Assistive Technologies to Empower Children with ADHD

Conceptual Framework and Technological Solutions

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PhD Dissertation

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Assistive Technologies to Empower Children with ADHD

Conceptual Framework and Technological Solutions

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Abstract

HCI researchers have for several years explored the potentials of using technology to empower people with various disabilities and deficits in dealing with the challenges of their condition. The exploration initially focused on designing technologies for people with outwardly visible physical impairments and disabilities, however, in recent years HCI researchers have begun to focus on assistive technologies for other patient groups and less visible impairments, e.g., people with cognitive or mental disorders. This movement has led to the design and development of several successful assistive technologies for a broad range of patient groups struggling with e.g., Bipolar Disorder, Autism Spectrum Disorder (ASD), and anxiety. However, only very limited research within HCI has focused on assistive technologies for the most common diagnosis for children and teens worldwide – Attention Deficit Hyperactivity Disorder (ADHD). The prevalence of ADHD is approximately 5-7% for all school age children and 2-3% for adults. The disorder is associated with both social and academic impairments, increased risk of criminal convictions, as well as poor quality of life. This signals a great loss for society, and an even greater loss for the individual with ADHD, as this handicap will affect them for the rest of their lives. ADHD is a major societal challenge and the annual estimated societal cost of ADHD (for children) has been estimated to be up to $52.4 billion in the United States alone.

The research objective of this dissertation has therefore been to contribute to the limited research on assistive technologies for the ADHD domain, in order to address the societal and personal challenges associated with ADHD. A design framework for the ADHD domain was developed through interdisciplinary collaborations with ADHD domain professionals including child psychiatrists, psychologists, teachers, and medical doctors. Furthermore, empirical studies, training and hands on experiences in caregiving for groups of children with ADHD added to the creation of the ADHD Design Framework. The ADHD Design Framework identifies central deficits and challenges associated with ADHD, provides specific design strategies, and visualizes a map of the design space. Together, these three components constitute the ADHD Design Framework and provide a lingua franca for HCI researchers in addition to establishing an initial foundation for researching and designing novel assistive technologies for people with ADHD.

Utilizing the ADHD Design Framework, three central ADHD deficits (attention-, emotional-, and sleep deficits) were addressed through the development of three novel research experiments that were all evaluated in real world contexts: CASTT, ChillFish, and MOBERO: 1) CASTT addresses attention deficits, and is a mobile intervention system that through wearable sensors detects attention lapses and has shown promise for assisting children with ADHD to regain attention in these classroom situations. 2) ChillFish addresses emotional deficits, and is a calming breathing exercise disguised as a biofeedback game that has successfully shown to calm down and reduce stress in adults and children with ADHD. Finally, 3) MOBERO addresses sleep deficits. MOBERO is a mobile application that assists families of children with ADHD to establish healthy morning and bedtime routines. MOBERO has showed to significantly improve sleep quality and reduce ADHD symptoms in children with ADHD.

Through these three research experiments and the ADHD Design Framework, this dissertation argues that assistive technologies for the ADHD domain hold potential for both novel research and for empowering people with ADHD.
Forskere inden for feltet ‘Human Computer Interaction’ (HCI) har i mange år udforsket mulighederne for teknologistøtte til personer med fysiske handicap. Dog er HCI-forskere i de seneste år også begyndt at fokusere på teknologistøtte til andre patientgrupper som f.eks. personer med mentale handicap. Denne bevægelse har resulteret i udviklingen af flere succesfulde teknologier til en bred gruppe af patienter inklusiv personer med bipolar lidelse, angst eller autisme. Der eksisterer dog kun i meget begrænset omfang forskning, som har fokusert på assisterende teknologier til den oftest stillede diagnose til børn og unge – Attention Deficit Hyperactivity Disorder (ADHD). Cirka 5-7% af alle børn og unge lider af ADHD og lidelsen er bl.a. forbundet med både sociale og akademiske handicap, forøget risiko for straffedomme samt dårligt livskvalitet. Dette udgør et stort tab for samfundet og et stort tab for den enkelte med ADHD, da lidelsen vil påvirke dem gennem hele livet. ADHD er en stor samfundsomvendt udfordring, hvilket bl.a. ses ved at det i 2005 blev anslået at ADHD årligt kostede det amerikanske samfund 52,4 milliarder USD (ca. 350 milliarder DKK).

Forskningen præsenteret i denne afhandling har til formål at bidrage til den stærkt begrensede forskning i assistierende teknologier til ADHD-domænet, for derved at afhjælpe de samfundsomvendte og personlige udfordringer, som er forbundet med ADHD. Afhandlingen indeholder et ADHD-designværktøj, som er udarbejdet i et tværfagligt samarbejde med bl.a. børnepsykiater, psykologer, lærere, læger og topforskere inden for ADHD-domænet. Derved udgør det præsenterede designværktøj en platform for at forske i og designe nyskabende teknologiske hjælpemidler til børn og unge med ADHD. Denne afhandling indeholder tre eksempler på nyskabende teknologier, der hver adresserer forskellige udfordringer forbundet med ADHD: Emotionelle udfordringer samt opmærksomheds- og søvnforstyrrelser: CASTT, ChillFish og MOBERO.

1) CASTT adresserer opmærksomhedsforstyrrelser og er et mobilt interventionssystem, der via sensorer registrerer faldende opmærksomhed. CASTT har vist lovende resultater i at hjælpe børn med ADHD i at genvinde opmærksomheden i skolesammenhæng.

2) ChillFish adresserer følelsesmæssige forstyrrelser og er en beroligende åndedrætsøvelse forklædt som et biofeedback-spil. Studier har vist at ChillFish er effektiv til at få børn med ADHD til at slappe af.

3) MOBERO adresserer søvnforstyrrelser. MOBERO er en mobil applikation der hjælper familier med børn med ADHD til at etablere sunde morgen- og sengerutiner. Studier har vist at brugen af MOBERO blev associeret med en markant forbedring af søvnkvaliteten og en reduktion af ADHD-symptomer hos børn med ADHD. Ydermere viste studier af MOBERO at forældrene reporterede mindre frustration omkring barnets morgen- og sengerutiner samt en forbedring i barnets selvstændighed.

Baseret på det præsenterede ADHD-designværktøj og de tre teknologiske forskningsekspedenter (CASTT, ChillFish og MOBERO) argumenterer denne ph.d.-afhandling for at assistierende teknologier til ADHD domænet indeholder et stort potentiale for både nyskabende forskning og for at forbedre livet for personer med ADHD.
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Dissertation Structure

The dissertation is divided into two parts. The first part presents an overview of the research activities that I have conducted over the last three years as a PhD Fellow, and is structured as follows:

**Chapter 1** introduces the work of this dissertation in terms of context, motivation, and domain. Furthermore, the research questions that have driven my work are presented.

**Chapter 2** presents background information related to the ADHD domain including ADHD diagnostic criteria and traditional treatment strategies.

**Chapter 3** presents the background and related work that the research presented in this dissertation builds upon; focusing on assistive technology, assistive technology for children, and the intersection between these fields and the ADHD domain: Assistive Technologies for Children with ADHD.

**Chapter 4** presents the general research approach used throughout my PhD work.

**Chapter 5** presents the first part of the ADHD Design Framework. The chapter identifies and presents central challenges associated with ADHD that are especially relevant for HCI researchers, as these challenges provide a practical understanding of the common challenges patients with ADHD struggle with.

**Chapter 6** presents the second part of the ADHD Design Framework. This chapter is concerned with design strategies for designing assistive technologies for children with ADHD. These strategies are based on a combination of findings from the ADHD literature and the conducted empirical studies described in chapter 4.

**Chapter 7** presents the third and final part of the ADHD Design Framework. The chapter proposes a design space for assistive technologies for the ADHD domain. The ADHD Design Space is based on two dimensions; a technological dimension and an ADHD impairments dimension that together span the domain for ADHD assistive technologies. Additionally, existing work are plotted in the ADHD Design Space and unexplored areas of the ADHD Design Space are discussed with regards to future opportunities for novel HCI research.

**Chapter 8** presents the CASTT research experiment. CASTT is a wearable and mobile system to assist children with ADHD to regain attention in critical school situations.

**Chapter 9** presents the ChillFish research experiment. ChillFish is a biofeedback game that is intended to assist children to calm down and relax e.g., after an emotional outburst or prior to bedtime.

**Chapter 10** presents the MOBERO research. MOBERO is a mobile application that addresses the issues of sleep deficits by assisting families of children with ADHD to establish healthy (morning and) bedtime routines.
Chapter 11 presents a reflection upon my work with assistive technologies for the ADHD domain as a HCI researcher.

Chapter 12 relates to the ChillFish research prototype from Chapter 9, however this chapter explores the potential of ChillFish beyond the ADHD domain by redesigning and evaluating ChillFish in blood drawing situations in a hospital context.

Chapter 13 concludes the work, summarizes the contributions, and outlines prospects for future work within the domain of assistive technology for people with ADHD.

The second part of this dissertation includes the five papers, which this dissertation is primarily based upon. Each paper holds its own contributions as briefly presented below:


This paper presents the design and evaluation of the ChillFish prototype during blood sampling procedures in a pediatric hospital context. Blood sampling is a common and necessary procedure in the treatment and diagnosis of a variety of diseases for children. However, blood sampling procedures often result in painful and stressful experiences for children. Designed in collaboration with domain experts, ChillFish is a breath-controlled biofeedback game that aims to distract and calm children down during blood sampling procedures. A Randomized-Controlled Trial (RCT) was conducted in which 20 children aged 6-11 were assigned to one of two conditions involving either passive distraction (watching a video) or active distraction (using the ChillFish prototype). Our study showed that medical staff rated ChillFish significantly more useful in facilitating the blood sampling procedure compared to passive distraction. Qualitative feedback from patients, parents, and medical staff further provided insights into aspects that impact the acceptance of breath-based active distraction. Our study highlights the potential of non-pharmacological assistive technology tools to reduce fear and pain for children undergoing painful or stressful medical treatment.


This paper presents a design framework for assistive technologies for the Attention Deficit Hyperactivity Disorder (ADHD) domain. The design framework is grounded in a combined analysis of empirical studies, the ADHD literature, and related work on assistive technologies for the ADHD and related domains. The design framework couples ADHD patient challenge areas to technological opportunities and provides a set of practical design strategies for developing successful assistive technologies for people with ADHD. In addition, we map existing technologies for the ADHD domain and unexplored
research opportunities to the design framework. The design framework provides HCI researchers with a foundation for designing and discussing assistive technologies for the ADHD domain.


This paper presents the interdisciplinary design process and evaluation of MOBERO, a smartphone-based system that assists families in establishing healthy morning and bedtime routines with the aim of assisting children with ADHD to become more independent and thereby lowering the parents’ frustration levels. In a two-week intervention with 13 children with ADHD and their families, MOBERO showed a statically significant improvement in the children’s independence and reduced the parents’ frustration levels. Additionally, the use of MOBERO was associated with a 16.5% reduction in core ADHD symptoms and an 8.3% improvement in the children’s sleep habits, both measured by standardized questionnaires. Our study highlights the potential of assistive technologies to change the everyday practices of families with children with ADHD.


This paper presents ChillFish, a breath-controlled biofeedback game designed in collaboration with ADHD domain professionals to investigate the possibilities of combining breathing exercises and game design. Based on a pilot study with 16 adults, ChillFish was found to have a positive effect on assisting the participants to reach a relaxed state similar to the one offered by traditional breathing exercises. Furthermore, we analyze the opportunities and challenges of creating a tangible respiration-based controller and use it as a core game mechanic. Finally, we discuss the challenge of balancing engagement and relaxation in physically controlled games for children with ADHD in order to make a game that can be calming and still sustain their attention.


The paper describes the empirical studies and the design and development behind CASTT, a real time assistive prototype that captures activities and assists the child in maintaining attention. Through several empirical studies conducted in school contexts and together with teachers and ADHD domain professionals design criteria for designing real time assistive technologies for children with ADHD was identified. Based on these design criteria, we
designed the Child Activity Sensing and Training Tool (CASTT). From a preliminary evaluation of CASTT with 20 children in several schools, we found that: 1) it is possible to create a wearable sensor system for children with ADHD that monitors physical and physiological activities in real time; and that 2) real time assistive technologies have potential to assist children with ADHD in regaining attention in critical school situations.

Additional Contributions

In addition to the five papers included in the second part of this dissertation, the following seven contributions have been produced as part of my PhD research:


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This dissertation addresses the subject of assistive technologies for the Attention Deficit Hyperactivity Disorder (ADHD) domain and the implications and potentials for Human Computer Interaction (HCI) researchers to develop novel technologies that can empower people with ADHD.

Figure 1: Two of the assistive technologies developed as part of this dissertation. On the left is the ChillFish biofeedback game that facilitates calming breathing exercises. On the right is the MOBERO mobile application that assists families in establishing healthy morning and bedtime routines.

For several years, HCI researchers have explored and showed how technology can assist a broad range of people with various handicaps and deficits including Bipolar Disorder (Bardram et al., 2013), Parkinson’s disease (Bächlin et al., 2010), and medication compliance for elderly (Dalggaard et al., 2013a; Wilcox et al., 2014). Initially, research on assistive technologies mostly focused on adults and elderslies, however, within the last couple of years, HCI researchers have increasingly begun to focus on designing assistive technologies for children with mental and physical handicaps. Especially research on assistive technologies for children with Autism Spectrum Disorder (ASD) has become a very active research field, with researchers from all over the world working on novel technologies and approaches for empowering children with ASD e.g., (Escobedo et al., 2012; Hayes et al., 2010; Hayes and Hosaflook, 2013; Hirano et al., 2010a; Kientz et al., 2013). In contrast, when I started my PhD in 2013, no published research on assistive technologies for children with ADHD was available in the ACM digital library, even though ADHD is the most common parent reported diagnosis for children and teens (Perou et al., 2013). Over the last three years, examples of assistive technologies for the ADHD domain have begun to emerge e.g., (Pina et al., 2014; Smit and Bakker, 2015; Weisberg et al., 2014). However, the domain is still greatly underexplored, especially compared to the high prevalence and the negative societal- and personal impact of ADHD.

ADHD is a mental disorder affecting approximately 5–7% of children and 2-3% of the adults worldwide (Faraone et al., 2015; Perou et al., 2013). The disorder is associated with inattention, hyperactivity, academic and social impairments, conduct disorders, increased risk of criminal convictions, and poor quality of life etc. (Faraone et al., 2015; Mannuzza et al., 2008; Masetti et al., 2008; Wehmeier et al., 2010). Thus, the consequences of ADHD affect the individual, the family, teachers, and the society as a whole. As an example of the last, it has been estimated that the annual societal cost of ADHD for children and adolescents in 2005 was estimated to be $36 – $52.4 billion in the United States alone (Pelham et al., 2007). More than 80% of children with ADHD have one additional diagnosis and more than 40% have two additional diagnoses. Some of the diagnosis that often co-exists with ADHD include learning- and conduct disorders, anxiety, and ASD (Wehmeier et al., 2010). However, though people can be
diagnosed with both ASD and ADHD, assistive technologies for the ASD domain cannot per se be used for people with ADHD (Sonne and Grønbæk, 2015) as the two disorders are very different.

The existing research on assistive technologies for children with e.g., ASD (Hayes and Hosaflook, 2013; Hiniker et al., 2013; Kientz et al., 2013), visual impairments (Stangl et al., 2014), and diabetes (Chen et al., 2011; Glasemann et al., 2010; Webster et al., 2015) have shown great promise for empowering and improving the life of children and adolescent. Therefore, the overall aim for the research presented in this dissertation has been to investigate the potentials for assistive technologies to empower children with ADHD. This has been achieved by researching the ADHD condition and to a large part also by designing, developing, and evaluating assistive technology prototypes with children with ADHD in real world contexts.

This dissertation presents a body of work where a fusion of existing research on ADHD and assistive technologies, interdisciplinary collaboration and co-design activities, together with the development of novel interactive technologies and evaluations of these in real-world context, has been the aim.

