compared to a no noise condition, it was predicted that using the ADHD Headmuffs and white noise would reduce RTV compared to the Control condition. Also, as the ADHD Headmuffs may help in reducing visual distractors, it was predicted that using the ADHD Headmuffs with no noise would reduce RTV compared to the Control condition. Finally, based on my arguments above about the established positive effect of white noise on RTV in children with ADHD and the potential effect of the ADHD Headmuffs in reducing visual distractors, it was predicted that using Headmuffs with white noise would reduce RTV for children with ADHD compared to Headmuffs with a no noise condition.

Therefore, the hypotheses tested in the study are as follows:

1. Both Headmuffs/WN and Headmuffs/NN will improve attention in children with ADHD. This leads to six more specific hypotheses:

    1a: The Headmuffs/WN condition will reduce the number of OEs in comparison to the Control condition

    1b: The Headmuffs/WN condition will reduce RTs (as measured by mean and median) in comparison to the Control condition

1c: The Headmuffs/WN condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the Control condition

1d: The Headmuffs/NN condition will reduce the number of OEs in comparison to the Control condition

1e: The Headmuffs/NN condition will reduce RTs (as measured by mean and median) in comparison to the Control condition

1f: The Headmuffs/NN condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the Control condition

2. There will be a difference between the effectiveness of the Headmuffs/WN and Headmuffs/NN in improving the attention of children with ADHD. This leads to three more specific hypotheses:

2a: The Headmuffs/WN condition will reduce the number of OEs in comparison to the Headmuffs/NN condition

2b: The Headmuffs/WN condition will reduce RTs (as measured by mean and median) in comparison to the Headmuffs/NN condition

2c: The Headmuffs/WN condition will decrease RTV (as measured by SD, CV and MAD) in comparison to the Headmuffs/NN condition

6.3.2 Method

6.3.2.1 Participants

The inclusion criteria for participation in this study were the same as the criteria used in Study 2 (see Chapter 4, section 4.2.1) and Study 3.

A pool of 50 children with ADHD was available through schools containing special programmes for children with ADHD, but many of these children failed to meet all the inclusion criteria (e.g., they had comorbidities). In addition, two children started the study, but became bored and requested to withdraw before the end of the study.

Therefore, 14 children with ADHD participated in the whole study and their data were included in the analysis. This comprised all 14 girls, aged 8 to 12 years, (mean age = 9.24, SD = 1.63). 9 children were diagnosed with ADHD-C type and 5 children were diagnosed with ADHD-I type. 4 children were diagnosed with ADHD prior to the age of 4 years while 10 children were diagnosed with ADHD between the age of 5 and 7 years (for full information for all the participants, see Appendix D.2). None of the participants who took part in Studies 2 or 3 participated in this study.

6.3.2.2 Design

A within-participants design was used for this study. Children performed the same Go/NoGo task with the same parameters as used in Study 3 (see Chapter 5, section 5.2.3) to measure their attention. The reason for choosing the same task as in Study 3, which used a slow ER, is that events in real life are slower and typically not as fast as the rate used in Study 2. Also, the results of Study 3 showed that white noise resulted in a greater or more obvious improvement in attention in children with ADHD compared to the results of Study 2.

The study involved one independent variable with three conditions: Headmuffs and white noise (Headmuffs/WN), Headmuffs without white noise (Headmuffs/NN) and a control of no Headmuffs and no white noise (Control). The design was chosen over a fully factorial design: 2 (White Noise vs No Noise) x 2 (Headmuffs vs No Headmuffs), for a number of reasons. First, this study was conducted in a school, in which I had very limited time available to work with the children, only one hour per day, with only one child being evaluated each day. Also, since very few children with ADHD in the school met the inclusion criteria, I had to collect the data for this study along with the next study (the user satisfaction study in Chapter 7) from each child on the same day. Additionally, children with ADHD get easily distracted and impatient so I had to think carefully about the most important conditions to include in this study. Lastly, I already confirmed in Studies 2 and 3 in this programme of research that white noise has a positive effect on the attention in children with ADHD and thus, I decided not to test that particular condition again in this study.

For a more ecologically valid assessment of attention, the study was conducted in classroom-like settings, which are typically noisy and distracting. This helped measure children’s performance in circumstances similar to under which attention fails.

This study also involved the same dependent variables that measure inattention as used in Study 3 (see section 5.2.2), namely omission errors (OEs), reaction times for the correct Go trials (RTs) and reaction time variability (RTV).

In this study, giving rewards or incentives to the children during the task was avoided, as this may improve arousal and performance in children with ADHD and rewards are not available all the time in real life (Adamo et al., 2019; Epstein et al., 2011a; Kofler et al., 2013).

Lastly, the most recent and relevant guidelines on how to conduct usability evaluations with children in school proposed by Sim et al. (2016) have been used when conducting this study.

6.3.2.3 Experimental Task

The study used the same visual Go/NoGo task and the same numbers of blocks and stimuli as in Study 3 (for more details, see Chapter 5, section 5.2.3). The study involved one block of 20 stimuli for practice, these were not analysed. The main part of the study consisted of 3 blocks of 70 stimuli each. All blocks contained 35 Go stimuli (50%) and 35 NoGo stimuli (50%).

6.3.2.4 Equipment and Material

A MacBook Pro running IOS Sierra with a 15-inch screen was used for the experiment. White noise was delivered at 77 dB, as in the study by Baijot et al (2016), using Buddy Headphones play model no. 72692BP-PLAY-GLACIER and an iPhone X. Both the headphones and the iPhone were used in the testing procedure.

To ensure that the headphones delivered the chosen dB accurately, I used the same testing procedure as explained in Study 2 (see Chapter 4, section 4.3.4).

6.3.2.5 Procedure

As stated earlier, I followed the guidelines for conducting evaluations with children in the school context proposed by Sim and colleagues (2016). These involve guidelines for the planning of the evaluation, the introduction of the evaluation session, during the evaluation session, and finishing up.

This study was conducted in a primary school; so direct contact with parents of children with ADHD was not possible. Instead, one week prior to the session, I met with the special education specialists at the school and explained the nature of the study and the inclusion criteria for children to participate. Since the specialists have up-to-date information about the children with ADHD, the children were chosen after confirming with the specialists that they met the inclusion criteria. Then, the specialists contacted the parents of the eligible children and told them briefly the nature of the study and got their verbal consent to give their children the study information sheets and consent forms. The specialists also told the parents that they would be attending all the sessions with me. After that, the children were given brochures and consent forms (see Appendix D.1) to give to their parents. The brochures contained information explaining the nature of the study and provided contact details, including an email and a phone number of the researcher so that parents could contact the researcher if they had any questions. During that week, I tried to build a good relationship with the teachers of special education who were assigned to specific children. The children were coming every day to the teacher's room to chat with their teachers or to arrange for getting assistance with solving individual tests or assignments. I used this chance to ask the teachers to introduce me to the children, so they would become familiar with me. I paid particular attention to how the teachers were communicating with children with ADHD and took notes, when necessary, about children whom parents agreed for them to participate in this study. I also tried to have little chats with the children, so they would feel comfortable with me when doing the study.

A majority of the children returned the consent form one day later, but some took more than a week to bring the forms back. Then, I started checking for the school scheduled breaks as well as test dates and times and the weekly reading breaks for every child. It turned out that children had tests and assessments for three weeks, so I had to carefully plan the sessions with the children's teachers at the children's reading breaks when possible.

During the first week, I examined the activity room at the school in which the study was to be conducted. The room was located on the same floor as the classrooms, in which the normal background noise level was about 65 - 72dB, similar to the noise level in a classroom. The room contained many round tables with chairs around them. One of the tables in front of a wall was chosen for conducting the study.

The child, myself, the specialist, and some other children doing some activities such as drawing or reading with their teacher were all present in the room when the study was conducted. Only myself and the child were sitting at the table chosen. Prior to the study, I conducted some small talks with the children about their age, brothers and sisters they may have, and their favourite hobby, to help them feel comfortable with the researcher. Then, I had a script about the study to introduce to the children, so all the children are given the same information. The script contained information about the nature and purpose of the study, the children's role, what would happen to the collected data, confidentiality agreement and consent and that the child can withdraw from the study any time if they wish to. The children also got to ask any questions they may have, so they feel comfortable participating in the study.

As in Studies 2 and 3, I asked the child to sit in front of the computer screen, explained to them the Go/NoGo task, helped them put the Headmuffs and presented the practice block to them (for more details, see chapter 4, section 4.2.6 and Chapter 5, section 5.2.6).

After finishing the practice phase, the child undertook the three experimental blocks of 70 stimuli each. The three blocks were performed in the three conditions (Headmuffs/NN, with Headmuffs/WN, and Control). The order of the blocks was counterbalanced in a circular manner as shown in Table. 6.1. The aim was to avoid practice and fatigue effects (Baijot et al., 2016). The child was given a five-minute rest between blocks. This study was immediately followed by another study (for how the session has been ended, see chapter 7, section 7.2.6).

Table 6.1 Counterbalancing the order of the conditions in Study 4

Child	**Order**
C1	1: Headmuffs/NN, 2: Headmuffs/WN, 3: Control
C2	2: Headmuffs/WN, 3: Control, 1: Headmuffs/NN
C3	3: Control, 1: Headmuffs/NN, 2: Headmuffs/WN

6.3.2.6 Data Analysis

As in Study 2 (see Chapter 4, section 4.2.7), to ensure reliable and valid estimates of the dependent variables, corrections to some trials were made. 0.10% of correct Go trials were removed in this way.

The number of OEs, RTs and RTV were calculated for every child for each block separately as in Study 2 (for how these measures were calculated, see Chapter 4, section 4.2.7).

The normality of the data in this study was evaluated as in Study 2. RT data in this study are non-normally distributed and thus, do not meet the requirements for parametric analysis. Also, the other measures calculated in this study, including OEs, mean RTs, median RTs, SDs, CVs and MADs are non-normally distributed in some or all blocks.

To compare all three conditions, Headmuffs/WN, Headmuffs/NN and Control conditions, three-group related samples Friedman tests were conducted on all variables (OEs, CEs, mean RTs, median RTs, SDs, CVs, MADs). All tests were two-tailed with a significance level of 0.05.

To test the hypotheses in section 6.3.1, Wilcoxon signed-rank tests were conducted on the different pair-wise combinations of conditions and on all dependent variables. It could be argued that Bonferroni adjustment on the probability level should be used in interpreting the Wilcoxon tests. This is because when making multiple comparisons, it is more likely that a result would be found to be significant when it is actually not (a Type I error) (Cairns, 2019). The adjusted significance level after the Bonferroni adjustment is 0.017 (.05/3) and thus, the critical probability level for a trend with Bonferroni adjustment would be 0.033. However, as I am making planned comparisons, it can also be argued that the standard p-value of 0.05 is still valid. Both probability levels were considered. All tests were two-tailed.

The effect size ‘r’ was calculated for Wilcoxon signed-rank tests using the same formula as in Study 2 (see Chapter 4, section 4.2.7). The effect size ‘W’ for the Friedman test was calculated as the Kendall’s Coefficient of Concordance as in Study

3 (see Chapter 5, section 5.2.7). The interpretation of the effect size ‘r’ and ‘W’ was based on the same Cohen’s benchmark used in Study 2 (see Chapter 4, section 4.2.7).

6.3.3 Results

Table 6.2 provides an overview of the results and whether the hypotheses outlined above were supported. The next sections provide details of the statistical analyses of each hypothesis.

Table 6.2 An overview of the results and whether the study hypotheses were supported

Condition	Hypothesis		Result
Headmuffs/WN vs Control	1a: The Headmuffs/WN condition will reduce the number of OEs in comparison to the Control condition		Strong support
	1b: The Headmuffs/WN condition will reduce RTs (as measured by mean and median) in comparison to the Control condition	mean	Strong support
		median	Weak support
	1c: The Headmuffs/WN condition will decrease RTV (as measured SD, CV, MAD) in comparison to the Control condition	SD	Strong support
		CV	Weak support
		MAD	Strong support
Headmuffs/NN vs Control	1d: The Headmuffs/NN condition will reduce the number of OEs in comparison to the Control condition		Strong support
	1e: The Headmuffs/NN condition will reduce RTs in comparison to the Control condition	mean	No support
		median	No support
	1f: The Headmuffs/NN condition will decrease RTV in comparison to the Control condition	SD	No support
		CV	No support
		MAD	Strong support
Headmuffs/WN vs Headmuffs/NN	2a: The Headmuffs/WN condition will reduce the number of OEs in comparison to the Headmuffs/NN condition		No support
	2b: The Headmuffs/WN condition will reduce RTs in comparison to the Headmuffs/NN condition	mean	Weak support
		median	No support
	2c: The Headmuffs/WN condition will decrease RTV in comparison to the Headmuffs/NN condition	SD	Weak support
		CV	Weak support
		MAD	No support

Note: Strong support = a significant p value, Weak support = a trend for a significant p value, no support = a non-significant p value.

6.3.3.1 Omission Errors (OEs)

The results of the mean and median numbers of OEs, standard deviations and semi-interquartile range of OEs during Headmuffs/NN, Headmuffs/WN, and Control conditions are presented in Figure 6.6. In addition, a summary of the statistical tests comparing the OEs in the different conditions is presented in Table 6.3.

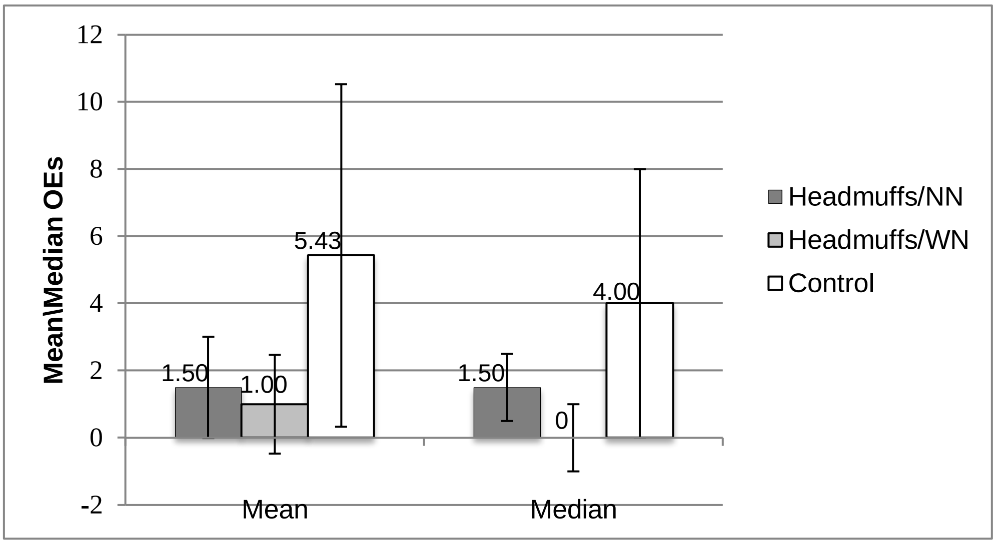


Figure 6.6 Median, mean. semi-interquartile range and standard deviation of omission errors (OEs) during Headmuffs/NN, Headmuffs/WN, and Control conditions

Table 6.3 Tests of OEs between conditions

Comparison	Test	Observed value	p value	Effect size
Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 13.09	0.001	W = 0.48
Headmuffs/WN vs Control	Wilcoxon	Z = -2.95	0.003 (++)	r = -0.55
Headmuffs/NN vs Control	Wilcoxon	Z = -2.63	0.008 (++)	r = -0.49
Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -1.31	0.191	r = -0.25

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

A repeated measures Friedman test showed a significant difference between the three conditions, with a medium to large effect size.

Headmuffs/WN vs Control

A follow-up Wilcoxon test showed a significant difference in OEs between Headmuffs/WN and Control both with and without the Bonferroni adjustment, with a large effect size. As can be seen in Figure 6.5, the median number of OEs was less in the Headmuffs/WN condition (*Mdn* = 0, *IQR* = 1.00) compared to the Control condition (*Mdn* = 4.00, *IQR* = 4.00). Using the means, the OE rate goes from 15.50% in the Control condition to 2.60% in the Headmuffs/WN condition, a decrease of approximately 13.00%. Using the medians, the OE rate goes from 11.40% in the Control condition to 0% in the Headmuffs/WN condition, a decrease of approximately 11.00%.

These results support hypothesis 1(a) (for the study hypotheses, see section 6.1) that the OEs in the Headmuffs/WN condition are significantly fewer than in the Control condition and supports the idea that attention of children with ADHD is better in the Headmuffs/WN condition.

Headmuffs/NN vs Control

A Wilcoxon test showed a significant difference in OEs between Headmuffs/NN and Control both with and without the Bonferroni adjustment, with a medium to large effect size. As can be seen in Figure 6.5, the number of OEs was less in the Headmuffs/NN condition (*Mdn* = 1.50, *SIQR* = 1.00) compared to the Control condition (*Mdn* = 4.00, *SIQR* = 4.00). Using the means, the OE rate goes from 15.51% in the Control condition to 4.29% in the Headmuffs/NN condition, a decrease of about 11.00%. Using the medians, the rate goes from a median of 11.43% in the Control condition to 4.29% in the Headmuffs/NN condition, a decrease of about 7.00%.

This supports hypothesis 1(d) that the OEs in the Headmuffs/NN condition are significantly fewer than in the Control condition and supports the idea that attention of children with ADHD is better in the Headmuffs/NN condition.

Headmuffs/NN vs Headmuffs/WN

A Wilcoxon test showed that there is no significant difference in OEs between Headmuffs/NN and Headmuffs/WN conditions. Thus, this provides no support for hypothesis 2(a) that the OEs in the Headmuffs/WN condition are lower than OEs in the Headmuffs/NN condition and provide no support the hypothesis that attention of children with ADHD are better in the Headmuffs/WN condition.

6.3.3.2 Reaction Times (RTs)

The results of the mean and median numbers, standard deviations and semi-interquartile ranges of the mean and median RTs for correct Go trials during the Headmuffs/NN, Headmuffs/WN, and Control conditions are presented in Table 6.4. In addition, a summary of the statistical tests comparing the mean and median RTs in the different conditions is presented in Table 6.5.

Table 6.4 Means, standard deviations, medians and semi-interquartile ranges for the mean and median RTs for correct Go trials

Measure	**Headmuffs/WN**		**Headmuffs/ NN**		**Control**	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
Mean RTs (ms)	639.20 (284.57)	537.40 (152.70)	676.75 (249.79)	621.62 (206.65)	745.44 (319.07)	610.54 (197.65)
Median RTs (ms)	588.61 (246.83)	500.50 (150.00)	598.50 (202.60)	553.50 (109.55)	683.64 (348.02)	540.75 (192.70)

Note: N/A = Not Applicable.

Table 6.5 Tests of mean and median RTs between noise conditions

Measure	**Comparison**	**Test**	**Observed value**	**p value**	**Effect size**
Mean RTs	Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 5.29	0.071	W = 0.19
	Headmuffs/WN vs Control	Wilcoxon	Z = -2.29	0.022 (+)	r = -0.43
	Headmuffs/NN vs Control	Wilcoxon	Z = -1.41	0.158	r = -0.27
	Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -1.73	0.084	r = -0.33
Median RTs	Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 5.29	0.071	r = 0.19
	Headmuffs/WN vs Control	Wilcoxon	Z = -1.79	0.074	r = -0.34
	Headmuffs/NN vs Control	Wilcoxon	Z = -1.10	0.272	r = -0.21
	Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -1.48	0.140	r = -0.28

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

A repeated measures Friedman test was conducted on the mean RTs and showed that there is a trend for an overall difference between the three conditions, with a low to medium effect size. A repeated measures Friedman test was also conducted on the median RTs and showed that there is a trend for an overall difference between the three conditions, with a low to medium effect size.

However, as I had specific a priori hypotheses about differences between the conditions, even though an overall significant effect was not found, I conducted tests on the specific comparisons.

Headmuffs/WN vs Control

A Wilcoxon signed rank test was also conducted on the mean RTs for the Headmuffs/WN and Control conditions for the correct Go trials. This found a significant effect between the two conditions without the Bonferroni adjustment and a statistical trend for an effect with the adjustment, with a medium to large effect size. As can be seen in Table 6.4, the mean RTs is less in the Headmuffs/WN condition (*Mdn* = 534.40, *SIQR* = 152.77) compared to the Control condition (*Mdn* = 610.54, *SIQR* = 197.65), a decrease of approximately 12.00% (14.00% using the mean).

A Wilcoxon signed-rank test was conducted between the median RTs for the Headmuffs/WN and Control conditions for the correct Go trials. This found a statistical trend for an effect between the two conditions without the Bonferroni adjustment and no significant effect without the adjustment, with a medium to large effect size. As can be seen in Table 6.4, the median RTs tended to be less in the Headmuffs/WN condition (*Mdn* = 500.50, *SIQR* = 150.00) compared to the Control condition (*Mdn* = 540.75, *SIQR* = 348.02), a decrease of approximately 7.00% (14.00% using the mean).

Thus, the results on the mean RTs provide support for hypothesis 1(b) (with the caveat that there was only a trend for an effect on mean and median RTs if the Bonferroni adjustment was made) that the mean RTs in the Headmuffs/WN condition is lower than the mean RTs in the Control condition. However, the results on the median RTs provide weak support for hypothesis 1(e) (with the caveat that there was no significant difference if the Bonferroni adjustment was made) that the median RTs in the Headmuffs/WN condition are lower than the median RTs in the Control condition.

Overall, the results provide weak support the hypothesis that the attention of children with ADHD is different in the two conditions.

Headmuffs/NN vs Control

A Wilcoxon signed-rank test was conducted between the mean RTs for the Headmuffs/NN and Control conditions for the correct Go trials. This found no significant difference between the conditions with or without the Bonferroni adjustment.

A Wilcoxon signed-rank test was also conducted between the median RTs for the Headmuffs/NN and Control conditions for the correct Go trials. This found no significant difference between the conditions with or without the Bonferroni adjustment.

Thus, the results on the mean and median RTs do not support hypotheses (1e) that the mean and median RTs in the Headmuffs/NN condition are lower than the median RTs in the Control condition and do not support the hypothesis that attention of children with ADHD is different in the two conditions.

Headmuffs/WN vs Headmuffs/NN

A Wilcoxon signed-rank test was conducted between the mean RTs for the Headmuffs/NN and Headmuffs/WN condition. This found a statistical trend towards a significant effect between the two conditions without the Bonferroni adjustment, but this was not significant with the adjustment, with a medium to large effect size. As can be seen in Table 6.4, the mean RTs tended to be less in the Headmuffs/WN condition (Mdn = 537.40, $SIQR$ = 152.77) compared to the Headmuffs/NN condition (Mdn = 621.62, $SIQR$ = 206.65), a decrease of approximately 14.00% (5.00% using the means).

A Wilcoxon signed-rank test was also conducted between the median RTs for the Headmuffs/NN and Headmuffs/WN condition and found no significant effect.

Thus, the result on the mean RTs provides weak support for hypotheses 2(b) (with the caveat that there was no effect on mean RTs if the Bonferroni adjustment was made) that the mean RTs in the Headmuffs/WN condition are lower in the Headmuffs/NN condition and thus support the hypothesis that attention of children with ADHD is different in the two conditions. However, the results on the median RTs do not support hypotheses 2(b) that the median RTs in the Headmuffs/NN condition are different from the Headmuffs/WN condition and thus do not support the hypothesis that attention of children with ADHD is different in the two conditions.

6.3.3.3 RT Variability (RTV)

The results of the means and medians, standard deviations and semi-interquartile ranges of the three measures of RTV (SD, CV and the MAD) during the Headmuffs/NN, Headmuffs/WN, and Control conditions are presented in Table 6.6. In addition, a summary of the statistical tests comparing the SD, CV and MAD of RTs in the different noise conditions are presented in Table 6.7.

Table 6.6 Means, standard deviations, median and semi-interquartile ranges for the SD, CV and MAD of RTs

Measure	**Headmuffs/NN**		**Headmuffs/WN**		**Control**	
	Mean (SD)	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**	**Mean (SD)**	**Median (SIQR)**
SD	289.13 (196.69)	258.49 (161.43)	223.22 (180.29)	142.47 (139.97)	350.24 (199.55)	302.98 (122.86)
CV	0.40 (0.18)	0.41 (0.14)	0.32 (0.17)	0.29 (0.11)	0.46 (0.16)	0.44 (0.14)
MAD	122.54 (93.49)	88.00 (56.70)	115.00 (102.11)	69.50 (45.15)	153.57 (105.11)	104.00 (55.50)

Note: N/A = Not Applicable.

A repeated measures Friedman test was conducted on the SDs of RTs and found a significant difference in SDs between the three conditions, with a small to medium effect size. A repeated measures Friedman test was also conducted on the CVs of RTs and found no significant difference in CVs between the three conditions. Another repeated measures Friedman test was conducted on the MADs of RTs and found a significant difference in MADs between the three conditions, with a small to medium effect size.

However, as I had specific a priori hypotheses about differences between the conditions, even though an overall significant effect was not found, I conducted tests on the specific comparisons.

Table 6.7 Tests of SD, CV and MAD of RTs between conditions

Measure	Comparison	Test	Observed value	p value	Effect size
SD	Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 7.43	0.024	W = 0.27
	Headmuffs/WN vs Control	Wilcoxon	Z = -2.48	0.013 (++)	r = -0.46
	Headmuffs/NN vs Control	Wilcoxon	Z = -1.48	0.140	r = -0.28
	Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -1.85	0.064	r = -0.34
CV	Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 2.71	0.257	W = 0.10
	Headmuffs/WN vs Control	Wilcoxon	Z = -1.79	0.074	r = -0.34
	Headmuffs/NN vs Control	Wilcoxon	Z = -1.22	0.221	r = -0.23
	Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -1.79	0.074	r = -0.34
MAD	Headmuffs/WN vs Headmuffs/NN vs Control	Friedman	Q = 7.89	0.019	W = 0.28
	Headmuffs/WN vs Control	Wilcoxon	Z = -2.97	0.003 (++)	r = -0.56
	Headmuffs/NN vs Control	Wilcoxon	Z = -2.23	0.026 (+)	r = -0.42
	Headmuffs/WN vs Headmuffs/NN	Wilcoxon	Z = -0.57	0.572	r = -0.11

Note: (++) = significant with and without Bonferroni adjustment. (+) = significant only without Bonferroni adjustment.

Headmuffs/WN vs Control

A Wilcoxon signed-rank test was conducted between the SDs of RTs for the Headmuffs/WN and Control conditions for the correct Go trials. This found a significant difference between the two conditions both with and without Bonferroni adjustment, with a medium to large effect size. As can be seen in Table 6.6, on this measure, RTV was less in the Headmuffs/WN condition (*Mdn* = 142.47, *SIQR* = 139.97) compared to the Control condition (*Mdn* = 302.98, *SIQR* = 122.86), a decrease of approximately 52.00% (36.00% using the means.

A Wilcoxon signed-rank test was conducted between the CVs of RTs for the Headmuffs/WN and Control conditions for the correct Go trials. This found a statistical trend towards a difference between the two conditions without the Bonferroni adjustment, but this was not significant with the adjustment, with a medium to large effect size. As can be seen in Table 6.6, on this measure, RTV tended to be less in the Headmuffs/WN condition (*Mdn* = 0.29, *SIQR* = 0.11) compared to the Control condition (*Mdn* = 0.44, *SIQR* = 0.14), a decrease of approximately 34.00% (30.00% using the means).

Finally, a Wilcoxon signed-rank test was conducted between the MADs of RTs for the Headmuffs/WN and Control conditions for the correct Go trials. This found a significant difference between the two conditions with and without Bonferroni adjustment, with a large effect size. As can be seen in Table 6.6, on this measure, RTV was less in the Headmuffs/WN condition (*Mdn* = 69.60, *SIQR* = 45.15) compared to the Control condition (*Mdn* = 104.00, *SIQR* = 55.50), a decrease of approximately 33.00% (25.00% using the means).

Thus, the results on the SDs and MADs of RTs support hypothesis 1(c) that RTV in the Headmuffs/WN condition is lower than RTV in the and Control condition and supports the hypotheses that attention of children with ADHD is different in the two conditions. However, the results on CV do not support for hypothesis 1(c) that RTV in the Headmuffs/WN condition is lower than RTV in the Control condition and do not support the hypotheses that attention of children with ADHD is different in the two conditions.

Headmuffs/NN vs Control

A Wilcoxon signed-rank test was conducted between the SDs of RTs for the Headmuffs/NN and Control conditions for the correct Go trials. This found no significant difference between the two conditions.

A Wilcoxon signed-rank test was also conducted between the CVs of RTs for the Headmuffs/NN and Control conditions for the correct Go trials. This found no significant difference between the two conditions.