1.1 Research Objectives

The research presented in this dissertation is partly motivated by the unexplored gap in the existing research on assistive technologies for children with ADHD, and partly motivated by a personal desire to empower and improve the quality of life for children living with ADHD. The exploration done in the scope of this dissertation haven been driven by six main research questions (RQ) that seeks to explore challenges and opportunities for assistive technologies for the ADHD domain, in order to provide a foundation for HCI researchers to design successful assistive technologies for this domain:

**RQ1** How can HCI researchers analyze and conceptualize the mental disorder domain of ADHD, in order to create the foundation for designing assistive technologies for this domain?

**RQ2** How can assistive technologies be designed to assist children with ADHD in handling their central deficits and challenges?

**RQ2.1** How can assistive technologies assist children with ADHD sustain attention in real-world contexts?

**RQ2.2** How can assistive technologies assist children with ADHD better regulate emotions?

**RQ2.3** How can assistive technologies assist children with ADHD and their families to establish healthy bedtime routines and improve sleep quality?

**RQ3** What potentials do interactive technologies hold as a supplement to traditional treatment methods for ADHD and other mental disorders?

These research questions haven addressed through: 1) An analysis of the ADHD literature and related work within the domains of assistive technologies and interactive technologies for children, 2) collection of empirical data related to ADHD by engaging
with teachers, psychologists, child psychiatrists, clinical ADHD researchers, parents, and children with ADHD, 3) building a series of functional and interactive research prototypes informed by related work, empirical studies, and co-design activities with ADHD professionals, 4) evaluation of these prototypes in real-world contexts with children with ADHD and parents of children with ADHD, and 5) synthesizing findings from these design processes and evaluations to inform future design of assistive technologies for the ADHD domain.

1.2 Structure of Dissertation

The first part of this dissertation is structured as follows: The next chapter provides a brief introduction to the ADHD domain by presenting the diagnostic criteria, existing treatment strategies, and highlighting the limitations of these traditional treatment strategies that partly motivates my work in this dissertation. Thereafter in chapter 3, I will present the background and work related to my research. In addition, I will situate my work in this dissertation within the domain of Assistive Technologies for Children with ADHD. In chapter 4, I present my research approach and the design process that has guided the research in this dissertation.

Thereafter chapter 5, 6, and 7 constitute and present the ADHD Design Framework. In chapter 5, I will present core deficits and challenges that children with ADHD often suffer from as knowledge about these are paramount for developing successful assistive technologies for the ADHD domain. Thereafter, I will in chapter 6 present design strategies that build upon the deficits and challenges in chapter 5. Finally, in chapter 7, I will introduce the ADHD Design Space that highlights unexplored research areas and technological opportunities for designing assistive technologies for the ADHD domain.

Having introduced the ADHD Design Framework, I will in chapter 8, 9, and 10 present three research experiments that target three central deficits (attention deficits, emotional dysfunction, and sleep deficits) identified in chapter 5. In chapter 8, I will introduce CASTT, a mobile and wearable system that is designed to assist children with ADHD to regain attention in critical school situations. In chapter 9, I will introduce ChillFish that is a calming biofeedback game designed to assist children with ADHD to calm down in situations of emotional outbursts. Finally, I will in chapter 10 present MOBERO, a smartphone-based system designed to assist families of children with ADHD to establish healthy morning and bedtime routines.

In chapter 11, I reflect upon my work and experiences from conducting research within the highly unexplored domain of assistive technologies for children with ADHD.

In chapter 12, I return to the ChillFish research experiment to illustrate the potentials of the presented research experiment beyond the ADHD domain by reporting on an initial RCT (randomized controlled trial) where ChillFish is used by children during blood sampling procedures in a hospital.

Lastly, chapter 13 contains the concluding remarks of this dissertation and future work, which together end the first part of this dissertation.

Enjoy the read!
In this chapter, I will provide an introduction to the Attention Deficit Hyperactivity Disorder, how it is diagnosed (and named) differently in the US and the EU, traditional treatment strategies, and highlight limitations of these traditional treatment strategies.

The ADHD diagnosis is highly debated, and some media often question the validity of the disorder and instead account the problems to e.g., poor childhood, upbringing or general bad behavior. I am personally of the opinion that ADHD is a real and valid disorder, and the challenges and deficits associated with this disorder cannot be accounted to the child or solely poor parenting, just as a child with ASD is not responsible for her disorder.

ADHD is a persistent neurodevelopmental disorder that is estimated to affect 5-7% of children and 2-3% of adults worldwide (Faraone et al., 2015; Perou et al., 2013). The diagnostic criteria for ADHD include a persistent pattern of inattention and/or hyperactivity-impulsivity that influence development and daily functioning (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013), for which three presentations (earlier called sub-types) exists: 1) Predominantly inattentive, 2) predominantly hyperactive/impulsive, and 3) combined inattentive hyperactive-impulsive.

In addition to the common central deficits and challenges associated with ADHD (presented in chapter 5), the disorder can cause devastating problems for the individual as expressed by Russell A. Barkley and other prominent leading ADHD researchers in their international consensus statement on ADHD:

“ADHD is not a benign disorder. For those it afflicts, ADHD can cause devastating problems. Follow-up studies of clinical samples suggest that sufferers are far more likely than normal people to drop out of school (32-40%), to rarely complete college (5-10%), to have few or no friends (50-70%), to underperform at work (70-80%), to engage in antisocial activities (40-50%), and to use tobacco or illicit drugs more than normal. Moreover, children growing up with ADHD are more likely to experience teen pregnancy (40%) and sexually transmitted diseases (16%), to speed excessively and have multiple car accidents, to experience depression (20-30%) and personality disorders (18-25%) as adults, and in hundreds of other ways mismanage and endanger their lives.” (Barkley, 2002).

In addition, ADHD is associated with increased risk of criminal convictions (42%-47% vs. 14%) (Dalsgaard et al., 2013; Mannuzza et al., 2008) and individuals with ADHD are 12 times more likely to have violent convictions (Dalsgaard et al., 2013). A recent study have showed that 26% of children with ADHD with no reported conduct problems in childhood end up with criminal convictions in adulthood (Dalsgaard et al., 2013). In short, ADHD is associated with poor quality of life and enormous societal challenges (Barkley, 2002; Faraone et al., 2015; Pelham et al., 2007; Wehmeier et al., 2010).
The cause of ADHD is naturally a highly debated topic, however it is outside the scope of this dissertation to discuss this topic, but with a 70-80% heritability, genetics is considered to be an important factor (Biederman and Faraone, 2005; Faraone et al., 2015). For more information on the cause of ADHD I would recommend the *Nature* publication by Faraone et al. (Faraone et al., 2015).

2.1 ADHD Diagnostic Criteria

In this dissertation I use the term ADHD, however as I write this dissertation in Denmark, it would be more correct to use the term Hyperkinetic Disorder (HKD). This is because in the United States, ADHD is diagnosed according to the Diagnostic and Statistical Manual, Fifth Edition (DSM-V) (*Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition*, 2013), whereas in Denmark and most of Europe, ‘ADHD’ is diagnosed according to the International Classification of Diseases-10 (ICD-10) as a hyperkinetic disorder (World Health Organization, 1992). However, in Denmark the term ADHD is often used for HKD, therefore the term ADHD is also used in this dissertation.

The main differences between the DSM-V and ICD-10 diagnostic criteria for ADHD/HKD are that ICD-10 requires symptoms from all three groups (inattention, hyperactivity, and impulsivity) whereas DSM only requires symptoms in one group (Swanson et al., 1998) as illustrated in Table 2-1 below. Furthermore, ICD-10 requires all symptoms to be present in two settings (i.e., home and school) whereas DSM-V only requires some of the symptoms to be present (*Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition*, 2013).

Due to the more restrictive ICD-10 diagnostic criteria the prevalence of DSM-V ADHD is also higher than ICD-10 HKD, which has sometimes been misinterpreted as ADHD is more common in the United States (Biederman and Faraone, 2005).

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>DSM-V</th>
<th>ICD-10 HKD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum six (of nine) inattentive symptoms</td>
<td>Either or both of following:</td>
<td>All of the following:</td>
</tr>
<tr>
<td>Minimum six (of nine) hyperactive or impulsive symptoms</td>
<td></td>
<td>Minimum three (of five) hyperactive symptoms</td>
</tr>
<tr>
<td>Minimum one (of four) impulsive symptoms</td>
<td></td>
<td>Minimum one (of four) impulsive symptoms</td>
</tr>
</tbody>
</table>

**Pervasiveness**

<table>
<thead>
<tr>
<th>DSM-V</th>
<th>ICD-10 HKD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some symptoms are present for more than one setting.</td>
<td>All criteria are met for more than one setting</td>
</tr>
</tbody>
</table>

Table 2-1: An overview of the main differences between the DSM-V (United Stated) and ICD-10 (Europe) diagnostic criteria for ADHD/HKD.

2.2 Traditional Treatment Strategies

Traditional treatment strategies for ADHD include pharmacological treatments (often with the stimulant drugs methylphenidate and amphetamine) and non-pharmacological
strategies like parent training, cognitive behavioral therapy, working memory training, and neurofeedback training.

In the EU, non-pharmacological treatments like parent training and education are often recommended before the use of pharmacological alternatives (“Attention deficit hyperactivity disorder | introduction | Guidance and guidelines | NICE,” 2015; Faraone et al., 2015), whereas in the US, medication is typically the first treatment strategy (Faraone et al., 2015).

Medication has shown to significantly reduce general ADHD symptoms (Biederman and Faraone, 2005; Faraone et al., 2015; Hechtman and Greenfield, 2003), however medication is also associated with potential limitations and drawbacks. First, common side effects of medication include sleep problems, stomach pains, decreased appetite, and mood disturbances (Cascade et al., 2010; Faraone et al., 2015). Cascade et al. found in their study of 325 patients that 48% reported having experienced side effects from ADHD medication, however only 20% of patients mentioned these side effects to their physician (Cascade et al., 2010). Second, pharmacological treatments are (currently) only effective in treating symptoms of ADHD and not the underlying condition. Thus, if the patient stops the medical treatment, the ADHD symptoms will reappear. Third, Langberg and Becker conducted a meta review on the effect of medication on academic outcome (N across studies = 8,721) and found that medication was associated with improvement in academic scores, however the magnitude of these improvements was small and they concluded that the educational and clinical significance was questionable (Langberg and Becker, 2012), which is supported by Chacko et al. (Chacko et al., 2014). Fourth, Storebø et al. recently made a review of the effect of methylphenidate (the most used drug in ADHD treatment) and questioned the magnitude of the effect on e.g., teacher-reported general behavior and ADHD symptoms and parent-reported quality of life among children and adolescents diagnosed with ADHD (Storebø et al., 2015).

An alternative treatment strategy is behavioral therapy training, which within the EU is recommended as a first step in the treatment of ADHD. An example is the parent training program ‘The Incredible Years’ that has shown to reduce parent-rated ADHD symptoms (Webster-Stratton and Jamila, 2003). The core elements in many parent-training programs consist of the following ‘rules’/advices: 1. Promote play and a positive relationship, 2. Give praise and rewards for positive behavior, 3. Deliver clear rules and commands, 4. Provide consistent and calm consequences for unwanted behaviors, and 5. Organize the child’s day to reduce tensions (National Collaborating Centre for Mental Health (Great Britain) and NCCMH, 2013). These five advices have provided valuable input to the work in this dissertation in general, and especially in the MOBERO project presented in chapter 10, which utilize all these core elements to establish healthy morning and bedtime routines for families of children with ADHD.

In addition to behavioral therapy training, neurocognitive interventions like neurofeedback and working memory applications have been proposed as alternative treatment strategies (see chapter 3.4 for examples). However, a 2014 meta-analysis only found limited effects on ADHD symptoms (Sonuga-Barke et al., 2014). Nevertheless, Chacko et al. argues that continued research on neurofeedback applications are important as they, in contrast to medication, have the potential to address the underlying neurocognitive deficits related to ADHD (Chacko et al., 2014), which could provide positive long term effects on ADHD symptoms.
Based on the number of existing neurofeedback and working memory applications available today (Gevensleben et al., 2009; Klingberg et al., 2005; Lim et al., 2012; Monastra et al., 2002), in combination with the limited documented effect of these technologies (Cortese et al., 2015; Sonuga-Barke et al., 2014), the research in this dissertation has focused on exploring other technological alternatives for supporting and empower children with ADHD.

2.3 Summary

In this chapter I have presented the ADHD disorder, discussed the differences between the diagnostic criteria for the US and the EU ADHD/HKD diagnoses, presented the traditional treatment strategies, highlighted advantages and limitations of pharmacological treatment, and discussed non-pharmacological treatments strategies like cognitive behavioral therapy and neurocognitive interventions.

The literature on the effect of ADHD pharmacological treatments tends to favor and highlight the positive effect on ADHD symptoms, however it is outside the scope of this dissertation to argue for or against pharmacological treatment. I do not consider or argue that technology should replace existing treatments (i.e., pharmacological and non-pharmacological), instead I will in this dissertation explore the potentials of using technology to support existing treatment strategies and clinicians in their work for providing the best care for ADHD patients. Moreover, even though there are still contradictory reports on the effect of neurocognitive technologies, it is an interesting area to which HCI researchers can contribute with great insights. Finally, I see a gap in the existing ADHD treatment space related to technologies that provide everyday support to patients with ADHD, caregivers, and teachers. In chapter 8, 9, and 10, I will present three examples of assistive technologies that fill this gap and provide assistance in concrete situations and activities, which would not be possible with the traditional treatment strategies.
3 Background and Related Work

In this chapter, I discuss background and work related to assistive technologies for children with ADHD. In particular, I present how my work fits into the areas of assistive technologies, interactive technologies for children, and ADHD as illustrated in Figure 3-1.

![Figure 3-1: Related research areas. The focus for this dissertation is within the underexplored intersection between the three research areas: Interactive Assistive Technologies for Children with ADHD]

Having provided an introduction to the ADHD domain in the previous chapter, I will in this chapter start by introducing the area of assistive technologies and provide examples of assistive technologies for adults with various deficits and disabilities. This is followed by a brief introduction to the area of interactive technologies for children. Then, related work within the intersection between assistive technologies and interactive technologies for children is presented. Finally, I discuss and relate my work to existing assistive technologies for children with ADHD.

3.1 Assistive Technologies

3.1.1 Defining assistive technologies

Although the term assistive technology is frequently used within HCI, a generally accepted definition within HCI has not yet been obtained. One formal definition of assistive technology from the United States legislation “The Assistive Technology Act of 1998” defines assistive technology as: “technology designed to be utilized in an assistive technology device or assistive technology service.” (“Assistive Technology Act of 1998 | Section508.gov,” 2016), where ‘assistive technology device’ is defined as “any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional

The World Health Organization (WHO) also had a definition of assistive technology, however WHO today suggest using the term Assistive Health Technology (AHT) instead, which WHO defines as “the application of organized knowledge and skills, procedures and systems related to provision of assistive health products. AHT is an umbrella term that covers both assistive health products and service provision, including its scientific application.” (“WHO | Global Cooperation on Assistive Technology (GATE),” 2016), where the term ‘assistive health products’ is defined as “form of external tool specially designed and produced or generally available, whose primary purpose is to maintain or improve an individual’s functioning and independence, to facilitate participation, and to enhance overall well-being.” (“WHO | Global Cooperation on Assistive Technology (GATE),” 2016).

In addition to the above two formal definitions of assistive (health) technologies, several informal definitions also exist (see (Hersh and Johnson, 2008) for examples), however the broader definition of assistive technology by Hersh and Johnson (Hersh and Johnson, 2008) is often used within HCI: “Assistive technology is a generic or umbrella term that covers technologies, equipment, devices, apparatus, services, systems, processes and environmental modifications used by disabled and/or elderly people to overcome the social, infrastructural and other barriers to independence, full participation in society and carrying out activities safely and easily.” (Hersh and Johnson, 2008).

It is outside the scope of this dissertation to come up with a new definition of assistive technology. Instead, I agree with both WHO and Hersh and Johnson (Hersh and Johnson, 2008) on the broad definition of assistive technology. However, especially when considering children with ADHD, autism, and other cognitive deficits I prefer the (more recent) WHO definition, as it does not categorize the individual as a ‘disabled person’, like it also explicitly include the purpose to enhance the overall well-being for the individual (child), which is not explicitly mentioned by Hersh and Johnson (Hersh and Johnson, 2008).

Thus, in this dissertation I use the WHO’s definition of the term ‘Assistive Health Technology’ and ‘Assistive Health Products’ when referring to assistive technology, however I will continue to write only assistive technology, as it is the current norm within HCI.