Finally, a Wilcoxon signed-rank test was conducted between the MADs of RTs for the Headmuffs/NN and Control conditions for the correct Go trials. This found a significant difference between the two conditions (without Bonferroni adjustment, a trend for an effect with the adjustment), with a medium to large effect size. As can be seen in Table 6.6, on this measure, RTV was less in the Headmuffs/NN condition (*Mdn* = 88.00, *SIQR* = 56.70) compared to the Control condition (*Mdn* = 104.00, *SIQR* = 55.50), a decrease of approximately 15.00% (20.00% using the means).

Thus, the results on MAD support hypothesis 1(f) (with the caveat that there was only a trend for an effect on MAD if the Bonferroni adjustment was made) that RTV in the

Headmuffs/NN condition is lower than RTV in the Control condition and supports the hypotheses that attention of children with ADHD is better in the Headmuffs/NN condition. However, the results on SD and CV do not support hypothesis 1(c) that RTV in the Headmuffs/NN condition is lower than RTV in the Control condition and do not support the hypotheses that attention of children with ADHD is different in the two conditions.

Headmuffs/WN vs Headmuffs/NN

A Wilcoxon signed-rank test was also conducted between the SDs of RTs for the Headmuffs/NN and Headmuffs/WN condition. This found a statistical trend for a difference between the two conditions without the Bonferroni adjustment, not significant with the adjustment, with a medium to large effect size. As can be seen in Table 6.6, on this measure, RTV tended to be less in the Headmuffs/WN condition (*Mdn* = 142.47, *SIQR* = 139.97) compared to the Headmuffs/NN condition (*Mdn* = 258.49, *SIQR* = 161.43), a decrease of approximately 45.00% (23.00% using the means).

A Wilcoxon signed-rank test was also conducted between the CVs of RTs for the Headmuffs and Headmuffs/WN condition. This found a statistical trend towards a difference between the two conditions without the Bonferroni adjustment, but this was not significant with the adjustment, with a medium to large effect size. As can be seen in Table 6.6, on this measure, RTV tended to be less in the Headmuffs/WN condition (*Mdn* = 0.29, *SIQR* = 0.11) compared to the Headmuffs/NN condition (*Mdn* = 0.41, *SIQR* = 0.14), a decrease of approximately 29.00% (20.00% using the means).

Finally, a Wilcoxon signed-rank test was also conducted between the MADs of RTs for the Headmuffs/NN and Headmuffs/WN condition and found no significant effect.

Thus, the results on the SDs and CVs of RTs provide weak support hypothesis 2(c) (with the caveat that there was no effect on SDs and CVs if the Bonferroni adjustment was made) that RTV in the Headmuffs/WN condition are lower than RTV in the Headmuffs/NN condition and provide weak support for the hypothesis that attention of children with ADHD is different in the two conditions. However, the results on the MADs of RTs do not support hypothesis 2(c) that RTV in the Headmuffs/WN condition is lower than RTV in the Headmuffs/NN condition.

6.3.4 Discussion and Conclusions

This study conducted an evaluation of the first prototype of an assistive technology, the ADHD Headmuffs, designed to improve attention for children with ADHD by playing white noise and reducing visual and auditory distractors. The study also investigated whether the ADHD Headmuffs with no noise (i.e., the wings and their reduction of visual distractors) have a positive effect on the attention of children with ADHD. In addition, the study investigated whether using the ADHD Headmuffs with white noise has a better effect on the attention of such children than using the ADHD Headmuffs with no noise.

The evaluation collected objective measures of cognitive performance using a Go/NoGo task with 14 children with ADHD. Similar studies involving children with ADHD such as Baijot et al. (2016), Söderlund et al., (2007, 2010, 2016) and Helps et al. (2014) have participant numbers ranging from 13 to 20 children, due to the strict inclusion criteria and the fact that children with ADHD often have comorbidities. Thus, the number of children in this study is comparable to previous studies. In addition, the study was conducted in classroom-like settings, which are typically noisy and distracting and this helped measure children's performance in circumstances similar to under which attention fails. This allowed for a more ecologically valid assessment of attention.

The results of this study supported the first hypothesis, that both the ADHD Headmuffs with white noise and the ADHD Headmuffs without noise will improve attention in children with ADHD. In the evaluation, both the ADHD Headmuffs with white noise and the ADHD Headmuffs without noise resulted in a positive effect on the attention of children with ADHD, as measured by a significant reduction in both OEs and RT variability (as measured by MAD). These results are in line with previous research which has separately shown positive results of the two aspects incorporated into the ADHD Headmuffs, white noise and reduction of visual distractors. So, in relation to white noise, Studies 2 and 3 in this programme of research, Söderlund and colleagues (2007, 2016) and Baijot and colleagues (2016) all found a positive effect of white noise for children with ADHD on a variety of cognitive tasks. Helps and colleagues (2014) and Söderlund and colleagues (2010) also found similar benefits of white noise with children who had attention problems but without a diagnosis of ADHD.

Similarly, in relation to distractors, particularly visual distractors, a range of studies have found that visual distractors decrease attention in children with ADHD (Adams et al., 2009; Berger & Cassuto, 2014; Cassuto & Berger, 2013; Gumenyuk et al., 2005; Parsons et al., 2007; Pelham et al., 2011). This is important considering that deficits in visual attention are very serious in such children (Lin et al., 2021).

However, on the RTs measures (mean and median RTs), there was a positive effect only for the ADHD Headmuffs with white noise and not for the ADHD Headmuffs without white noise. These results are in line with the results obtained from Study 3 in this programme of research that showed that white noise resulted in a significant reduction in mean and median RTs.

In this context, the effect of visual distractors on RTs in children with ADHD has not been well studied in the literature. Thus, there is no obvious explanation as to why reducing visual distractors through the wings in the ADHD Headmuffs with no noise condition improved OEs and RTV but has no effect on mean and median RTs. Nonetheless, one possible explanation could be that RTs may have a different neurological basis than OEs and RTV (Goetz et al., 2017; Perri et al., 2017), resulting in a different effect of distractors on RTs. In addition, Gumenyuk et al. (2005) found that auditory distractors had a negative effect on RTs in children with ADHD. Thus, to improve RTs, one may need to reduce auditory distractors, which was achieved using white noise in the Headmuffs with white noise condition. White noise may have also worked as an extra-task stimulation that is helpful to improve RTs and thus, attention in children with ADHD as found in this study and in Study 3 in this programme of research. Nonetheless, reduction of auditory distractors could also be achieved through using noise cancellation headphones instead of the regular headphones used in the current design of the ADHD Headmuffs; however, whether this will make a difference in attention as indicated by RTs is unknown and should be considered in future research.

Turning to the second hypothesis, that there will be a difference between the effectiveness of the Headmuffs with white noise and Headmuffs with no noise in improving the attention of children with ADHD, the results of this study provided support for this hypothesis. The results showed that the ADHD Headmuffs with white noise produced more improvement in attention than the ADHD Headmuffs without noise on some variables.

In the evaluation, the ADHD Headmuffs with white noise resulted in a more positive effect on the attention of children with ADHD than the ADHD Headmuffs without noise, as measured by a weak reduction in the mean RTs and the two measures of RT variability (SD and CV). The results on the OEs, the median RTs and the MADs are in the right direction but did not reach significance. This could be attributed to the small number of children involved in this study and to the diverse nature of children with ADHD, even those with the same form of ADHD. Also, looking at the performance of children, there was very high variability in their data and thus, it was surprising but gratifying to get significant effects and one should also appreciate even getting a trend for an effect.

While this study represents a very positive first assessment of the objective performance of the ADHD Headmuffs, there were a number of limitations in the evaluation that should be addressed in future work. The number of children in the study was relatively small at 14. This is in line with a number of the relevant studies of children with ADHD, as discussed above, although one study included 133 children with ADHD (Berger & Cassuto, 2013) but this study was part of medical research and did not say how long it took them to run the study. As noted in the Participants section, the final number of children reduced from 50 to 14 due to the strict inclusion criteria, particularly the fact that having comorbidities is very common in children with ADHD. It would also be important to conduct this evaluation with boys with ADHD since this study was conducted only with girls with ADHD in a public school for girls.

Some may argue that the positive effect of the ADHD Headmuffs on the attention found in this study may have resulted from the novelty effect of wearing the ADHD Headmuffs. Therefore, future research should look at using the ADHD Headmuffs for a longer period of time and investigate whether attention continues to be improved or whether the effect wears off with time.

In addition, during the evaluation, I attempted to create an ecologically valid context by conducting the study in a classroom-like setting with other children present and active. However, this meant that the auditory and visual distractors were not controlled and may have fluctuated during the study. This would have been a random effect, rather than a systematic one which may have affected one condition in particular. Nonetheless, it would be interesting to conduct studies with controlled auditory and visual distractors to understand the relationships between the nature and magnitude of the distractors and the improvements in attention.

Another limitation is that only one cognitive task, the Go/NoGo task, was used in the study. This was largely due to the limited time available with the children for the research, the need to explain a task to the children, and the fact that the children get easily distracted and impatient. Although this task has been used in a number of studies on this topic, it would be beneficial to use a variety of different cognitive tasks, at the very least to investigate the robustness of the significant effects, but also to explore differences with different types of tasks. The Go/NoGo task produces a number of dependent variables, but opinions on the validity of some of the measures are somewhat mixed (for more details, see Chapter 2, section 2.4.2.2). OEs and RTV are widely accepted as measures of attention. However, there is some discussion about how to measure RTV as discussed in section 6.1. There are numerous ways of measuring RTV, with most researchers using parametric statistics, in spite of the fact that RTs are very likely to be skewed and therefore not appropriate for these statistics.

In conclusion, this study was the first step in evaluating the ADHD Headmuffs. The study assessed the effectiveness of the ADHD Headmuffs and found that the Headmuffs whether with or without white noise are beneficial in improving attention and reducing distractors of children with ADHD. However, as described in section 6.1, effectiveness is only one aspect of the usability of the ADHD Headmuffs and the other aspects should also be considered. Therefore, in the next study in this programme of research, another evaluation of the Headmuffs will be conducted in order to measure the satisfaction and acceptability of children with ADHD with the ADHD Headmuffs.

Chapter 7 – Study 5: Measuring the Satisfaction and Acceptability of Children with ADHD with the ADHD Headmuffs

7.1 Introduction

Study 4 (see Chapter 6) assessed the effectiveness of the assistive technology, the ADHD Headmuffs, in improving attention and reducing visual and auditory distractors in children with ADHD. The results showed that the ADHD Headmuffs are effective in improving the children's attention and reducing distractors of the surrounding environment.

However, as described in Chapter 6 (section 6.1), effectiveness is one important aspect of the usability of the ADHD Headmuffs as it aims to objectively measure whether the ADHD Headmuffs result in improvement in the attention of children with ADHD. However, other aspects should also be considered. Satisfaction is one of these aspects, which refers to the "extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user's needs and expectations" (ISO 9241-11, 2018). Satisfaction is a subjective measure that, in this case, aims to measure children's opinions about the ADHD Headmuffs. I considered evaluating satisfaction directly with children with ADHD important, as researchers have found that "proxy-reporting" through experts, parents, or teachers of children is not sufficient and that self-report opinions, behaviours and attitudes of target children should be elicited directly from them (Markopoulos et al., 2008). Therefore, in this study, the satisfaction of children with ADHD with the ADHD Headmuffs was evaluated.

Satisfaction is usually measured using semi-structured interviews that include rating scales and open-ended questions (Pearson, 2009). Researching the literature about assessment tools designed for measuring satisfaction level with assistive technologies for children, no studies could be found. What was found were studies that measured children's satisfaction with games, websites and toys using bespoke questionnaires that were specifically designed for these studies (e.g., Alhussayen et al., 2015; Bul et al., 2015). In addition, no studies were found that fully measured the satisfaction levels of children with wearables. In this context, although a study by Smit and Bakker (2015) checked the satisfaction of the child involved in the study with the wearable assistive technology for emotion regulation for children with ADHD, called Blurtline, the satisfaction was measured by only asking the child one question about if he was satisfied with wearing the technology or not (for more information about Blurtline, see Chapter 2 section 2.7.2). This is certainly not enough and a much deeper evaluation of the satisfaction and acceptability of the children to such technologies are necessary.

However, there are a number of widely used standardized usability questionnaires that aim to measure adults' satisfaction with websites, apps and computer systems. These include the System Usability Scale (SUS) (Brooke, 1996), the Computer System Usability Questionnaire (CSUQ) (Lewis, 1995) and the Usability Metric for User Experience (UMUX) (Finstad, 2010). Adapted lists of items from these questionnaires were used by a number of studies that evaluated the satisfaction of children with technologies. For instance, the study by Kinsella et al. (2017) evaluated the usability of a wearable social skills training technology that included a worn eyeglasses and an app, for children with autism using an adapted list of items from the SUS.

Other assessment tools that aim to measure the satisfaction levels of adults with technologies were also found. For instance, Knight and colleagues (2002, see also Knight & Baber, 2005) proposed a tool, the Comfort Rating Scales (CRS), that focuses on measuring comfort with wearable computers. Also, Crane and colleagues (2004) proposed a tool, the Wheelchair Seating Discomfort Assessment Tool (WcS-DAT), to measure seating discomfort that wheelchair users experience. However, both the CRS and WcS-DAT were developed for adults and never adapted for children. Obviously, what works for adults may not work for children. For example, for adults the aesthetic aspect of a wearable may relate to being fashionable, whereas children may be more concerned about it being fun with interesting colours and stickers.

Another important point to note is that wearable technologies in general, including assistive ones, typically involve some or all of three components: the hardware that is to be worn; software that processes input and output; and an interface that allows interaction with the wearable. In the case of the ADHD Headmuffs, no software or interface for the child is currently included. Thus, the satisfaction of the children was measured with respect to the hardware alone.

None of the standardized questionnaires or the list of aspects to measure satisfaction that were found in previous studies were fully suitable for my aims and many aspects that could be of relevance and importance to the usability and acceptability of the ADHD Headmuffs were not covered in these two tools. Therefore, in this study, a list of aspects that measures the satisfaction of children with the hardware component of a wearable assistive technology is proposed and used to measure the satisfaction of children with ADHD with the ADHD Headmuffs. The list of aspects was inspired by the standardized questionnaires discussed above and proposed tools that measure satisfaction with wearables. A number of other aspects were also added after consulting a number of ADHD specialists and usability experts.

This study was an exploratory study that aimed to evaluate the user satisfaction and acceptability levels of the ADHD Headmuffs by children with ADHD. The study used semi-structured interviews with children with ADHD after having the children experience wearing the ADHD Headmuffs and undertaking tasks while wearing them for approximately 30 minutes. The study also used the researcher's observations of children while wearing the ADHD Headmuffs and undertaking the tasks.

7.2 Method

7.2.1 Participants

The same children with ADHD who took part in Study 4 (see Chapter 6, section 6.2.1), participated in this study.

7.2.2 Design

The study used semi-structured interviews to measure the satisfaction and acceptance levels of children with ADHD with the ADHD Headmuffs. The interviews were conducted after finishing the experimental tasks in Study 4 (section 6.2.2). The interviews consisted of asking the children to rate different aspects related to using the ADHD Headmuffs. In addition, some of the ratings had follow up open-ended questions. The interviews also included three general open-ended questions about their likes and dislikes about the ADHD Headmuffs (see section 7.2.3). To collect the ratings from the children, the Smileyometer tool from the fun tool kit (Read et al., 2002; Read & MacFarlane, 2006) was used. The Smileyometer is a Visual Analogue Scale (VAS), which uses pictorial representations to help identify the feelings and opinions of children aged 7 years and above (Read, 2008).

Druin (2002) emphasized that when children act as evaluators of a prototype, both direct feedback from children as well as direct observation of their attitudes towards the prototype should be collected. Therefore, both direct observations of children by me and direct feedback through asking children to rate a set of satisfaction and acceptance aspects and to answer open-ended questions were used. For consistency, in rating the aspects requiring observation (see section 7.2.3), I used the same Smileyometer as used by the children.

Measuring satisfaction in this context, which stemmed from the ISO definition of the user satisfaction stated in section 7.1, addresses whether the physical, cognitive and emotional responses of the children resulting from using the ADHD Headmuffs meet their needs and expectations. In particular, satisfaction addresses whether children find the ADHD Headmuffs comfortable, useful, easy to use and aesthetically appealing. Although there are no studies on how children and adults perceive the different aspects of satisfaction of a product, it is important to note that some aspects are undoubtedly different for children in comparison to adults. For instance, the aesthetic aspect of a wearable for adults may relate to being fashionable, whereas children may be more concerned about it being fun with interesting colours and stickers. My own experience of parenting children and consulting specialists of ADHD in children as well as specialists in usability might have helped me with making an appropriate list of aspects that are suitable for children.

As discussed in section 7.1, none of the standardized questionnaires, proposed tools or the list of aspects to measure satisfaction that were found in previous studies were fully suitable for my aims. Therefore, in this study, a bespoke questionnaire was developed which consists of a list of proposed aspects that measures the satisfaction levels of children with the hardware component of a wearable assistive technology as shown in Table 7.1. The list of aspects was inspired by some of the existing standardized questionnaires which include user satisfaction such as the SUS (Brooke, 1996) and by tools such as the CRS (Knight et al., 2002) and the WcS-DAT (Crane et al., 2004) which measure satisfaction with different wearables (for more details, see section 7.1).

However, measuring satisfaction does not cover all aspects of usability and particularly acceptability of technologies, such as whether children would be willing to wear the ADHD Headmuffs in class. Therefore, a number of aspects for measuring the acceptance of children with technologies was also added (see Table 7.1). In addition, some other aspects were added after consulting ADHD specialists and usability experts.

In this study, a set of guidelines for survey design for children was adopted from Markopoulos and colleagues (2008). The relevant guidelines include: keeping the survey short so children do not feel bored and lose motivation, which in turn increases the chance of the satisficing problem in which a child seeks to give an answer that they think the researchers wants to hear; piloting the language with children and checking it with teachers of children; reading aloud written questions especially for young children, if possible; limiting or avoiding having the children write anything themselves; avoiding Yes/No questions and use the Visual Analogue Scale (VAS), instead. Another important guideline that was taken from Sim et al. (2016) is to make the question wording neutral to avoid the suggestibility problem in which a question is worded in a specific way that makes the child more inclined to give a particular answer.

As Studies 2, 3 and 4 in this programme of research, the most recent and relevant guidelines on how to conduct usability evaluations with children at school proposed by Sim et al. (2016) have been used when conducting this study.

While video recordings are widely used to reveal usability problems or users' attitudes toward a product or software (Sim et al., 2016), in this study I avoided using this medium. This is because using video recordings might have made the children who participated in this study self-conscious and anxious. In addition, this study was conducted in an activity room at a school, so if video recording was used other children or teachers may be captured accidently and this could result in ethical issues, since their consent was not obtained.

7.2.3 Materials

The Materials for the Interviews

There were five main categories of aspects that were covered in this study, including the comfort, usefulness, ease of use, aesthetics, and acceptance of the ADHD Headmuffs. Each category was divided into more specific aspects. The semi-structured interviews asked the children to rate the aspects in the five categories. Some aspects also had follow-up open-ended questions depending on the ratings given. Table 7.1 lists the aspects, the questions that children were asked, and the kinds of observations used for the associated researcher ratings (for the full interview, see Appendix E.1, for the researcher observation sheet, see Appendix E.2). In addition, the interview included some general open-ended questions, which were:

- What are most things you like about the ADHD Headmuffs?
- What are the things you did not like about the ADHD Headmuffs?
- What would you like to change about the ADHD Headmuffs?

The interview questions were written in a manner that the questions were clear for children, not ambiguous, not abstract, simple and not multi-dimensional so it easier for children to state their opinions. As advised by Sim and colleagues (2016), the wording of the questions was written to be neutral, so they do not lead children to give particular answers or ratings. This is of a particular importance to minimize the suggestibility problem mentioned above. The wording of the questions was also revised with two teachers of English for children to ensure that they were suitable and understandable to children. Afterwards, the interview questions were translated into Arabic by myself and then, the translated version was checked by the same two teachers. Then, the wording of the questions was checked in a pilot study with two children, one with ADHD and one without ADHD (see section 7.2.5).

Table 7.1 The aspects, questions that children were asked, and the kinds of observations used for the researcher ratings

Aspects	Questions	Researcher observation
Comfort		
Weight	Do you feel the Headmuffs are light enough on your head or too heavy?	Observe child while wearing the Headmuffs
Size	Do you feel the size of the Headmuffs fits you well or not?	Observe child while wearing the Headmuffs
Shape	Do you think the shape of the Headmuffs is good or not?	N/A
Movement	Can you move around enough while wearing the Headmuffs?	Ask child to pick up pens and bag on the table and from the floor; turn head right and left, observe ease in performing these tasks
Wanting to remove	Do you want to remove them when you are wearing them or not?	Observe if child touches Headmuffs too much
Hurting	Does wearing the Headmuffs hurt at all? Rating 3 or below: where does it hurt?	Observe child while wearing the Headmuffs
Causing pain	Does wearing the Headmuffs make your neck or shoulders hurt? If rating is 3 or below: where does it hurt?	Observe child while wearing the Headmuffs
Usefulness		
Cut view of distractions	Do they cut out the view of things around you that might distract you?	Observe if child turns heads or responds to visual distractors
Help focus	Do you think wearing the Headmuffs helps you focus?	N/A
Ease of use		
Easiness of wear	Is it easy to put on and take off the Headmuffs?	Ask child to take off and then put on the Headmuffs again and to adjust the wings, observe ease in performing these tasks
Quickness of wear	Can you put the Headmuffs on and take them off quickly?	
Need of help for correct wear	Do you need any help in correctly putting them on so they are comfortable?	
Aesthetics		
Likes its look	Do you like how the Headmuffs look?	N/A
Customization	Do you want to change their colour or texture? If rating is 3 or below: What changes you want?	N/A

Aspects	Questions	Researcher observation
Acceptability		
Wear in front of others	Would you feel OK wearing the Headmuffs in class (in front of others)? If rating is 3 or below: if some of your classmates or teachers wear the Headmuffs, would you wear them?	N/A
Felling relaxed	Do you feel relaxed when you wear the Headmuffs?	Observe child while wearing the Headmuffs
Wear frequently	Would you like to wear the Headmuffs frequently?	N/A

Note: N/A = Not Applicable.

The Smileyometer

The Smileyometer is based on a five-point Likert item, labelled Brilliant (= 5) to Awful (= 1) (see Figure 7.1). The Smileyometer is presented to the children in a horizontal row along with supporting words under the faces, as recommended by Hox et al. (2003). Children were asked to tick one face from the Smileyometer. The supporting words help children in deciding which face really represents their opinion.

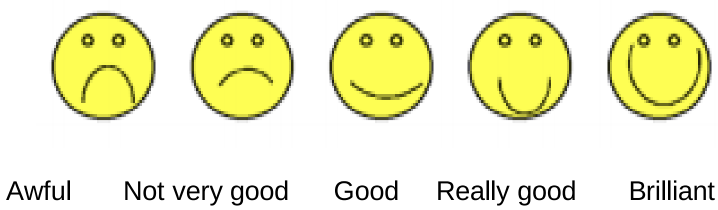


Figure 7.1 The Smileyometer (Source: Read & MacFarlane, 2006)

7.2.5 Pilot Study

A pilot study was conducted to check for the clarity of the wording of the Arabic version of the interview questions used in this study. It was conducted with two children; one was 8 years with ADHD and one was 11 years without ADHD. The children reported that the questions were clear and easy to understand. No issues were found. The child with ADHD who participated in the pilot study were not included in the main study.

7.2.6 Procedure

As stated earlier, I followed the guidelines for conducting evaluations with children in school context proposed by Sim et al. (2016). These include guidelines for the planning of the evaluation, the introduction of the evaluation session, during the evaluation session, and finishing up.

This interview was conducted with the same children and on the same day as the experimental tasks in Study 4 (Chapter 6, section 6.2.2). After the children finished the tasks, they were given a five-minute break if they wished; otherwise, I started with this study straight away. The researcher started by reading a script about the study as she did in Study 4. Then, each child had an interview sheet in which their ratings as well as answers were registered. At that point, I had shown the children the ADHD Headmuffs, explained their parts and helped them put on the ADHD Headmuffs and adjust the wings for optimal coverage. Afterwards, I started the interview by asking the children to rate the different satisfaction aspects using the Smileyometer (see Table 7.1, section 7.2.3). For some aspects, the child was also asked open-ended questions when the rating they gave was three or below. I read out the questions to the children, and then the children had to tick the face in the Smileyometer that represented their rating of each aspect. To reduce the satisficing problem, I tried my best to be neutral when asking questions or receiving answers from children as suggested by Sim and colleagues (2013). For the answers to the open-ended questions, I wrote the answers for the children on the interview sheet.

To collect information about some of the satisfaction aspects, I also observed the children while they were doing the experimental tasks in Study 4 and made appropriate notes during that period. For some other aspects, including the movement and the ease of use aspects, I asked children to do particular tasks as explained in Table 7.1, column 3. These tasks were prompts for both the child to give the ratings and for me to make my ratings to these aspects. After the rating questions, the children were asked the three general open-ended questions.

When the interview was completed, I thanked the child for participating in the study and explained again to the child about what I will use the collected data for and ensure that the child was still consenting on that. Then, the child was given a gift of a toy such as LEGO or building blocks and was taken back to their classroom.

7.2.7 Data Analysis

Both the data from the semi-structured interviews and the data from my observations of the children were analysed. Therefore, quantitative analysis of the ratings the children gave and the ratings I made during the observations was conducted. In addition, qualitative analysis of the comments the children made and the comments from my observations of the children was performed.

Since not all the ratings were normally distributed, non-parametric statistics were used, including nonparametric one-sample Wilcoxon tests for ratings for each aspect against the midpoint of 3 of the Smileyometer scale.

7.3 Results and Discussion

Table 7.2 shows the medians and semi-interquartile ranges for the researchers' ratings when applicable and for the children's ratings of the aspects with results of Wilcoxon signed-rank tests. Wilcoxon signed-rank tests were used to test whether the median ratings of children were significantly above the midpoint of the Smileyometer scale.

There were five main categories of aspects that were covered in this study, including the comfort, usefulness, ease of use, aesthetics, and acceptance of the ADHD Headmuffs. Each category was divided into more specific aspects that were simple and one-dimensional to make it easier for children to state their opinions as explained in section 7.2.3. From Table 7.2, it is clear that all the ratings of children to the usability and acceptance aspects of the ADHD Headmuffs were significantly positive, meaning that the children found the ADHD Headmuffs significantly comfortable, useful, easy to use, aesthetically appealing and acceptable.

Table 7.2 Medians and semi-interquartile ranges for children's and researcher's ratings with results of Wilcoxon signed-rank tests (for children's ratings only)

Aspect	Child ratings Median (SIQR)	W	p value	Researcher's ratings Median (SIQR)
Comfort				
Weight	5.00 (0.00)	3.74	0.000	5.00 (0.75)
Size	5.00 (0.50)	3.46	0.000	5 00 (0.75)
Shape	5.00 (0.00)	3.42	0.001	N/A
Can move while wearing	5.00 (0.00)	3.74	0.000	5.00 (0.00)
Not wanting to remove	5.00 (0.00)	3.74	0.000	5.00 (0.00)
Not hurting	5.00 (0.00)	3.56	0.000	5.00 (0.00)
Not causing pain	5.00 (0.00)	3.74	0.000	5.00 (0.00)
Usefulness				
Obstructs visual distractors	5.00 (0.00)	3.74	0.000	5.00 (0.00)
Helps focus	5.00 (0.00)	3.50	0.000	N/A
Ease of use				
Easy to put on/off	5.00 (0.00)	3.74	0.000	5.00 (0.00)
Puts on/off quickly	5.00 (0.00)	3.42	0.001	5.00 (0.00)
Needs help to put on/off	5.00 (0.50)	3.22	0.001	5.00 (0.00)
Aesthetics				
Likes how it looks	5.00 (0.00)	3.74	0.000	N/A
Not wanting to change colour/texture	3.50 (1.50)	0.97	0.332	N/A
Acceptance				
Happy to wear in class	5.00 (1.50)	3.14	0.033	N/A
Feels relaxed wearing	5.00 (0.00)	3.61	0.000	5.00 (0.00)
Will wear frequently	5.00 (0.00)	3.21	0.001	N/A

Note: N/A = Not Applicable.

For the comfort aspect, overall, based on the children's and researcher's ratings, the children felt comfortable wearing the ADHD Headmuffs. Minor issues related to the size and weight were found for some of the children who had small heads. Although not reported by the children, I observed another issue with three children with small heads in that the ADHD Headmuffs were big and slightly heavy and this seemed to slightly limit their ability to move. Similarly, while all children reported they can move easily while wearing the ADHD Headmuffs, I noticed that the same three children with small heads mentioned above were not moving easily and they had to adjust the ADHD

Headmuffs and put them in place again when they pick something from the floor. However, this is not considered a major usability problem in the long term since the current version of the ADHD Headmuffs is the first prototype and in future iterations, different sizes of the ADHD Headmuffs that fit different head sizes could be easily produced. All the children seemed to like the shape of the ADHD Headmuffs.

None of the children wanted to remove the ADHD Headmuffs but four children were touching the ADHD Headmuffs a little to feel if they were there and adjusted properly, but this is expected when wearing anything new until children get used to it. None of the children reported having shoulder or muscle pain but two children reported that they got hurt a little when wearing the ADHD Headmuffs and they pointed to their ears. After close observation, the source of pain was because those children had slightly big heads for the size of headphones, so the headphones were pressing on their ears and causing some pain. Again, this should not be a problem in the long term as bigger headphones that properly fit the children's head size can be produced in the future.

For the usefulness aspect, both the ratings by the children and my observations showed that the wings of the ADHD Headmuffs were useful in cutting the view of visual distractions around the children. All children also reported that the ADHD Headmuffs helped them focus except for one child who gave a neutral rating on that aspect. This child (P14) seemed anxious about wearing the ADHD Headmuffs and as the evaluation went along, her ratings for the later aspects, especially the ease of use and acceptance aspects were neutral or below neutral as explained below. I thought that she might have felt bored and wanted to go to class and so asked her if she wanted to stop the study, but she stated that she wanted to complete the evaluation.

For the ease of use aspect, both the ratings by the children and my observations showed that the ADHD Headmuffs were very easy to use. Children were easily and quickly able to put the ADHD Headmuffs on correctly and take them off. This may come from the fact that the ADHD Headmuffs are built with headphones that most children are familiar with wearing. However, two children had a slight problem and needed some help with putting the ADHD Headmuffs on quickly. Initially, they attempted to fold the upper part of their outer ear into the ear pads of the ADHD Headmuffs. When I asked why they were doing this, it emerged that these children had never owned or used headphones before.

For the aesthetic aspect, all the children seemed to like how the ADHD Headmuffs looked. Interestingly, when children were then asked whether they want to customize the ADHD Headmuffs, seven children did not want to change the colour or texture of the ADHD Headmuffs, but seven other children said they want to customize the ADHD Headmuffs by changing either the colour of the Headphones or the wings or both and one child wanted to add stickers to the wings.

It is interesting that the children who wanted to customize the ADHD Headmuffs had initially stated that they liked how the ADHD Headmuffs look. This might be because they do genuinely like how the ADHD Headmuffs currently look but, at the same time, think that customisation would be a good idea. It might also be that these children when asked about liking how the ADHD Headmuffs look, they did not know that there was a possibility for customizing the ADHD Headmuffs until being asked the second question about customization. At the same time, the children may have felt that they wanted to satisfy the researcher and say that they liked how the ADHD Headmuffs look and this implies the problem called satisficing (Read & Fine, 2005).

Sim et al. (2016) suggested that satisficing happens when a child gives answers that they think will please the researcher and are what the researcher wants to hear. It is a problem that is challenging to deal with in all usability and user experience studies conducted with children. It usually results from the nature of the relationship between the child and the researcher (Sim et al., 2016).

Nonetheless, the aesthetics of the ADHD Headmuffs is very important. Thus, the children's comments about wanting to customize the ADHD Headmuffs are very interesting and important to consider for future developments.

For the acceptance aspect, when children were asked if they would wear the ADHD Headmuffs in class, 11 out of the 14 children indicated they would have no problem in doing so. However, three children said that they would not wear the ADHD Headmuffs in class. One child did not say why but the two children said:

It is a shame to wear it in class (P14)

No, I cannot wear it. Other students will stare at me (P13)

It is important to note that “Shame” in Arabic and particularly in the Saudi culture is much stronger than in English (in which it can be the equivalent of “it’s a pity”) and it reflects something very negative and unacceptable from the perspective of cultural and social norms.

Moon et al. (2019) suggested that people may resist wearing assistive wearable technologies in front of others and as such I expected that some children may resist the idea of wearing the ADHD Headmuffs in front of their peers and teachers. In particular, this was expected with children with ADHD, as Barkley (2006) found that the majority of children with ADHD have low self-esteem and a lack of confidence. These factors may make children feel sceptical about what the ADHD Headmuffs will do for them. These problems also may make children feel scared of standing out or being stigmatized when wearing the ADHD Headmuffs.

Other factors that may lead to children not wanting to wear assistive technologies such as the ADHD Headmuffs are the social and cultural backgrounds, beliefs, and customs of children with ADHD. Their parents, along with people around them, play an important role in adopting or abandoning assistive technologies as suggested by King, et al. (1999) and Moon et al. (2019). This was obvious from the use of the word “shame” in P14’s comment, which reflects something very negative and unacceptable from the perspective of cultural and social norms, as discussed above.

Moon et al. (2019) also suggested that people usually value being accepted and not standing out from their peers and therefore may refuse devices or technology that may draw attention to them. This attitude may come from the child themselves or their parents. This suggestion was confirmed when children in this study were asked whether they would wear the ADHD Headmuffs if some of their classmates or teachers were also wearing them. Children said that they would not mind wearing the ADHD Headmuffs in class because in this case they would not be the only ones wearing Headmuffs and would not stand out. Therefore, to improve the acceptability of Headmuffs in this respect, other classmates and teachers could also be asked to wear them in class until children with ADHD get used to the ADHD Headmuffs.

13 out of the 14 children felt relaxed while wearing the ADHD Headmuffs and reported that they would be happy to wear the ADHD Headmuffs frequently as they helped them concentrate more. Only one child reported that she was not sure that the ADHD Headmuffs helped her focus or feel relaxed and thus she may not continue wearing them. This is the same child (P14) who reported that it is a “shame2 to wear the ADHD Headmuffs in class. So, her later negative responses may have been affected by asking her about wearing the ADHD Headmuffs in class and her negative feelings about that aspect.

For the open-ended questions, only three children offered answers to these questions. The responses of the children to the open-ended questions and the children’s age are shown in Table 7.3.

Table 7.3 Age and responses of children to the open-ended questions

Participant	**Age**	**Likes**	**Does not like**	**Wants to change**
P2	11.2	“I like the shape and colour”	“Nothing”	“I would like to change the colour of the Headmuffs to pink”
P3	11.7	“It makes me focus more”	“I do not like the colour of the headphones”	“I want to change the colour [of the headphones] to blue”
P7	12	“I like how it looks”	“I do not like the black colour of these [wings]”	“I want to put stickers on these [wings]”

The children who answered the questions were all over the age of 11 years whereas the remaining 11 children were under the age of 11 years. According to Jean Piaget (see Ojose, 2008), a pioneer of developmental psychology, children under the age of 11, are likely to be at the concrete operational stage of development and will be able to think creatively. However, children at this stage have not yet developed adult-level critical thinking processes. I speculate that children with ADHD might even be slower in moving to the next development stage. Thus, the open-ended questions might have been too challenging for the younger children in the study.

Another important factor, as suggested by Kesteren and colleagues (2003) and Markopoulos & Bekker (2003), that may affect the ability to answer open-ended questions and verbalize usability problems is whether children are used or having experience with speaking up to adults. Also, Markopoulos & Bekker (2003) highlighted the effect of child personality characteristics, such as being introverted or extroverted, on the ability to speak up and verbalise problems.

Even with the three children's answers to the open-ended questions, their answers did not add new information and they were similar to what they provided when rating the aspects such as changing the colour or the texture of the ADHD Headmuffs or adding stickers. This might be because children were asked to rate a lot of aspects about the ADHD Headmuffs and therefore had nothing else to add.

This study provides a useful first step to understanding the satisfaction of children with ADHD with the ADHD Headmuffs and it shows that children overall are very satisfied and accepted using the Headmuffs. However, the study methods of measuring the children's satisfaction and acceptance levels through questionnaire and observation had a number of limitations. For instance, the children only wore the ADHD Headmuffs for a short period of time (approximately 30 minutes) and thus there might be a novelty effect. Therefore, it is important that a future study investigates the long-term lived experience of children with ADHD with the ADHD Headmuffs in real classrooms.

In addition, the children were asked to help with the researcher with a new device, so there may well have been two problems, social desirability and satisficing. The social desirability problem results from children wanting to be helpful and encouraging to the researcher. Satisficing of answering to the questionnaires occurs when children tend to satisfy the researcher and provide answers that they think the researcher wants to hear, particularly by picking the extreme positive point in the Smileyometer. Despite the efforts to deal with these problems when designing and conducting this study through making the questions neutral and building good relationships with children prior and during the study, social disability and satisficing are inherent in usability evaluations with children and are extremely hard to avoid. Nonetheless, the problems could have been better mitigated in the context of this evaluation by asking the children's parents or a teacher, whom they feel very comfortable with, to ask the questions in this evaluation. The researcher could observe the children later using a video recording to ensure the parents or teachers are asking the questions properly as well as observe the children while they are wearing the Headmuffs. However, having parents or teachers ask the children the questions might affect the validity of the results as they are not experienced in how to conduct interviews, including, for example, being neutral when asking the children the questions.

Another important limitation is the potential researcher bias in the observation of the children. This could have been mitigated by asking another researcher who did not develop the assistive technology to observe the children. This was not possible in this study as it is part of a PhD programme and no other researchers were available to help. This problem could have also been dealt with by using video recordings of the children, and then having the analysis of the children's behaviour undertaken by a number of researchers. This solution also was not possible in this study due to restrictions at the school, which did not allow me to video record the children.

Another limitation of this study is that very few children answered the open-ended questions. The possible reasons were discussed above but this problem could potentially be addressed using a group evaluation method. This interesting idea was used by Kantosalo & Riihiaho (2019) in their usability testing study with children. In their study, they conducted group-based evaluations with extrovert children allocated to different groups with other children. Another thing I envision to be useful is to have older children distributed amongst discussion groups as well, since I found in this study that older children were the ones who answered the open-ended questions. This technique might be useful for encouraging younger or more introverted children in the group to talk and express their opinions.

Another limitation of this study is that it only considered the children's own satisfaction with the ADHD Headmuffs. Parents' and teachers' satisfaction with using the ADHD Headmuffs, whether at home or in class, are very important and are complementary to this study and thus, needs to be considered a future study.

One interesting lesson I learned from this study is regarding the use of the Smileyometer scale. The use of the scale seemed to be straightforward when asking most questions. However, a problem emerged when children had to rate the aspect that involves changing the ADHD Headmuffs. More explicitly, when children were asked: would you like to change the colour or texture of the ADHD Headmuffs? children either shook (to indicate "no") or nodded (to indicate "yes") their heads and only chose the extreme positive point on the scale. The suggested solution is to inform children about the side of the scale indicating wanting to change and the side indicating not wanting to change. Alternatively, a Visual Analogue Scale (VAS) with customized labels could be used.

Markopoulos et al. (2008) as well as other studies with children (e.g., MacFarlane et al.,2005; Obrist et al., 2009; Read & MacFarlane, 2006; Sim et al., 2016) have suggested that while VASs are very useful for eliciting children's opinions about products whether software or hardware, very young children tend to almost always chose the two highest ratings on the scale. In this study, many children chose the extreme positive end of the Smileyometer labelled "Brilliant". Nonetheless, I thought that the children might be really satisfied with the ADHD Headmuffs as their ratings were very close to the researcher's ratings. However, a future study on the long-term lived experience of children with ADHD with the ADHD Headmuffs may reveal different outcomes.

7.4 Conclusions

In conclusion, the results of this study were largely positive in relation to the usability and acceptability of the Headmuffs by the children with ADHD, which is gratifying, but it is important that one be very cautious in interpreting these results, due to the social desirability, satisficing aspects, researcher bias and the possible problems with the Smileyometer. In addition, the design of the ADHD Headmuffs needs to be refined and the comments from the children about wanting to customize them are very important. Thus, future work could include co-design workshops with children about how they would like to customize the ADHD Headmuffs. It would also be important to conduct this kind of evaluation with boys with ADHD since this study was only conducted with girls with ADHD in a public school. This may help reveal any usability issues from the boys' perspective. Another useful evaluation of the usability and acceptability of the Headmuffs could be conducted with usability experts and children, which will be considered in the next study (Study 6) of this programme of research.

Chapter 8 – Study 6: Evaluation by Experts of the Usability and Acceptability of the ADHD Headmuffs

8.1 Introduction

Two aspects of the usability of the ADHD Headmuffs, the effectiveness and user satisfaction, were investigated in Studies 2 and 3 (Chapters 4 & 5), respectively.

Another important method for evaluating the usability and acceptability of the ADHD Headmuffs is to have experts conduct evaluations (Lazar et al., 2017). Expert evaluations are typically performed by people who have expertise in human computer interaction, particularly usability. It would also be valuable that some of these experts have experience in the field of the product being evaluated (Petrie, 1997). Expert evaluations are very useful method and typically result in a list of usability problems (Nielsen, 1994; Petrie & Bevan, 2009). These evaluations can be done face-to-face or remotely (Petrie et al., 2006). Due to the ongoing coronavirus pandemic, I had to conduct this study remotely through online meetings and questionnaires.

There are several forms of expert evaluations, which include Consistency Inspection (Lazar et al., 2017), Guidelines Review (Dix et al., 2004), Cognitive Walkthrough (Lewis & Wharton, 1997), but the most well-known method is Heuristic Evaluation which was developed by Molich and Nielsen (1990) (for more expert evaluation types, see Petrie & Bevan, 2009). However, all these methods have been designed and used for evaluating computer software and websites.

As discussed in Chapter 7 (section 7.1), wearable assistive technologies may have all or some of three components, including hardware to be worn, an interface to help users interact with the wearable, and software for processing input and output. In the current prototype of the ADHD Headmuffs, no software or interface is included. Thus, the expert evaluation was conducted with respect to the hardware alone.

Researching the literature on design principles or guidelines for the hardware component of wearables in general and wearable assistive technologies specifically, only two studies were found. Knight et al. (2002, see also Knight & Baber, 2005) proposed a tool, the Comfort Rating Scales (CRS), that measures the comfort of wearable computers. Also, Crane and colleagues (2004) proposed a tool, the Wheelchair Seating Discomfort Assessment Tool (WcS-DAT), to measure seating discomfort that wheelchair users might experience. However, both the CRS and WcS-DAT were not developed or adapted for use for technology for children and obviously, what is appropriate for adults may not be appropriate for children. Also, these two tools do not cover many aspects that could be of relevance and importance to the usability and acceptability of the ADHD Headmuffs.

Thus, as existing guidelines are not suitable, one may argue that an expert review could be used. The expert review method involves a usability expert inspecting a product to check for any potential usability issues without the support of specific guidelines, instead, using their expert knowledge. The expert identifies usability problems and may then propose solutions for fixing them (Petrie & Bevan, 2009). To improve on this method, in this study, a bespoke questionnaire consisting of a set of appropriate aspects relevant to the usability and acceptability of the hardware involved, the ADHD Headmuffs, was created that would help guide the expert through the evaluation. The list of aspects was mostly built upon the list of aspects for measuring the satisfaction level and acceptance of children with ADHD with the ADHD Headmuffs used in Study 5 (see Chapter 7, section 7.2.3). Other important and relevant aspects for evaluating the ADHD Headmuffs by experts were also added.

This study evaluated the usability and the acceptability of the ADHD Headmuffs with experts in HCI, assistive technologies for children, including children with ADHD. The study involved online meetings between myself and each expert to explain and discuss the research, demonstrate the ADHD Headmuffs and answer any questions the experts may have, followed by online questionnaires completed by the experts after the meetings.

8.2 Method

8.2.1 Participants

Most participants in this study were recruited through the email list run by the British Computer Society Human-Computer Interaction Group (BCS-HCI). Some participants were recruited through the HCI research group at King Saud University in Saudi Arabia where I work. The inclusion criteria for participation in this study were one or more of the following:

A. experience with HCI and usability evaluations

B. experience with assistive technologies

C. experience with usability evaluation for assistive technologies

D. experience with technologies for children

E. experience with technologies for ADHD

Experts who volunteered were asked to rate their level of experience on the following scale for each of these criteria: none, basic, medium, high.

Ten experts in HCI, assistive technologies and children including those with ADHD participated in this study. Table 8.1 summarises the experience levels on each of the criteria for the experts.

Table 8.1 Background information for expert participants

Participant	**Nationality**	**Work field**	**Level of experience for each criterion**				
			A	**B**	**C**	**D**	**E**
P1	Saudi	Academic/ Business	High	High	High	Medium	Medium
P2	British	Business	High	High	High	High	High
P3	Japanese	Business	High	Medium	No	High	None
P4	British	Business	High	High	High	Medium	None
P5	Chinese	Academic	High	High	High	Basic	None
P6	British	Academic	High	High	High	Medium	None
P7	American	Academic	High	Medium	High	Medium	High
P8	American	Academic	High	Medium	Medium	High	High
P9	Saudi	Academic/ Business	High	High	High	Medium	High
P10	Saudi	Academic	Medium	Medium	Medium	Medium	Basic

8.2.2 Design

This study was an online expert evaluation that evaluated the usability and acceptability of the ADHD Headmuffs with experts in HCI, assistive technologies and children with or without ADHD. The study comprised online meetings between meself and each expert followed by online questionnaires completed by the experts after the meetings.

The online meetings consisted of a presentation of slides explaining the research and demonstrating the ADHD Headmuffs through pictures and a video, along with an explanation of the scenarios of use of the ADHD Headmuffs, and the list of aspects for evaluating the ADHD Headmuffs. The meetings also involved a more general discussion between myself and the experts as well as answering any questions the experts may have had.

The questionnaire consisted of asking the experts to rate different aspects related to the usability and acceptability of the ADHD Headmuffs, in addition to commenting on the ratings given (see Section 8.2.4). Ratings were made on five-point rating items. The questionnaire also included an open-ended question asking the experts about their overall opinion of the usability and acceptability of the ADHD Headmuffs. The evaluation of the usability and acceptability of the ADHD Headmuffs was conducted using three scenarios of use. The scenarios were based on the chosen context of use of the ADHD Headmuffs, which is in educational settings. The scenarios were developed from my experience of the educational settings of my child with ADHD and after working with children with ADHD and talking to the parents of children with ADHD in the previous studies of this programme of research (For more details, see Chapter 6, section 6.2).

As discussed in section 8.1, none of the standardized questionnaires or proposed tools for expert evaluations that were found in previous studies were fully suitable for my aims. Therefore, a bespoke questionnaire was developed, which consisted of a set of aspects relevant to the usability and acceptability of the ADHD Headmuffs that would help guide the expert evaluation. The list of aspects was built upon the list of aspects for measuring the satisfaction levels and acceptance of children with ADHD with the ADHD Headmuffs used in Study 5 (see Chapter 7, section 7.2.3). Other important and relevant aspects for evaluating the ADHD Headmuffs by experts were also added. The added aspects were important for a deeper discussion about some aspects such as usefulness, ease of use and acceptability particularly acceptance of the ADHD Headmuffs to teachers and parents of children with ADHD.

8.2.3 Materials

Materials for the online meetings

The materials for the online meetings consisted of introductory information about me and the research (given verbally), including what would happen to the data collected and the confidentiality agreement, and asking for experts' verbal informed consent. It also consisted of a presentation given verbally by me that contained: textual information about ADHD, its symptoms, underlying sources of problems and the probable resulting impairments for experts who had no previous knowledge of ADHD and pictures of the design stages of the ADHD Headmuffs (see Chapter 6, Figures 6.1, 6.2, 6.4, 6.5). This was followed by a demonstration video of a child wearing the ADHD Headmuffs, both textual and verbal descriptions of the scenarios of use for the ADHD Headmuffs and the list of evaluation aspects of the ADHD Headmuffs and lastly, how to respond to these aspects (for the online meeting materials, see Appendix F.3).

Scenarios of use of the ADHD Headmuffs

As discussed in section 8.2.2 above, based on the context of use of the ADHD Headmuffs, which is in educational settings, scenarios of how the ADHD Headmuffs would be used were developed. These include three scenarios of use of the ADHD Headmuffs:

Scenario 1: Doing homework at home

Peter is an 8-year-old child, diagnosed with ADHD. Peter has come home from school and had a rest and now needs to start working on his homework. To start with, his mother, Sara, tells him what tasks he needs to do this afternoon and gives him some initial guidance on how to do these tasks. Then, Sara helps Peter to put on the ADHD Headmuffs and turn on white noise. Peter picks up his pen from his bag or the desk and starts doing his homework. When Peter has questions, he turns off white noise and takes off the ADHD Headmuffs. They can then discuss his question. Peter might wear the ADHD Headmuffs for 30 to 45 mins straight. He might also remove them when he needs to take a break.

This scenario illustrates the following points along with the usability or acceptability aspects addressed (for the full list of aspects, see Table 8.2):

- Peter takes off and puts on again the Headmuffs when wanting to talk to his mother or take a break. Aspect addressed: Ease of use (all aspects except for quickly put in and taking off Headmuffs since Peter does not have restricted time when doing his homework)
- Peter picks anything he needs from his bag or desk. Aspects addressed: Comfort (restrict movement)
- Peter wears the Headmuffs for a period of 30 to 45 mins. Aspects addressed: Comfort (pain and muscle fatigue)
- The Headmuffs helps Peter concentrate when doing his homework. Aspects addressed: Usefulness
- Peter wears the Headmuffs whenever he wants to do his homework. Aspects addressed: Acceptability of children (feeling relaxed and continue wearing the Headmuffs)
- Peter's mother helps him wear the Headmuffs. Aspects addressed: Acceptability of parents (safe and wear the Headmuffs at home)

Scenario 2: Taking a test in class

Peter is in class and is about to take a written test. Initially, Peter gets instructions from the teacher about how to take the test. Then, the teacher helps Peter to put on the ADHD Headmuffs and turn on the white noise. Peter picks up his pen from his bag or desk and the test paper and starts working on the test. If the teacher wants to talk to Peter or all children in the class, there is an application that connects the teacher's microphone to Peter's ADHD Headmuffs. This allows the teacher to remotely turn off white noise and then talk with Peter through the ADHD Headmuffs. And when the teacher finishes talking, the teacher turns on the white noise again. Similarly, when Peter has a question or wants to talk to the teacher, the teacher turns off the white noise. And when they are finished, the teacher turns on the white noise. During the test, Peter may pick anything he needs from his bag or desk. The tests on average last 15 to 30 mins. Peter can then take off the ADHD Headmuffs.

This scenario illustrates the following points and the related aspects (see Table 8.2 for the list of aspects):

- Peter puts on the Headmuffs to start the test and takes them off when he is finished. Aspects addressed: Ease of use
- Peter picks anything he needs from his bag or desk. Aspect addressed: Comfort (restrict movement)
- Peter wears the Headmuffs for a period of 15 to 30 mins. Aspects addressed: Comfort (pain and muscle fatigue)
- The Headmuffs helps Peter concentrate when taking a test. Aspects addressed: Usefulness.
- Peter wears the Headmuffs when he takes a test. Aspects addressed: Acceptability of children (feeling relaxed, continue wearing the Headmuffs, feeling embarrassed and feeling conspicuous), Acceptability of parents (safe and wear the Headmuffs in class)
- Peter's teacher helps him wear the Headmuffs. Aspects addressed: Acceptability of teacher (safe and wear the Headmuffs in class when taking a test)

Scenario 3: Attending a lesson in class

Peter is in class and needs to listen to the teacher explaining the lesson. The teacher helps Peter put on the ADHD Headmuffs to eliminate some of the visual distractions around him. Peter can then listen to the teacher talking through the ADHD Headmuffs. In this situation, he would not turn on the white noise. However, once he needs to solve an exercise, he can turn on the white noise to also down auditory distractions. Peter may solve the exercise verbally or by writing the answer in his book. Peter may pick anything he needs from his bag or desk. The lessons on average last 30 to 45 mins. When the lesson is finished, Peter can take off the ADHD Headmuffs.

This scenario illustrates the following points and the usability or acceptability aspects addressed (for the full list of aspects, see Table 8.2):

- Peter puts on the Headmuffs when the lesson starts and takes them off when the lesson is finished. Aspects addressed: Ease of use
- Peter picks anything he needs from his bag or desk. Aspects addressed: Comfort (restrict movement)
- Peter wears the Headmuffs for a period of 30 to 45 mins. Aspects addressed: Comfort (pain and muscle fatigue)

- The Headmuffs helps Peter concentrate when attending a lesson. Aspects addressed: Usefulness.
- Peter wears the Headmuffs when he attends a lesson. Aspects addressed: Acceptability of children (feeling relaxed, continue wearing the Headmuffs, feeling embarrassed and feeling conspicuous), Acceptability of parents (safe and wear the Headmuffs in class)
- Peter's teacher helps him wear the Headmuffs. Aspect addressed: Acceptability of teacher: safe, wear the Headmuffs in class when attending a lesson

Materials for the online questionnaire

The online questionnaire consisted of two sections:

a. Introduction – This was aimed to give introductory information about the researcher, the aim of the study, what would happen to the data collected, confidentiality agreement and informed consent form and instructions on how to complete the questionnaire. Although all this information was described during the online meetings, it was thought appropriate to give this information to the experts again since some experts had decided to fill in the questionnaires one or two weeks after the online meetings. When the expert gave their consent (for the information sheet and consent form, see Appendix F.1), they were presented with the next section.

b. Usability and acceptability of the ADHD Headmuffs – This section involved 24 aspects (see Table 8.2) which were categorized into two main categories: 1) usability, which included four sub-categories related to the design, comfort, ease of use, and usefulness of the ADHD Headmuffs and 2) acceptability, which included two sub-categories acceptability of the ADHD Headmuffs to children with ADHD and acceptability to parents and teachers of children with ADHD. Grouping relevant aspects into categories was designed to lower the cognitive load on the experts and allowed them to concentrate and think more deeply about aspects in a specific category, instead of having questions about different aspects listed randomly in the questionnaire (Lazar et al., 2017). The questionnaire asked the experts to rate the aspects and to comment on the ratings they had given. As illustrated above, the ADHD Headmuffs were shown to the experts and based on that the experts rated and commented on the design aspects. However, the other aspects included specific scenarios to explain the context of use of the ADHD Headmuffs (see Table 8.2). The ratings were made on five-point rating items, in which only the two extreme ends of each rating item were labelled. At the end of the questionnaire, the experts were asked an open-ended question to provide their overall opinion about the usability and acceptability of the ADHD Headmuffs (for the full questionnaire, see appendix F.2).

Table 8.2 Online questionnaire categories, aspects and questions for the experts, with associated rating endpoints

Aspects and Questions	Rating endpoints
1. Usability aspects	
1.1 Design aspects	
Size - Is the size of the Headmuffs appropriate for an average 8-year-old child with ADHD, like Peter?	Very appropriate (5) – Not appropriate at all (1)
Weight - Is the weight of the Headmuffs light enough or too heavy for an average 8-year-old child?	Very light – Very heavy
Shape - Is the shape of the Headmuffs appropriate for an average 8-year-old child?	Very appropriate – Not appropriate at all
Easily customised - Is it good to make the Headmuffs easily customized in terms of colour or texture to better fit the children's taste or gender?	Very good – Very bad
Pleasing design -Is the design of the Headmuffs is pleasing?	Very pleasing – No pleasing at all
1.2 Comfort	
Restrict movement - Would the Headmuffs restrict movement for an average 8-year-old child, as illustrated in all scenarios?	Very restrictive – Not restrictive at all
Being Pain - Would the Headmuffs be painful for an average 8-year-old child, as illustrated in all scenarios?	Very painful – Not painful at all
Causing muscle fatigue - Would the Headmuffs cause muscle fatigue in an average 8-year-old child, as illustrated in all scenarios?	Very much muscle fatigue – No much muscle fatigue at all
1.3 Ease of use	
Independently put on/off - Would it be easy or not for an average 8-year-old child to independently put on and take off the Headmuffs, as illustrated in all scenarios?	Very easy – very difficult
Quickly put on/off - Would an average 8-year-old child be able to put on and take off the Headmuffs quickly enough or not, as illustrated in scenario.2, 3?	Very quickly – very slowly
Easy to adjust - Would it be easy to adjust the Headmuffs to fit an average 8-year-old child's heads appropriately, as illustrated in all scenarios?	Very easy – very difficult
Easy to correctly put on - Would an average 8-year-old child be able to easily correctly put on the Headmuffs, as illustrated in all scenarios?	Very easy – very difficult

Aspects and Questions	Rating endpoints
1.4 Usefulness	
Concentrate more at home -Would the Headmuffs help an average 8-year-old child concentrate more when doing homework at home as illustrated in scenario.1?	Very helpful – Not helpful at all
Concentrate in class during a test - Would the Headmuffs help an average 8-year-old child concentrate more when taking a test in class as illustrated in scenario.2?	Very helpful – Not helpful at all
Concentrate more in class during a lesson - Would the Headmuffs help an average 8-year-old child concentrate more when attending a lesson in class as illustrated in scenario.3?	Very helpful – Not helpful at all
2. Acceptability aspects	
2.1 Acceptability of children	
Feeling embarrassed - Would the Headmuffs embarrass an average 8-year-old child during the use in class, as illustrated in scenario. 2 and 3?	Very embarrassing – Not embarrassing at all
Feeling relaxed - Would an average 8-year-old child would find it relaxing or not to wear the Headmuffs, as illustrated in all scenarios?	Very relaxing – Not relaxing at all
Feeling conspicuous - Would an average 8-year-old child would feel conspicuous or not when wearing the Headmuffs, as illustrated in scenario. 2 and 3?	Very conspicuous – Not conspicuous at all
Continue wearing - Would an average 8-year-old child would continue wearing the Headmuffs, as illustrated in all scenarios?	Very frequently – Very rarely
2.2 Acceptability of parents and teachers	
Safe - Would the Headmuffs be safe for an average 8-year-old child to use or not, as illustrated in all scenarios?	Very safe – Not safe at all
Parents happy for the child to wear them to at home - Would an average 8-year-old child's parents be happy for him to wear the Headmuffs at home as illustrated in scenario.1?	Very happy – Not happy at all
Parents happy for the child to wear them to in class -Would an average 8-year-old child's parents would be happy for him to wear the Headmuffs in class as illustrated in scenario.2 and 3?	Very happy – Not happy at all
Teachers happy for the child to wear them to during a test - Would an average 8-year-old child's teachers be happy for him to wear the Headmuffs when taking a test, as illustrated in scenario.2?	Very happy – Not happy at all
Teachers happy for the child to wear them during a lesson - Would an average 8-year-old child's teachers be happy for him to wear the Headmuffs when attending a lesson, as illustrated in scenario.3?	Very happy – Not happy at all

8.2.4 Pilot Studies

A pilot study was conducted to check for clarity of the wording of the questionnaire. It was conducted with two experts in usability and questionnaires. No issues were found. The two experts who participated in the pilot study did not participate in the main study.