3.1.2 Related assistive technologies

Early assistive technologies often referred to technologies designed to assist elderly people (like Hersh and Johnson also explicitly mentioned elderly people in their definition of assistive technology). Examples of assistive technologies for elderly people include physical/cognitive rehabilitation (Gerling et al., 2010; Rodriguez-Isasi et al., 2014; Uzor and Baillie, 2014), medication compliance (Dalgaard et al., 2013a, 2013b; Lee and Dey, 2014; Wilcox et al., 2014), and self-monitoring/care (Kusk et al., 2013; Papadopoulos et al., 2010; Verdezoto and Grönvall, 2016).

More related to the application domain of this dissertation are assistive technologies for adult individuals with cognitive deficits and mental disorder, for which a wide variety
of technologies exist. For example, the MONARCA system (Bardram et al., 2013) designed for adult Bipolar Disorder patients. Through collection and analysis of mobile phone usages, MOBERO provides insight into the condition for both patient and their clinician. Other examples include assistive technologies that focus on mitigating anxiety by e.g., using virtual reality (Repetto et al., 2013) or tangible objects (Lee, 2013). This inspired my work on ChillFish (as presented in chapter 9), where a tangible device combined with a biofeedback game is used to assist children to calm down.

Related to my work on MOBERO as presented in chapter 10 are assistive technologies related to sleep, as sleep problems are common for individuals with ADHD (cf. chapter 5.5). Choe et al. were among the first to identify opportunities of using technology to support healthy sleep habits (for adults) (Choe et al., 2011, 2010). This work has been followed by several examples of sleep technologies including Lullaby (Kay et al., 2012), ShutEye (Bauer et al., 2012), and SleepTight (Choe et al., 2015).

The Lullaby system captures and provides feedback on sleep and environment parameters like temperature, light level, and noise level (Kay et al., 2012). The adult user is provided with feedback and simple advices on the environmental parameters through a touch screen device, allowing the user to learn about environmental conditions that can negatively impact sleep (Kay et al., 2012). Lullaby was evaluated with four adult participants for two weeks as part of a feasibility study, which provided insight into designing sleep technologies and personal informatics tools for adults (Kay et al., 2012).

Another example of sleep assistance is ShutEye (Bauer et al., 2012), which in contrast to Lullaby is a purely smartphone based solution. ShutEye is a peripheral display application that works by replacing the user’s smartphone wallpaper / background image with time-based recommendations and guidance to promote healthy sleep habits. ShutEye was evaluated with 12 adult participants over a four-week period and showed to be an effective way to improve adults’ awareness of healthy sleep habits (Bauer et al., 2012).

Lastly, the SleepTight application (Choe et al., 2015) is similar to ShutEye as it is purely smartphone based. However, SleepTight is different than both ShutEye and Lullaby as it focuses on providing low-burden self-reporting of sleep habits. Choe et al. argue that self-reporting of sleep habits can lead to reflection and positive changes of sleep habits, why an easy way to report such data is critical. In their study, Choe et al. investigated the effect of two ways of reporting sleep habits (one based on an Android widget solution and one without the widget solution) and found the participants using the widget version had a higher compliance rate (92%) compared to the non-widget version (75%).

Moving to the intersection between assistive technologies and the ADHD domain as represented in Figure 3-1, ParentGuardian (Pina et al., 2014) is maybe the best known assistive technology for the ADHD domain within HCI. ParentGuardian is designed to parents of children with ADHD and provides in situ support for coping with stressful interactions with their child. The parent’s stress level is measured through a wrist worn electro dermal activity (EDA) sensor, and when a high level of stress is detected, ParentGuardian triggers a visual reflective “heat of the moment” strategy (text + accompanied illustration) on the parents smartphone and on a peripheral tablet display.
placed on a strategic location in their house (Pina et al., 2014). The visual reflective strategy is based on parental behavioral therapy and include examples like “Fill your lungs with air: Take three full, deep breaths”, “Choose self-control, over out of control”, and “Stop, Look, and Listen” (Pina et al., 2014). Pina et al. conducted a two-phase study each lasting seven days with ten parents; in the first phase the ParentGuardian system was triggered on an hourly basis, and in the second phase the reflective strategies was triggered based on sensor data from the worn EDA sensor (Pina et al., 2014). Based on their studies, Pina et al. found that in situ cues were effective in reminding parents to use parental behavioral therapy strategies in situations of high stress (Pina et al., 2014). The ParentGuardian system inspired me to work on technologies that supports calming, which ChillFish (chapter 9) is an example of.

3.2 Interactive Technologies for Children

Designing interactive technologies for and with children is a very active research area within HCI with the Interaction Design for Children (IDC) conference as the main venue for this community. Some of the major fields within this area relates to education and learning technologies (Marshall, 2007, 2007; Noack et al., 2008), (exer)games (Gronbaek et al., 2007; Landry et al., 2013; Mansour et al., 2009), and design methods for including children in the design process (Dindler et al., 2005; Frauenberger et al., 2012; Iversen and Smith, 2012; Leong and Iversen, 2015). In addition, assistive technology for children with various deficits, challenges, and disabilities is also a major field within IDC and related communities, as demonstrated in the sub-chapter below.

3.3 Assistive Technologies for Children

Having presented assistive technologies (for adults) and interactive technologies for children, I now present work within the intersection of these two areas.

Assistive technologies for children is unsurprisingly an active research area, and many assistive technologies have been presented for children with e.g., diabetes (Chen et al., 2011; Glasemann et al., 2010; Webster et al., 2015), visual impairments (Stangl et al., 2014), and autism (Kientz et al., 2013). However, in the following I will especially focus on assistive technologies for the autism domain, as this research shares some resemblance to my work.

The first example of an assistive technology for the autism domain is vSked (Hirano et al., 2010a). vSked is a collective and interactive visual scheduling system designed to be used in a classroom context. vSked is similar to the analog visual schedules used in many classrooms (especially in classes with children with special needs) to visualize school activities. However, in addition to the analog schedules, vSked provides interactive feedback in terms of e.g., time visualization and a reward mechanism.

Another example of a technology that uses structure to support children and youth with autism is HygieneHelper (Hayes and Hosaflook, 2013). HygieneHelper is a mobile application designed to educate and track healthy hygiene behaviors. Through a combination of audio, video, and text, the user is educated about healthy hygiene routines and how to perform these (e.g., brushing teeth, showering, etc.).
The third and last example is MOSOCO (Escobedo et al., 2012), which provides social skills training using augmented reality. The training in MOSOCO is based on the social compass curriculum that provides eight steps/stages for training a social skill starting with a teacher introducing the social skill and ends with a step that encourages the student to practice the newly learned skill in a real-life situation (Escobedo et al., 2012).

Though ASD and ADHD share some deficits, technologies and findings from the ASD domain cannot automatically be used within the ADHD domain, as the two diagnostic criteria are fundamentally different (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013). Instead, the work on novel assistive technologies for the ASD domain inspired me to work with the ADHD domain, and many of the strategies that are beneficial for children with autism is also beneficial for children with ADHD e.g., routines and structure as I use in MOBERO in chapter 10.

3.4 Assistive Technologies for Children with ADHD

The above-presented work has been related to assistive technologies for adults, interactive technologies for children, and the intersection between these two areas (assistive technologies for children). In the following, I will preset work within the cross-section between these areas and ADHD: Assistive technologies for children with ADHD as depicted in Figure 3-1.

Assistive technologies for children with ADHD is a young and underexplored research area in general and especially within HCI as illustrated in Table 3-1, where TangiPlan (Weisberg et al., 2014; Zuckerman et al., 2015) and BlurtLine (Smit and Bakker, 2015) are among the very few contributions from the HCI domain.

<table>
<thead>
<tr>
<th>System</th>
<th>User</th>
<th>Context</th>
<th>Targeted ADHD challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Timer</td>
<td>Children + adults</td>
<td>Home / School</td>
<td>Attention deficits, hyperactivity/impulsivity, working memory deficits</td>
</tr>
<tr>
<td>TangiPlan</td>
<td>Children</td>
<td>Home</td>
<td>Working memory deficits</td>
</tr>
<tr>
<td>CogoLand</td>
<td>Children</td>
<td>Home</td>
<td>Attention deficits, working memory deficits</td>
</tr>
<tr>
<td>CogMed</td>
<td>Children</td>
<td>Home</td>
<td>Attention deficits, working memory deficits</td>
</tr>
<tr>
<td>BlurtLine</td>
<td>Children</td>
<td>School</td>
<td>Hyperactivity/impulsivity</td>
</tr>
<tr>
<td>‘Smart wristband’</td>
<td>Children</td>
<td>School</td>
<td>Emotional self-control</td>
</tr>
<tr>
<td>SmartPen</td>
<td>Children</td>
<td>School</td>
<td>Attention deficits</td>
</tr>
</tbody>
</table>
In contrast to the broad purpose of Time Timer, TangiPlan is specifically designed to assist children with ADHD to complete their morning routines (Weisberg et al., 2014; Zuckerman et al., 2015). TangiPlan consists of a web interface that can be used to compose the activities that constitutes the child’s morning routine. TangiPlan utilizes tangible objects that each represents a task for example brushing teeth. These tangible objects are placed in the context of were the child is expected to execute the task associated with it (i.e., in the bath room for the teeth brushing activity). An array of LED lights on the tangible objects is used to inform the child about the remaining time for each task. TangiPlan was designed through a user-centered design process and an early paper based prototype was presented for three families (Weisberg et al., 2014) and a later enhanced 3D printed model was evaluated in a preliminary study with two families of children with ADHD with positive feedback (Zuckerman et al., 2015).

TangiPlan and Time Timer are similar to MOBERO (chapter 10) in providing assistance to complete certain activities. However, MOBERO assists in establishing both morning and bedtime routines, where TangiPlan only focuses on morning routines.

CogoLand (Lim et al., 2012) and CogMed (Klingberg et al., 2005) are different from Time Timer, TangiPlan, and the other examples of related work presented in this chapter, as these two types of systems focus on training rather than providing assistance in specific situations. CogoLand is a neurofeedback game that aims to train and improve the attention capabilities of children with ADHD. In CogoLand the child controls an avatar in a 3D world with the goal of completing a race as fast as possible (Lim et al., 2012). The speed of the player avatar is based on the child’s attention level, which is measured from a headband with dry electroencephalography (EEG) sensors embedded. 20 children with ADHD participated in a study of CogoLand for eight weeks that showed a significant improvement in parent rated ADHD symptoms (Lim et al., 2012).

Similar to CogoLand is CogMed (Klingberg et al., 2005), however CogMed is not a biofeedback application and does not require the user to wear special equipment. Instead, CogMed is a collection of several simple memory games that are designed to improve working memory (Klingberg et al., 2005). Through a five-week randomized control trial (RCT) with 53 children Klingberg et al. found that the training group showed significant improvements in working memory and parent rated ADHD symptoms (Klingberg et al., 2005).

Nevertheless, while neurofeedback and working memory interventions like CogoLand and CogMed have shown promising results, the overall picture of the effect of these interventions are inconsistent and often based on small populations, which makes it hard to draw definitive conclusions (Chacko et al., 2014).

Returning to assistive technologies that provide assistance in-situ, I will now present BlurtLine (Smit and Bakker, 2015) and a smart wristband prototype (McHugh et al., 2010). BlurtLine is an interactive belt that monitors breathing patterns to predict and prevent a child with ADHD from blurting (impulsive speaking behavior) through a discrete vibration signal. A lab study of BlurtLine with seven adults (without ADHD) was first conducted to evaluate the system’s ability to detect breathing patterns, as rapid inhalation can be a precursor for blurring (Smit and Bakker, 2015). Unfortunately, BlurtLine has only been evaluated with one child with ADHD in a school context with mixed feedback from the child and teachers.
Similar to BlurtLine is the smart wristband prototype from McHugh et al. (McHugh et al., 2010). McHugh et al.’s prototype is a modified wristband connected to a heart rate monitor with the aim to alert children with emotional challenges prior to an emotional outburst. When the system detects a sudden increase in heart rate (which is associated with a forthcoming emotional outburst), the wristband notifies the child to initiate a breathing exercise (which they were introduced to prior to the study). Though McHugh et al. only present three case studies, and none of these included children with ADHD; the smart wristband is very relevant to my work and assistive ADHD technologies in general due to the emotional deficits many children with ADHD experience (as further described in chapter 5.4).

The work by especially McHugh et al. (McHugh et al., 2010) was an inspiration in the work on both CASTT (chapter 8) and ChillFish (chapter 9) as they use data from physiological sensors to provide assistance and to assist a child to perform a calming breathing exercise.

Finally, the smart pen system by DePrenger et al. (DePrenger et al., 2010) is different from the above related work as it focuses mainly on the attention deficits associated with ADHD. The portable smart pen system is a pen shaped object with an embedded accelerometer and microcontroller that via a simple machine learning algorithm is able to detect concentrations lapses during reading activities (DePrenger et al., 2010). When the smart pen detects that the child has stopped reading it will remind the child to resume reading by lighting a LED or a discrete vibration pattern. Currently, DePrenger et al. have conducted a feasibility study with focus on the technical implementation, which unfortunately revealed issues with their machine-learning algorithm in real world reading situations (DePrenger et al., 2010).

The smart pen system did inspire my work on CASTT (chapter 8), however CASTT focuses on detecting attention lapses in general (through analysis of physical and physiological activity), whereas the smart pen system only focus on detecting concentration lapses during reading activities.

3.5 Summary of Related Work

Research on assistive technologies within the HCI domain initially focused on supporting people with physical handicaps, however, in recent years researchers have begun to explore the potentials of assistive technologies for people with a wider variety of handicaps and deficits including anxiety, visual impairments, and autism. However, only very limited HCI research has explored the potential of assistive technologies for the most common disorder for children and adolescent: ADHD. Assistive technology for the ADHD domain is a highly unexplored area and the very limited existing HCI research is based on early stage prototypes and preliminary evaluations with a narrow focus on evaluating the particular technology.

The research presented in this dissertation aims to address the unexplored research space of assistive technologies for children with ADHD by building upon the existing work on assistive technologies for e.g., ADHD, ASD, Bipolar Disorder, and anxiety. Through the development of the ADHD Design Framework, which identifies common deficits and challenges associated with ADHD (chapter 5), design strategies (chapter6), and technological opportunities (chapter 7); this dissertation provides a lingua franca for
discussing assistive technologies for the ADHD domain in addition to providing an initial foundation for HCI researchers to design novel assistive technologies for children with ADHD. In addition, through the development and evolution of three technological research experiments (CASTT, ChillFish, and MOBERO presented in chapter 8, 9, and 10 respectively) this dissertation contributes to and advance state-of-the-art assistive technologies for children with ADHD.
4 Research Approach

Designing assistive technologies for the ADHD domain requires an understanding of the disorder and the challenges associated with it. Throughout my work, I have conducted several empirical studies using multiple methods including observation, hands on training, interviews, and workshops. Together with related literature from the especially the ADHD domain, the empirical studies have helped to establish an initial foundation for designing assistive technologies for the ADHD domain. Based on this acquired knowledge about the ADHD domain, several research experiments have been developed through iterative co-design processes involving teachers, parents, and ADHD domain professionals (e.g., psychologists, child psychiatrists, clinicians, and ADHD researchers). The research prototypes that emerged from these design processes were all evaluated with children with ADHD when possible (in some cases adults or children without ADHD were included in the early evaluation process), using a mix of qualitative and quantitative methods. This lead to findings related to opportunities and challenges for using assistive technologies to support children with ADHD. Therefore, the presented research in this dissertation can be viewed within Mackay and Fayard’s framework for cross-disciplinary triangulation (Mackay and Fayard, 1997), where HCI research is described as movements between theory, observations, and the design of artifacts. At the end of this chapter, I will use Mackay and Fayard’s framework to provide a visual overview of my research process related to each of the three research prototypes presented later in this dissertation: CASTT (Figure 4-2), ChillFish (Figure 4-3), and MOBERO (Figure 4-4).

In the following, I will provide an overview of the general research approach and the methodology used in the different phases of my research.