A further pilot study was conducted with a PhD student in HCI and usability to check whether the content of the online meeting was clear and comprehensive. As suggested by the student, more information about ADHD and more pictures of the Headmuffs were added to the slides. No other issues were found. The student who participated in the pilot study did not participate in the main study.

8.2.5 Procedure

The study was conducted with experts individually and conducted remotely due to the restrictions resulting from the Coronavirus pandemic. Zoom meetings were arranged with the experts at their convenience. At the beginning of the meeting, introductory information about the researcher, the study aims, what would happen to the data collected and the confidentiality agreement were explained verbally to the expert. I then asked the experts for their verbal informed consent to complete the meeting. Then, if the expert has no previous knowledge of ADHD, I gave a brief presentation about ADHD, its symptoms, underlying sources of problems and the probable resulting impairments. Then, I presented and explained pictures for the design stages of the ADHD Headmuffs to the expert followed by a demonstration video of a child wearing the Headmuffs. The scenarios of use of the Headmuffs were then presented textually and explained briefly to the expert. This was followed by examples of the proposed aspects for the usability and acceptability evaluation of the ADHD Headmuffs and how to respond to these aspects in terms of rating the aspects and commenting on the ratings the experts had given. I also informed the experts about the weight of the ADHD Headmuffs, as the experts could not physically examine or wear them. I had discussions with the experts about the Headmuffs and about other topics such as their experience with other assistive technologies. At the end of the meeting, I answered any questions that the experts might have, informed them to write any comments or points they had discussed during the meeting in the online questionnaire and thanked them for their participation. After the meeting, an email was sent to the experts including a link to the online questionnaire and the study materials including, the scenarios of use of the ADHD Headmuffs and the presentation slides so the expert can check them at their leisure. The online meetings lasted on average 20 minutes.

8.2.6 Data Analysis

Only the data from the online questionnaire was included in the analyses in this study. Since not all the ratings were normally distributed, non-parametric statistics were used, including nonparametric one-sample Wilcoxon signed-rank tests for the ratings for each aspect against the neutral midpoint of 3 on the 1 to 5 rating items.

The analysis started with simple content analysis (Hsieh & Shannon, 2005) by categorising the aspects into positive, neutral and negative, depending on the experts' ratings and the content of the comment. The content analysis was used because I had a priori categories (Flick, 2014), mentioned above. A positive aspect is generally an aspect that is significantly positive above the midpoint of the rating item or has a trend towards a positive difference. A neutral aspect is an aspect with no significant difference from the midpoint of the rating item. A negative aspect is an aspect that is significantly below the midpoint of the rating item or has a trend towards a negative difference (for more information, see section 8.3.1). In addition, in each aspect, if specific issues were raised, these were noted, but there were not enough additional issues to add further categories (for more information, see section 8.3.2).

However, there were a number of interesting issues that emerged, which cut across the aspects and the answers to the open-ended questions and Thematic Analysis (Clark & Braun, 2014). was conducted to extract these (for more information, see section 8.3.4). This was carried out by two independent researchers who then worked together until reaching an agreement on the themes.

8.3 Results and Discussion

8.3.1 Analysis of Expert Ratings

The medians and semi-interquartile ranges for the 24 aspects against the neutral midpoint on the rating items are shown in Figure 8.1.

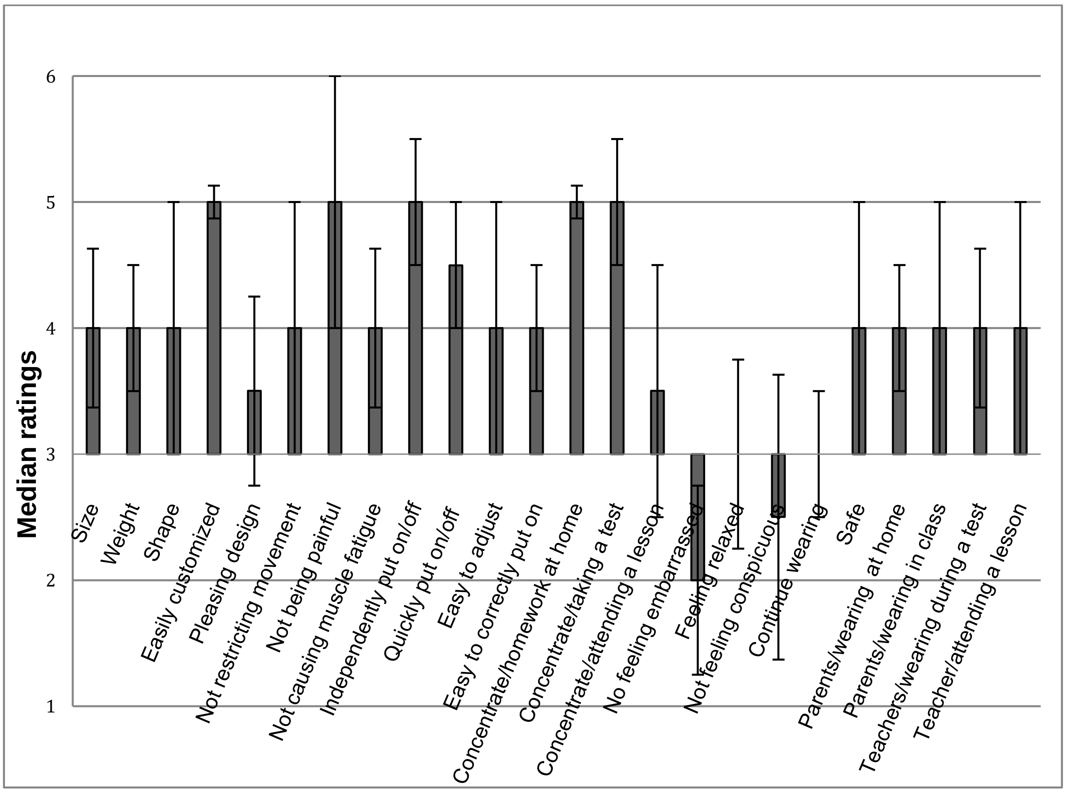


Figure 8.1 Medians and semi-interquartile ranges for the 24 aspects against the neutral point on the rating scale

The medians and semi-interquartile ranges of the ratings by the experts of the 24 aspects of the design, comfort, ease of use, usefulness and acceptability of children, parents and teachers to the ADHD Headmuffs are presented in Table 8.3. In addition, this table presents the results of one-sample Wilcoxon signed-rank tests to investigate whether the ratings were significantly different from the neutral midpoint of 3 on the 1 to 5 rating items.

Table 8.4 shows the 24 aspects of the ADHD Headmuffs and whether each aspect constitutes a positive or neutral aspect. There were no aspects that constituted negative aspects. There are 19 positive aspects, four aspects of the design, all aspects of the comfort, all aspects of the ease of use, two aspects of the usefulness, and six aspects of the acceptability of the ADHD Headmuffs. Five aspects, on the other hand, are only neutral aspects, one aspect of the design, one aspect of the usefulness, and three aspects of the acceptability of the ADHD Headmuffs.

Table 8.3 Medians and semi-interquartile ranges for the 24 aspects of the ADHD Headmuffs with results of one-sample Wilcoxon signed rank tests

Aspects	Expert ratings Median(SIQR)	W	p value
Design			
Size	4.00 (0.63)	1.82	0.018
Weight	4.00 (0.50)	1.34	0.059
Shape	4.00 (1.00)	1.86	0.024
Easily customized	5.00 (0.13)	2.65	0.004
Pleasing design	3.50 (0.75)	0.75	n.s.
Comfort			
Not restricting movement	4.00 (1.00)	1.95	0.062
Not being painful	5.00 (1.00)	2.12	0.011
Not causing muscle fatigue	4.00 (0.63)	1.67	0.053
Ease of use			
Independently put on/off	5.00 (0.50)	2.60	0.004
Quickly put on/off	4.50 (0.50)	2.59	0.004
Easy to adjust	4.00 (1.00)	2.25	0.015
Easy to correctly put on	4.00 (0.50)	2.59	0.004
Usefulness			
Concentrate more when doing homework at home	5.00 (0.13)	2.53	0.004
Concentrate more when taking a test in class	5.00 (0.50)	2.53	0.005
Concentrate more when attending a lesson in class	3.50 (1.00)	1.31	n.s.
Acceptability			
Not feeling embarrassed	2.00 (0.75)	0.82	n.s.
Feeling relaxed	3.00 (0.75)	0.97	n.s.
Not feeling conspicuous	2.50 (1.13)	0.97	n.s.
Continue wearing	3.00 (0.50)	1.63	0.059
Safe	4.00 (1.00)	2.07	0.024
Parents happy for the child to wear them at home	4.00 (0.50)	2.59	0.006
Parents happy for the child to wear them in class	4.00 (1.00)	1.82	0.046
Teachers happy for the child to wear them in a test	4.00 (0.63)	2.43	0.010
Teachers happy for the child to wear them in a lesson	4.00 (1.00)	2.27	0.015

Note: n.s = Not significant.

Table 8.4 The 24 aspects of the ADHD Headmuffs and whether each is positive or neutral

Aspect	Positive	Neutral
Design		
Size	X	
Weight	X	
Shape	X	
Easily customized	X	
Pleasing design		X
Comfort		
Not restricting movement	X	
Not being painful	X	
Not causing muscle fatigue	X	
Ease of use		
Independently put on/off	X	
Quickly put on/off	X	
Easy to adjust	X	
Easy to correctly put on	X	
Usefulness		
Concentrate more when doing homework at home	X	
Concentrate more when taking a test in class	X	
Concentrate more when attending a lesson in class		X
Acceptability of children, parents and teachers		
Not feeling embarrassed		X
Feeling relaxed		X
Not feeling conspicuous		X
Continue wearing	X	
Safe	X	
Parents happy for the child to wear them at home	X	
Parents happy for the child to wear them in class	X	
Teachers happy for the child to wear them taking a test	X	
Teachers happy for the child to wear them during a lesson	X	

8.3.2 Analysis of Expert Comments for Each Aspect

As discussed above, there are two categories of aspects: positive aspects and neutral aspects. The analysis and detailed discussion of each aspect in the two groups are provided below.

Category 1: Positive Aspects

As discussed above, 19 aspects of the ADHD Headmuffs fit into this group, design (size, weight, shape and easily customised), comfort (not restricting movement, not being painful, not causing muscle fatigue), ease of use (independently put on/off, quickly put on/off, easy to adjust, and easy to correctly put on), usefulness (concentrate more when doing homework at home and concentrate more when taking a test in class), and acceptability (continue wearing, safe, parents happy for the child to wear them at home, parents happy for the child to wear them in class, teachers happy for the to wear them taking a test, and teachers happy for him to wear them during a lesson).

Design: The size of the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 to the size of the ADHD Headmuffs, a significantly positive result. 7 experts gave positive ratings on this aspect (i.e. a rating higher than the midpoint on the rating item) and commented that the size of the ADHD Headmuffs is appropriate for an average 8-year-old child with ADHD and that the size is in line with other head-worn devices:

> *From what I saw, I think the size is good.* (P1)
>
> *I think about the headset in comparison to a bike helmet or similar equipment, this seems in line with other headworn devices.* (P7)
>
> *They seem to be of the right size to be comfortable for the average 8 year old child.* (P5)

These results are in line with the results from the children in Study 5 (see chapter 7, section 7.2.6). Overall, the children found that the ADHD Headmuffs fit them well. It is worth mentioning that the current version of the ADHD Headmuffs is the first prototype and in future iterations, different sizes of the ADHD Headmuffs that fit different head sizes could be easily produced.

Only three experts gave ratings that were neutral or below neutral about the size of the ADHD Headmuffs. Two experts thought that smaller Headmuffs would be better to increase the acceptance and reduce the negative feelings of wearers of the ADHD Headmuffs even though we had obtained a satisfactory response from children in Study 5. The two experts' comments were:

> *I hypothesise that the same effect can be achieved with smaller headmuffs - or at least, a satisfactory effect, balanced with the obtrusiveness/height. This could be future work - and it would be interesting to see relative performance gains with different headmuff sizes - balanced with acceptance metrics.* (P6)
>
> *I think a smaller form factor - but closer to the eye would look better.* (P8)

It would be interesting in the future to investigate the degree of effectiveness of the different sizes of the wings in improving attention and reducing distractors in children with ADHD.

Design: The weight of the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 to the weight of the ADHD Headmuffs, a significantly positive result. All experts, including six experts who gave positive ratings and four experts who provided neutral or below neutral ratings on this aspect, thought that the ADHD Headmuffs are appropriately light in weight. However, some experts suggested that the weight might be problematic after using the ADHD Headmuffs for an extended period of time and that breaks during use would be required to avoid fatigue:

> *The weight doesn't appear excessive at all. However, it would be crucial to test such a weight for extended periods of time. Children and adults wear headphones and headsets, trouble-free, for extended periods of time, particularly with working from home as so many are currently. It would be interesting to monitor if, in the long-term, this has any detrimental effects.* (P2)
>
> *While they seem to be light enough, how heavy/light they should probably dependent on how long they are worn.* (P3)
>
> *It may not be too heavy for a short period, but it may be the case for longer time.* (P4)
>
> *I think, as you explained, the weight was rather acceptable. Although breaks would still be required.* (P6)

The positive results about the weight of the ADHD Headmuffs are in line with the results obtained from children with ADHD in Study 5, in which children found the ADHD Headmuffs to be light in weight. Researching the literature, no studies were found that investigated the effect of wearing headphones for long period of time on children. So, it would be interesting in a future study to examine this effect and provide advice on the recommended time for wearing the ADHD Headmuffs, accordingly. As for now, children are expected to wear the ADHD Headmuffs for a period of half an hour, which is the average typical class time and then take a break for about five to ten minutes.

Design: The shape of the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 for the shape of the ADHD Headmuffs, a significantly positive result. Six experts gave positive ratings on this aspect and thought that the shape of the ADHD Headmuffs is good, considering that one of the aims of the ADHD Headmuffs is to reduce visual distractors, so the shape serves that aim. Examples of experts' comments:

> *To an extent a compromise always has to be reached. Indeed, the purpose of the headmuffs is to minimise 'external' distraction and hence you are limited on the extent to which you can make them unobtrusive and still achieve the desired effect.* (P2)
>
> *The shape, form and size of the shield seem appropriate to reduce the child's field of vision and help them stay focused on their tasks. This prototype's shape restricts vision but still allows the child to see the objects placed in front of him/her.* (P9)

These positive results about the shape of the ADHD Headmuffs are in line with the results obtained from children with ADHD in Study 5, in which children were very satisfied with the shape of the ADHD Headmuffs.

However, four experts were neutral about the shape of the ADHD Headmuffs. Only two of them provided comments, which were similar to their comments on the size aspects, in which they suggested that smaller Headmuffs would be better:

> *I think this is related to my comments for 2a [the size aspect].* (P6)
>
> *As [I] said [I] think smaller would look better / especially in social settings.* (P8)

These comments seemed to be more related to the acceptability of children aspects, particularly feeling embarrassed or conspicuous aspects and not really to the size or shape of the ADHD Headmuffs.

Design: Easily customized

Overall, the experts gave a median rating of 5.00 to this aspect, a significantly positive result. Nine experts gave positive ratings on this aspect and thought that it is better to make the ADHD Headmuffs easily customized in terms of colour and texture to fit the child's taste and preference and to increase acceptability:

> *[Customization] will make it more attractive to the child, and by consequence more appealing to use.* (P5)
>
> *I think [Customization] is very important for acceptance. (P9)*
>
> *If the Headmuffs are designed in an attractive way, the children may find it fun. Or if they have the control to design or customise their own. Like changing the Headmuff color or adding stickers. (P10)*

The need for customization emphasised by experts is in line with the results obtained from the user satisfaction study (Study 5, chapter 7), in which children also stressed the need for customization of the ADHD Headmuffs.

The results are also in line with previous research by Kinsella and colleagues (2017) that evaluated the usability of a wearable social skills training technology for children with Autism Spectrum Disorder (ASD) and found that customization is very important for the usability and acceptability of children to the technology. In addition, Ariyatum et al. (2005) and Shinohara and Wobbrock (2016) linked the aesthetic appeal of wearable assistive technologies with users' acceptance. Similarly, Desmet (2003) has found that children showed great interest and appreciation for the aesthetic qualities of wheelchairs. In this context, Gielen (2015) suggested that the acceptance of users to assistive technologies would increase if their appearance matched their personality as well as the aesthetic preferences of these users.

In this context, one expert suggested conducting co-design sessions with children to increase the acceptability of the ADHD Headmuffs:

> *In a classroom context, kids can contribute in a co-designing exercise, and possibly making this assistive technology more acceptable - being the product*

of everyone in the room. Kids would be proud to look at it, and wearers might feel proud wearing something that everyone is happy with. (P7)

The ADHD Headmuffs, in the current design, allow for reasonable customization in terms of choosing the preferred brand and colour of the headphones, changing the colour and texture of the fabric of the side wings and adding stickers to match the taste of the children. Nonetheless, as I proposed earlier in Study 5 (chapter 7) and as suggested by one of the experts, it would be very interesting to conduct co-design workshops with children to increase the usability and acceptability of the ADHD Headmuffs.

Interestingly, one expert was neutral about this aspect and thought that although customization is a good idea, she argued that there are not many colour variations for headphones. She said:

Potentially yes. Having said that, we don't see many different colour variations when it comes to existing headsets. (P3)

However, looking at the market of headphones, there are nowadays considerable variations in headphones in terms of colours and designs.

Comfort: Not restricting movement

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Six experts gave positive ratings to this aspect and thought that the ADHD Headmuffs would not restrict movement at all:

I see no reason why they would be restrictive. (P2)

Not at all while they are sitting there. (P4)

They would not restrict movement, but only visual range, which is the point of the ADHD Headmuffs to focus attention. (P5)

The positive result indicating that the ADHD Headmuffs are not restrictive at all is in line with the results obtained from Study 5 (Chapter 7). In Study 5, both children's ratings and the researcher's observations confirmed that the movement of the children was not restricted at all considering the expected scenarios of use of the ADHD Headmuffs.

However, four experts were neutral about this aspect and thought that there might be slight restriction of movement:

> *I'm not sure. [S]ome tiny weight on head may affect movement. [T]he answer would be to test it on several children from different age bands* (P1)

> *I suspect that this restriction of movement might actually be part of limited stimuli. Although lightweight, the visual affordances of the headset might lead children to think they had to keep their heads still or limit sudden gestures.* (P7)

As for P1's comment, Study 5 (see chapter 7), which was conducted on children with ADHD with age between 7 to 12, showed that there was no restriction of movement at all as reported by most children or observed by the researcher. The only exception was for two children who had slight movement restrictions. These two children had small head sizes, so the ADHD Headmuffs were slightly big for them and thus, they were not able to move freely. Turning to the comment above from P7, this raises an interesting point that wearing the ADHD Headmuffs may make children think that they should not move their heads at all and thus lead to restriction of movement. This was not noticed when conducting the user satisfaction study (Study 5) with children with ADHD. Nonetheless, it would be interesting to check this issue in the future with other children with ADHD.

One of the experts who gave a neutral rating about this aspect raised concerns about social interaction with other peers:

> *While this may sound contradictory to the key purpose of the headset, I wonder if the headmuffs can limit the interaction with peers in the classroom learning situation. (P3)*

This was discussed in more detail in a separate theme in section 8.3.4.

Comfort: Not painful

Overall, the experts gave a median rating of 5.00 to this aspect, a significantly positive result. Seven experts gave positive ratings to this aspect and thought that the ADHD Headmuffs are not painful at all as they are built on standard headphones. One expert commented:

> *With the headband design from the headphones and the light weight of the headmuffs, as long as it does not compress to much the ears it should not be painful.* (P5)
>
> *There are certainly no sharp or protruding elements of the design, and it is covered with a soft fabric, so it is unlikely to be painful.* (P2)

These positive results are in line with the results obtained from the user satisfaction study (Study 5, in Chapter 7). In Study 5, the majority of children with ADHD stated that the ADHD Headmuffs did not cause any pain. Only two children reported having some pain and after close observation, the pain was because the head size of the two children was big for the size of the headphones used.

However, three experts thought that the ADHD Headmuffs might be painful but only if used for extended periods of time and if created using poor quality headphones:

> *They look alright, probably it can get painful when worn for a long time.* (P3)
>
> *I think this all hinges on the quality of the headsets. I've worn low quality headsets which are quite painful after an hour or so of use.* (P6)

So, it is reasonable that with good quality headphones and the right fit for the children, the ADHD Headmuffs would not be painful. As for P3's comment, this highlights a very important issue and interestingly, there are no studies in the literature that have investigated the effect of the long-term use of headphones on children despite their long history. Therefore, this issue needs to be investigated in a future study looking at the long-term experience of children with ADHD with the ADHD Headmuffs.

Comfort: No causing muscle fatigue

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. 6 experts gave positive ratings on this aspect and thought that the ADHD Headmuffs will not cause muscle fatigue at all as they are light in weight and built on standard headphones. One expert said:

> *No, I don't think fatigue will be an issue. They seem light enough and do not require the user to hold an unnatural position.* (P7)

The positive results for this aspect are also in line with the results obtained from the user satisfaction study (Study5, in Chapter 7), in which children with ADHD stated that the ADHD Headmuffs did not cause muscle fatigue.

However, four experts were neutral about whether the ADHD Headmuffs may result in muscle fatigue and suggested that this may happen after the ADHD Headmuffs are worn for a long period of time:

> *Again, it probably depends on how long they are worn.* (P3)

> *...it depends on long-er term observation/experience. I suspect that it won't cause fatigue, but anything worn/performed for a sustained period of time may cause fatigue (even if it sounds inconsequential at first).* (P6)

> *It is not clear if the added weight would strain the muscles. Anthropometric analysis of the human head (cephalometry) for the target age group would provide insights on fatigue (with precision) for different contexts (e.g. gender, weight, height).* (P9)

Thus, wearing the ADHD Headmuffs for a long time, as suggested by some experts, may cause muscle fatigue. Nonetheless, as discussed above in the "causing pain aspect", further investigation of this aspect in a future study looking at the long-term experience of children with ADHD with the ADHD Headmuffs should be considered.

Ease of Use: Independently put on and take-off the ADHD Headmuffs

Overall, the experts gave a median rating of 5.00 to this aspect, a significantly positive result. All experts gave positive ratings on this aspect and thought that the children could independently put on and take off the ADHD Headmuffs as they are built on standard headphones that children are used to. Examples of comments:

> *Once these are set up, I foresee they will be no more problematic than putting on a regular set of headphones - something 8 year olds are perfectly adept at doing.* (P2)

> *Due to the headphone design which most persons are familiar with, it should not pose a problem.* (P4)

These positive results are in accordance with the results from Study 5 in which children were able to independently put on and take off the ADHD Headmuffs.

Ease of use: Quickly put on and take-off the ADHD Headmuffs

Overall, the experts gave a median rating of 4.50 to this aspect, a significantly positive result. All experts gave positive ratings on this aspect and thought that the children can quickly put on and take-off the ADHD Headmuffs as they are built on standard headphones that many children are used to, two representative comments were:

> *Once these are set up, I foresee they will be no more problematic than putting on a regular set of headphones - something 8 year olds are perfectly adept at doing.* (P2)
>
> *Due to the headphone design which most persons are familiar with, they are easy to take off in a moments notice.* (P5)

These positive results are in accordance with the results from Study 5 in which children were able to quickly put on and take off the ADHD Headmuffs.

Ease of use: Easily adjust the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Seven experts gave positive ratings on this aspect and thought that the ADHD Headmuffs can be easily adjusted to fit the child's head appropriately:

> *Yes, it seems easy.* (P3)
>
> *Due to the headphone design which most persons are familiar with, they are adjustable to the head of the wearer.* (P5)
>
> *Based on ease of use of helmets and other headphones, I would not expect a problem. … I would imagine that this device would accommodate that.* (P6)

However, three experts were neutral about this aspect as it depends on the headphones being used. Physical examination of the ADHD Headmuffs would have helped experts to judge whether it is easily adjusted, but this was not possible in the context of the online evaluation. One expert said:

> *It seems easy, however, it is challenging to tell how easy or difficult to adjust by just looking at photos.* (P3)
>
> *It depends on the headsets being used. But generally speaking, headsets are quite adjustable, and it's not a "new" technology for children.* (P6)

The comments from the experts were related to adjusting the headphones only. However, the experts never mentioned adjusting the wings, which could be adjusted as well by bending them inward or moving them up and down. Nonetheless, I found in Study 5 (see chapter 7, section 7.2.6) that after initial training children were able to easily adjust both the headphones and the wings as well.

Ease of use: Easily correctly put on the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. All experts gave positive ratings on this aspect and thought that the children can easily correctly put on the ADHD Headmuffs after initial training. Also, some experts thought that the ADHD Headmuffs are built on standard headphones that children are used to:

> *Once these are set up, I foresee they will be no more problematic than putting on a regular set of headphones - something 8 year olds are perfectly adept at doing.* (P2)
>
> *It seems straightforward, but it's better to be verified with actual tests.* (P3)
>
> *It should not be hard after some initial training.* (P4)
>
> *I don't see anything that is tricky about putting on the headset.* (P7)

These results are in line with the results obtained from Study 5 (see chapter 7, section 7.2.6). Children, overall, were able to easily correctly put on and take off the ADHD Headmuffs except for a very few children who had never worn headphones before and thus needed some training on putting them correctly.

Usefulness: Help concentrate more when doing homework at home

Overall, the experts gave a median rating of 5.00 to this aspect, a significantly positive result. Nine experts gave positive ratings on this aspect and thought that the ADHD Headmuffs will help children concentrate more when doing homework at home:

> *I think this is the best scenario for using this wearable. (P1)*
>
> *I believe the previous response applies: The key breakthrough here is the focusing and directing of attention. There are two distinct features: the devices ability to remove visual and auditory distraction (or stimulation), but also it's ability to direct focussed attention. (P2)*
>
> *I think it will help even non ADHD children since it focuses their attention and mental resources to the task at hand, in this case homework.* (P5)
>
> *I believe that this would be quite effective at home.* (P6)
>
> *The private setting of a home environment would be ideal for such devices.* (P9)

However, one expert was neutral about the effectiveness of the ADHD Headmuffs in helping children concentrate more when doing homework at home due to the novelty effect:

> *Hard to say. I would expect that controlling visual and audio stimuli will help, in general. And the novelty of the device might help in the short term.* (P7)

Usefulness: Help concentrate more when taking a test in class

Overall, the experts gave a median rating of 5.00 to this aspect, a significantly positive result. Nine experts gave positive ratings on this aspect and thought that the ADHD Headmuffs will help children concentrate more when taking a test in class and they provided the same comments for the previous aspect. Nonetheless, two experts thought that while the ADHD Headmuffs are helpful for improving the concentration of children with ADHD when taking a test, this would be greatly affected by the social context and the children's acceptance of wearing the ADHD Headmuffs in class:

> *It however depends on how that student feels about wearing it in class.* (P6)
>
> *[Yes], but due to the social situation acceptance might be less.* (P8)

This is certainly in line with previous research that found that both user and peer acceptance affect adopting or abandoning assistive technologies (Parette & Scherer, 2004; Scherer, 2005). In this context, Sahin et al. (2018) and Parette and Scherer (2004) emphasised the importance of peer acceptance in the inclusion of children with disabilities and the adoption of assistive technologies.