4.1 Research Method

The primary research method used in this dissertation is that of experimental computer science (Grønbæk, 2015) as depicted in Figure 4-1. This method takes its onset in real world challenges and state-of-the-art technologies, which is similar to how my research is also based on the challenges that children with ADHD experience, state-of-the-art technologies, and related work. The experimental computer science research approach is based on an iterative four-stage design process (analysis, design, prototype, and evaluate) with the objective to generate generalizable results, advance state-of-the-art, or industrial deployment (Grønbæk, 2015).

In the following, I will elaborate on each of the four steps in the experimental computer science research approach and relate these and other common HCI research methods, to the work presented in this dissertation.
4.2 Initial Analysis – Understanding the ADHD domain

Contextual inquiries as introduced by Holtzblatt and Beyer (Holtzblatt and Beyer, 2014) was frequently used in the initial analysis and understanding process of this dissertation. Therefore, e.g., observations, contextual interviews, and hands-on training were used as part of a user centered design process as highlighted in Table 4-1. For example, as part of understanding the ADHD domain, I volunteered to take care of children with ADHD every Tuesday for half a year, while the parents received parent training at Center for ADHD, Aarhus, Denmark. In addition, I followed several psychologists during school observations of children as part of the normal ADHD diagnostic process. Finally, I did several observations and interviews with child psychiatrists as part of diagnosing children with ADHD.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hands-on training at Center for ADHD, Aarhus, Denmark</td>
<td>More than 50 hours (2.5 ~ 3 hours each week for 20 weeks)</td>
</tr>
<tr>
<td>Hands-on training and discussions with two psychologists</td>
<td>~ 25 hours</td>
</tr>
<tr>
<td>Observations in clinics with follow up interviews with child psychiatrists and psychologists</td>
<td>11 hours</td>
</tr>
<tr>
<td>Shadowing two psychologists during their observations of children being examined for ADHD in school contexts</td>
<td>Two school days</td>
</tr>
<tr>
<td>Extensive classroom observations of children with ADHD (2nd - 5th grade) in addition to interviews with seven teachers from four different elementary schools and two pedagogues, who all had extensive experience working with children with ADHD</td>
<td>Several school days</td>
</tr>
</tbody>
</table>

Table 4-1: Examples of the empirical studies conducted as part of the initial analysis phases in this dissertation.

Having presented the initial analysis phase that served to provide me with a background understanding of challenges children with ADHD experience and how these affect...
caregivers and teachers, I will in the following present the interaction cycle for each of the three research experiments presented later in this dissertation (i.e., CASTT, ChillFish, and MOBERO).

The research approach applied in these three research experiment is similarly to the research through design approach outlined by Zimmerman et al. (Zimmerman et al., 2007), as I have applied knowledge from the ADHD domain together with my expertise in developing interactive technologies to design research artifacts. These research artifacts were evaluated with the intended user group in the intended context (when possible) in order to gain insights about both the research artifact, the user group, and the implications for future HCI research.

4.3 Analyze, Design, Prototype, and Evaluate Iterations

In the following, I will provide a brief overview of the empirical studies conducted as part of the three research experiments CASTT, ChillFish, and MOBERO presented in chapter 8, 9, and 10 respectively.

4.3.1 Developing technologies that provide attention assistance in school (CASTT)

Based on the analysis of several conducted contextual inquiries in school contexts, numerous designs for providing attention assistance in schools were developed and discussed with teachers and psychologists. Based on feedback and insights from these domain professionals, the CASTT prototype was developed (as further described in chapter 8 and in Paper E). Through a series of studies with 11 children with ADHD and nine children without ADHD that wore CASTT in real-world school contexts, the functionality and wear ability of the various CASTT components were evaluated, analyzed, and re-designed as further described in chapter 8.4.

4.3.2 Developing technologies that provide calming assistance (ChillFish)

The hands-on training at Center for ADHD supported by analysis of the ADHD literature, recognized that children with ADHD often experience emotional outbursts and furthermore find it difficult to calm down afterwards (Faraone et al., 2015). Based on design workshops with three fellow volunteers at Center for ADHD (all psychology students) and two psychologists employed at Center for ADHD the initial concept for the calming ChillFish biofeedback game (chapter 9 and Paper D) emerged. As a first step in evaluating ChillFish, 16 adults were recruited to participant in a within-subject study. Findings from this study provided qualitative insights about the interaction technique (direct breath-based) and the challenges of balancing relaxation and engagement in calming biofeedback games.

Having evaluated the ChillFish with adults with positive results, we improvements to the ChillFish prototype was made based on the interview analysis of the first study. Furthermore, the study design was re-designed to include a visual overview of the study plan, a questionnaire for the parents, and a visual ranking system for the children to rate ChillFish to the other activities in the study plan (i.e., playing PAC-MAN and doing a traditional breathing experience). These study design adjustments where to a high degree based on the design strategies in the ADHD Design Framework as presented in chapter 6. 12 children with ADHD were recruited at an ADHD summer holiday camp to evaluate the calming effect of ChillFish. Unfortunately, due to technical issues only four of the 12 children did complete the evaluation. Nevertheless, findings from the
evaluation provided insights into the calming effect of ChillFish on children with ADHD and how to improve the technical construction of ChillFish to avoid short circuits as further described in chapter 9.

4.3.3 Developing technologies that support healthy family routines (MOBERO)

MOBERO (chapter 10 and Paper C) was designed through a series of mini design workshops and evaluations in collaboration with child psychiatrists, sleep researchers, and families of children with ADHD. A pre-study with a functional prototype of MOBERO was subsequently evaluated with two families of children with ADHD for four and three weeks respectively. The purpose of this pre-study was to evaluate MOBERO in real-world contexts and gain insights about bedtime habits, challenges, and techniques from parents. The pre-study evaluations mainly relied on observations and semi-structured interviews, however all interactions within MOBERO was also logged and analyzed. In addition, parents were asked to complete a daily sleep diary to investigate any effect of the child’s sleep habits. The two pre-studies allowed for insights into family dynamics and challenges around bedtime and morning routines in addition to concrete ideas for improving MOBERO and the following main study design.

Based on insights from the pre-study, 13 children with ADHD and their families were recruited for a four-week study of MOBERO. The first two weeks functioned as a baseline and the last two weeks as an intervention period (where they began to use MOBERO). During all four weeks, parents completed a daily assessment questionnaire related to their child’s independence and their own frustration around morning and bedtime routines. Semi-structured interviews were conducted with all families before, immediately after, and one month after the study. These interview data were analyzed using a bottom up thematic coding process as suggested by Braun and Clarke (Braun and Clarke, 2006). In addition, several quantitative analyses were conducted based on validated clinical questionnaires and daily parent assessments as further described in chapter 10 and in Paper C.

4.4 The Research in a Triangulation Perspective

Having presented an overview of the research approach and design process behind the three research experiments (i.e., CASTT, ChillFish, and MOBERO), I will in this section present these three research experiments in the scope of Mackay and Fayard’s framework for cross-disciplinary triangulation (Mackay and Fayard, 1997). As mentioned above, Mackay and Fayard’s triangulation framework describes HCI research as a movement between theory, empirical studies, and the design of artifacts. As the work in this dissertation to a high degree builds upon transitions between these three activities, I have used the triangulation framework to provide an overview on the transitions between these activities in each of the three research experiments presented in this dissertation. Below, Figure 4-2, Figure 4-3, and Figure 4-4 illustrate the triangulation processes for each of the three research experiments CASTT, ChillFish, and MOBERO. The figures show how empirical observations, theory, or both informed each of the research experiments, and how each research experiment resulted in generalizable outcome that can inform the design of new artifacts.
Figure 4-2: Illustration of how triangulation has been used in Paper E (CASTT).

Figure 4-3: Illustration of how triangulation has been used in Paper D (ChillFish).

Figure 4-4: Illustration of how triangulation has been used in Paper C (MOBERO).
I will in chapter 8, 9, and 10, further elaborate on the three research experiments and the outcome of these. However, before I do, I will over the next three chapters present the ADHD Design Framework. Chapter 5 identifies central challenges associated with ADHD, thereafter chapter 6 addresses design strategies for designing assistive technologies for the ADHD domain, and finally chapter 7 presents a design space of ADHD assistive technologies that highlight research and technological opportunities within this domain.
5 ADHD Design Framework
- Central ADHD Deficits and Challenges

In this and the following two chapters, I will give an account of the *ADHD Design Framework* (which is a combination of Paper B and Paper I (Sonne and Grønbæk, 2015)). The *ADHD Design Framework* consists of three components that are covered separately in this and the following two chapters:

1. Identify Central Deficits and Challenges Associated with ADHD (this chapter)
2. Develop Design Strategies (chapter 6), and
3. Investigate Opportunities for Designing Novel Assistive Technologies for the ADHD Domain (chapter 7)

Below, Figure 5-1 illustrates the three components of the *ADHD Design Framework*. The arrows between the components illustrate that the design framework was developed as an iterative process. In this dissertation, the *ADHD Design Framework* is presented as a linear process for clarity, however findings related to one component also often contributed with ideas or insights to the two other components.

![Figure 5-1: The three components that constitute the ADHD Design Framework.](image)

The term *framework* has a variety of meanings within HCI and frameworks can be used in a number of ways (Rogers and Muller, 2006). The *ADHD Design Framework* presented in this dissertation is a conceptual framework that identifies challenges, design strategies, and future technological opportunities in order to provide HCI researchers with a foundation for developing and discussing assistive technologies for the ADHD domain. Many existing frameworks for assistive technologies focus on broad technical requirements and implementations of software applications that allow researchers to, for example, collect various forms of patient data, data processing and security implementations (Gabriele Spina, 2013). As these frameworks tend to be generic rather than focused on assistive technologies for specific groups, researchers have begun to propose frameworks that target specific conditions. In particular, frameworks for technologies for the ASD domain have received significant attention from HCI researchers (e.g. Benton et al., 2014; Frauenberger et al., 2010; Moore et al., 2000; Park et al., 2012). To the best of my knowledge, there are no other similar frameworks for the ADHD domain. It is therefore the aim that the presented *ADHD Design Framework* can serve as a foundation and inspiration for HCI researchers in designing novel assistive technologies that empower children with ADHD.
In the remaining of this chapter I will present central deficits and challenges associated with the ADHD disorder, as insights into these core deficits provide a foundation for developing successful assistive technologies for the ADHD domain. In the next chapter, I will present five design strategies that build upon and address these central deficits and challenges. Finally, in chapter 7, I will first present a design space for assistive technologies for the ADHD domain and highlight unexplored research areas that hold opportunities for designing novel assistive technologies for the ADHD domain. Thereafter, I will summarize the ADHD Design Framework and discuss how it addresses RQ1.

5.1 Central Deficits and Challenges Associated with ADHD

ADHD is associated with a broad range of deficits and challenges that negatively affect daily functioning and quality of life (Biederman and Faraone, 2005; Dalsgaard et al., 2013; Faraone et al., 2015; Virring et al., 2014; Wehmeier et al., 2010). In this chapter, I will provide an overview of some of the central and most common deficits and challenges associated with ADHD (especially for children). The presented deficits and challenges provide HCI researchers and designers with an initial understanding of the challenges children with ADHD often encounter, which are crucial in designing for this domain. However, it is important to remember that ADHD is a highly heterogeneous disorder, why it often manifests and impacts individuals to varying degree.

“If you have met one child with ADHD, you have met one child with ADHD”

Helle Hartung, Manager at Center for ADHD, Aarhus, Denmark

Below, common deficits and challenges associated with ADHD are grouped and presented according to the core deficit/challenge for clarity, however several of the deficits and challenges do span more than one group.

5.2 Attention Deficits

Attention deficits are core to ADHD (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013) and individuals with a high degree of inattention is often described as daydreamers. These individuals often find it hard to sustain attention (Barkley, 1997; Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013) especially when involved in tasks associated with low motivation for the individual e.g., school work or challenging tasks (Barkley, 1997). Additionally, from the conducted empirical studies I found that transitions between activities were especially challenging for children with ADHD. This was supported in interviews with parents in the MOBERO research experiment (Paper C) where a mother said “There can be a thousand inputs on your way […] you always have your ‘antennas’ out so you cannot focus on the task originally planned”. As a consequence, people with ADHD often experience challenges organizing tasks and following through on instructions. In addition, to being easily distracted and forgetful (Barkley, 1997).
5.3 Challenges of Hyperactivity/Impulsivity

Like attention deficits, hyperactivity and impulsivity are core challenges to ADHD (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013). As a consequence, individuals with a high degree of hyperactivity/impulsivity often struggle to e.g., control their actions, blurt out answers, do not seem to listen when spoken to, run and climb in inappropriate situations, interrupts conversations, and have a high degree of fidgeting (Handen et al., 1994). In addition, these individuals often find it challenging to wait for turn taking, stand in line, remain seated in school, and doing quiet tasks (e.g., reading and writing).

5.4 Working Memory and Emotional Self-Regulation Deficits

In addition to attention deficits and hyperactivity-impulsivity challenges, behavioral inhibition and deficits in the executive functions are also central to ADHD (Barkley, 1997). In contrast to the ‘concrete’ deficits and challenges mentioned above, executive function deficits are more complex and for example working memory deficits are associated with a range of deficits e.g., holding a sequence of event in mind, perceiving time, and acting on events, which have a wide range of practical implications for the individual. Below, Figure 5-2 illustrates a representation of Barkley’s theoretical model for a unifying theory of ADHD that links behavioral inhibition to four executive functions and Barkley argues that ADHD should be associated with secondary impairments in the four executive functions (Barkley, 1997). It is outside the scope of this dissertation to discuss all elements in Barkley’s theoretical model, however the two first executive functions ‘working memory’ and ‘self-regulation of affect / motivation / arousal are presented below, as these are especially relevant for the HCI community when developing assistive technologies for the ADHD domain.
Barkley and many other researchers agree that working memory deficits are a core deficit in ADHD (Barkley, 1997; Klingberg et al., 2005; Kofler et al., 2008). Working memory is an executive function that relates to e.g., holding events in mind, initiation of complex behavior sequences, prospective functioning (forethought), and sense of time (Barkley, 1997).

Another form of deficits is emotional self-regulation (Barkley, 1997), which relates to e.g., self-regulation of drive and motivation and regulation of arousal in the service of goal-direction actions (Barkley, 1997). Poor self-control of emotions is critical in relation to social interactions and self-regulation of drive and motivation is important abilities in especially academic performance. Over the last two decades there has been increasing evidence that children with ADHD suffer from deficits in motivation (Barkley, 1997; McInerney and Kerns, 2003; Volkow et al., 2011; Volkow ND et al., 2009), and that this deficit is likely to originate from a disruption of the dopamine reward pathway in the brain causing a reduction of dopamine synaptic markers (Volkow ND et al., 2009).

5.5 Sleep Deficits

Sleep deficits and sleep problems are common for children with ADHD (Cortese et al., 2009; Virring et al., 2016). A 2009 meta-analysis found that children with ADHD did exhibit significantly more bedtime resistance, sleep onset difficulties, night awakenings, sleep disordered breathing, and difficulties waking up in the morning compared to neurotypical children (Cortese et al., 2009). This is also supported by two studies of
families of children with ADHD, where both Segal (Segal, 1998) and Firmin and Phillips (Firmin and Phillips, 2009) reported bedtime routines as especially challenging for parents. Sleep is a natural and important process for the developing child, and the impact of poor sleep have shown to negatively affect e.g., executive functioning (Gruber et al., 2011), daytime sleepiness (Dewald et al., 2010; Gruber et al., 2011), mood (Dahl, 1996), and school performance (Dewald et al., 2010). In fact, Gruber et al. showed that restricting a child’s sleep duration with one hour for six nights led to a significant score reduction in Conners’ Continuous Performance Test (CPT) and even that “The performance of children with ADHD following sleep restriction deteriorated from subclinical levels to the clinical range of inattention on two-thirds of CPT outcome measures.” (Gruber et al., 2011). For further insights into the negative consequences of poor sleep the reader is referred to (Cortese et al., 2009; Dahl, 1996; Dewald et al., 2010; Gruber et al., 2011; Virring et al., 2016).

5.6 Social Challenges Associated with ADHD

Even though the above presented challenges and deficits only represent a fragment of all deficits and challenges associated with ADHD, it should be clear that these negatively impact the individual’s quality of life. For example, children with ADHD often experience conflicts when interacting with teachers, parents, and peers (Storebø et al., 2014). This is supported by a recent study that found that 70% of third graders with ADHD reported that they had no close friends (Wehmeier et al., 2010). In addition, ADHD is also associated with academic impairments (Faraone et al., 2015; Massetti et al., 2008).