One expert thought that specific arrangements for children with ADHD when taking a test, such as having those children do the test in a separate room, may help with the stigma issue:

> *A test-taking context in a group setting (e.g. classroom at school) does provide some justification for such arrangements which might consequently address any perceived stigma for the child.* (P9)

The same expert who was neutral about the effectiveness of the ADHD Headmuffs in helping children concentrate when doing homework at home due to the novelty effect, provided the same rating and comment for this aspect as well.

This is indeed very interesting if future research could assess the long-term use of the ADHD Headmuffs and whether the attention improves further or the positive effect found in Study 4 (effectiveness of the ADHD Headmuffs in Chapter 6), wears off.

Acceptability: Children continue wearing the ADHD Headmuffs

Overall, the experts gave a median rating of 3.00 to this aspect, a significantly positive result. Four experts gave positive ratings on this aspect and thought that children would continue wearing the ADHD Headmuffs particularly at home, and highlighted three conditions for this to happen: (a) the ADHD Headmuffs become more aesthetically appealing, (b) children find the ADHD Headmuffs beneficial for them, and (c) parents or teachers asked them to do that:

> *…[A] child would continue wearing it, especially at home environment that is free from social stigma mentioned in the previous questions.* (P3)
>
> *I think this is highly likely … [when] the device as 'trendy' and inconspicuous as possible by looking at the vast range of headphones on the market and 'borrowing' styling and design features.* (P7)
>
> *[Yes, children will continue wearing the ADHD Headmuffs], as long as it has a benefit* (P8)
>
> *They may not wear it by themselves. Parents or teachers would ask them to do it.* (P10)

However, six experts were neutral about whether the children would continue wearing the ADHD Headmuffs. Experts highlighted very important factors for adopting or abandoning the ADHD Headmuffs, including aesthetics appeal and risk of bullying and stigma:

> *I think it depends on the measures that will be taken by the teachers to protect patients from being bullied by other peers.* (P1)
>
> *Many factors contribute toward assistive technology abandonment, including how aesthetics relates to stigma, how the assistive technology user is perceived in society (context of use) and how this affects device abandonment… [and] device aesthetics* (P9)

Stigma has repeatedly been associated with the use of assistive technologies in general (Parette & Scherer, 2004) and with the aesthetic appeal of these assistive technologies in particular (Dos Santos et al., 2020; Parette & Scherer, 2004; Shinohara &

Wobbrock, 2011, 2016). Bullying is also another problem that might be related to using the ADHD Headmuffs at school. These issues are discussed below in more detail in two separate themes, Stigma and Bullying (see section 8.3.4).

One expert also shed light onto the novelty effect on the user experience of children with the ADHD Headmuffs:

> *Hard to say. I do think that testing will need to extend beyond the novelty phase.* (P7)

This is very interesting and needs to be considered in a future study that investigates the long-term lived experience of children with ADHD with the ADHD Headmuffs.

Acceptability: The safety of the ADHD Headmuffs

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Six experts gave positive ratings on this aspect and thought that the ADHD Headmuffs are very safe for the children but they also highlighted some interesting points:

> *Again, I feel this would be context dependent. In the scenarios outlined, absolutely. I might be more concerned regarding safety outside of safe environments, such as walking along a pavement alongside a road; not that this is being suggested by the study. I wonder if they WERE to be used in such a scenario for prolonged periods if neck ligament damage could be caused with the increased rotation of the neck required to see the complete environment, but that's probably the focus for another study.* (P2)
>
> *Yes, the only possible hazard is the headphone's cable, and the headmuffs themselves I don't see them posing any serious source of injury.* (P5)
>
> *As long as the child is not moving around the classroom while wearing the device, I don't see a safety hazard.* (P7)

In this context, experts were told about one design consideration that was adopted to make the ADHD Headmuffs safe by covering any sharp edges with several layers of soft material (see Chapter 6, section 6.2).

Experts' comments about the safety of the ADHD Headmuffs were influenced mainly by the context of the use of the ADHD Headmuffs described in the scenarios, such that children would not wear them when walking or moving. One expert (P5) though thought that the headphone cable may cause injuries, but wireless headphones are now widely available in the market. Another expert (P2) raised an interesting issue about the safety of the ADHD Headmuffs on the child's neck when the ADHD Headmuffs are worn frequently for a very long time. This should be considered in a future study in collaboration with specialists in ergonomics and human factors engineering to come up with specific guidelines for using the ADHD Headmuffs.

However, four experts were neutral about the safety aspect. One expert was worried about the safety of noise volume and noise cancellation headsets for children:

> *I'm not sure whether noise cancellation tech is harmful for children. You need to confirm that. The noise presentation level needs to be calibrated to avoid noise-induced hearing loss.* (P1)

Nonetheless, according to the World Health Organization (2015), sounds below 85dB are considered safe for individuals when used for a maximum of eight continuous hours. In addition, the volume of white and pink noise used in this research was at 77dB, which is in line with the previous research with children (e.g. Baijot et al., 2016, Helps et al., 2014; Söderlund et al., 2007, 2010, 2016), in which the noise volume ranged from 65 to 85dB. As for noise cancellation headphones, they were not used in the studies in this programme of research. Also, no studies that have investigated the safety of using children to noise-cancellation headphones could be found in the literature. So, until positive evidence is developed, one should be careful when using them with children.

Two experts thought that the ADHD Headmuffs would be safe although this is dependent on the context of use:

> *This is a very important consideration. Limiting the visual/auditory senses will of course restrict reactivity - and therefore overall safety. There should be clear guidelines on their use in a school context.* (P6)
>
> *[This] depends on context....* (P8)

In the context of safety, a few experts thought that the ADHD Headmuffs might be unsafe because they restrict activity or block the environment. However, the ADHD Headmuffs are expected to be worn only while children are seated and doing tasks requiring attention such as reading, writing, or listening. Indeed, blocking the vision of distractors is one of the main aims of making the ADHD Headmuffs, so they should not be worn in situations in which awareness of the surroundings is important.

Acceptability: Parents' acceptance of children wearing the ADHD Headmuffs at home

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Nine experts gave positive ratings to this aspect and thought that parents will be happy for their children to wear the ADHD Headmuffs at home:

> *If they work as well as the research suggests in the context, I am sure parents would be happy to find a solution that improves their child's ability to concentrate, focus, and learn more effectively.* (P2)
>
> *Parents/guardians might feel happy that some technology is helping their children focus more and improve their learning.* (P6)

One expert was neutral on this aspect and suggested that the attitudes of parents towards their children wearing the ADHD Headmuffs at home must be assessed:

> *Attitudes of parents and/or caregivers would need to be assessed independently and are influenced by socio-cultural factors.* (P9)

Parents' acceptance of using the ADHD Headmuffs is indeed very important. Previous research on assistive technologies (see, Lang et al., 2014; Parette & Scherer, 2004; Sahin et al., 2018; Shinohara & Wobbrock, 2016) suggested that parents' attitudes towards disability and assistive technologies play a very important role in their children adopting or abandoning assistive technologies. Thus, it would be interesting in a future study to investigate the perceived usability and acceptability of parents of children with ADHD to using the ADHD Headmuffs.

Acceptability: Parents' acceptance of children wearing the ADHD Headmuffs in class

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Six experts gave positive ratings to this aspect and thought that parents would be happy for their children to wear the ADHD Headmuffs in class:

> *If [the ADHD Headmuffs] work as well as the research suggests in the context of doing school work, I am sure parents would be happy to find a solution that*

improves their child's ability to concentrate, focus, and learn more effectively. I would hope that the school were accommodating and as mentioned, make the introduction of the device something to be acknowledged to lessen the impact on the user. (P2)

If they are instructed as to how it works and why it's important. Additionally, social endorsement might be needed for parents to be confident that their child is not going to be bullied by being different. (P3)

[T]hey will be glad once they see the results, and hopefully also if his/her classmates cause no problems. (P5)

However, four experts were neutral or below neutral about whether parents would be happy for their children to wear the ADHD Headmuffs in class due to the risk of bullying:

I'm not sure. parents might be worried about their child being bullied because of that. (P1)

It all depends on the protocols in place - I suspect that parents may fear bullying. (P8)

Clearly, experts, whether they gave positive or neutral ratings, emphasized the risk of bullying when the ADHD Headmuffs are worn in school.

As with the previous aspect, one expert suggested that the attitudes of parents towards using the ADHD Headmuffs in class must be assessed and she provided the same comment. Parette and Scherer (2004) emphasized that even if a child is happy to use an assistive technology, their parents may not allow the child to use it in public settings. This is because parents may think that the visibility of the technology would draw negative attention to their children and make them stigmatised (Faucett et al., 2017; Parette & Scherer, 2004). So, elaborating upon the discussion in the previous aspect about the importance of assessing the parents' attitudes towards using the ADHD Headmuffs at home, it would be even more crucial to assess their attitudes towards the use of the ADHD Headmuffs in class. This is because the classroom setting is a place with a high potential for risk of bullying and stigma (Sahin et al., 2018).

Acceptability: Teachers' acceptance of children wearing the ADHD Headmuffs when taking a test

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Eight experts gave positive ratings on this aspect and thought that teachers would be happy for the child to wear the ADHD Headmuffs when taking a test, as this would be helpful for the child's attention:

> *… I am sure would be happy to find a solution that improves the child's ability to concentrate, focus, and learn more effectively.* (P3)
> *…[Teachers] will be glad once they see the results.* (P5)
> *[Teachers will be happy], if it helps the child focus and does not introduce potential for conflict and distraction in the long term…* (P7)

However, two experts were neutral about this aspect and they thought that teachers' acceptance of using the ADHD Headmuffs in class is dependent on the teachers' attitude toward assistive technologies and children with disabilities and this is also influenced by both social and cultural factors:

> *Teachers might show some resistance in using in-class new technology untrained teachers might also show resistance in dealing with children with special needs.* (P1)
>
> *Attitudes of teachers … are influenced by socio-cultural factors.* (P9)

Both comments from P1 and P9 are in accordance with several research studies on teachers and assistive technologies. For instance, Parette and Scherer (2004) stated that the positive attitudes of teachers towards accepting children with developmental disorders and assistive technologies facilitate the effective use of assistive technologies in the classroom and vice versa. They also suggested that the reasons for the negative attitude of teachers may come from the stigma of children with developmental disorders due to cultural or social factors (Parette & Scherer, 2004; Scherer, 2005). The negative attitude of teachers may also result from "technophobia", a term meaning that teachers may fear using technologies (Scherer, 2005).

In addition, Bauer and Piazza (1998) stated that teachers who have effective training in both assistive technologies and cultural diversity were more inviting to children with developmental disorders in their classrooms. This is consistent with results from a recent study by O'Sullivan et al. (2021), in which teachers reported that their lack of knowledge, skills and confidence in dealing with assistive technologies affected their perception and attitudes towards the use of assistive technologies by their students.

Undoubtedly, teachers play an important role in keeping children with disabilities in their class informed about assistive technologies used by children with developmental disorders. This in turn helps facilitate acceptance and minimize the negative impact of stigma on such children (Parette & Scherer, 2004).

Therefore, to maximise acceptance and successful implementation of assistive technologies in classroom settings, it is very important to keep teachers informed about the conditions of children with developmental disorders and the assistive technologies that may help them.

In this context, one expert (P9) suggested that the attitudes of teachers should be assessed:

> *Attitudes of teachers would need to be assessed independently* ... (P9)

This indeed is very important and may reveal important factors that affect the successful adoption of the ADHD Headmuffs by children with ADHD in classroom settings and thus should be considered in a future study.

Acceptability: Teachers' acceptance of children wearing the ADHD Headmuffs when attending a lesson

Overall, the experts gave a median rating of 4.00 to this aspect, a significantly positive result. Seven experts gave positive ratings to this aspect and thought that teachers would be happy for the child to wear the ADHD Headmuffs when attending a lesson as this will be helpful for the child's attention. They provided the same comments for the pervious aspect about teachers being happy about wearing the ADHD Headmuffs when taking a test.

However, three experts were neutral about this aspect. One expert thought that teachers' acceptance of using the ADHD Headmuffs is dependent on several factors, including the schooling system, the teaching style and the classroom setup. Another expert, as in the previous aspect, thought that teachers' acceptance is influenced by both social and cultural factors:

> *It depends on the teaching style, and the classroom setup - which is generally smaller groups, in a circular configuration. Not sure how this technology would affect learning … depends on the schooling system.* (P6)

> *Attitudes of teachers … are influenced by socio-cultural factors.* (P9)

All the discussion on the previous aspect about the importance of teachers' acceptance as well as training on assistive technologies and children with developmental disorders are certainly applicable here. Another important point raised by P6 was that the use of the ADHD Headmuffs during a lesson is highly dependent on the teaching style and the schooling system. So, if the lesson used collaborative learning, the ADHD Headmuffs would not be appropriate to be used. In the case of primary schools in Saudi Arabia, for example, the main channel for taking the lesson is through the teacher who explains the lesson to the whole class using the whiteboard. During that time children could be expected to wear the ADHD Headmuffs to improve their attention and reduce distractions. Depending on the subject, teachers may then put children in groups to facilitate collaborative learning and in this case, children would take off the ADHD Headmuffs.

Category 2: Neutral Aspects

As discussed above, five aspects of the ADHD Headmuffs fit into this group, design (pleasing design), usefulness (concentrate more when attending a lesson in class) and acceptability (not feeling embarrassed, feeling relaxed and not feeling conspicuous).

Design: Pleasing design

Overall, the experts gave a median rating of 3.5 to this aspect, a result not significantly different from the midpoint. Five experts gave positive ratings to this aspect and thought that the ADHD Headmuffs have a pleasing design. Five other experts were neutral or below neutral in their opinions about whether the design of the ADHD Headmuffs is pleasing. Nonetheless, all experts agreed on the strong need for customization of the colour and texture of the wings to increase the acceptability of the ADHD Headmuffs to children:

> *Understandably, the design is at a functional stage that considers user safety … the side coverings could be made in a variety of colours and designs, and are easily washable as well, which is a useful additional feature.* (P2)

> *It is not very aesthetically pleasing but functional.* (P3)
>
> *OK, but maybe there is room to improve depending on children's preferences.* (P4)
>
> *…Yes, very pleasing, even myself would like to have one. But I recommend to not using dark colour for children and make it attractive to them.* (P10)

The same discussion in the "Easily customized" aspect emphasizing the importance of aesthetics of the ADHD Headmuffs and its relation to the acceptance of children and minimizing stigma is certainly applicable to this aspect. As suggested earlier, it is important in a future study to focus on the aesthetics of the ADHD Headmuffs and to redesign the ADHD Headmuffs, particularly, the wings to make their design more pleasing and appealing to the children.

Usefulness: Help concentrate more when taking a lesson at class

Overall, the experts gave a median rating of 3.5 to this aspect, a result not significantly different from the midpoint. Five experts gave positive ratings and thought that the ADHD Headmuffs would help children concentrate more when taking a lesson in class. However, they raised concerns about social interaction or when having group work:

> *For focussing attention, I am convinced the device will be beneficial. However, context will be key. If the class a set a collaborative verbal activity, the device may impede and this would be good to research…* (P6)
>
> *They will be more concentrated but might miss the social aspects of class. and also acceptance by other students might be a problem. (P8)*
>
> *Yes but it shouldn't isolate children from any class interaction or discussion.* (P10)

However, five experts were neutral or below neutral about this aspect. Examples for their comments:

> *This depends on the measures that will be used within the class.* (P1)
>
> *I think that learning is more than just looking at the board while listening to the teacher. Learning takes place in group sometimes, or by listening to other kids share their thoughts. So, no I wouldn't say it would be helpful for the lesson task.* (P6)

> *[T]hey will be more concentrated but might miss the social aspects of class. [A]nd also acceptance by other students might be a problem.* (P8)

It is obvious that experts, regardless of their ratings, suggested that learning is more than just looking at the board while listening to the teacher and it takes place sometimes in groups, or by listening to other children sharing their thoughts. This certainly is highly dependent on the schooling system and teaching style and cannot be generalised (Ravneberg & Soderstrom, 2017). Also, the ADHD Headmuffs are expected to be worn in the case where classmates' interaction or group teaching is not taking place. Finally, one expert suggested that wearing the ADHD Headmuffs in class is dependent on the measures taken by the school and by looking at her previous comments, she was referring to measures to prevent stigma and bullying of these children.

Acceptability: Feeling embarrassed

Overall, the experts gave a median rating of 2.00 to this aspect, a result not significantly different from the midpoint. Eight experts gave neutral or below neutral ratings on this aspect. Some of them thought that children would feel embarrassed when wearing the ADHD Headmuffs as they will stand out and feel stigmatized from their classmates:

> *Children can be subject to be stigmatized from wearing unusual headset. A number of measures need to be considered to reduce this effect, for examples, other selected healthy children may wear a similar fake headmuffs to normalize its usage.* (P1)

> *There is a possibility a child feels embarrassed using the ADHD Headmuffs, as they would look 'different' from other children. It could be mitigated by all children in the class to wear the Headmuffs for specific tasks where attention is needed.* (P3)

> *In its current form, I think my child might resist wearing something so different from classmates...* (P7)

> *Usually doing something different than their classmates cause embarrassment.* (P10)

Some experts attributed the feeling of embarrassment to the aesthetics of the ADHD Headmuffs as well as to the social acceptance of assistive technologies:

> *In its current form, I think my child might resist wearing something so different from classmates. Perhaps if the form factor were more whimsical and/or customizable, it would take on more of a quality of super hero helmet...(*P7)
>
> *The Headmuffs' users might feel stigmatized due to device aesthetics and social acceptance… Research has shown that aesthetics influence how assistive technologies and their users are perceived.* (P9)
>
> *It could be, that will depend more on the social pressure of his/her classmates. But other students using them also could alleviate the social pressure.* (P5)

These ideas are consistent with results from previous research investigating the use of assistive technologies by people with disabilities. For instance, Ariyatum et al. (2005) suggested that the aesthetic appeal affects the acceptance of using wearable assistive technologies. Similarly, a study by Dos Santos et al. (2020) found that the positive perception and acceptance by users of assistive technologies is strongly related to the aesthetics of assistive technologies which contribute to stigma and social acceptance. The study also found that people with disabilities reported feeling embarrassed when wearing assistive technologies as these technologies drew unwanted attention and stigma (Dos Santos et al., 2020). The aesthetic qualities of assistive technologies also affect the feeling of stigma and thus the social acceptance (Shinohara & Wobbrock, 2016). Similarly, Parette and Scherer (2004) suggested that the aesthetics of the assistive technologies contribute to people with disabilities feeling deviant and stigmatised.

Experts (P1), (P3) and (P5) in their comments above suggested that the feeling of embarrassment could be alleviated by asking some other classmates to volunteer to wear the ADHD Headmuffs. Perhaps teachers would also help in this by wearing the ADHD Headmuffs from time to time to normalise their use.

Expert (P6) provided an interesting comment:

> *I suspect that in class, students wearing this will be "labelled" through technology that is supposed to help…Now, in class, this might be a universal technology for specific cognitively expensive tasks - worn by all students when concentration is necessary. Having individual students wear it, might make an invisible condition, very visible – unfairly.* (P6)

Looking at P6's experience, he indicated that he has no previous knowledge of ADHD. While his argument about making the invisible condition visible may apply to some kinds of disabilities, it may not necessarily apply to ADHD. ADHD is a behavioural disorder, and its symptoms are apparent to varying degrees, depending on the severity level, to people in contact with a child with ADHD. In addition, from the field studies that I conducted in an inclusive school, it was clear that if the child has a neurodevelopmental disorder such as autism or ADHD, the child's classmates were aware of that.

On the other hand, two experts gave positive ratings on this aspect and thought that the ADHD Headmuffs would not be embarrassing. They commented about factors that may affect the feeling of embarrassment, including other classmates wearing the ADHD Headmuffs, school policies and roles, the type of school the child is attending, whether mainstream or for special education. One expert also emphasized the importance of well-informed societies that are inclusive and accepting:

> *This is closely linked with the environment in which the child is using the Headmuffs ... educating and spreading awareness of the condition is the only way to make society more inclusive and accepting of difference. It would depend too on if the child is attending mainstream school or a more bespoke educational institution.* (P2)
>
> *Maybe a little but if a few are using it, it should be alright* (P4)

Acceptability: Feeling relaxed

Overall, the experts gave a median rating of 3.00 to this aspect, a result not significantly different from the midpoint. Four experts gave positive ratings and stated that children would feel relaxed when their concentration improves. One of the experts' comments was:

> *I suspect that an 8 year old child will be more inclined to forget all about the fact they're wearing the device, particularly if - as the research suggests - they are able to concentrate more readily on the task at hand…* (P1)
>
> *…[I]t could be relaxing to have distractions reduced and to be able to focus…* (P7)
>
> *I guess when it helps for concentration they would find it relaxing.* (P8)

These positive results are in line with the results obtained from children with ADHD in Study 5, in which children reported feeling relaxed when wearing the ADHD Headmuffs.

However, six experts gave neutral or below neutral ratings and two of them commented that children may not feel relaxed as they might feel embarrassed or stigmatised when wearing the ADHD Headmuffs:

> *[C]hildren can be subject to be stigmatized from wearing unusual headset. …* (P1)

> *There is a possibility a child feels embarrassed using the Headmuffs, as they would look 'different' from other children. It could be mitigated by all children in the class to wear the Headmuff for specific tasks where attention is needed.* (P3)

One of the experts who gave a neutral rating thought that children may feel relaxed when they can perform better:

> *Just wearing them maybe not so much due to the restrictive nature of the headmuffs for their vision, but for when doing a task, I think it can be relaxing, especially since they will feel they are doing better and get a sense of accomplishment.* (P6)

Another expert highlighted factors that may affect relaxation of children while wearing the ADHD Headmuffs, she said:

> *A child's perceived comfort in wearing a device varies depending on the context of use, duration of wearing the device and the child's attitude toward assistive technologies* (P9)

Certainly, factors including attitudes of children towards assistive technologies, feeling embarrassed or stigmatised affect the acceptance of children with ADHD to wearing the ADHD Headmuffs. These factors have a negative effect on children feeling relaxed when wearing the ADHD Headmuffs. This is expected to be particularly apparent in public settings such as at school.

Acceptability: Feeling conspicuous

Overall, the experts gave a median rating of 2.50 to this aspect, a result not significantly different from the midpoint. Eight experts gave neutral or below neutral ratings to this aspect and thought that the ADHD Headmuffs would make the children stand out. They also thought that both the social acceptability and the child's own acceptance of using the Headmuffs would contribute to feeling conspicuous or not:

> *They will surely be outstanded by wearing this headset.* (P1)

> *This can be decided by the environment in which a child lives. If someone says something about the Headmuff wearing, this can trigger the sense of conspicuousness.* (P3)
>
> *In a class setting it will draw some attention from his/her classmates, but once they accept the Headmuffs and others start using it also, I bet it would be less.* (P5)
>
> *Again, the form factor of current prototype stands out, especially compared to other kids gear like bike helmets, backpacks, tshirts, toys, etc.* (P7)
>
> *[This] depends on the child.* (P8)
>
> *[Yes because of the] visibility of the device.* (P9)

This is in accordance with research by Parette and Scherer (2004) that suggested that an unusual device draws unwanted attention and triggers feelings of being conspicuous, especially in public settings.

However, two experts gave positive ratings and thought that children might initially feel conspicuous when wearing the ADHD Headmuffs but then after they get used to them and understand their benefits, this feeling will disappear. One expert commented:

> *…[P]erhaps initially conspicuous but I think if the device is introduced, acknowledged, and explained, then in a practical sense the user will very soon merely focus on the task at hand.* (P2)

8.3.3 Analysis of the Open-Ended Question

At the end of the questionnaire, experts were asked an open-ended question about their overall opinion about the usability and acceptability of the ADHD Headmuffs. Experts, overall, provided comments similar to their comments to the ratings they had given. This might be because experts were asked to rate a lot of aspects about the ADHD Headmuffs and therefore had nothing else to add. I included the answers to the open-ended question in the thematic analysis as explained below.

8.3.4 Emergent Themes

There were clearly a number of themes, which the experts raised in discussing the specific aspects of the ADHD Headmuffs and in their answers to the open-ended question which cut across numerous aspects. Therefore, their comments beyond their specific comments about the aspects were analysed using the thematic analysis method. Three themes emerged: risk of stigma, risk of bullying, and lack of social interaction. These are discussed in the next sub-sections.

Risk of stigma

Stigma was frequently mentioned in the experts' comments, particularly their comments on the acceptability aspects of wearing the ADHD Headmuffs. Experts linked stigma to many factors including aesthetic appeal, visibility of the ADHD Headmuffs, standing out when wearing unusual device, acceptance of children and social acceptance (for examples of the experts' comments about stigma, see section 8.3.2).

Crocker et al. (1998) defined a stigmatised person as "a person whose social identity, or membership in some social category, calls into question his or her humanity - the person is devalued, spoiled, or flawed in the eyes of others" (p. 504). Stigmatization has been linked to assistive technologies (Brickfield, 1984; Parette & Scherer, 2004; Luborsky, 1993; Zimmer & Chappell, 1999) and usually leads to the abandonment of these technologies. Nonetheless, a large body of literature (e.g., Barker, 1948; Fine & Asch, 1988; Goffman, 1963; Parette & Scherer, 2004) has also discussed for a long time the stigmatization of persons due to having disabilities.

In the context of ADHD, a recent study by Metzger and Hamilton (2021) has confirmed the stigma of ADHD found by previous research (see Walker et al., 2008; Law et al., 2007). Metzger and Hamilton (2021) found that teachers have stigmatized children once they were diagnosed with ADHD and expected them to perform poorly regardless of their results on subject tests. They suggested that the perception and the negative behaviour of teachers towards children with ADHD are affected by negative cultural beliefs and stereotypes around ADHD (Metzger & Hamilton, 2021). As discussed earlier, teachers play an important role in the understanding and acceptance of their students to children with developmental disorders and to assistive technologies.

Therefore, while the design aspects such as the aesthetic appeal and visibility of the assistive technology including the ADHD Headmuffs are important, collaborative efforts and regulations are needed to correct the misconceptions about children with developmental disorders and assistive technologies and to ensure social acceptance.

For instance, society should be well-informed about children with developmental disorders and their use of assistive technologies (Parette & Scherer, 2004). In particular, teachers need to be trained about the conditions of children with developmental disorders and their use of assistive technologies.

One important consideration with relation to stigma is that while the experts emphasized the effect of stigma due to wearing the ADHD Headmuffs in class, the majority of children, in Study 5 (see Chapter 7), said they would be happy to wear the ADHD Headmuffs in class. It might be that a study of the actual use of the ADHD Headmuffs in the classroom and the long-term lived experience of children with ADHD with the Headmuffs especially in classroom settings may reveal different results. It might also be that children do not perceive stigma the same way the adult experts did and this interestingly has not been investigated before in the literature as far as I am aware.

Risk of bullying

Bullying is another issue that was emphasized in the experts' comments, particularly on some of the acceptability aspects of wearing the ADHD Headmuffs in schools (see section 8.3.2 for examples of the experts' comments about bullying).

Bullying was first defined as "group violence against a deviant individual that occurs suddenly and subsides suddenly", which was then expanded "to include systematic one-on-one attacks of a stronger child against a weaker child" (Smith et al., 2002). Bullying can be verbal or physical or both.

Certainly, bullying is always an issue for children in school (Abdulrazzaq & Abass, 2021; Sahin et al., 2018) and children with disabilities are at greater risk of bullying (Menesini & Salmivalli, 2017). However, this is highly dependent on the schooling system and policies, which play an important role in reducing bullying for such children (Ravneberg & Soderstrom, 2017).

In addition, Maguire and colleagues (2019) suggested that training teachers is very important in order to reduce bullying in schools, as teachers may have a great influence on students, and therefore, are able to promote positive attitudes toward students with disabilities. So, it is apparent that this problem and the stigma problem are rooted in society and the perception of individuals towards disability and assistive technologies.

Thus, customising the ADHD Headmuffs to make them more aesthetically appealing may not necessarily alleviate this problem and collaborative efforts from different parties are required.

Lack of social interaction

Some experts suggested that the ADHD Headmuffs would prevent social interaction with other children in the classroom. This is in particular during collaborative activities that require group discussion (for examples of the experts' comments about the effect of the ADHD Headmuffs on social interaction, see section 8.3.2).