Faraone et al. proposed five broad categories for how ADHD impacts quality of life as illustrated in Figure 5-3: Social disability, academic and occupational failure, health problems and psychiatric co-morbidities, psychological dysfunction, and risky behaviors (Faraone et al., 2015). The challenges and deficits presented in this dissertation can be matched to these five categories, like the proposed design framework in chapter 7 also use these categories to span the ADHD impairments dimension.
Summary and Contribution

In this chapter, selected common deficits and challenges associated with ADHD were presented as the first part of the ADHD Design Framework. Attention deficits, challenges of hyperactivity/impulsivity, working memory deficits, emotional deficits, sleep deficits, and social challenges are all central to ADHD. These central deficits and challenges are important for researchers designing assistive technologies for the ADHD domain, as they provide a critical foundation for understanding the user group, their challenges, and the ADHD domain in general. However, it is important to emphasize that the presented deficits and challenges do not represent an exclusive or exhaustive list of challenges for the ADHD disorder. In addition to the presented challenges, additional challenges might arise from comorbid disorders (for example conduct- and learning disorders), as more than 80% of people with ADHD are likely to have an additional psychiatric disorder. Furthermore, more than 50% have two additional disorders (Wehmeier et al., 2010), which means that ADHD is more often associated with at least one comorbid disorder than without any.

In this dissertation, I have particularly addressed the issues of attention deficits, emotional deficits, and sleep deficits through the design and evaluation of three research experiments (i.e., CASTT, ChillFish, and MOBERO) presented in chapter 8, 9, and 10.

Identifying central challenges associated with ADHD is the first step in designing for the ADHD domain; the next step is to develop design strategies that take these deficits into account in order to design successful assistive technologies; this is addressed in the second part of the ADHD Design Framework, which is presented in the following chapter.
6 ADHD Design Framework - Design Strategies

In this chapter, I will present the second part of the ADHD Design Framework. I will build upon the central deficits and challenges addressed in the previous chapter by presenting five design strategies that address these deficits and challenges. The design strategies are based on a combined analysis of the ADHD literature and findings from the contextual inquiries conducted as part of this dissertation. The design strategies are neither definitive nor finite, but should instead be seen as initial suggestions for HCI researchers to design and develop successful assistive technologies for the ADHD domain.

6.1 Support Attention and Facilitate Activity Completion Through Structure

ADHD is associated with deficits in sustaining attention, transitioning between activities, and holding a sequence of events in mind (cf. chapter 5.2 and 5.4). Both the ADHD literature and the empirical work conducted as part of this dissertation suggest that providing and supporting structure is beneficial for people with ADHD, as they are more likely to succeed in completing activities if these occur in a predictable pattern (Barkley, 2013).

Firmin and Phillips found in their study of families of children with ADHD “routine and structure as being paramount to navigating daily life successfully.” (Firmin and Phillips, 2009). In addition, Barkley argues that children and teens with ADHD need more structure than neurotypical children to successful accomplish tasks (Barkley, 2013). Today, some families use printed routine charts in the home to assist children with ADHD to complete certain activities or routines as seen in Figure 6-1. However, as uncovered during the MOBERO research experiment (Paper C), paper-based charts have shortcomings in that they are often mislaid or damaged, and several families expressed that these charts did not always motivate the child. Furthermore, findings from the MOBERO research experiment showed that the parents also often failed to keep using these charts over longer periods (Paper C).
HCI researchers can use structure as a strategy on two levels: On a practical level, incorporating a clear structure in the assistive technology assists the child in maintaining attention on the technology. On a conceptual level, developing assistive technologies that use structure to facilitate initiation, retention, and completion of (challenging) activities hold potential for establishing sound routines for these activates and for increasing child independence. MOBERO (Paper C) and TangiPlan (Weisberg et al., 2014) are examples of assistive technologies for the ADHD domain that utilizes both levels of structure as described above.

6.2 Support Rewards and Praise to Encourage Engagement and Improve Parent-Child Relationship.

ADHD is associated with emotional dysregulation and motivational deficits (cf. chapter 5.4), and the consequences of this in real-world situations include that children with ADHD e.g., require stronger incentives to modify their behavior, show failure to delay gratification, and have preferences for immediate small rewards over delayed larger rewards (McInerney and Kerns, 2003; Volkow et al., 2011). Today, parents and teachers can use rewards charts that allows a child to earn rewards for doing (or avoid doing) certain activities or behaviors as a way to motivate the child as seen in Figure 6-2.
Related to rewards is parent / teacher praise. Rewards and praise are core elements in many parent-training programs (as described in chapter 2.2) as rewards and praise promote positive and desired behaviors in the child (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013; National Collaborating Centre for Mental Health (Great Britain) and NCCMH, 2013). Instead of criticizing unwanted behaviors, for instance shouting at a child for running around, parents and teachers should instead praise the child when exhibiting desired behaviors (e.g., sitting still or concentrating on doing homework), as this can cause and sustain a modification of behavior (National Collaborating Centre for Mental Health (Great Britain) and NCCMH, 2013).

HCI researchers can similarly to the structure design strategy (chapter 6.1), use the reward and praise design strategy on both a practical and a conceptual level.

On a conceptual level, developing technologies that through rewards can motivate the child to initiate, maintain, and complete low-motivation activities for example, doing homework, hold potentials that goes beyond the technology itself as for example improved academic performance. Furthermore, technologies that can remind and assist parents in praising their child (similar to ParentGuardian (Pina et al., 2014)) can positively impact the child-parent relationship and over time positively modify the child’s behavior.

On a practical level, this strategy highlights the potential and importance of incorporating small and immediate rewards into technologies, which aim to assist children with ADHD in activities that they do not have a natural incentive or motivation to do. In addition, due to the reward driven behavior, incorporating rewards in any technology for children with ADHD is an effective way to keep children engaged and positive toward the technology. However, designers should also keep in mind that children with ADHD might exhibit more frustration when expecting a reward and

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**Figure 6-2:** An example of a physical artifact collected during contextual inquires with a family of a child with ADHD - a paper-based reward chart.
thereafter do not get it as discovered during the MOBERO research experiment (Paper C).

6.3 Support Family Dynamics

ADHD is highly heritable as described in chapter 2, and researchers designing assistive technologies for children with ADHD should therefore take into account that 70-80% of parents of children with ADHD might also have ADHD (Biederman and Faraone, 2005; Faraone et al., 2015) and thus struggle with some of the (same) challenges as their child. This poses additional challenges for the family, as the parents might find it hard to provide the needed structure for establishing e.g., healthy morning, bedtime, and homework routines, which as a consequence can result in a vicious circle where the child never establishes routines for these activities, which can cause frustration for both child and parents. Thus, designing for family dynamics (including the probability of ADHD in parents) is an important factor in developing successful technologies for children with ADHD.

In the MOBERO research experiment, I designed a separate mobile application to remind the parents to report daily assessments, as they would otherwise forget this as we learned from our preliminary studies (Paper C). Furthermore, MOBERO included specific activities for parents as part of the bedtime routines (presented in detail in chapter 10) to acknowledge that parents might find it hard to provide the needed structure that a healthy bedtime routine requires.

6.4 Avoid Stigmatization when Designing Technology

As children with ADHD are already potential victims of bullying as a consequence of their disorder e.g., disruptive behavior, social impairments, hyperactive activities as presented in chapter 5.6 (Faraone et al., 2015; Wehmeier et al., 2010), researchers should avoid to stigmatize children with ADHD with technology. From the contextual inquiries at schools I found that children with ADHD often just wanted to ‘fit in’ and ‘be normal’ and teachers emphasized that technology should make this easier and not harder. Furthermore, the teachers expressed doubt about whether children with ADHD would use technology if they felt there was a chance that their peers could ‘use it against them’.

Thus, HCI researchers should be aware not to stigmatize children with technology, as the child might quickly stop using the technology. In the CASTT research experiment (Paper E), support for an EEG headset was included in the initial prototype as EEG holds potentials for assessing (Haapalainen et al., 2010) and supporting attention, however this would require the child to wear an EEG headset in class, hence only children without ADHD wore the EEG headset for explorative purposes in the CASTT studies.

6.5 Avoid Creating New Distractions

As presented in chapter 5, attention deficit is one of the core characteristics of ADHD (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, 2013). To alleviate this in school contexts, special spaces are frequently constructed as seen in Figure 8-7 to limit external distractions, like headphones are also often used for the same reason.
Therefore, researchers should take care when designing assistive technologies for children with ADHD to not unintentionally end up distracting the child. This includes simple precautions like disabling all system notifications in mobile assistive technologies and not interrupting the child with self-assessments in critical situations. However, if distracting the child is unavoidable (if for example the child has to self-assess attention during school) researches might find it beneficial to use the above structure and rewards and praise design strategies to assist the child to return to the original task as illustrated in the CASTT research experiment presented in chapter 8.

6.6 Summary and Contribution

In this chapter, five design strategies for designing assistive technologies for the ADHD domain were presented as the second part of the ADHD Design Framework:

1. Support Attention and Facilitate Activity Completion Through Structure
2. Support Rewards and Praise to Encourage Engagement and Improve Parent-Child Relationship.
3. Support Family Dynamics
4. Avoid Stigmatization when Designing Technology
5. Avoid Creating New Distractions

These five design strategies have emerged from a combined analysis of the conducted contextual inquiries with children with ADHD and the ADHD literature, and they are all relevant in relation to addressing RQ2: ‘How can assistive technologies be designed to assist children with ADHD in handling their central deficits and challenges?’. The presented design strategies do compose an initial (but not an exhaustive) list of design strategies for the ADHD domain. In combination with the central deficits and challenges for children with ADHD presented in the chapter 5, the presented design strategies offer HCI researchers an initial foundation for understanding and designing successful assistive technologies for children with ADHD.

Having provided insights into the challenges children with ADHD experience in chapter 5 and design strategies for designing for these challenges in this chapter, I will in the next chapter introduce the last part of the ADHD Design Framework, which identifies technological opportunities for the ADHD domain.
7 ADHD Design Framework
– Opportunities for Assistive Technology

In this chapter, I will present the last part of the ADHD Design Framework, where technology and research opportunities for designing assistive technologies for the ADHD domain are discussed. I will first present a design space of existing assistive technologies for the ADHD. Thereafter, I will investigate the unexplored spaces in the design space, and discuss the opportunities for HCI researchers to conduct novel research and advance state-of-the-art technology for the ADHD domain. At the end of this chapter, I will discuss how this and the previous two chapters (that together constitute the ADHD Design Framework) addresses RQ1: ‘How can HCI researchers analyze and conceptualize the mental disorder domain of ADHD, in order to create the foundation for designing assistive technologies for this domain?’

7.1 Constructing the Design Space

The ADHD Design Space consists of two dimensions, a technological dimension that relates to the question of how an assistive technology provides assistance; and an ADHD impairments dimension that relates to the challenges and quality of life impairments associated with ADHD. In the following, both dimensions are presented in more detail.

7.1.1 The technological dimension

The technological dimension in the ADHD Design Space is partly inspired by a survey of different types of assistive technologies within the HCI domain and partly by the ‘Context-Aware Functions’ presented by Dey et al. as part of their framework for context-aware applications (Dey et al., 2001). However, as not all technologies are context aware in the ADHD Design Space, the technological dimension consists of three broad categories of assistive technologies:

1) Manually interacting with information and services (MIIS)
2) Automatically executing services based on in-situ analysis of context information (AES)
3) Capturing contextual data for later retrieval (CCD).

<table>
<thead>
<tr>
<th>MIIS: Manually interacting with information and services</th>
<th>AES: Automatically executing services based on in-situ analysis of context information</th>
<th>CCD: Capturing contextual data for later retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technologies for in-situ assistance in context</td>
<td>Services for research</td>
<td>Services for personal reflection</td>
</tr>
<tr>
<td>Technologies for training</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7-1: The three categories in the technological dimension within the ADHD Design Space
The MIIS category covers assistive technologies that are manually triggered or interacted with, and is divided into two subcategories: ‘Technologies for in-situ assistance in context’ and ‘technologies for training’. ‘Technologies for in-situ assistance in context’ relates to assistive technologies that provide assistance for the individual to overcome specific situations. The second subcategory, ‘technologies for training’ relates to assistive technologies that have a long-term focus as for example working memory training.

The AES category covers context aware technologies (cf. (Dey et al., 2001)) that provide in-situ assistance based on analysis of captured sensor data about the user.

The last category is CCD, and covers technologies that capture contextual data over time, but does not automatically act on the users’ behalf (cf. (Dey et al., 2001)). The CCD category is divided into two subcategories: ‘Services for research’ and ‘services for personal reflection’. The ‘services for research’ subcategory covers technologies that mainly provide collected raw or analyzed contextual data to researchers for further analysis. The ‘services for personal reflection’ subcategory covers technologies that mainly provide analyzed contextual data to individuals for personal reflection for example informing parents about their child’s unhealthy sleep habits and the potential consequences of these unhealthy habits.

7.1.2 The ADHD impairments dimension

The ADHD impairments dimension in the ADHD Design Space contains five broad categories that relate to quality of life impairments associated with ADHD as presented by Faraone et al. (Faraone et al., 2015).

<table>
<thead>
<tr>
<th>Social disability</th>
<th>Academic and occupational failure</th>
<th>Health problems and psychiatric co-morbidities</th>
<th>Psychological dysfunction</th>
<th>Risky behaviors</th>
</tr>
</thead>
</table>

Figure 7-2: The categories in the ADHD impairments dimension within the ADHD Design Space

The first category, ‘social disability’, relates to poor social skills, poor peer/family relationships, and parenting problems. The second category, ‘academic and occupational failure’, relates to special education needs, academic failure, and grade repetition. The third category, ‘health problems and psychiatric co-morbidities’, relates to disruptive behaviors, executive dysfunction, learning disabilities, and language and speech disorders. The fourth category is ‘psychological dysfunction’, and this relates to emotional dysfunction, low self-esteem, lack of motivation, and suicidal ideations. The fifth category is ‘risky behaviors’, and this category relates to accidents, injuries, and unplanned pregnancies etc.

The reason for using the categories presented by Faraone et al. (Faraone et al., 2015) to span the ADHD impairments dimension, and not the central deficit and challenges associated with ADHD presented in chapter 5, is because the categories by Faraone et al. covers implications of ADHD not covered in chapter 5. Figure 7-3 illustrates the relationship between the presented deficits and challenges in chapter 5 and the ADHD impairments dimension.
Together, the technological dimension and the ADHD impairments dimension spans the ADHD Design Space for assistive technologies for the ADHD domain as seen in Figure 7-4.

**ADHD Design Space - The ADHD Impairments Dimension**

<table>
<thead>
<tr>
<th>Social disability</th>
<th>Academic and occupational failure</th>
<th>Health problems and psychiatric co-morbidities</th>
<th>Psychological dysfunction</th>
<th>Risky behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3 Challenges of Hyperactivity / Impulsivity</td>
<td>5.2 Attention Deficits</td>
<td>5.2 Attention Deficits</td>
<td>5.4 Emotional Self-regulation Deficits</td>
<td></td>
</tr>
<tr>
<td>5.6 Social challenges associated with ADHD</td>
<td>5.3 Challenges of Hyperactivity / Impulsivity</td>
<td>5.4 Working Memory &amp; Emotional Self-regulation Deficits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5 Sleep deficits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7-3**: The central deficits and challenges associated with ADHD presented in chapter 5 and their placement within the five broader categories of the ADHD Impairments Dimension within the ADHD Design Space.
Figure 7-4: The ADHD Design Space with related work plotted in their respective areas.
7.2 Investigating the Unexplored Areas in the Design Space

In Figure 7-4 it can be seen that unexplored areas exist in both the technological and ADHD impairments dimension of the ADHD Design Space. In the ADHD impairments dimension, we see that no assistive technology has addressed the ‘risky behaviors’ category, and in the technological dimension, we see that no existing assistive technology for the ADHD domain can be categorized within the CCD category.

That no assistive technologies exist for the ‘risky behaviors’ category in the ADHD impairments dimension might not come as a big surprise, as technology that e.g., can limit or avoid injuries is not easy or straightforward to design, implement, or evaluate. Looking at related work from other fields does not provide clear suggestions for how to develop technologies for this category. However, assistive technologies within the MIS – ‘technologies for training’ category might hold potentials for educating and training a child with ADHD to avoid common risky behaviors or train children with ADHD to ‘count to five’ in situations that might be dangerous. In addition, even though AES technologies that utilize physiological sensor data to determine potential forthcoming accidents might today be a futuristic idea, a few years out in the future this type of technology might hold potentials for limiting risky behaviors.

Looking at the unexplored spaces in the CCD category in the technological dimension it is interesting that no existing research exists within this category, especially as technology within this category has been explored in other domains with great success. MONARCA (Bardram et al., 2013) is an example of an assistive technology for bipolar patients that can be categorized within the CCD category. MONARCA collects, analyses, and presents subjective and objective data to the bipolar patients themselves (CCD – ‘services for personal reflection’) and for their clinician (CCD – ‘services for research’) in order to provide insights into the parameter that influences the patient’s disorder (Bardram et al., 2013).

Another example is Lullaby (Kay et al., 2012) that visualizes and provides access to captured data form a range of sensors including light, audio, motion, and temperature in order to assist the user to improve and understand their sleep and sleep environment (Kay et al., 2012). By enabling the user to explore the collected data and reflect upon potential connections, Lullaby is an example of a CIID – ‘services for personal reflection’ technology.

The successful MONARCA and Lullaby systems suggest that CCD technologies hold novel research and application potentials for the ADHD domain as these technologies can provide unique opportunities for supporting researchers and individuals with ADHD in reflecting on and gaining insights into their own conditions, which within HCI has been popularized as personal informatics (Li et al., 2010).

7.3 Summary and Contribution

Below, I will first summarize this chapter, where after I summarize the ADHD Design Framework and relate this to RQ1.
In this chapter, the *ADHD Design Space* for assistive technologies for the ADHD domain was presented. The *ADHD Design Space* consists of two dimensions (a technological dimension and an ADHD impairments dimension), which together span the design space of assistive technologies for the ADHD domain. From the visual representation of the *ADHD Design Space*, it became clear that several unexplored areas existed, which can be used by HCI researchers to conduct novel research and advance state-of-the-art technology for the ADHD domain.

A weakness of the *ADHD Design Space* is that when looking at the visualization of the design space in Figure 7-4, it can incorrectly give the impression that a certain space is already explored if one or two existing assistive technologies are plotted in this space. However, this is not necessarily true and may instead be a consequence of the broad categories in the ADHD impairments dimension, why in the future, when more work is reported within this domain, these categories should be further divided into subcategories.

The *ADHD Design Space* is to the best of my knowledge, the first of its kind for the ADHD domain, and having identified the unexplored areas within the domain of assistive technologies for the ADHD domain it can provide HCI researchers with a starting point for exploring and designing future novel technologies for ADHD patients.

### 7.3.1 Concluding the ADHD Design Framework

Over the last three chapters I have presented the three components that constitute the *ADHD Design Framework* (see Figure 7-5): Central deficits and challenges associated with ADHD target domain (chapter 5), design strategies for designing assistive technologies for children with ADHD (chapter 6), and finally in this chapter I have through the *ADHD Design Space* investigated current and future technological opportunities for empowering children with ADHD.

![Figure 7-5: The three components of the ADH Design Framework](image)

I will argue that the *ADHD Design Framework* provides a solid foundation for understanding the ADHD domain and for developing assistive technologies for the ADHD domain. Therefore, the *ADHD Design Framework* is one way to address RQ1 ‘How can HCI researchers analyze and conceptualize the mental disorder domain of ADHD, in order to create the foundation for designing assistive technologies for this domain?’.

Having presented the *ADHD Design Framework*, I will over the next three chapters provide three examples of research experiments that build upon and utilize the *ADHD Design Framework*. 
8 Attention Assistance – The CASTT Research Experiment

In this chapter, I will give an account of Paper E by describing the design, development, and evaluation of the CASTT prototype. CASTT is a mobile and wearable system designed to assist children with ADHD regain attention in critical school situations. In relation to this dissertation CASTT addresses RQ2.1 ‘How can assistive technologies assist children with ADHD sustain attention in real-world contexts?’

![Figure 8-1: CASTT sensors and sensor placement.](image)

Below, Table 8-1, provides an overview of the targeted ADHD challenges, design strategies used, and CASTT’s placement in the ADHD Design Space.

<table>
<thead>
<tr>
<th>Targeted ADHD challenges cf. chapter 5</th>
<th>Applied design strategies cf. chapter 6</th>
<th>Placement in the ADHD Design Space cf. chapter 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention Deficits</td>
<td>Support attention and facilitate activity completion</td>
<td>Impairments Dimension: Academic and occupational failure</td>
</tr>
<tr>
<td>Working Memory</td>
<td>Support rewards and praise to encourage engagement</td>
<td>Technological Dimension: AES</td>
</tr>
<tr>
<td>Self-regulation of drive and motivation</td>
<td>Avoid stigmatization with technology</td>
<td></td>
</tr>
</tbody>
</table>

Table 8-1: The targeted ADHD challenges and the applied design strategies used in CASTT together with CASTT’s placement in the ADHD Design Space.

CASTT addresses the ‘Academic and occupational failure’ category in the ADHD impairments dimension. As the purpose of CASTT is to automatically provide
assistance based on assessment of the child’s physical activity (we assume a high degree of hyperactivity correlates to low attention level), CASTT falls within the AES category on the technology dimension.

8.1 Motivating CASTT – Supporting Attention in School

CASTT is motivated by the advancement in wearable sensor technologies (Bächlin et al., 2010; Harms et al., 2009; Ploderer et al., 2016), human activity recognition (Reiss and Stricker, 2013; Stisen et al., 2015), and related work on assistive technologies that successfully support children with autism in school contexts (Cramer et al., 2011; Fage et al., 2014). As described in chapter 5.2, attention deficits are core to ADHD, which naturally poses challenges and causes impairments in academic performance. The aim with CASTT was to explore the potentials of using technology to sense and recognize inattention and to assist children to regain attention in critical school situations (RQ2.1), as this could have a major impact on learning and the academic performance of the child.

The CASTT prototype presented in this dissertation is the first in a series of planned prototype iterations aimed at providing attention assistance to children with ADHD in school contexts.

8.2 The CASTT Design Process

Below, Figure 8-2 depicts a simplified representation of the iterative CASTT design process.

![Figure 8-2: A simplified visual representation of the iterative CASTT design process.](image)

As it can be seen from Figure 8-2, several evaluations with children without ADHD where conducted before children with ADHD were included in the evaluation. This was due to 1) practical issues in recruiting children with ADHD and getting permissions to evaluate CASTT in school contexts, and 2) as children with ADHD is a vulnerable target group and we intervened in their school activities, we wanted to make sure that CASTT did not compromise their learning activities and that all technical issues were fixed prior to evaluating with these children.
8.3 CASTT: A Real-time Sensor-based Technology to Provide Attention Assistance

In the following, I will describe the technical implementation of CASTT. CASTT combines wearable sensor technologies, mobile sensing, and a mobile intervention to provide real time assistance to regain attention for children with ADHD. The CASTT prototype is designed around three main components for providing real time assistance: Sensing, recognizing, and assisting:

8.3.1 Sensors utilized by CASTT
CASTT supports five distinct sensor types to sense physical and physiological activities as illustrated in Figure 8-1: DUL accelerometers (Brynskov et al., 2012), a smartphone, a webcam, an EEG headset, and a HR monitor. The EEG headset violates the design strategy in chapter 6.4, however as the EEG technology has shown promise to assess cognitive load (Haapalainen et al., 2010), EEG data from children without ADHD was collected to explore relations between EEG attention and physical activity and / or heart rate variability (HRV).

![Figure 8-3: Special made textile bands were designed to facilitate a comfortable and easy to strap on solution for attaching the DUL sensors to the children’s wrists and ankles.](image)

8.3.2 Machine learning recognition in CASTT
For recognition, CASTT calculates 42 features for each connected accelerometer (up to eight DUL accelerometers and one smartphone) in real time on a sliding window of 128 samples with a 50% overlap. The 42 different features are adopted from Figo et al. (Figo et al., 2010), and are intended to be used as a first iteration to recognize characteristic ADHD lower body excessive motoric behaviors. The findings related to the machine learning recognition are presented in 8.5.1.

8.3.3 Assistance provided by CASTT
The smartphone used by CASTT works as both sensor and assistive intervention. The goal of the assistive intervention is to guide the child’s attention back to a school task in situations where the child has lost concentration and are not working on the expected school task.

The assistive intervention is implemented through a quiz-application as illustrated in Figure 8-4. The quiz-application was selected as it both provides opportunities for rewarding the child after each question (design strategy 6.2) and holds a natural termination i.e., after each reply (design strategy 6.1). Thus, when CASTT detects that the child has lost attention, the smartphone uses the built-in vibration functionality to discretely notify the child to bring forth the smartphone and play the quiz. When the child has answered a few quiz questions, the quiz automatically ends, and a termination screen is presented to the child as seen on Figure 8-4. The termination screen, utilizes
design strategy 6.1 and in a clear and structured way, the child is guided to return to the school task in front of him/her through a three-task list. The findings from this evaluation of the assistive intervention are presented below in chapter 8.5.2.

**Figure 8-4:** The assistive component of CASTT. On the left is the quiz-game interface; on the right is the termination screen that provides structure and guidance for the child to regain attention on school assignments.

### 8.4 CASTT Study Design

As RQ2.1 relates to how assistive technology can assist children with ADHD in real-world contexts to sustain attention; the design and evaluation of CASTT involved a high degree of empirical studies in schools to understand the design requirements and evaluate the many critical components of CASTT. Observations in schools and interviews with teachers and pedagogues guided the early design process. Based on findings from these observations and interviews CASTT was designed and evaluated through several empirical studies.

#### 8.4.1 Participants and empirical studies

11 children with ADHD and nine children without ADHD wore the CASTT prototype during normal school lectures. The children came from four different schools and attended 3rd, 4th, or 5th grade. All experiments were conducted during normal school classes and the children followed the teaching as normal. The experiments were video recorded, which worked as ground truth when later analyzing the sensor data. Additionally, five adults without ADHD evaluated the machine-learning algorithm due to unexpected issues in collecting enough reliable sensor data of movement behavior from children with ADHD. A total of five studies were conducted to evaluate the three main components of CASTT (see Figure 8-5) as briefly presented in the following.
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants with ADHD</th>
<th>Participants without ADHD</th>
<th>Primary purpose</th>
<th>Total duration of CASTT evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1</td>
<td>2</td>
<td>9</td>
<td>Evaluation of system design</td>
<td>7 hours and 6 minutes</td>
</tr>
<tr>
<td>Study 2</td>
<td>8</td>
<td>0</td>
<td>Collection movement data</td>
<td>3 hours and 30 minutes</td>
</tr>
<tr>
<td>Study 3</td>
<td>0</td>
<td>5 (adults)</td>
<td>Backup data collection</td>
<td>~25 minutes</td>
</tr>
<tr>
<td>Study 4</td>
<td>1</td>
<td>0</td>
<td>Evaluation of the assistive component</td>
<td>1 hour and 35 minutes</td>
</tr>
<tr>
<td>Total</td>
<td>11 children</td>
<td>9 children and 5 adults</td>
<td>Full cycle evaluation</td>
<td>13 hours and 31 minutes</td>
</tr>
</tbody>
</table>

Figure 8-5: An overview of the conducted CASTT evaluation studies.

8.4.2 Study I - Evaluate the unobtrusiveness and comfort of CASTT

The first study was intended to evaluate the unobtrusiveness and comfort of CASTT. This study was conducted in a normal school class with two children with ADHD and nine without ADHD.

![Figure 8-6: Illustration of the setup for the first evaluation of CASTT in a normal school class with 10 children without ADHD and one child with ADHD.](image)

8.4.3 Study II – Collecting characteristic ADHD lower-body movement behaviors

The primary goal of the second study was to collect sensor data of characteristic ADHD lower-body movement behaviors, in order to investigate the relationship between lower body movement behavior and attention. For this study, eight children with ADHD from two special schools were recruited, however, due to the physical setup of the classroom (see Figure 8-7), it was not possible to collect enough reliable sensor data.
The third study was not originally planned, however due to challenges in collecting enough sensor data in study II, an additional study was conducted with five adults without ADHD. In order to create a separate training set for the machine-learning algorithm, I wore the CASTT system (only accelerometers mounted on ankles) and imitated six observed lower body excessive motoric behaviors for 2 x 10 minutes each. Test data was gathered by having five adults without ADHD wear the CASTT system and imitate each of the six behaviors for approximately five minutes. All features were calculated in real time by CASTT, and no post processing or optimizations were performed for either the training or test set. The standard built in WEKA RandomForest algorithm (Witten and Frank, 2005) were used to create a classifier from the training data, which was then evaluated against each of the test sets.

The fourth study focused on evaluating the CASTT assistive intervention. Due to challenges in recruiting children with ADHD, the assistive intervention was only evaluated with one child with ADHD in a natural school context. The participating child evaluated CASTT during a 1.5-hour math lecture. As the recognition component of CASTT was not finalized at the moment of the evaluation, a Wizard of Oz experiment (Dahlbäck et al., 1993) was chosen as appropriate for evaluating the effect of the CASTT assistive intervention. Thus, an extended increased activity level detected by CASTT in conjunction with the present researcher’s subjective assessment of the child’s attention level was used to decide when the assistive intervention was triggered.

Findings from the Five CASTT Studies

The research aim of CASTT was to address the potentials of using technology to assist children with ADHD in regaining attention in school contexts (RQ2.1). As related work had shown potential for sensing physical activity (Bächlin et al., 2010; Faedda et al., 2016) and attention (in lab settings) (Haapalainen et al., 2010), the focus of the CASTT studies was on completing a full cycle from sensing, recognizing, to providing assistance. Below, findings related to the recognizing and assisting components are discussed with relation to RQ2.1.
8.5.1 Machine learning has potentials to recognize characteristic ADHD behavior

Using the standard WEKA built in RandomForest classifier, the produced learner achieved an average accuracy of 81.83% (σ=8%) on five test sets produced by adults without ADHD (separate training and test sets). The results were based on the five adults imitating six lower body excessive motoric activities seen on the ground truth video. Ideally, sensor data from the children that exhibited these excessive motoric activities would have been used as test data for the classifier. However, as previously mentioned, it was not possible to capture sufficient amounts of sensor data of such behaviors from the conducted studies with children with ADHD.

<table>
<thead>
<tr>
<th>Participant</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Correctly Classified Instances</td>
<td>75.44%</td>
<td>93.91%</td>
<td>73.95%</td>
<td>84.94%</td>
<td>80.91%</td>
</tr>
</tbody>
</table>

Table 5: The accuracy of the machine learner for the five adults imitating six lower body observed ADHD movement behaviors.

Based on related work on human activity recognition for patients with Bipolar disorder and ADHD (Faedda et al., 2016) in combination with the results from adults imitating characteristic ADHD lower-body behaviors it seems realistic that machine learning can be used to recognize characteristic ADHD movement behaviors.

8.5.2 Assistive technology holds potentials for providing attention assistance

Evaluating the CASTT mobile assistive intervention with one child with ADHD in a school context suggests that assistive technology can be used to assist children in regaining attention in critical school situations. The assistive intervention was triggered at 11:01 AM (40 minutes into the class), and in the minutes leading up to this triggering event, the child seemed unable to keep focus and exhibited a high degree of rapid self-stimulating behaviors. Figure 8-8 shows the aggregated variance for all accelerometer sensor data in two-minute intervals from the study, and the two blue bars indicate the time of the assistive intervention. As seen in Figure 8-8, the child had a 10-minute low activity period following the assistive intervention. Furthermore, the child did return to his math assignment in front of him after the intervention, and the ground truth video recordings suggest that he stayed focused on the school task in front of him in the 10-12 minutes following the intervention.
Even though the findings from this wizard of Oz experiment are very promising, additional studies are needed before general conclusions can be made on if and how the assistive intervention can help children with ADHD in classroom settings. Nevertheless, the initial findings show promise for further experiments on real-time assistive technologies for children with mental disorders like ADHD.

8.6 Summary and Contribution

In this chapter, I described the CASTT research experiment and the five studies conducted as part of the evaluation of the three main components of CASTT (i.e., sensing, recognizing, and assisting).