However, this is not relevant to the context of the use of the ADHD Headmuffs in the school settings (see scenario.2 and 3 of the use of the ADHD Headmuffs, section 8.2.3). For instance, when taking an exam, children are typically expected to solve the exam individually and thus no social interaction with peers is possible. The ADHD Headmuffs are also expected to be worn when attending a lesson in the classroom, in which the lesson is initially explained solely by the teacher using the whiteboard or other illustration materials. Teachers may then set up group discussions or collaborative activities and in these cases, children would not wear the ADHD Headmuffs so they can interact with their peers. This is the teaching style in the majority of schools in Saudi Arabia and the teaching style might be different in schools around the world.

8.4 Conclusions

All in all, this study has revealed positive aspects and neutral aspects of the ADHD Headmuffs in relation to the Headmuffs' usability and acceptability; no negative aspects or usability problems have been identified, which is pleasing. It has also emerged from this study that in the opinion of the experts, the usability and acceptability of the ADHD Headmuffs is dependent on the context of use, including at home or in a classroom. Classrooms could also be inclusive classrooms, special education classrooms, or mainstream classrooms and the latter may pose more problems related to the acceptance of assistive technologies by children and teachers. The usability of the ADHD Headmuffs is also affected by the task at hand including studying at home, taking a test or attending a lesson in a classroom, and the latter may pose usability problems especially in classrooms with collaborative learning. Finally, the usability and acceptability of the ADHD Headmuffs are strongly affected by their aesthetics. Therefore, as proposed in Study 5 (Chapter 7), co-design workshops with children are important to refine the design and improve the aesthetic appeal of the ADHD Headmuffs. Other future work suggested by the experts included checking for the novelty effect of using the ADHD Headmuffs on their effectiveness and user experience, as well as the long-term lived user experience of children with ADHD with the ADHD Headmuffs, future work which was already proposed in Study 5.

While this study provides insightful considerations about the usability and acceptability of the ADHD Headmuffs, the study had a number of limitations. For instance, this study was conducted online due to restrictions imposed by the Coronavirus pandemic. To mimic the physical experience of being able to inspect and wear the ADHD Headmuffs, I informed the experts about the exact weight of the wings and the ADHD Headmuffs overall. I also showed the experts several pictures of the ADHD Headmuffs from several angles as well as a video of a child wearing the ADHD Headmuffs. Nonetheless, some experts commented that it would be better if they could have examined the ADHD Headmuffs physically themselves.

Another limitation is that this study only involved experts in HCI or technologies for children with or without ADHD. It would be interesting to involve specialists in children with ADHD who are not necessarily usability experts, but I was unable to recruit such experts due to the pandemic situation. It is important to note that although the majority of experts in this study have experience working with children to varying degrees, I found that experts who have a deeper understanding of children provided very insightful information and were very critical compared to experts with less knowledge of children. Therefore, it emerged that not all the criteria in section 8.2.1 may be essential for the expert review of the ADHD Headmuffs and in hindsight I would have had experts who have experience in usability evaluations and good understanding of children. The understanding of children might be due to having or working with children. However, it emerged in this study that a good understanding of the experts of ADHD and its impairments in children is very important since ADHD results in issues such as low self-confidence which might affect the usability and acceptability of wearable assistive technology.

In conclusion, the results of this study were useful and largely positive in that the experts thought that the ADHD Headmuffs are usable and acceptable to children with ADHD and their parents and teachers, which is gratifying. The results were mostly in line with the results from the user satisfaction study (Study 5, Chapter 7) conducted with children with ADHD. However, experts were concerned about issues such as the stigma and bullying which were not mentioned by the children in Study 5. Thus, further evaluations of the usability and acceptability of the Headmuffs with teachers and parents of children with ADHD in the future would be very useful and may uncover issues not revealed in the evaluation with children with ADHD in Study 5 (Chapter 7) or the evaluation by experts in this study.

Chapter 9 – Overall Discussion and Conclusions

9.1 Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent neurodevelopmental disorders (NDDs) amongst children. Approximately 5% to 7% of children worldwide have ADHD (Polanczyk & Rohde, 2007; Polanczyk et al., 2014; Willcutt, 2012). Children with ADHD have problems with attention and distractibility, which interfere with development and lead to serious functional impairments (for more details, see Chapter 2, section 2.6). Based on the literature review in Chapter 2, I concluded that there are very few studies on assistive technologies and technological interventions to improve the attention of children with ADHD and there is also a lack of technology for reducing distractors whether auditory or visual in such children (see Chapter 2, section 2.7). In addition, while environmental variables such as sound may have an effect on the attention and distractibility in children with ADHD, there is little research on the different kinds of sounds and their effects on children with ADHD (see Chapter 2, section 2.8).

This programme of research aimed to design, build and evaluate an assistive technology, which can be used to help improve attention and reduce visual and auditory distractors in children with ADHD. To do this, the assistive technology incorporated an environmental variable, particularly sound, to improve attention and reduce auditory distractors. The assistive technology also included two wings that help reduce visual distractors in the surrounding environment.

This chapter provides an overall discussion and conclusions for this programme of research. This chapter is divided as follows: section 9.2 gives an overview of the studies and their outcomes in relation to the research questions; section 9.3 presents the contributions of this programme of research; section 9.4 discusses the lessons I learned from conducting this programme of research and finally section 9.5 discusses the limitations of this research and future directions of research.

9.2 Overview of the Programme of Research

To achieve the aim of this programme of research, this research was divided into three phases that helped answer six research questions as follows:

The first phase involved one study, Study 1 (Chapter 3), and aimed to answer two research questions:

- RQ1: What are the experiences of parents of children with ADHD with behavioural interventions and environmental variables and interventions?
- RQ2: Would parents of children with ADHD accept using technological interventions and assistive technologies to help their children?”

Study 1 aimed to investigate the experiences of parents of children with ADHD with technological interventions and environmental variables and interventions involving sound, colour schemes and lighting interventions to help their children. This study found that parents (or at least mothers) were in general aware of the effect of environmental variables on their children and were willing to use technological interventions and assistive technologies to help their children perform better. The most interesting finding though was that all the mothers stated that having their child listen to a reading of the Quran helped the children calm down and concentrate more. Apart from the Quran, the mothers were not generally aware of the effects of sounds or noise on their children. Since Quran is a read text that has melodic and rhythmic features, it may act as a distractor when doing educational tasks and thus cannot be used for the purpose of this research. White noise is a sound that has no melody or rhythm that was found by Söderlund et al. (2007, 2016) and Baijot et al. (2016) to improve the cognitive performance of children with ADHD. My results and those of Söderlund et al. (2007, 2016) and Baijot et al. (2016) inspired me to explore the use of sound in an assistive technology to help children with ADHD in the next studies.

The second phase involved two studies, Studies 2 and 3 (Chapters 4 and 5), and aimed to answer three research questions:

- RQ3: Does white noise have a positive effect on the attention in children with ADHD?

- RQ4: Does pink noise have a positive effect on the attention in children with ADHD?

- RQ5: How can I best measure the effects of white and pink noise on attention?

Study 2 (Chapters 4) investigated the effect of white noise and Study 3 (Chapter 5) investigated the effect of both white and pink noise on the attention of children with ADHD. Both studies measured the performance of the children using a Go/NoGo task with different sets of parameters in each study. The two studies found that white noise improved attention in children with ADHD which is consistent with the results of the previous studies mentioned above. Study 3 found that pink noise also improved attention in these children. To answer RQ5 above, in Studies 2 and 3 I investigated the use of the Go/NoGo task on the resulting dependent variables. OEs are widely accepted as a valid measure of attention and this measure produced more robust results than other measures. RTV is also widely accepted as a measure of attention. However, there is some discussion about how to measure RTV. Although I have used both parametric and non-parametric statistics to measure RTV, it did not seem to produce robust results across the studies with significant effects on some occasions, using non-parametric measures, but not significant effects using the parametric ones, and vice versa. There is a debate about whether RTs measure attention or impulsivity and there is also no robust measure for RTs. Indeed, RTs also did not seem to produce robust results in my studies. Lastly, CEs are assumed to measure impulsivity but there is some debate in previous studies about its validity.

The positive results found in Studies 2 and 3 about the beneficial effect of white and pink noise meant that both white and pink noise can be used in an assistive technology that would help improve attention and reduce distractors in children with ADHD. In the third phase, the assistive technology was developed and its effectiveness, usability and acceptability were evaluated. This phase involved two sub-phases and aimed to answer three research questions:

- RQ6: Will an assistive technology incorporating sound, particularly white noise or pink noise, be helpful for improving attention and reducing visual and auditory distractors in children with ADHD?

- RQ7: Will children with ADHD be satisfied and accept using this assistive technology?

- RQ8: How will experts evaluate the usability and acceptability of the assistive technology?

The first sub-phase involved one study, Study 4 (Chapter 6), and aimed to evaluate the effectiveness of the ADHD Headmuffs in improving attention and reducing visual distractors in children with ADHD, measured using the Go/NoGo task. The study found that the ADHD Headmuffs both with and without white noise resulted in a positive effect on improving attention and reducing visual and auditory distractors. The results also showed that there is a trend for a more improvement in the attention using the ADHD Headmuffs with white noise than the ADHD Headmuffs without noise. As discussed above, listening to white or pink noise improves attention in children with ADHD. Another added benefit of white noise is masking some of the auditory distractors. The wings on the ADHD Headmuffs help reduce visual distractors in the surrounding environment, which in turn improves the attention in children with ADHD.

The second sub-phase aimed to evaluate the satisfaction levels and acceptability of the ADHD Headmuffs using three approaches of evaluation and it involved two studies, Studies 5 and 6 (Chapters 7 and 8). Study 5 evaluated user satisfaction and acceptability of the ADHD Headmuffs of children with ADHD in relation to a number of usability and acceptability aspects, using both interviews with children and the researcher's observations. Both the subjective opinions of children and the observations showed that children with ADHD were in general satisfied and accepted using the ADHD Headmuffs, but children highlighted the need for refining and customizing the ADHD Headmuffs.

Lastly, Study 6 (Chapter 8) evaluated the usability and acceptability of the ADHD Headmuffs with experts in HCI, assistive technologies for children, including those with ADHD. The study showed that experts thought that the ADHD Headmuffs would be overall usable and acceptable to children with ADHD and their parents and teachers. Although the results were generally positive, experts highlighted that the usability and acceptability of the ADHD Headmuffs are highly dependent on the context of use, with more issues arising when the ADHD Headmuffs are used in a public setting such as a classroom. These issues include bullying and the potential for stigma (for more discussion about these issues and potential solutions, see Chapter 8, section 8.3 and 8.4).

All the three approaches to the evaluation of the usability and acceptability of the Headmuffs, including the direct evaluation by children, researcher observations and the expert evaluations showed that the Headmuffs are overall usable and acceptable to children with ADHD. However, each approach highlighted various different needs or issues, which means that these approaches complement each other to provide the best overall evaluation of the usability and acceptability of the Headmuffs. For instance, although experts showed concerns about issues such as stigma and bullying due to wearing the ADHD Headmuffs in class, the majority of children said they would be happy to wear the ADHD Headmuffs in class. It might be that a study of the actual use of the ADHD Headmuffs in the classroom and the long-term lived experience of children with ADHD with the Headmuffs especially in classroom settings may reveal different results, including issues of stigma and bullying. It might also be that children do not perceive stigma the same way the adult experts did, and this interestingly has not been investigated before in the literature as far as I am aware. In addition, in a number of instances children gave neutral or below neutral ratings for some aspects of the Headmuffs but were not able to justify their ratings (e.g. the shape of the Headmuffs and whether they will wear the Headmuffs frequently). Therefore, the observation of the children was very important to supplement or explain the ratings the children gave for some aspects. Furthermore, some approaches have limitations that may affect the results. For instance, when conducting the evaluation with the children in Study 5, the children were asked to help with the researcher with a new device, so the results of this study may well have been affected by two problems, social desirability and satisficing. These problems are inherent in usability evaluations with children and are hard to mitigate but can be addressed in future research. Furthermore, there is a potential for researcher bias in the observation of the children since the same researcher who developed the Headmuffs was conducting the observation. This might well have affected how the children reacted to the Headmuffs and how the researcher reacted to the children. More discussion about these limitations and potential solutions for how to deal with these problems in future research can be found in section 9.5 and in Chapter 7 (section 7.3).

9.3 Contributions of this Programme of Research

Before discussing the major contributions of this programme of research, a minor contribution of this research was the first study conducted to explore the experiences of parents of children with ADHD with technological interventions and assistive technologies and environmental variables and interventions involving sound, colour schemes and lighting interventions to help their children.

Researching the literature, one area of interest in ADHD research, which has only received a very limited amount of research, is the effect of the environmental variables such as sounds, colour schemes and lighting on children with ADHD (see Chapter 2, section 2.8). There may be both positive and negative effects of these environmental variables on attention, hyperactivity and impulsivity in children with ADHD. To the best of my knowledge, no studies have investigated whether parents of children with ADHD have noticed any effects of these environmental variables on their children. In addition, no studies have investigated the attitudes of parents toward using technological interventions and assistive technologies to help their children with ADHD. Therefore, the first minor contribution of this research was to bridge these gaps and to conduct the first study as stated above. The results suggested that Saudi mothers are aware of the effect of environmental variables, particularly sound and lighting, but are less aware of the effects of colours on their children. However, mothers are not aware of the effects of white or pink noise. Mothers are also open to using assistive technologies that might be helpful for their children.

Considering the major contributions of this programme of research, the first major contribution was about the effectiveness of white and pink noise. The literature review in Chapter 2 (section 2.8.1) showed that there are very small number of studies by Söderlund and colleagues (2016) and Bajiot and colleagues (2016), using a number of cognitive tasks that found that white noise improves attention in children with ADHD. These studies inspired me to explore the use of sound in an assistive technology to help children with ADHD perform better. Baijot et al. (2016) was the only study that used the Go/NoGo task, one of the most commonly used cognitive tasks to that provides objective measures of the performance of children in ADHD research. As discussed in Chapter 2 (section 2.4.2.1), changing the parameters of the Go/NoGo task may affect the performance of the children. Therefore, one part of the first major contribution of this programme of research was validating the effects of white noise, in creating a positive effect on the attention of children with ADHD using a variety of parameters of the Go/NoGo task as opposed to the study by Baijot et al. (2016) that used only one set of parameters. In addition, pink noise is another form of background noise that may be more pleasant to listen to than white noise. To the best of my knowledge, this research is the first to investigate the effect of pink noise on the attention of children with ADHD as the only previous study of the effects of pink noise on children with ADHD only investigated its effect on impulsivity (Metin et al., 2016). Therefore, another part of the first major contribution of this programme of research was discovering the effects of pink noise in improving the attention in children with ADHD.

The second major contribution of this programme of research was the design, development and evaluation of an assistive technology, the ADHD Headmuffs, to help improve attention and reduce visual and auditory distractors in children with ADHD.

As discussed in Chapter 2 (section 2.3), attention deficits and distractibility are two core deficits in children with ADHD. To the best of my knowledge, very little research has been conducted on assistive technologies for improving attention (see Chapter 2, section 2.7.4) and there is a lack of an assistive technology for reducing distractors, whether visual or auditory in children with ADHD. Therefore, one part of the second major contribution of this research was developing and evaluating the effectiveness of the assistive technology, the ADHD Headmuffs, incorporating white or pink noise to improve attention and reduce auditory distractors and using the wings to reduce visual distractors in children with ADHD. The evaluation of the effectiveness of the assistive technology in this research was based on objective measures in comparison with the evaluations in the previous studies in the literature that mainly used subjective measures for evaluating the effectiveness of their assistive technologies (for more details, see Chapter 2, section 2.7). The results of the evaluation showed that the ADHD Headmuffs, whether with white noise or without noise, have a positive effect on the attention of children with ADHD. This suggests that children with ADHD can use the ADHD Headmuffs whenever and wherever children need to focus and be less distracted.

It is very important when evaluating assistive technologies to measure the satisfaction levels and acceptability of real users with the technologies. As discussed in Chapter 7 (section 7.1), wearable assistive technologies may have all or some of three components, including hardware to be worn, an interface to help users interact with the wearable, and software for processing input and producing output. In the current prototype of the ADHD Headmuffs, no software or interface is included. Thus, the evaluation with children was conducted with respect to the hardware alone. Researching the literature on design principles or guidelines for assessing the hardware component of wearables in general and wearable assistive technologies specifically, only two studies were found. One study by Knight et al. (2002) proposed guidelines to measure comfort with wearable computers. Another study by Crane et al. (2004) proposed guidelines for assessing comfort with wheelchairs. However, these existing guidelines are not fully suitable for measuring the usability and acceptability of wearable assistive technologies with children as they were designed for adults and never tested on children. Therefore, the second part of the second major contribution of this research was proposing a list of aspects for measuring children's satisfaction and acceptance of the hardware component of a wearable assistive technology and using the list to measure the satisfaction and acceptability of the ADHD Headmuffs with children with ADHD. This evaluation employed two approaches, direct subjective evaluations by children and observations by the researcher. Both approaches of evaluation showed that children were overall satisfied and accepted using the ADHD Headmuffs but the children highlighted the need for refining and customizing the ADHD Headmuffs. As discussed in section 9.2, the positive results from this evaluation may have been affected by a number of problems, including social desirability, satisficing and researcher bias but can be addressed in future research.

In addition to evaluations with users, another important method for evaluating the usability and acceptability of assistive technologies is to have experts conduct evaluations. As discussed above, in the current prototype of the ADHD Headmuffs, no software or interface is included. Thus, the expert evaluation was conducted with respect to the hardware alone. However, the existing guidelines proposed by Crane et al. (2004) and Knight et al. (2002) described above, are not fully suitable for measuring the usability and acceptability of wearable assistive technologies for children. One may argue that a general expert review could be conducted without specific guidelines.

However, to improve on a generic method, a set of appropriate aspects relevant to the usability and acceptability of the hardware aspects of a wearable assistive technology was created that would help guide the experts through the evaluation and was used by experts to evaluate the usability and acceptability of the ADHD Headmuffs. This was the third part of the second major contribution of this research. The experts found that the ADHD Headmuffs are overall usable and would be highly acceptable for children with ADHD and their parents and teachers. When the experts were asked whether they had further comments about the ADHD Headmuffs at the end of the assessment, they commented that the list of aspects covered so many aspects about the ADHD Headmuffs to a point where they had nothing else to add.

9.4 Lessons Learned from Conducting the Programme of Research

Throughout this research, I had tremendous challenges in recruiting children with ADHD. I tried every possible way to recruit children with ADHD, including approaching clinics both private or public, visiting the Saudi association for ADHD, attending events dedicated for ADHD awareness, visiting schools, using snowball sampling and even using Twitter to post requests for participation and ask ADHD professionals to retweet these requests. Amongst tens of clinics, I was only able to get support from two clinics. The reasons for this low support rate are largely that clinics get lots of requests from researchers and they are worried about the effect of research on the children and complaints from parents. Apparently, at least from my own experience, unless you know a specialist in the clinics, they will not support you. As for schools, I was only able to access two schools that have programmes for children with ADHD and the access was only for two months during the whole of my PhD period. This is because the Ministry of Education in Saudi Arabia only gives approval for a duration of two months for researchers to conduct research in schools during their degree.

It is important to note that from my own experience in this programme of research, I found schools with programmes for children with ADHD to be the best method of recruiting the children. This is because a larger number of children with ADHD are available in schools and the parents do not have to spend extra efforts and times to take their children to particular locations for the research that might be inconvenient. Schools are in particular very useful if researchers are interested in children with mild to moderate ADHD, as in my studies, since children with severe ADHD are typically referred to specialised schools for children with special needs. Then, the second-best way of recruiting children with ADHD is through clinics or hospitals, in which children have follow up visits for treatment plans. One problem that I found with recruiting children through hospital or clinics is that most of the children recruited do not meet the inclusion criteria, since most of children referred to hospitals or clinics have severe ADHD or comorbidities. The last way I used to recruit children with ADHD for the research, which resulted in the fewest number of children recruited in my studies was through Twitter.

There were also a number of additional challenges that I faced when recruiting children with ADHD. The fact that I followed strict inclusion criteria similar to those used in previous research with children with ADHD such as Baijot et al. (2016), Söderlund et al. (2007, 2016) substantially lowered the number of children who were eligible to participate in my studies. In particular, more than 60% of children with ADHD have at least one comorbid disorder that typically persists into adulthood (Gillberg et al., 2004), such as Conduct Disorder (CD), anxiety, depression and Oppositional and Defiant Disorder (ODD) (Gnanavel et al., 2019). In this programme of research, a pool of 154 children with ADHD was recruited, but 73 children (47%) were rejected as they had comorbidities.

Another challenge was from the parents of children with ADHD who often refused to allow their children to be part of my studies for many reasons. First of all, some parents felt sensitive about letting their children be part of experimentation. Other parents had a prior bad experience with having their children participate in experiments, as they had the hope of getting something helpful for their children, but researchers did not provide useful feedback about the results. Thus, I found that it is very important to share the study results with the parents as soon as possible. In addition, some parents were not sure about the safety of the experiments for their children. In relation to this, I found it very useful to have the research approved by a well-known professional in ADHD whom the parents trusted and I wrote about their approval in the information sheets about the studies.

9.5 Limitations and Directions for Future Work

While this programme of research has provided a design and evaluation of an assistive technology to improve attention and reduce distractors in children with ADHD, there are a number of limitations in the research, which need to be discussed.

The first limitation is that the number of children in this research was relatively small, ranging from 14 to 16 children with ADHD. This is in line with a number of relevant studies with children with ADHD such as Baijot et al. (2016), Söderlund et al. (2007, 2016) and with children with attention problems but without a diagnosis with ADHD such as Helps et al. (2014) and Söderlund et al. (2010). As noted in the Participants sections in Studies 2, 3, 4 and 5, the final number of children reduced from 154 to 45 children due to the strict inclusion criteria, particularly the fact that having comorbidities is very common in children with ADHD, as discussed above (see section 6.4). This is in addition to the other challenges in recruiting children as discussed above (see section 6.4). Therefore, future research should look at recruiting larger pools of participants to confirm the results of this research. This is important as I observed very high variability in the children's data in this programme of research, undoubtedly due to the diverse nature of children with ADHD, even those with the same form of ADHD.

Another limitation in this programme of research is the use of only one cognitive task, the Go/NoGo task, to measure attention and impulsivity in children with ADHD in Studies 2, 3, and 4. Therefore, it would be interesting in the future to use different tasks which will provide different objective measures of attention and impulsivity to validate the results found in this research.

Opinions on the validity of some of the measures which the Continuous Performance Tests (CPTs), including the Go/NoGo task, provide are somewhat mixed (for more details, see Chapter 2, sections 2.4.2.1 and 2.4.2.2). OEs are widely accepted as a valid measure of attention. CEs are assumed to measure impulsivity but there is some debate in previous studies about its validity. There is also a debate about whether RTs measure attention or impulsivity. There is also no robust measure for RTs. RTV is also widely accepted as a measure of attention. However, there is some discussion about how to measure RTV. Therefore, more research is needed on whether some of the measures from the Go/NoGo task are valid measures of attention and impulsivity.

As discussed in Chapter 2 (section 2.4.2.1), the majority of previous research used parametric statistics to measure RTs and there are numerous ways of measuring RTV, with most researchers using parametric statistics, in spite of the fact that RTs are very likely to be skewed and therefore not appropriate for these statistics. Therefore, researchers have to establish whether their data meet the criteria for parametric analysis. Researchers also need to determine the best measure for RTs and RTV.

In addition, in the Go/NoGo task, two stimuli were used, the Go stimulus (i.e., a picture of an aeroplane) and the NoGo stimulus (i.e., a picture of a bomb). The reason for choosing these two stimuli was that I wanted to have interesting stimuli in a form of pictures that stimulate a computer game and are language independent, instead of using words, for example. In addition, these particular stimuli were chosen because they were used in previous studies, such as a study by Brophy et al. (2002) and a study by Rubia et al. (2001), involving both boys and girls with ADHD. However, on reflection, these stimuli are certainly not particularly child-friendly or appropriate, particularly for girls. Therefore, in hindsight, I would have chosen other stimuli that are more interesting and appropriate for both girls and boys.

The studies on evaluating the effectiveness, satisfaction and acceptance of children with ADHD with the ADHD Headmuffs provided an initial evaluation, but it may well have been susceptible to many problems such as the novelty effect, socially desirable and researcher satisficing answering. The novelty effect usually occurs when evaluating new or unusual items and for a short period of time. It also happens when the participant is brought into an evaluation environment that is unusual or with the presence of the researcher even in usual environments (Kite & Whitley, 2012). I tried to minimise the effect of novelty by conducting the evaluation of the ADHD Headmuffs with children in their school. I also tried to build a good relationship with the children by coming to the school for several days prior to the evaluation and chatting with them. Building a good relationship with children was also advised by Sim et al. (2017) to minimise satisficing.

Nonetheless, the ADHD Headmuffs are a new item for the children and the evaluation was conducted after the children had only experienced the ADHD Headmuffs for 30 minutes. Therefore, the longer-term lived experience of the children with the ADHD Headmuffs should be investigated in a future study. This could be accomplished by evaluating the effectiveness of the ADHD Headmuffs with children with ADHD two times, once in an initial study (after a similar experience to the current studies, approximately 30 minutes to introduce the ADHD Headmuffs to the children) and once after having the same children use the ADHD Headmuffs at home for a period of weeks. The performance of children could then be compared to investigate if the ADHD Headmuffs remain effective in improving the attention after the novelty effect wears off. Also, the satisfaction and acceptability of children with the ADHD Headmuffs could be measured again after they get used to the ADHD Headmuffs.

Another important issue that could then be investigated in future research is the long-term lived experience of such children with the ADHD Headmuffs at school. Children could be asked to wear the ADHD Headmuffs in some classes for a period of weeks, potentially their teachers or any volunteering classmates could also be asked to wear the ADHD Headmuffs. The behaviour of the children and their classmates towards the ADHD Headmuffs could then be observed. This would help with minimising the social desirability and researcher satisficing found in the initial evaluation of the satisfaction and acceptability of children with the ADHD Headmuffs.

This programme of research has focused mainly on the acceptance of the ADHD Headmuffs by children with ADHD, as investigated in Study 5. Nonetheless, King, et al. (1999) and Moon et al. (2019) suggested the children's parents, along with people around them, play an important role in adopting or abandoning assistive technologies. Therefore, the acceptance of the ADHD Headmuffs by parents of children with ADHD, whether of the children wearing them at home (e.g., for doing homework) or in the classroom, is also very important. Their rejection of the ADHD Headmuffs would constitute a major barrier for the successful adoption of the ADHD Headmuffs. Equally important is the acceptance of teachers of their students with ADHD wearing the ADHD Headmuffs in their classroom. Therefore, future research should directly investigate the acceptance of parents and teachers of children with ADHD to the use of the ADHD Headmuffs in different contexts of use.

In addition to the future work discussed above to overcome some of the limitations of this research, there are also a number of other aspects that need to be investigated. Future work is discussed below.

The studies on the effect of white and pink noise as well as the usability of the ADHD Headmuffs in this programme of research included children with ADHD according to strict inclusion criteria. This included children aged between 6 and 12 years old inclusive who are diagnosed with mild or moderate ADHD-I or ADHD-C; with IQ of more than 80; with no psychiatric comorbidities; with no sensory deficits and not taking any pharmacological treatments. Future research should investigate the effect of white and pink noise as well as the usability of the ADHD Headmuffs on participants with different characteristics such as children in the same age range but with severe ADHD, or with comorbidities or on medication, children and adolescents aged above 12 years with ADHD, adults with ADHD and children with other disorders such as children with Autism Spectrum Disorder (ASD) who also have attention problems.

Another interesting area of research would be to investigate the effect of other kinds of sounds, music or noise on children with ADHD. Research could also investigate the effect of different levels of white and pink noise.

Designing a "cool" assistive technology that is aesthetically appealing and that makes the children feel happy wearing it, may help with the child's acceptance of the assistive technology. Although children were in general satisfied and accepted using the ADHD Headmuffs, they highlighted the need for refining and customizing the ADHD Headmuffs (see section 9.1). Therefore, future work could include co-design workshops with children and possibly their parents about how they would like to customize the ADHD Headmuffs. Some techniques have been used in the literature when co-designing with children such as Rabid Analysis of Ideas (RAID) and Drawing Intervention, which is mostly suitable for physical or tangible interactions (see Sim et al., 2021).

In the current design of the ADHD Headmuffs, regular headphones were used. It would be interesting in the future to make another ADHD Headmuffs using noise cancellation headphones that eliminate auditory distractors. Then, future research would investigate whether using the ADHD Headmuffs with noise cancellation headphones with or without white noise would make a difference in the attention of children with ADHD compared to using the ADHD Headmuffs with regular headphones with or without white noise.

Lastly, an interesting area of research would be to investigate other designs that could potentially serve similar purposes to the ADHD Headmuffs. One interesting design is to use eyeglasses with side shields. The side shields would help reduce the visual distractors but this needs investigations with children with ADHD.

9.6 Conclusions

ADHD symptoms can be very detrimental to the development and daily functioning of children with ADHD. ADHD symptoms result in educational impairments with varying presentations and severity levels and also result in occupational and social impairments that without proper early intervention may persist into adulthood (see Chapter 2, section 2.6). As discussed in Chapter 2 (section 2.3), attention deficits and distractibility are two core deficits in children with ADHD.

This programme of research has yielded a prototype of an assistive technology, the ADHD Headmuffs, that have been found to be useful in improving attention and reducing visual and auditory distractors in children with ADHD. This assistive technology is non-invasive and highly usable according to the opinions of children with ADHD and experts in usability and assistive technologies for children, including those with ADHD. The ADHD Headmuffs are context-independent, in that they could be used anytime and anywhere children need to focus and be less distracted. One important finding of this programme of research is the positive effect of white and pink noise on the attention of children with ADHD. Thus, the benefit of the ADHD Headmuffs is the possibility of incorporating sound, particularly white or pink noise to improve the attention of children with ADHD and potentially serve as a masker for auditory distractors.

Appendix A

A.1 - Assistive Interventions for Children with ADHD Project - Study 1: Consent Form and Information Sheet (The original sheet was in Arabic and this is a translated version):

Thank you for offering to take part in this study. Below are the information sheet and the consent form to sign.

1. **Who is running the study?**

The study is being run by Nouf Alromaih, a PhD student in the Department of Computer Science at the University of York. Nouf is supervised by Prof Helen Petrie who is a Professor of Human Computer Interaction at the same department.

2. **What is the purpose of the study?**

This study is part of our ongoing work on providing support for children with ADHD to improve their attention. In this study, we would like to collect some information about your experience of the effects of behavioural and environmental variables on their children's ADHD and their attitudes towards technological interventions to help their children.

3. **What will I have to do?**

You will be asked some questions about your experience of the effects of behavioural and environmental variables on their children's ADHD and their attitudes towards technological interventions to help your child(ren). You will also be asked basic personal information. The study will take on average 30 mins

4. **Who will have access to the study data?**

Only myself, Nouf Alromaih and my supervisor, Professor Helen Petrie, will have access to the study data.

5. **Will my participation in the study be kept confidential?**

Any information you provide will be completely confidential and stored securely and no comments will be ascribed to you by name in any written document. Nor will any data be used from the study that might identify you individually. Any extracts from what you will write that are quoted in any public document (reports, journal papers) will be reported in anonymised manner to protect your identity.

6. Do I have to take part of the study?

Your participation in the study is completely voluntary. If you feel uncomfortable at any point, you are completely free to withdraw from the interview.

Before you participate in this study, please complete Section A, printing your name in the first space and then sign at the end.

Section A

I, ______________________, give my consent for participating in this study concerning the technological interventions for children with ADHD project. I have been informed about and feel that I understand the basic nature of the study. I understand that my child and I may withdraw from the study at any time without prejudice.

I also understand that my information is confidential. Only Helen Petrie and Nouf Alromaih will have access to the data collected today in its original format and anything made public will be in a completely anonymised format. I was not forced to complete the study. All my questions have been answered and I do not mind being recorded.

Signature ____________________________ Date ____________

A.2 - Study 1: Interview Guide (The original interview guide was in Arabic and this is a translated version):

1. Introduction (5 mins) – This was aimed to give introductory information about the researcher, the aim of the study, what would happen to the data collected, confidentiality agreement and asks if they mind being recorded, if appropriate. When the parents gave their consent, they were presented with the next section.

2. Warm-up demographic questions (5 mins):

- Can you please tell me some information about you, including your age and educational level?
- Can you please tell me some information about you child(ren), including child(ren)'s gender, age and specific ADHD diagnosis?

3. Main questions (+30 mins):

a. Understanding parents' experiences and attitudes towards behavioural interventions:

- Do you have experience with behavioural interventions, that are non-technological strategies, therapies and techniques, to improve the attention in your child and/or decrease the hyperactivity and impulsivity? If yes:
  - What are these interventions?
  - How did you know about these interventions?
  - How did you apply these interventions?
  - What effects have you noticed on your child from using these interventions?

b. Understanding parents' experiences and attitudes towards environmental variables and interventions:

- Do you have experience with environmental variables and interventions related to sounds, colour schemes or lightings to improve the attention in your child and/or decrease the hyperactivity and impulsivity? If yes: (note: the following questions are repeated for every environmental variable)
  - What are these interventions?

- How did you know about these interventions?
- How did you apply these interventions?
- What effects have you noticed on your child from using these interventions?

c. Understanding parents' experiences and attitudes towards technological interventions and assistive technologies: This section contained the following questions asked to parents:

- Would you adopt and use technological interventions and assistive technologies that would help improve your child's attention? If no: can you explain why you would not use them?

4. Closing questions (1 -10 mins):

- Do you have anything else to add or discuss?
- Do you any questions for me?

5. Debriefing (5 mins).

6. Expected time: on average 45 minutes.

Appendix B

B.1 - Questionnaire for parents of children with ADHD to ensure children meet inclusion criteria (The original questionnaire was in Arabic and this is a translated version):

1. Your child was diagnosed with (Provide medical report):
    a. ADHD-Inattentive type
    b. ADHD- Hyperactive type
    c. ADHD-Combined type

2. Your child age: -------
3. Your child IQ is more than 80:
    a. Yes (Provide certificate)
    b. No
4. Your child has psychiatric comorbidities:
    a. Yes
    b. No
5. Your child has sensory deficits
    a. Yes
    b. No
6. Your child undertaking pharmacological treatments other than methylphenidate:
    a. Yes
    b. No
7. At what age your child was diagnosed with ADHD? -------

B.2 - Assistive Interventions for Children with ADHD Project - Study 2: Information Sheet and Consent Form (The original sheet was in Arabic and this is a translated version):

Thank you for offering to take part in this study. Below are the information sheet and the consent form to sign.

7. **Who is running the study?**

The study is being run by Nouf alromaih, a PhD student in the Department of Computer Science at the University of York. Nouf is supervised by Prof Helen Petrie who is a Professor of Human Computer Interaction at the same department.

8. **What is the purpose of the study?**

The study is part of our ongoing work on providing support for children with ADHD to improve their attention. In this study, we would like to collect some information about whether using white noise would improve the attention of a child with ADHD.

9. **What will my child and I have to do?**

Your child will be asked to finish a task called Go/NoGo task, once when your child is wearing headphones to listen to white noise and once without the headphones and the white noise. The Go/NoGo task is like a computer game in which the child has to press a button as fast and as accurate as possible when they say a picture of an aeroplane and withhold pressing when they see a picture of bomb. The task helps measure the attention and impulsivity of the child. Then you and your child will also be asked some questions about white noise. When the study is finished, your child will be given a gift for their participation. The study will take about 30 mins.

10. **Who will have access to the study data?**

Only myself, Nouf Alromaih and my supervisor, Professor Helen Petrie, will have access to the study data.

11. Will my and my child's participation in the study be kept confidential?

Any information you provide will be completely confidential and stored securely and no comments will be ascribed to you or your child by name in any written document. Nor will any data be used from the study that might identify you individually. Any extracts from what you will write that are quoted in any public document (reports, journal papers) will be reported in anonymised manner to protect your identity.

12. Do my child and I have to take part of the study?

Your child and your participation in the study is completely voluntary. If you or your child feel uncomfortable at any point, you are completely free to withdraw from the study.

If you would like to receive the results of your child or the results of the whole study, please write your email here: ---

Before your child participates in this study, please complete Section A, printing your name in the first space and then sign at the end.

Once the study is over and you have been debriefed, you will be asked to initial the three statements in Section B, to indicate your agreement.

Section A

I, ______________________, give my consent for my child to participate in this study concerning the technological interventions for children with ADHD project. I have been informed about and feel that I understand the basic nature of the project. I understand that my child and I may withdraw from the study at any time without prejudice.

I also understand that my information is confidential. Only Helen Petrie and Nouf Alromaih will have access to the data collected today in its original format and anything made public will be in a completely anonymised format.

Signature ____________________________ Date ____________

Section B

Please initial each of the following statements when the study has been completed and you have been debriefed.

My child and I have been adequately debriefed Your initials:

My child and I were not forced to complete the study Your initials:

All my questions have been answered Your initials:

B.3 – Full information of all participants for Study 2

Table B.1 Full information for all the participants

Participant	Sex	Age	Diagnosis
P1	Girl	7	ADHD-C
P2	Girl	8.2	ADHD-I
P3	Boy	10	ADHD-C
P4	Girl	9	ADHD-I
P5	Boy	9.5	ADHD-C
P6	Boy	9.4	ADHD-I
P7	Girl	7.6	ADHD-C
P8	Girl	8.5	ADHD-I
P9	Boy	8.11	ADHD-C
P10	Girl	7.8	ADHD-C
P11	Girl	11	ADHD-I
P12	Boy	9	ADHD-C
P13	Girl	8	ADHD-I
P14	Girl	8.4	ADHD-C
P15	Boy	9	ADHD-C
P16	Boy	8.2	ADHD-C

B.4 – The statistical and graphical normality tests for RTs

Table B.2 Statistical test of normality for RTs

Variable	Shapiro–Wilk Test	Kolmogorov–Smirnov Test
RTs – White Noise	.000	.000
RTs – No Noise	.000	.000
RTs – White Noise 1	.000	.000
RTs – White Noise 2	.000	.000
RTs – No Noise 1	.000	.000
RTs – No Noise 2	.000	.000

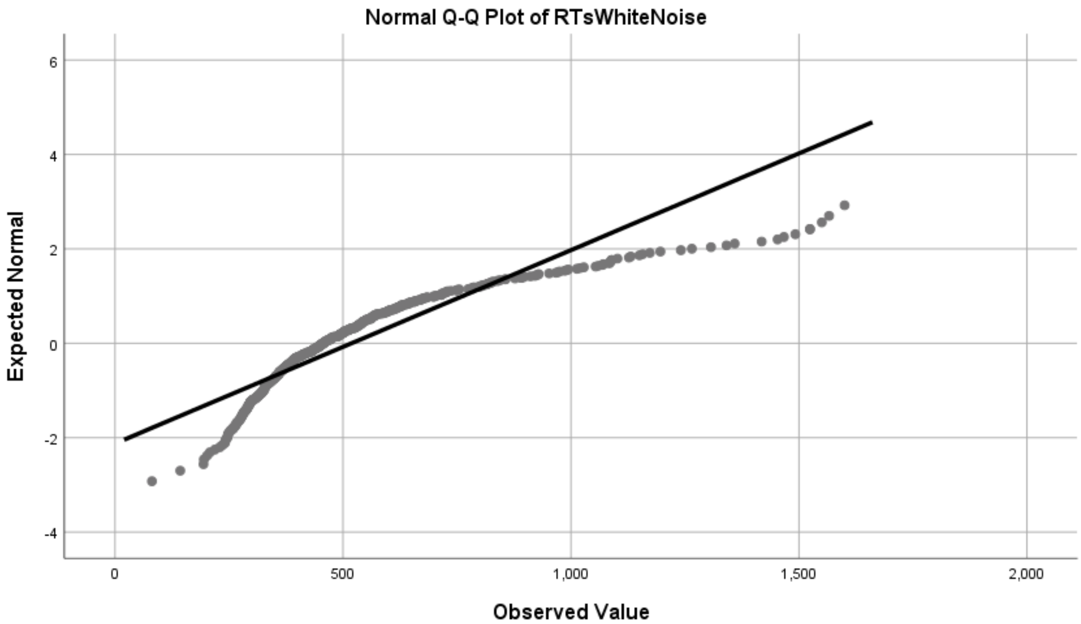


Figure B.1 QQ plot for RTs in the White Noise condition showing that RTs no normally distributed

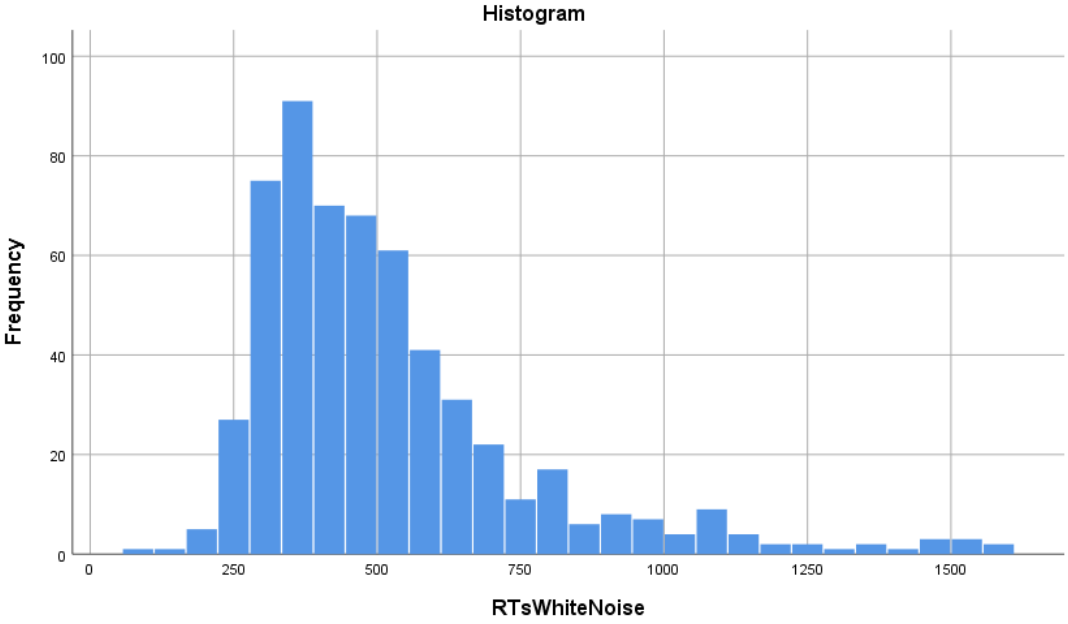


Figure B.2 Histogram for RTs in the White Noise condition showing that RTs are positively skewed and thus no normally distributed

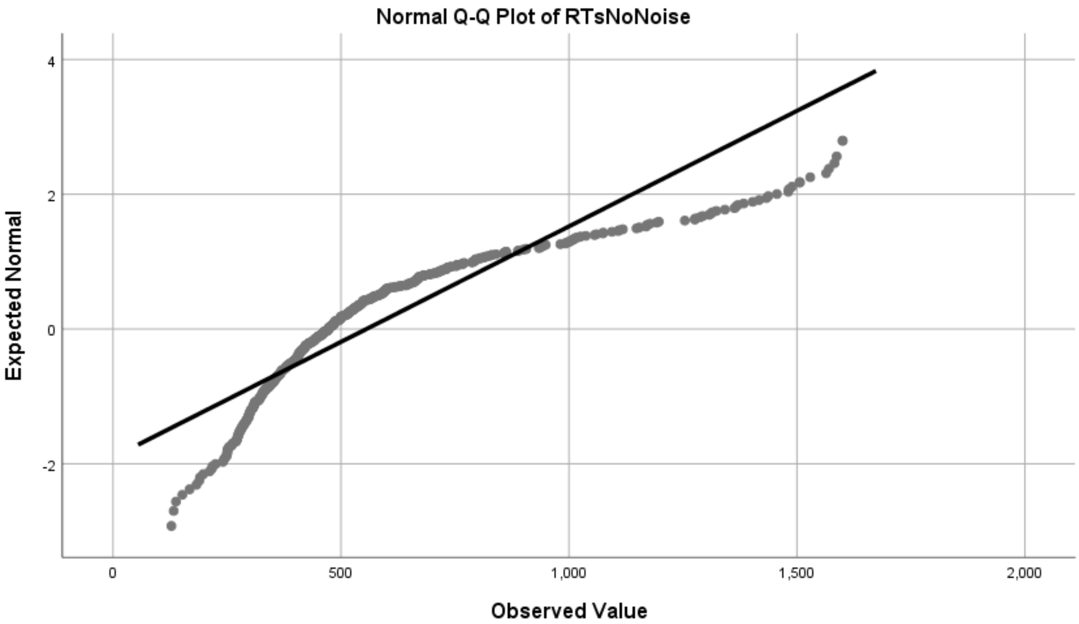


Figure B.3. QQ plot for RTs in the No Noise condition showing that RTs no normally distributed

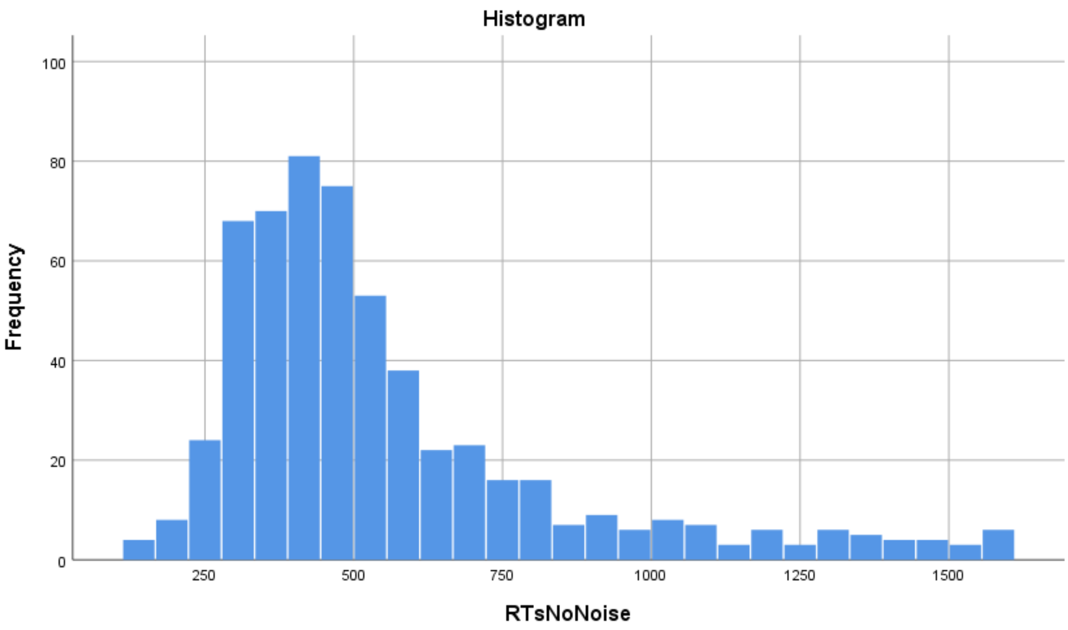


Figure B.4. Histogram for RTs in the No Noise condition showing that RTs are positively skewed and thus no normally distributed

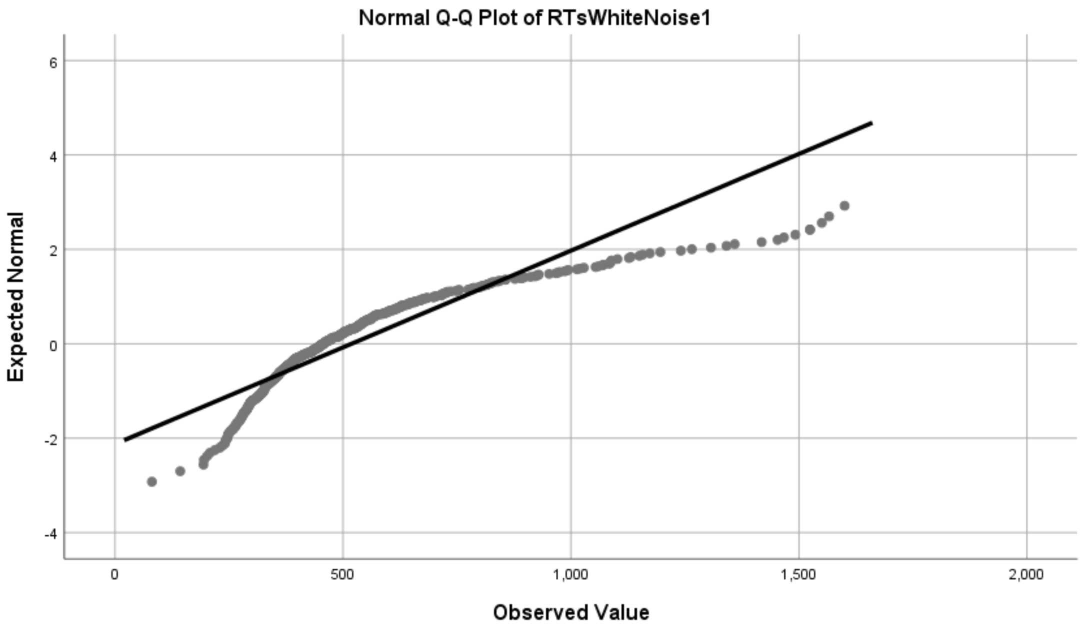


Figure B.5. QQ plot for RTs in the White Noise Block 1 condition showing that RTs no normally distributed

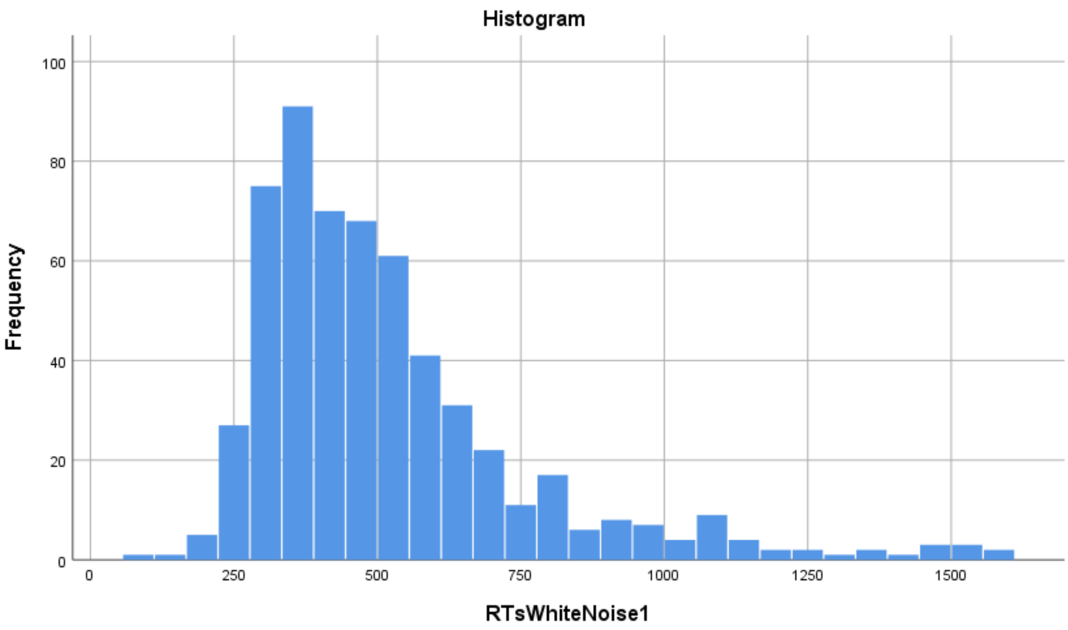


Figure B.5 Histogram for RTs in the White Noise Block 1 condition showing that RTs are positively skewed and thus no normally distributed

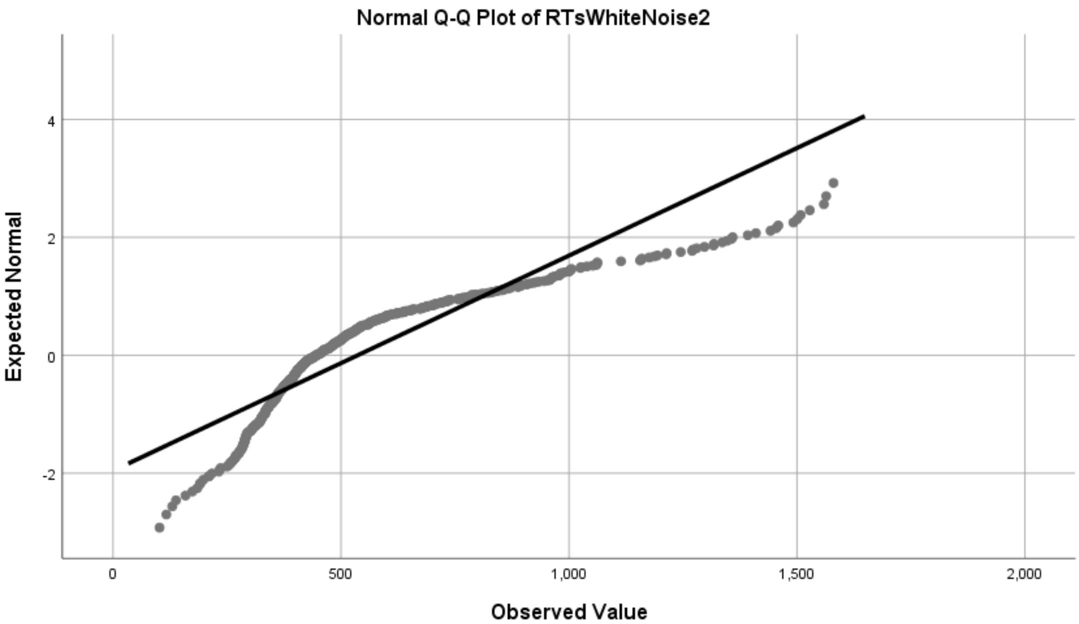


Figure B.6 QQ plot for RTs in the White Noise Block 2 condition showing that RTs no normally distributed

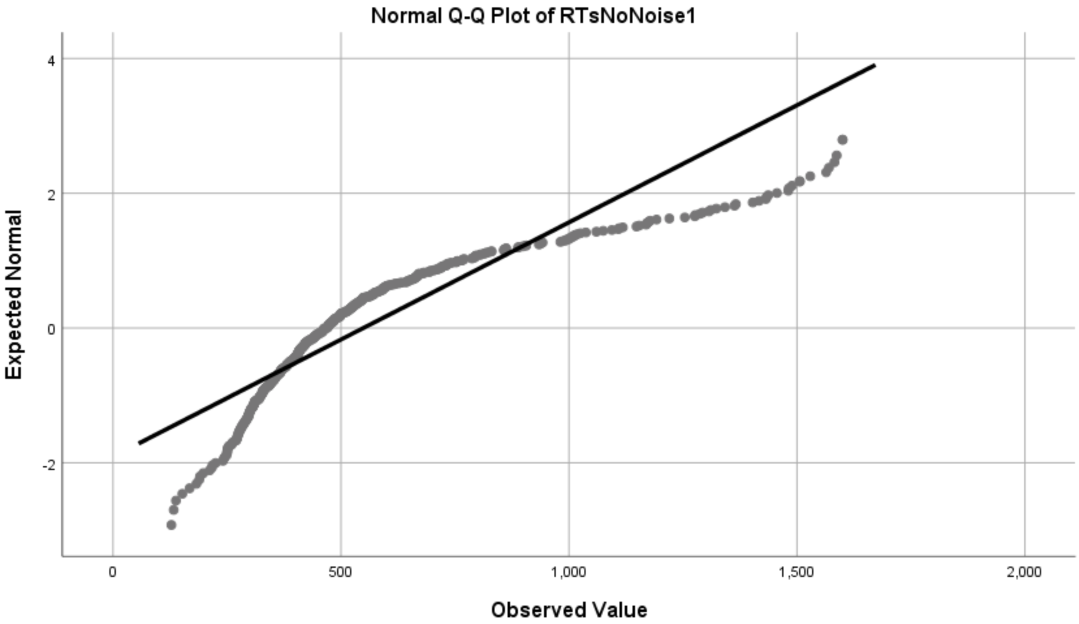


Figure B.7 QQ plot for RTs in the No Noise Block 1 condition showing that RTs no**n-** normally distributed

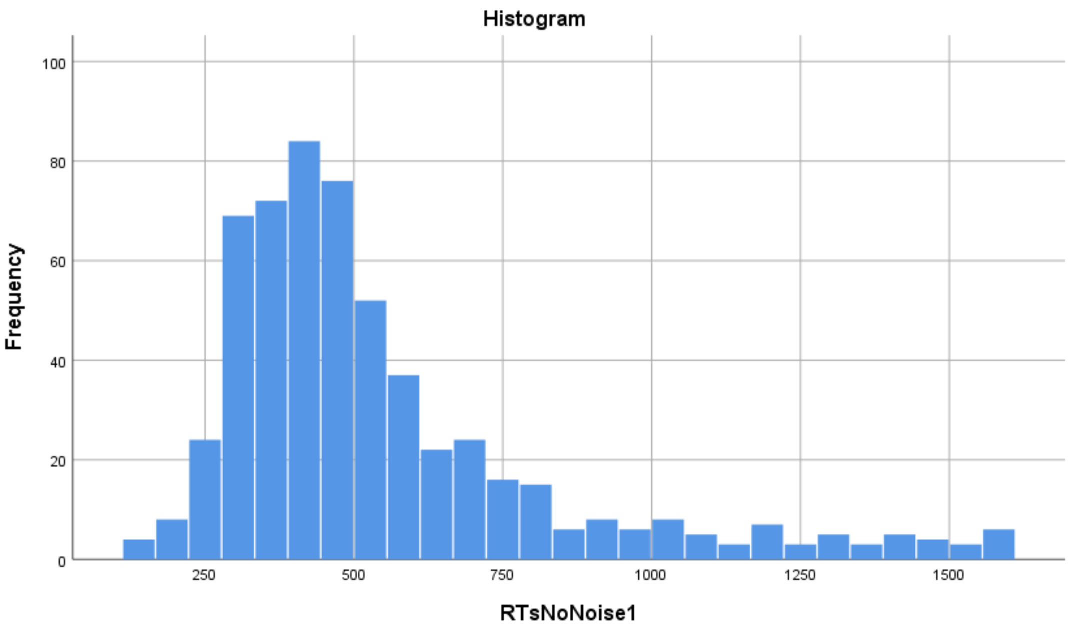


Figure B.8 Histogram for RTs in the White Noise Block 21condition showing that RTs are positively skewed and thus no normally distributed