CASTT is a mobile and wearable assistive technology that is aimed at providing assistance in regaining attention in critical school situations where the child has lost his/her attention. More than 13 hours of in the wild evaluations with 20 children (11 with ADHD) were conducted in order to address RQ2.1 ‘How can assistive technologies assist children with ADHD sustain attention in real-world contexts?’ Based on these evaluations, it seems that assistive technology do hold opportunities for assisting children with ADHD in sustaining and regaining attention in real-world contexts.

The conducted field studies showed that it is possible to unobtrusively collect physical activity and heart rate data, which is the first step in providing sensor-based attention assistance. Unfortunately, it was not possible to capture enough reliable sensor data of characteristic off-task ADHD behaviors to provide insights into the potentials of assessing attention using machine learning in combination with physical and physiological activity data. Nevertheless, related work on both machine learning and attention suggest this is possible. Finally, based on a Wizard of Oz evaluation of the
assistive component of CASTT with one child with ADHD, it indeed seems that assistive technology does have potentials to assist children with ADHD regain attention in school contexts.
9 Calming Assistance
– The ChillFish Research Experiment

In this chapter, I will give an account of Paper D by presenting ChillFish, a calming biofeedback game designed to provide a calming effect for children with ADHD. ChillFish addresses RQ2: ‘How can assistive technologies assist children with ADHD better regulate emotions?’

![ChillFish](image)

Figure 9-1: ChillFish is a calming biofeedback game controlled by breathing through the ChillFish controller built in LEGO.

Table 9-1 provides an overview of the target ADHD challenges; design strategies used in ChillFish, together with ChillFish’s placement in the ADHD Design Space.

<table>
<thead>
<tr>
<th>Targeted ADHD challenges cf. chapter 5</th>
<th>Applied design strategies cf. chapter 6</th>
<th>Placement in the ADHD Design Space cf. chapter 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotional self-regulation</td>
<td>Support rewards and praise to encourage engagement</td>
<td>Impairments Dimension Psychological Dysfunction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological Dimension: MIIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9-1: The targeted ADHD challenges and the applied design strategies used in ChillFish together with ChillFish’s placement in the ADHD Design Space.

ChillFish can be categorized within the Psychological Dysfunction category in the ADHD impairments dimension within the ADHD Design Space. The ‘psychological dysfunction’ category relates to emotional dysregulation, which is also the main motivation behind ChillFish. On the technological dimension ChillFish is categorized as
a MIIS technology. ChillFish, as presented in this dissertation, would be categorized within the *Technologies for in-situ assistance in context* MIIS subcategory. However, ChillFish also holds potentials for being used as a training device to teach children to perform calming breathing exercises, and in such situations it would be categorized within the *Technologies for training* MISS subcategory.

## 9.1 Motivating ChillFish: Facilitating Emotional Regulation Through Play

As presented in chapter 5.4, children with ADHD experience challenges with emotional regulation and outburst, why technologies that can facilitate calming breathing exercises do hold potential to assist children with ADHD to regulate their emotions. Performing a calming breathing exercise affects the parasympathetic nervous system causing the body to relax (Jerath et al., 2006a) and existing HCI research on calming biofeedback technologies have already shown positive results in alleviating stress in adults (Moraveji et al., 2011; Parnandi et al., 2014). However, existing research have used worn sensors (breast straps) to detect breathing patterns in adults, which is not optimal if a child is emotionally upset. Instead, ChillFish is designed to be an engaging and nonintrusive calming biofeedback game for children with ADHD.

## 9.2 The ChillFish Design Process

Below, Figure 9-2 depicts a simplified representation of the iterative ChillFish design process.

![Figure 9-2: A simplified visual representation of the iterative ChillFish design process.](https://en.wikipedia.org/wiki/Flappy_Bird)

The inspiration for the ChillFish emerged from a combined analysis of the hands-on training at Center for ADHD, observations in schools, and from interviews with teachers. Through several simple design processes with ADHD professionals and my fellow volunteers (psychology students) at Center for ADHD, the ChillFish concept and prototype emerged. The earlier concepts were inspired by the Flappy Bird game\(^1\) (which at that time was very popular). However, during the design process it became clear that a game where the player character will eventually die could cause frustration for the child. Based on these insights, the game concept was changed so that in the presented

\(^1\) https://en.wikipedia.org/wiki/Flappy_Bird
version of ChillFish, the player cannot die; instead the goal is to collect as many starfish as possible in a certain amount of time. As with the CASTT research experiment, ChillFish was first evaluated with adults to verify the technical implementation and evaluate the calming effect, where after it was evaluated with children with ADHD.

9.3 ChillFish: A Respiration Game for Children with ADHD

ChillFish consist of two main components, the ChillFish game and the ChillFish tangible controller as described below.

9.3.1 The ChillFish game

The ChillFish game takes place in a side-scrolling underwater 2D world. The gameplay is simple; the player controls a puffer fish (the player character) with the goal of collecting as many starfish (points) as possible within a given time frame. The vertical position of the puffer fish is determined based on the player’s breathing through the ChillFish controller (see Figure 9-4); when the player exhales, the puffer fish expands in size and moves towards the top of the screen as illustrated on Figure 9-3. The starfish are placed in a curve, so that in order to collect all the starfish, the player has to breath in a continuous slow-pace, which is similar to the breathing exercise Sama Vritti or “Equal Breathing”, i.e. inhaling for 5 seconds and exhaling for 5 seconds continuously.

9.3.2 Technical implementation of ChillFish

The ChillFish game is implemented in the Unity Game Engine (“Unity - Game Engine,” 2016), and the ChillFish controller is built in LEGO as seen in Figure 9-4. Inside the ChillFish controller, a thermistor and a microphone is used to detect inhalation and exhalation. The thermistor and microphone is connected to an RFDuino that transmits the sensor data via a wireless Bluetooth 4.0 connection to a computer or tablet device running the ChillFish game. The ChillFish game analyzes the incoming sensor data and moves the puffer fish up or down depending on whether the child exhales or inhales respectively.

Figure 9-3: Screenshots from the ChillFish game. The position size and position of the puffer fish is directly determined by the player’s breath. When exhaling through the physical ChillFish controller, the puffer fish expands and moves towards the top. Inhaling causes the fish to shrink in size and move it towards the bottom.

Figure 9-4: The ChillFish controller built with LEGO® bricks with electronics embedded inside.
9.4 ChillFish Study Design I - Evaluating ChillFish with Adults

As ChillFish both represents a novel unobtrusive technological approach to detecting respiration (i.e., non-worn sensing) and a novel interaction technique (i.e., using breath as a core game mechanic) we decided to evaluate the interaction and the calming effect of ChillFish with 16 adults without ADHD through a within-subject design study, before evaluating ChillFish with children with ADHD.

9.4.1 Participants

16 adults (14 males, two females), aged between 25 and 41 were recruited to evaluate ChillFish in a lab setting.

9.4.2 Dependent variables

Heart Rate Variability (HRV) was used as a stress/calming indicator as research have shown a connection between HRV and stress (Clark and Hirschman, 1990; Song and Lehrer, 2003) like existing HCI research have also used HRV in similar studies (Harris et al., 2014a; Parnandi et al., 2014).

9.4.3 Procedure

To evaluate the impact of ChillFish on the participants’ HRV and compare the effect to other activities, all participants completed the same sequence of activities:

1. Introduction to the study (casual conversation) : 2–4 minutes
2. Play test of ChillFish : 2 minutes
3. Play test of PAC-MAN : 2 minutes
4. Play test of ChillFish : 2 minutes
5. Casual conversation about ChillFish and PAC-MAN : 2-4 minutes
6. Traditional breathing exercise : 2 minutes
7. Casual conversation summing up the participants’ experiences with the different activities (i.e., ChillFish, PAC-MAN, and the traditional breathing exercise)

These activities allowed for comparing the effect of ChillFish to a traditional breathing exercise. In addition, the PAC-MAN game activity was chosen to simulate a stressful situation for the participants, which allowed for evaluating the effect of ChillFish when the participants were in a stressed situation. The casual conversations worked as a baseline between activities as further discussed in Paper D.

9.5 ChillFish Study Design II - Evaluating ChillFish with Children with ADHD

After having successfully evaluated ChillFish with 16 adults, a study with 12 children with ADHD were designed to evaluate ChillFish with the intended target group. In the following, the planned study design is presented, however unfortunately only four children completed the study due to technical issues as described in (Sonne and Jensen, 2016b).

9.5.1 Procedure

The 12 participating children all attended an ADHD summer camp, where the study was also conducted. Electro dermal activity (EDA) was added as a supplement to the HRV
sensor data to provide even more reliable sensor data related to the child’s stress level. All children had to complete a sequence of activities:

1. Introduction
2. PAC-MAN
3. ChillFish / Traditional respiration exercise
4. PAC-MAN
5. Traditional respiration exercise / ChillFish
6. Interview

As the purpose of the study was to compare the effect of ChillFish to a traditional breathing exercise, activity 3 and 5 was changed between each participating child to counterbalance possible carry-over effects.

9.5.2 Adapting the ChillFish study design to children with ADHD

Several changes were made to the study design compared to the study design used to evaluate ChillFish with adults.

First, as described in chapter 5, children with ADHD have challenges in maintaining attention (chapter 5.2) and holding a sequence of events in memory (chapter 5.4). As proposed in chapter 6, structure can be used as a design strategy to assist children with ADHD maintain attention and facilitate activities. Therefore, a visual overview (see Figure 9-5) of the study activities were used to present the study to the participants like a smartphone application inspired by the MOBERO research experiment (chapter 10) was also used to visualize remaining time for each activity.

Second, after each activity the child was asked to rate how fun and difficult they found the activity and to estimate the duration of the activity (always two minutes) using the Fun Toolkit (Read and MacFarlane, 2006) as seen on Figure 9-6. In addition to the child’s feedback, the parent who was present during the study also received a questionnaire that they were asked to complete during the study. The parent questionnaire related to how they perceived their child’s attention- and stress level during the activities.
Having presented both the study design from evaluating ChillFish with adults without ADHD and with children with ADHD, the next section presents selected findings from these studies.

9.6 Quantitative Findings from the ChillFish Studies

Analyzing the calming effect of ChillFish in the study with 16 adults without ADHD as described in Paper D, showed a significant difference in HRV values between the activities. A post-hoc test Tukey’s pairwise comparison showed that HRV values associated with the casual conversation activities were not significantly different, suggesting that these conversations worked well as a baseline measurement.

Furthermore, the relaxation activity did not differentiate significantly from the baseline scores, though the mean HRV values were higher than the baseline activities. The HRV values associated with the PAC-MAN activity both had the lowest mean value and was significantly different from all other activities, suggesting that playing PAC-Man indeed did stress the participants. Finally, analyzing the two ChillFish activities showed no
significant difference between baseline and the first ChillFish activity, however a significant difference was found between baseline and the second ChillFish activity as also seen on Figure 9-7, suggesting that ChillFish can provide a calming effect.

Looking at Figure 9-8 of the four children with ADHD that completed the study, we see a similar tendency; ChillFish was effective in calming a child after a stressful event.

![Comparison of mean HRV values between activities](image)

Figure 9-8: Normalized mean HRV values from four children with ADHD completing the second ChillFish study.

### 9.7 Summary and Contribution

In this chapter, I have presented the ChillFish research experiment in order to address RQ2.2 ‘How can assistive technologies assist children with ADHD better regulate emotions?’.

ChillFish is a calming biofeedback game where the child uses breathing to directly control the y-position of a puffer fish in a virtual underwater game with the goal of collecting as many starfish points as possible. The starfish are positioned in a curve that assembles a relaxing breathing rate, thus the child will complete a relaxing breathing exercise to collect the starfish. From the analysis of the two studies of the ChillFish prototype, the HRV data suggest that assistive technologies like ChillFish can be used to provide support for regulating emotions (RQ2.2). However, as both studies were conducted in lab-like settings it is hard to predict the effect and use in a real-world context. Nevertheless, the conducted studies showed the potential of using assistive technologies to assist children regulate emotions, and future work should therefore explore how such technologies can be evaluated in real-world contexts.
10 Sleep Assistance  
– The MOBERO Research Experiment

In this chapter, I will give an account of Paper C by presenting the MOBERO research experiment. MOBERO is a smartphone-based system designed to assist families of children with ADHD to establish healthy morning and bedtime routines and improve the sleep quality for the child. MOBERO addresses RQ2.3 in this dissertation: ‘How can assistive technologies assist children with ADHD and their families to establish healthy bedtime routines and improve sleep quality?’

Below, Table 10-1 provides an overview of the central ADHD challenges targeted by MOBERO, the design strategies used in the design and development of MOBERO, and how MOBERO is positioned in the ADHD Design Space.

<table>
<thead>
<tr>
<th>Targeted ADHD challenges cf. chapter 5</th>
<th>Applied design strategies cf. chapter 6</th>
<th>Placement in the ADHD Design Space cf. chapter 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenges of hyperactivity / impulsivity</td>
<td>Support Attention and facilitate activity completion</td>
<td>Impairments Dimension: Health problems and psychiatric co-morbidities</td>
</tr>
<tr>
<td>Sleep deficits</td>
<td>Support rewards and praise to encourage engagement</td>
<td>+ Social disability</td>
</tr>
<tr>
<td>Social challenges associated with ADHD</td>
<td>Support family dynamics</td>
<td>Technological Dimension: MIIS</td>
</tr>
</tbody>
</table>

Table 10-1: The targeted central ADHD challenges, the applied design strategies used in MOBERO, and its position in the ADHD Design Space.

On the technological dimension in the ADHD Design Space (chapter 7), MOBERO would be categorized within the MIIS category, and more specifically the “Technologies for in-situ assistance in context”-subcategory. As MOBERO both addresses impaired family relationships and sleep disorders, MOBERO can be
categorized within both “social disability” and “Health problems and psychiatric comorbidities” in the ADHD impairments dimension.

10.1 Motivating MOBERO – Improving Family Routines

Two major factors influenced the motivation for designing MOBERO: 1) Family conflicts and frustration caused around the child’s bedtime, and 2) The consequences of inadequate sleep for children.

In two studies of family dynamics in families of children with ADHD, morning and bedtime activities were reported as especially challenging for parents (Firmin and Phillips, 2009; Segal, 1998). Morning routines were often reported stressful due to time pressure and constraints (Firmin and Phillips, 2009) and around bedtime, parents reported breakdown in communication and a general disintegration in interaction between child and parent (Firmin and Phillips, 2009). The challenges around bedtime are supported by a meta-review finding that parents of children with ADHD report more child bedtime resistance than parents of neurotypical children (Cortese et al., 2009).

In addition to the negative consequences on child-parent relationship caused by the challenges around morning and bedtime, the consequences of poor sleep is wide-ranging and negatively impacts e.g., learning and school performance, behavior, mood, wellbeing, general cognitive functioning, and quality of life (Cortese et al., 2009; Dewald et al., 2010).

Thus, if an assistive technology like MOBERO can alleviate some of these unfortunate consequences by utilizing relevant design strategies from chapter 6, it can potentially lower the parenteral frustration and improve the parent-child relationship over time. Furthermore, by supporting consistent and structured bedtime routines, MOBERO also holds potential for improving the sleep of children with ADHD, which as mentioned previously, would positively impact many aspects of the child’s wellbeing.

10.2 The MOBERO Design Process

The MOBERO design process (see Figure 10-2) involved three psychologists, two child psychiatrists, three medical doctors and two sets of parents of children with ADHD.

![Figure 10-2: A simplified visual representation of the iterative MOBERO design process](image)

The initial concept for MOBERO was established and later (iteratively) refined in collaboration with the ADHD professionals. Initially, MOBERO only focused on
assisting families to establish sound bedtime routines and improving sleep. However, from evaluating an early version of MOBERO with two families of children with ADHD, support for morning routines was incorporated into MOBERO on request from the first family. The first family used and evaluated MOBERO for four weeks followed by the second family who used MOBERO for three weeks.

As ADHD is highly heritable (Biederman and Faraone, 2005), parents might themselves experience challenges in providing the structure needed to establish and maintain a consistent and healthy bedtime routine for their child. MOBERO was therefore designed to support family dynamics as suggested in chapter 6.3 by providing assistance around the bedtime routines for both children and parents.