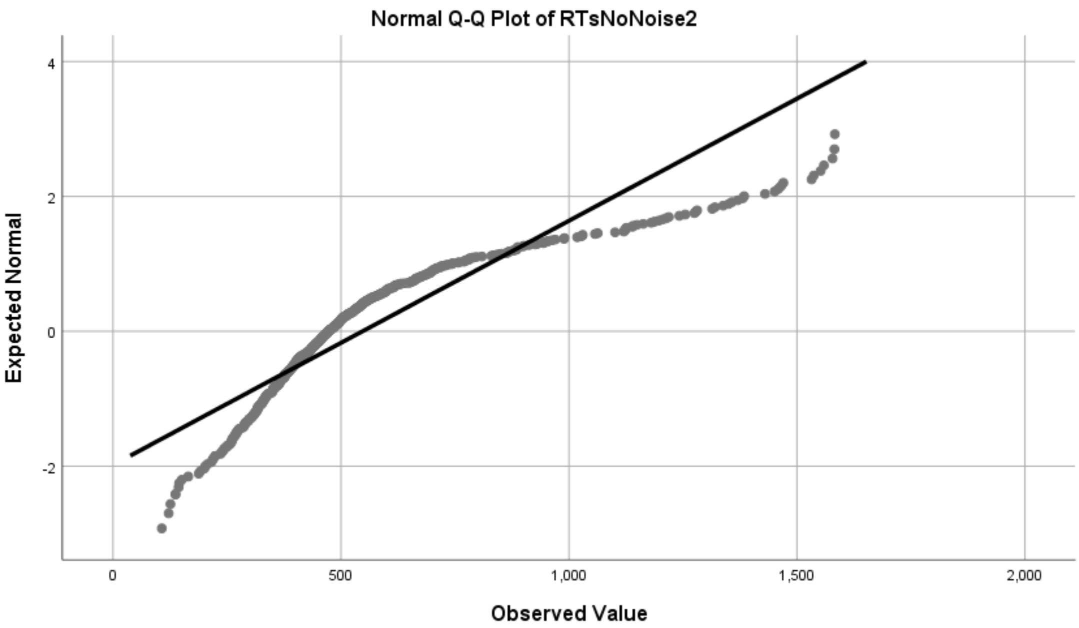


Figure B.9 Histogram for RTs in the No Noise Block 2 condition showing that RTs are positively skewed and thus no normally distributed

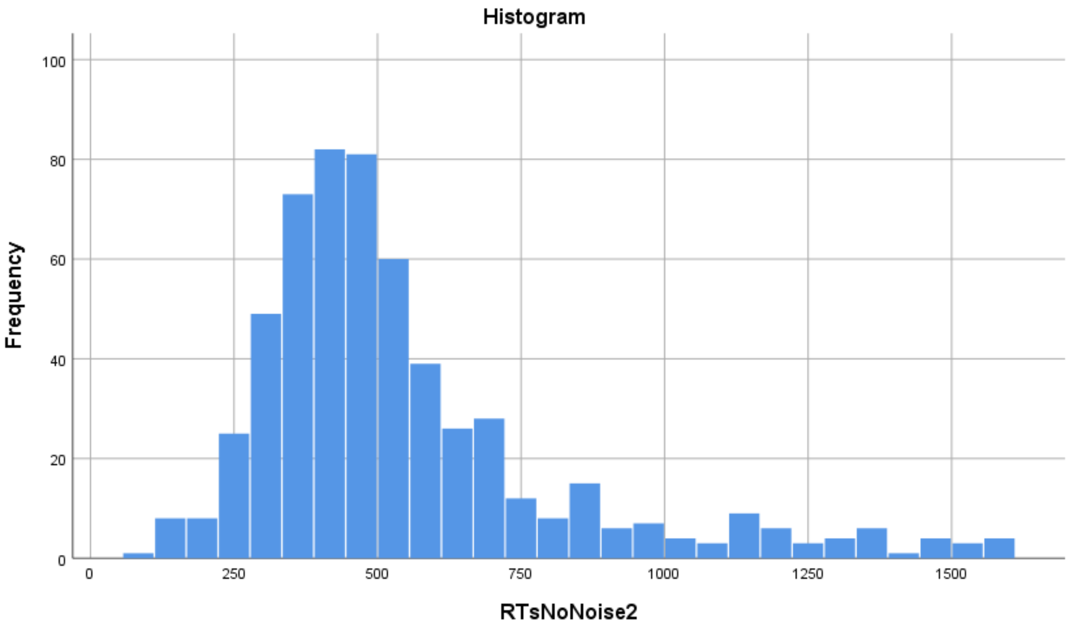


Figure B.10 Histogram for RTs in the No Noise Block 2 condition showing that RTs are positively skewed and thus no normally distributed

Appendix C

C.1 - Assistive Interventions for Children with ADHD Project - Study 3: Consent Form and Information sheet (The original sheet was in Arabic and this is a translated version):

1. **Who is running the study?**

The study is being run by Nouf Alromaih, a PhD student in the Department of Computer Science at the University of York. Nouf is supervised by Prof Helen Petrie who is a Professor of Human Computer Interaction at the same department.

2. **What is the purpose of the study?**

The study is part of our ongoing work on providing support for children with ADHD to improve their attention. In this study, we would like to collect some information about whether using white noise and pink noise would improve the attention of a child with ADHD. The study design and safety have been approved by Dr.xxxx, who is a psychiatrist and a consultant in behavioural and developmental disorders in children.

3. **What will my child and I have to do?**

Your child will be asked to finish a task called Go/NoGo task, once when your child is wearing headphones to listen to white noise, once when your child is wearing headphones to listen to pink noise and once without the headphones and the white and pink noise. The Go/NoGo task is like a computer game in which the child has to press a button as fast and as accurate as possible when they say a picture of an aeroplane and withhold pressing when they see a picture of bomb. The task helps measure the attention and impulsivity of the child. Then you and your child will also be asked some questions about white noise. When the study is finished, your child will be given a gift for their participation. The study will take about 30 mins.

4. **Who will have access to the study data?**

Only myself, Nouf Alromaih and my supervisor, Professor Helen Petrie, will have access to the study data.

5. Will my and my child’s participation in the study be kept confidential?

Any information you provide will be completely confidential and stored securely. and no comments will be ascribed to you or your child by name in any written document. Nor will any data be used from the study that might identify you individually. Any extracts from what you will write that are quoted in any public document (reports, journal papers) will be reported in anonymised manner to protect your identity.

6. Do my child and I have to take part in the study?

Your child and your participation in the study are completely voluntary. If you or your child feels uncomfortable at any point, you are completely free to withdraw from the study.

If you would like to receive the results of your child or the results of the whole study, please write your email here: ---

Before your child participates in this study, please complete Section A, printing your name in the first space and then sign at the end.

Once the study is over and you have been debriefed, you will be asked to initial the three statements in Section B, to indicate your agreement.

Section A

I, _______________________, give my consent for my child to participate in this study concerning the technological interventions for children with ADHD project. I have been informed about and feel that I understand the basic nature of the project. I understand that my child and I may withdraw from the study at any time without prejudice.

I also understand that my information is confidential. Only Helen Petrie and Nouf Alromaih will have access to the data collected today in its original format and anything made public will be in a completely anonymised format.

Signature _____________________________ Date ____________

Section B

Please initial each of the following statements when the study has been completed and you have been debriefed.

My child and I have been adequately debriefed Your initials:

My child and I were not forced to complete the study Your initials:

All my questions have been answered Your initials:

C.2 - Full information for all the participants in Study 3

Table C.1. Full information for all the participants

Participant	Sex	Age	Diagnosis
P1	Girl	7	ADHD-C
P2	Girl	8.2	ADHD-I
P3	Boy	10	ADHD-C
P4	Girl	9	ADHD-I
P5	Boy	9.5	ADHD-C
P6	Boy	9.4	ADHD-I
P7	Girl	7.6	ADHD-C
P8	Girl	8.5	ADHD-I
P9	Boy	8.11	ADHD-C
P10	Girl	7.8	ADHD-C
P11	Girl	11	ADHD-I
P12	Boy	9	ADHD-C
P13	Girl	8	ADHD-I
P14	Girl	8.4	ADHD-C
P15	Girl	9	ADHD-C

Appendix D

D.1 - Assistive Interventions for Children with ADHD Project - Study 4: Consent Form and Information Sheet (The original sheet was in Arabic and this is a translated version):

1. **Who is running the study?**

The study is being run by Nouf Alromaih, a PhD student in the Department of Computer Science at the University of York. Nouf is supervised by Prof Helen Petrie who is a Professor of Human Computer Interaction at the same department. The specialist at the school will be attending when the study is conducted with your child.

2. **What is the purpose of the study?**

The study is part of our ongoing work on providing support for children with ADHD to improve their attention. In this study, we would like to collect some information about whether an assistive technology called ADHD Headmuffs would improve the attention of a child with ADHD. The study design and safety have been approved by Dr.xxxx, who is a psychiatrist and a consultant in behavioural and developmental disorders in children.

3. **What will your child have to do?**

Your child will be asked to finish a task called Go/NoGo task, once when your child is wearing the ADHD Headmuffs with white noise, once Headmuffs only and once without the ADHD Headmuffs and without noise. The Go/NoGo task is like a computer game in which the child will press a button as fast and as accurate as possible when they see a picture of an aeroplane and withhold pressing when they see a picture of a bomb. Then, your child will be asked a few questions about their satisfaction and acceptability of the ADHD Headmuffs. When the study is finished, your child will be given a gift for their participation. The study will be conducted during the free time of your child (not including the lunch break). It will take from 30 to 45 mins.

4. **Who will have access to the study data?**

Only myself, Nouf Alromaih and my supervisor, Professor Helen Petrie, will have access to the study data.

5. **Will my child's participation in the study be kept confidential?**

Any information you provide will be completely confidential and stored securely. and no comments will be ascribed to you or your child by name in any written document. Nor will any data be used from the study that might identify you individually. Any extracts from what you will write that are quoted in any public document (reports, journal papers) will be reported in anonymised manner to protect your identity.

6. **Do my child have to take part in the study?**

Your child's participation in the study is completely voluntary. Your child's consent to participate will be taken verbally throughout the study. If your child feels uncomfortable at any point, they are completely free to withdraw from the study.

If you have any questions or concerns about the study, please contact me: Nouf Alromaih, at na916@york.ac.uk, or using my mobile no. 050xxxxxxx.

If you would like to receive the results of your child or the results of the whole study, please write your email here: ---

If you agree to allow your child to participate in this study, please complete Section A, printing your name in the first space and then sign at the end.

Section A

I, ______________________, give my consent for my child to participate in this study concerning the technological interventions for children with ADHD project. I have been informed about and feel that I understand the basic nature of the study. I understand that my child and I may withdraw from the study at any time without prejudice. All my questions have been answered and my child and I were not forced to complete the study.

I also understand that my information is confidential. Only Helen Petrie and Nouf Alromaih will have access to the data collected today in its original format and anything made public will be in a completely anonymised format.

Signature ____________________________ Date ___________

D.2 - Full information for all the participants in Study 3

Table D.1 Full information for all the participants

Participant	**Sex**	**Age**	**Diagnosis**
P1	Girl	9	ADHD-C
P2	Girl	11.2	ADHD-I
P3	Girl	11.7	ADHD-C
P4	Girl	7	ADHD-I
P5	Girl	9	ADHD-C
P6	Girl	8.7	ADHD-I
P7	Girl	12	ADHD-C
P8	Girl	9.2	ADHD-I
P9	Girl	8.11	ADHD-C
P10	Girl	7	ADHD-C
P11	Girl	11	ADHD-I
P12	Girl	8	ADHD-C
P13	Girl	8.5	ADHD-C
P14	Girl	9	ADHD-C

Appendix E

E.1 – Children with ADHD Satisfaction Questionnaires (The original questionnaire was in Arabic and this is a translated version):

Child code: ---------------

1. **Comfort**

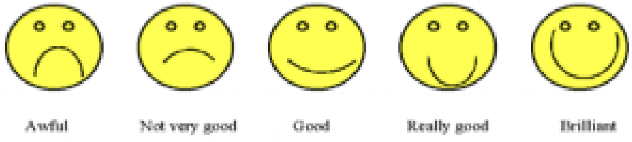
- Do you feel the ADHD Headmuffs are light enough on your head or too heavy?

- Do you feel the size of the ADHD Headmuffs fits you well or not?

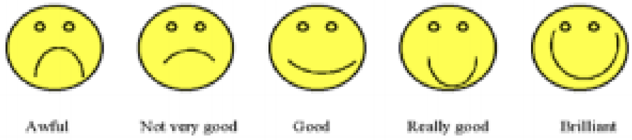
- Do you think the shape of the ADHD Headmuffs is good or not?

- Can you move around enough while wearing the ADHD Headmuffs?

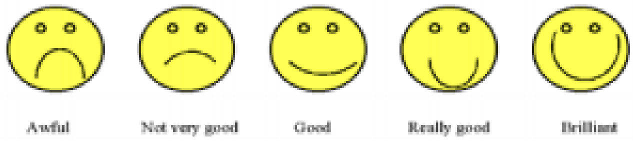
- Do you want to remove them when you are wearing them or not?



- Does wearing the ADHD Headmuffs hurt at all? If rating given is 3 or below: where does it hurt? Comment: --

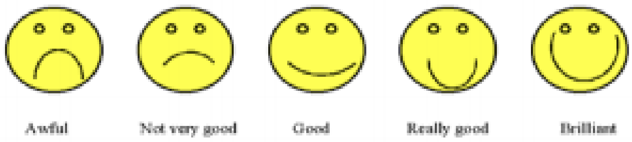


- Does wearing the ADHD Headmuffs make your neck or shoulders hurt? If rating given is 3 or below: where does it hurt? Comment: -----------------------------------

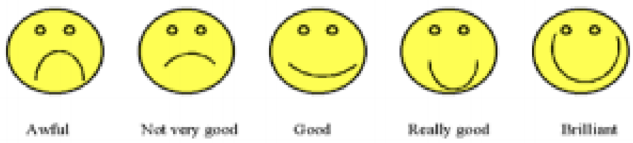


2. Usefulness

- Do they cut out the view of things around you that might distract you?

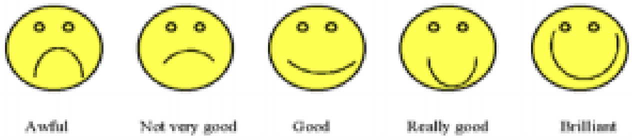


- Do you think wearing the ADHD Headmuffs helps you focus?



3. Ease of use

- Is it easy to put on and take off the ADHD Headmuffs?

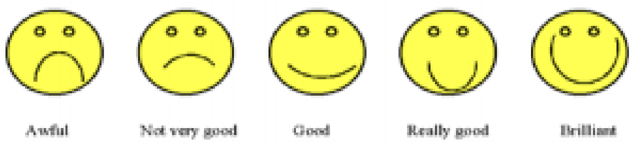


- Can you put the ADHD Headmuffs on and take them off quickly?

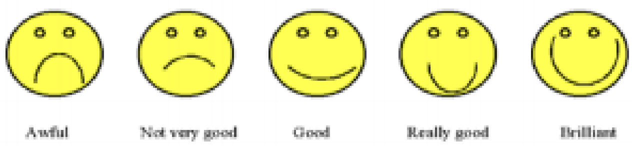
- Do you need any help in correctly putting them on so they are comfortable?

4. Aesthetics

- Do you like how the ADHD Headmuffs look?

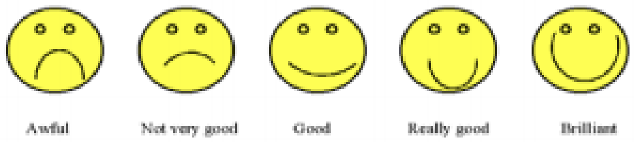


- Do you want to change their colour or texture? If 3 or below: What changes you want? Comment: ---



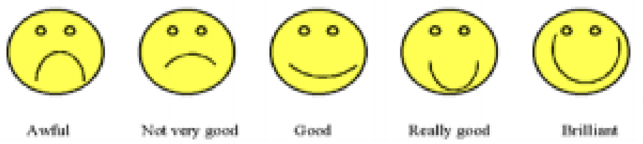
5. Acceptability

- Would you feel OK wearing the ADHD Headmuffs in class (in front of others)? Rating 3 or below: if some of your classmates or teachers wear the ADHD Headmuffs, would you wear them? Comment: --



- Do you feel relaxed when you wear the ADHD Headmuffs?

- Would you like to wear the ADHD Headmuffs frequently?



6. Open ended questions:

- What are most things you like about the ADHD Headmuffs?

- What are the things you did not like about the ADHD Headmuffs?

- What would you like to change about the ADHD Headmuffs?

E.2 – Researcher observation sheet

Child code: ----------------

Aspect	Type of observation	Rating	Comments
Comfort			
Weight	Observe child while wearing the ADHD Headmuffs		
Size	Observe child while wearing the ADHD Headmuffs		
Movement	Ask child to pick up pens and bag on the table and from the floor; turn head right and left, observe ease in performing these tasks		
Wanting to remove	Observe if child touches Headmuffs too much		
Hurting	Observe child while wearing the ADHD Headmuffs		
Causing pain	Observe child while wearing the ADHD Headmuffs		
Usefulness			
Cut view of distractions	Observe if child turns heads or responds to visual distractors		
Ease of use			
Easiness of wear	Ask child to take off and then put on the ADHD Headmuffs again and to adjust the wings, observe ease in performing these tasks		
Quickness of wear			
Need of help for correct wear			
Acceptability			
Felling relaxed	Observe child while wearing the ADHD Headmuffs		

Appendix F

F.1 - Evaluation by Experts of the Usability and Acceptability of the ADHD Headmuffs Information Sheet and Consent Form:

Thank you so much for offering to take part in this study.

This study is part of a PhD research for Nouf Alromaih under the supervision of Professor Helen Petrie. This study aims at evaluating the usability and the acceptability of an assistive technology, the ADHD Headmuffs, with experts in HCI, assistive technologies and children, including those with ADHD.

Only myself, Nouf Alromaih and my supervisor, Professor Helen Petrie, will have access to the study data. Any information you provide will be completely confidential and stored securely. If it is used in any public document (reports, journal papers), it will be reported in anonymised manner to protect your identity.

This study consists of an online questionnaire that involve 24 aspects that are categorized into two main categories: 1) usability which included four sub-categories related to the design, comfort, ease of use, and usefulness of the ADHD Headmuffs and 2) acceptability which included two sub-categories acceptability of the ADHD Headmuffs to children with ADHD and acceptability to parents and teachers of children with ADHD. You are kindly asked to rate the aspects on five-point rating items, in which only the two extreme ends of each rating item were labelled. In addition, you need to comment on the ratings you give.

In only the first category of the usability of the ADHD Headmuffs, the design aspects, you will need to rate and comment on the aspects based on the pictures and videos of the ADHD Headmuffs I showed you during the online meeting. However, the other aspects include specific scenarios to explain the context of use of the ADHD Headmuffs.

The questionnaire should take from 20 to 30 minutes to complete. If you have any questions, please email me, Nouf alromaih, at na916@york.ac.uk. You have the right to withdraw from the study at any time without giving any justifications.

If you give your consent to participate in this study, please press “Start” button below to start the online questionnaire.

Appendix F.2:

The usability of the ADHD Headmuffs:

1. **Design aspects:**
   a. Is the size of the ADHD Headmuffs appropriate for an average 8-year-old child with ADHD, like Peter?

      ❑ ❑ ❑ ❑ ❑

      Very appropriate   Not at all appropriate

      Comment on the given rating:

   b. Is the ADHD Headmuffs light enough or too heavy in weight for an average 8-year-old child?

      Too heavy ❑ ❑ ❑ ❑ ❑ Too light

      Comment on the given rating:

   c. Is the shape of the ADHD Headmuffs appropriate for an average 8-year-old child?

      ❑ ❑ ❑ ❑ ❑

      Very appropriate   Not at all appropriate

      Comment on the given rating:

d. Is it good to make the ADHD Headmuffs easily customized in terms of colour or texture to better fit the children's taste or gender?

Very good ❑ ❑ ❑ ❑ ❑ Very bad

Comment on the given rating:

e. Is the design of the ADHD Headmuffs pleasing?

❑ ❑ ❑ ❑ ❑

Very pleasing Not at all pleasing

Comment on the given rating:

2. Comfort aspects:

a. Will the ADHD Headmuffs restrict movement for an average 8-year-old child, as illustrated in all scenarios?

Very restrictive ❑ ❑ ❑ ❑ ❑

Not at all restrictive

Comment on the given rating:

b. Will the head-muffs be painful for an average 8-year-old child, as illustrated in all scenarios?

❑ ❑ ❑ ❑ ❑

Very painful　　　　Not at all painful

Comment on the given rating:

c. Will the head-muffs cause muscle fatigue in an average 8-year-old child, as illustrated in all scenarios?

❑ ❑ ❑ ❑ ❑

Very much muscle　　　　No muscle fatigue at all

Comment on the given rating:

3. **Ease of use aspects:**

a. Will it be easy or not for an average 8-year-old child to independently put on and take off the ADHD Headmuffs, as illustrated in all scenarios?

❑ ❑ ❑ ❑ ❑

Very easy　　　　Not at all difficult

Comment on the given rating:

b. Will an average 8-year-old child be able to put on and take off the ADHD Headmuffs quickly enough or not, as illustrated in scenario. 2, 3?

Very quickly ❑ ❑ ❑ ❑ ❑ Very slow

Comment on the given rating:

c. Will it be easy to adjust the ADHD Headmuffs to fit an average 8-year-old child's heads appropriately, as illustrated in all scenarios??

Very easy ❑ ❑ ❑ ❑ ❑ Very difficult

Comment on the given rating:

d. Will an average 8-year-old child be able to easily correctly put on the ADHD Headmuffs, as illustrated in all scenarios??

Very easy ❑ ❑ ❑ ❑ ❑ Very difficult

Comment on the given rating:

4. **Usefulness aspects:**

a. Will the ADHD Headmuffs help an average 8-year-old child concentrate more when doing homework at home as in scenario.1?

❑ ❑ ❑ ❑ ❑

Very helpful Not at all helpful

Comment on the given rating:

b. Will the ADHD Headmuffs help an average 8-year-old child concentrate more when taking a test in class as in scenario.2?

Very helpful ❑ ❑ ❑ ❑ ❑ Not at all helpful

Comment on the given rating:

c. Will the ADHD Headmuffs help an average 8-year-old child concentrate more when attending a lesson in class as in scenario.3?

Very helpful ❑ ❑ ❑ ❑ ❑ Not at all helpful

Comment on the given rating:

The acceptability of the ADHD Headmuffs:

1. **Acceptability of children:**

    a. Will the ADHD Headmuffs embarrass an average 8-year-old child during the use in class, as illustrated in scenario. 2 and 3?

Very embarrassing ❑ ❑ ❑ ❑ ❑ Not at all

Comment on the given rating:

b. Will an average 8-year-old child find it relaxing or not to wear the ADHD Headmuffs, as illustrated in all scenarios?

❑ ❑ ❑ ❑ ❑

Very relaxıng Not at all relaxing

Comment on the given rating:

c. Will an average 8-year-old child feel conspicuous or not when wearing the ADHD Headmuffs, as illustrated in scenario. 2 and 3?

❑ ❑ ❑ ❑ ❑

Very conspicuous Not at all conspicuous

Comment on the given rating:

d. Will an average 8-year-old child continue wearing the ADHD Headmuffs, as illustrated in all scenarios?

Very frequently ❑ ❑ ❑ ❑ ❑ Very rarely

Comment on the given rating:

e. Will an average 8-year-old child think the ADHD Headmuffs are fun to wear?

Very fun ❑ ❑ ❑ ❑ ❑ Very boring

Comment on the given rating:

2. **Acceptability of parents and teachers:**

a. Will the ADHD Headmuffs be safe for an average 8-year-old child to use or not, as illustrated in all scenarios?

Very safe ❑ ❑ ❑ ❑ ❑ Not at all safe

Comment on the given rating:

b. Will an average 8-year-old child's parents be happy for him to wear the ADHD Headmuffs at home, as in illustrated in scenario.1?

Very happy ❑ ❑ ❑ ❑ ❑ Not at all happy

Comment on the given rating:

c. Will an average 8-year-old child's parents be happy for him to wear the ADHD Headmuffs in class, as illustrated in scenario.2 and .3?

Very happy ❑ ❑ ❑ ❑ ❑ Not at all happy

Comment on the given rating:

d. Will an average 8-year-old child's teachers be happy for him to wear the ADHD Headmuffs when taking a test, as illustrated in scenario.2?

Very happy ❑ ❑ ❑ ❑ ❑ Not at all happy

Comment on the given rating:

e. Will an average 8-year-old child's teachers be happy for him to wear the ADHD Headmuffs when attending a lesson, as illustrated in scenario.3?

Very happy ❑ ❑ ❑ ❑ ❑ Not at all happy

Comment on the given rating:

Appendix F.3 – Materials for the online meetings

A Wearable Technology for Eliminating Distractors and Improving Attention in Children with ADHD

Presented by: Nouf AlRomaih, PhD student at the University of York, UK
Supervised by: Prof.Helen Petrie

1

What is ADHD?

- Attention Deficit Hyperactivity Disorder
- Two main symptom clusters:
  - Inattention
  - Hyperactivity/Impulsivity

2

ADHD clusters

Two main symptom clusters:

- Inattention:
  - often has difficulty sustaining attention in tasks or play activities (e.g. has difficulty remaining focused during lectures, conversations or lengthy reading)
  - often does not follow through on instructions and fail to finish schoolwork or duties (e.g. difficulty in morning and bedtime routines and starts tasks but quickly losing focus)
  - often has difficulty organizing tasks and activities (e.g. difficulty managing sequential tasks, messy, has poor time management, fails to meet deadlines)
  - is often forgetful in daily activities (e.g. returning to class, paying bills, keeping appointments)

3

ADHD clusters cont.

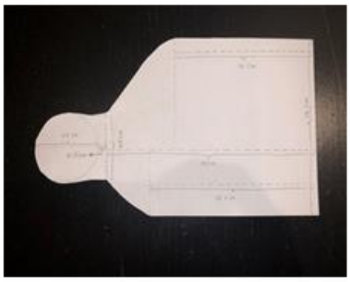
- Hyperactivity/Impulsivity:
  - often fidgets with hands or feet or squirm in seat
  - often leaves seat in situations where remaining seated is expected (e.g. leaves her or his place in the classroom, in the office or other workplace, or in other situations that require remaining in place)
  - often has difficulty awaiting turn (e.g. while waiting in line)

4

The Wearable Technology cont.

7

The Wearable Technology cont.



8

The Wearable Technology cont.

9

The Wearable Technology cont.

10

The ADHD Headmuffs

11

The ADHD Headmuffs - Video

- Child_wearing the ADHD_Headmuffs.mp4

12

The Effectiveness of the ADHD Headmuffs

- Study 3:
  - White noise+ADHD Headmuffs → Best performance
    - Improved attention and eliminated visual and audible distractors
  - White noise+no ADHD Headmuffs → Good performance
    - Visual distractors no eliminated
  - No white noise+no ADHD Headmuffs → Worst performance
- Study 4:
  - Children were overall very satisfied with the technology and willing to use it

13

Questionnaire of the Usability of the ADHD Headmuffs

- Involves 24 aspects that are categorized into two main categories:
  - usability which included four sub-categories related to the design, comfort, ease of use, and usefulness of the ADHD Headmuffs
  - acceptability which included two sub-categories acceptability of children with ADHD to using the ADHD Headmuffs and acceptability of parents and teachers of children with ADHD.

14

Scenarios of use

- Doing homework at home
- Doing test in class
- Attending lesson in class

15

Thank you!

16

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