10.3 MOBERO: A Smartphone Application for the Whole Family

MOBERO is a smartphone-based application designed to assist families of children with ADHD to establish healthy morning and bedtime routines, and through that improve the child-parent relationship as well as improving the child’s sleep quality.

MOBERO consists of two modules, a morning module and a bedtime module, in the following both modules are introduced.

10.3.1 The MOBERO morning module

The MOBERO morning module consists of three general activity views as seen in Figure 10-3: a main view (left), a specific activity view (middle), and a reward view (right).

![Figure 10-3: The three main activities in the MOBERO morning module.](image)

The main view (1) consists of a list of activities that constitutes the child’s morning routine. A small icon and a textual description represent each activity in the list. In addition to the main view, each activity has its own separate view (2). This separate activity view features a circular timer representing the time elapsed/remaining and how this is related to a reward (illustrated with small representations of medals around the circular timer). The third view (3) shows the total number of medals collected from completing the morning activities.
10.3.2 The MOBERO bedtime module

The MOBERO bedtime module consists of bedtime activities for both parents and child as seen on Figure 10-4.

Figure 10-4: The flow of the MOBERO bedtime module.

(1) 15 minutes prior to the set bedtime, MOBERO notifies the parents to initiate their bedtime routine for the child. The parents can either choose to snooze MOBERO for 15 minutes or begin the bedtime preparing activities. Having completed their activities, which includes advice and activities for improving conditions for the child’s sleep, MOBERO displays a countdown view (2), which after 15 minutes notifies the child to start her bedtime routine (3). The representation of the child’s bedtime activities is similar to the morning module, where a list of activities constitutes the child’s bedtime routine, and where each activity has its own view. However, in contrast to the morning module, the child is not rewarded for completing activities within a certain timeframe, as this could stress the child, which could negatively affect the ability to fall asleep. Having completed all bedtime activities, the child is rewarded with a physical self-glowing star that they can attach to a laminated A4-sized reward chart (4) inspired by the design strategy ‘Support Rewards and Praise to Encourage Engagement and Improve Parent-Child Relationship.’ in chapter 6.2.

10.4 MOBERO Study Design

A four-week within-subject study design was chosen to evaluate the effect of MOBERO. The four-week study consisted of a two-week baseline period (routines as usual) followed by a two-week intervention period where the families used MOBERO.

10.4.1 Participants

13 children with ADHD and their families were recruited to participate in a four-week field study of MOBERO. All children were either clinically diagnosed with ADHD or under investigation for ADHD, and all had an ADHD-RS score (see Table 10-2) within the normal ADHD range. In addition, only children with ADHD as the primary diagnosis were included in the study.

10.4.2 Dependent variables

Table 10-2 provides a visual overview of the quantitative data collected as part of the MOBERO experiment. In addition, several semi-structured interviews were conducted before and after the experiments as described in chapter 4. For further information on the data collection methods, analysis etc. related to MOBERO the reader is referred to Paper C.
<table>
<thead>
<tr>
<th>Data Collection</th>
<th>Collected information</th>
<th>Collection frequency</th>
<th>Statistical method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAA</strong>&lt;br&gt;- Daily Assessment App</td>
<td>Child bedtime, sleep time, wakeup time and parent assessment of frustration and child independence.</td>
<td>Daily during both baseline and intervention period.</td>
<td>Two-tailed Wilcoxon Signed Rank tests</td>
</tr>
<tr>
<td><strong>ADHD-RS</strong>&lt;br&gt;- The ADHD rating scale (Szomlaiiski et al., 2009)</td>
<td>Child ADHD symptoms.</td>
<td>Prior to the baseline period and after the intervention period</td>
<td>Two-tailed t-test</td>
</tr>
<tr>
<td><strong>CSHQ</strong>&lt;br&gt;-The Children’s’ Sleep Habit Questionnaire (Owens et al., 2000)</td>
<td>Child sleep habits.</td>
<td>Prior to the baseline period and after the intervention period</td>
<td>Two-tailed t-test</td>
</tr>
<tr>
<td><strong>MOBERO-Q</strong></td>
<td>Parent assessment of frustration and conflicts, and insights into family routines.</td>
<td>Prior to the baseline period, after the intervention period, and one-month after the intervention period.</td>
<td>Two-tailed Wilcoxon Signed Rank tests</td>
</tr>
</tbody>
</table>

Table 10-2: An overview of the quantitative data collected as part of the MOBERO study.
* Clinically validated.

10.5 Evaluating the Impact of MOBERO on Sleep

In this section, selected findings from the MOBERO study related to the use of the MOBERO bedtime module are presented. For more detailed information, including findings related to the MOBERO morning module see Paper C.

10.5.1 Improvements in the child’s sleep habits

From the analysis of the Children’s’ Sleep Habit Questionnaire (CSHQ (Owens et al., 2000)) we see a statistically significant 8.3% improvement in the parent’s responses after the MOBERO study compared to their responses prior to the MOBERO study, \( t(12) = 2.43, p<0.05, \text{Cohen's } d=0.67 \). This suggests that the use of MOBERO was associated with an improvement in the children’s sleep habit quality.

10.5.2 Parents report higher child independence when using MOBERO

Based on analysis of the daily parent-reported answers to the question “[The child’s name] was independent during the bedtime routines?” a significant improvement in responses was observed between baseline (median = 3: neutral) and the intervention period (median=4: agree), \( z = -2.02, p<0.05, r = 0.40 \) (also see Figure 10-5).
Parents report lower frustration during their child’s bedtime routines

Based on analysis of the daily parent-reported answers to the question “I experienced the bedtime routines as frustrating” a significant improvement in responses was observed between baseline (median = 3: neutral) and the intervention period (median=2: disagree), z = 2.76, p<0.01, r = 0.54 as also depicted in Figure 10-6. This is supported by the qualitative findings as exemplified by comparing one family’s description of their bedtime routines before and after the use of MOBERO “There is yelling and screaming from all sides, even from ours, up until the last half hour before he [Brian] sleeps or is in his bed [...]. (Interviewer) How does this make you feel? (Mother) Super frustrated. We have of course often been very upset when putting him to bed, and mad, and frustrated and yes. (Father) When you come downstairs, you simply just collapse. (Mother) There have been times when I almost did not have the strength to put him to bed [...] and the same family after having used MOBERO “we’ve got calmer and better evenings, and it has been pleasant to tuck him in. There have been more loving and quiet moments than conflict, and it's really nice” (Paper C).
10.5.4 Improvements in parent reported ADHD-RS scores (ADHD symptoms)

In addition to the sleep related findings, a 16.5% improvement was observed in the ADHD-RS scores between baseline period (M=39.4, SD=5.4) and intervention period (M=32.9, SD=5.5), \( t(12) = 2.59, p<.05, \) Cohen's \( d=0.73 \). This suggests that the use of MOBERO was associated with a parent perceived improvement in the children’s ADHD symptoms.

Using a version of the ADHD-RS that includes a behavior category (the behavior category is often used in the European countries as ADHD is diagnosed according to the ICD-10 as described in chapter 2), we observed a 26.3% reduction in behavior score between baseline and intervention periods. This suggests that MOBERO was associated with a significant improvement in the child’s behaviors, which supports the above presented findings in chapter 10.5.2 and 10.5.3.
Summary and Contribution

In this chapter, I have presented MOBERO, a smartphone-based system aimed to assist in establishing healthy morning and bedtime routines for children with ADHD. MOBERO was designed and evaluated in order to address RQ2.3 ‘How can assistive technologies assist children with ADHD and their families to establish healthy bedtime routines and improve sleep quality?’.

The use of MOBERO was associated with significant improvements in children’s sleep quality and parent rated ADHD symptoms based on validated clinical questionnaires. In addition, parents rated their child’s level of independence around morning and bedtime significantly higher in the intervention period compared to the baseline period. Furthermore, parents also rated their own frustration level around morning and bedtime to be significantly lower in the intervention period compared to the baseline period.

Findings from the MOBERO research experiment as presented in this chapter and in Paper C suggest that assistive technologies can assist in establishing and improving bedtime routines and sleep quality for children with ADHD. MOBERO relied heavily on several of the presented design strategies in chapter 6 as illustrated in Table 10-1 and on collaboration with ADHD domain professional, why these are important in addressing RQ2.3.

Having presented the three research experiments (i.e., CASTT, ChillFish, and MOBERO) and illustrated how they build upon and utilized the ADHD Design Framework, I will in the following chapter reflect upon my experiences of working as an HCI researcher within the highly unexplored space of assistive technologies for the ADHD Domain.
11 Reflecting on Designing Assistive Technologies for the ADHD Domain

In the ADHD Design Framework presented in chapter 5, 6, and 7, I analyzed and conceptualized central deficits and challenges associated with the ADHD disorder (chapter 5); design strategies for designing assistive technologies for the ADHD domain (chapter 6); and a design space that identified unexplored opportunities for assistive technology for the ADHD domain (chapter 7). Thereafter in the chapters 8 to 10, I presented three research experiments that build upon the ADHD Design Framework as examples of my research on designing and evaluating assistive technologies for the ADHD domain. These three research experiments focused on providing assistance for three central ADHD challenges (i.e., attention deficits, emotional deficits, and sleep deficits) presented in chapter 5.

In this chapter, I will reflect upon the work I have done within the highly unexplored domain of assistive technology for children with ADHD. I will first reflect upon the research process and illustrate how it guided the work in addressing the research questions and how it can also provide guidance for future research within this domain. Thereafter, I will discuss how the three research experiments (i.e., CASTT, ChillFish, and MOBERO) advance state-of-the-art-assistive technologies for the ADHD domain based on the ADHD Design Space presented in Chapter 7. Finally, I will discuss how the ADHD Design Framework and the presented research experiments as a whole can guide future research both within and beyond the ADHD domain.

11.1 The Research Process for CASTT, ChillFish, and MOBERO

The research process behind CASTT, ChillFish, and MOBERO follows four activities, where the first three are similar to the three components of the ADHD Design Framework (chapters 5 to 7) as illustrated in Figure 11-1:

Understand the target domain: In chapter 5, central deficits and challenges associated with ADHD were presented in order to provide HCI practitioners with an initial understanding of this domain.

Develop design strategies: In chapter 6, five design strategies for designing assistive technologies for the ADHD domain were discussed. These design strategies were identified through a combined analysis of findings from contextual inquires, empirical evaluations, and literature reviews. These design strategies addressed common deficits and challenges as presented in chapter 5.

Identify technological opportunities: In chapter 7, I presented a design space that highlighted the unexplored (research and technology) spaces within the field of assistive technologies for the ADHD domain.

Design, build, and evaluate assistive technologies (iteratively): In chapter 8, 9, and 10, three research experiments of assistive technologies for children with ADHD were presented.
These activities guided the research and allowed for addressing the research questions presented in chapter 1.1. In the following, I will discuss the work in each of these activities in relation to how they address the research questions of this dissertation.

11.2 Understand the Target Domain, Develop Design Strategies, and Identify Technological Opportunities

The first research question (RQ1) in this dissertation relates to how HCI researchers can establish a foundation that can guide the design of assistive technologies for a mental disorder domain like ADHD:

RQ1: How can HCI researchers analyze and conceptualize the mental disorder domain of ADHD, in order to create the foundation for designing assistive technologies for this domain?

In order to establish a foundation for designing assistive technologies for any mental disorder domain, I will argue that HCI researchers need to 1) acquire a deep understanding of the target domain, and especially the deficits and challenges associated with the disorder; 2) use this knowledge to develop design strategies that can inspire and guide future research; and 3) identify technological opportunities for targeting core deficits or challenges through the use of the identified design strategies.

In this dissertation, the first activity (understand the target domain) was achieved through hands-on training; contextual inquiries in schools and clinics; and from ADHD and HCI literature reviews. Based on this work, common deficits associated with ADHD was identified as presented in chapter 5. Thereafter, several co-design activities with especially subject matter experts (including teachers, child psychiatrists, psychologists, ADHD researchers etc.) and parents were conducted. These co-design activities together with the obtained understanding of the target domain resulted in a set of design strategies for designing assistive technologies for children with ADHD as
presented in chapter 6. I thereafter developed an early version of the ADHD Design Space presented in chapter 7. These insights, in combination with related work from other domains, were used to explore opportunities for assistive technologies for the ADHD domain. This process resulted in the design and development of three research prototypes presented in chapter 8, 9, and 10.

The above research activities constituted the foundation for designing assistive technologies for the ADHD domain used in the presented research (Sonne et al., 2015b, 2016a, 2016c; Sonne and Grønbæk, 2015; Sonne and Jensen, 2016a, 2016b). I will therefore argue, that these research activities constituting the ADHD Design Framework addresses RQ1. Furthermore, though this dissertation has focused on assistive technologies for the ADHD domain, I will argue that the research activities proposed herein are also highly relevant and applicable for designing assistive technologies for other mental and development disorders.

11.3 Design, Build, and Evaluate Assistive Technologies

Having presented how the initial research led to the development of the ADHD Design Framework, I will now reflect upon the value of involving subject matter experts in the design process. Furthermore, I will argue for the importance of iterative development and evaluation of prototypes in context when designing assistive technologies for the ADHD domain. Together, these activities address RQ2:

RQ2: How can assistive technologies be designed to assist children with ADHD in handling their central deficits and challenges?

Common for the three research experiments presented in chapter 8, 9, and 10 is that they build upon the same foundation of knowledge – the ADHD Design Framework. However, in addition to the ADHD Design Framework, a major factor for the successful outcome of the presented research experiments can be attributed to the involvement of experienced subject matter experts in the design process. For example, several psychologists, a child psychiatrist, and medical researchers with specialty in sleep and ADHD contributed with valuable insights and expertise in the MOBERO research experiment (Paper C).

Another beneficial factor behind CASTT, ChillFish, and MOBERO was the early and frequent iterations and evaluations of prototypes. In each of the three research experiments, the design process from early concept to functional prototype was iterative and involved development and discussion of several concepts with subject matter experts and parents. In addition, evaluating early functional prototypes in real-world context with children with ADHD also provided valuable insights in improving the final prototype and study design as also discussed in chapter 4.

The above reflection of the research process behind CASTT, ChillFish, and MOBERO is relevant in order to address RQ2. Thus, a way to address RQ2 is to: 1) Establish a deep understanding of the ADHD domain, 2) develop design strategies, 3) identify technological opportunities, 4) collaborate with subject matter experts to come up with successful concepts and prototypes, and 5) iteratively improve the technology through evaluations in real-word settings.
11.4 Advancing State of the Art Assistive Technologies for the ADHD Domain

As described in chapter 7, several unexplored areas exist for assistive technologies for the ADHD domain. In Figure 11-2, the three ADHD research prototypes presented in this dissertation are mapped out in the *ADHD Design Space*.

![ADHD Design Space](image)

**Figure 11-2:** The *ADHD Design Space* shown with existing research and technologies for the ADHD domain. The contributions in this dissertation are highlighted with a bold font and an asterisk after their name.

As illustrated in Figure 11-2, MOBERO and ChillFish populate previously unexplored spaces in the *ADHD Design Space*. In contrast, CASTT shares a space with the SmartPen prototype (DePrenger et al., 2010). However, even though CASTT and the SmartPen prototype both relate to attention deficits, CASTT is a more advanced system focusing on detecting attention lapses in general, and via a mobile intervention assists the child to regain attention. In comparison, the SmartPen only detect if a person is reading or not. As discussed in chapter 7, the broad categories of the ADHD impairments dimension is a weakness of the *ADHD Design Space* as technologies such as CASTT and the SmartPen (DePrenger et al., 2010) can seem more similar than they are.

Collectively, CASTT, MOBERO, and ChillFish therefore advance state-of-the-art technologies for the ADHD domain.

11.5 Assistive Technologies Beyond the ADHD Domain

In the following, I will reflect upon perspectives for how the general concepts of CASTT and MOBERO can have potentials beyond the ADHD domain. In chapter 12, I will provide a brief account of Paper A where ChillFish is evaluated in a hospital blood drawing context outside the ADHD domain.
11.5.1 CASTT potentials beyond the ADHD domain

CASTT is a wearable and mobile sensing- and intervention platform that supports collection of physical and physiological data. In Paper E, CASTT is intended to detect attention lapses and when detected assist the child to regain attention.

One example of expanding the application domain for CASTT is to use the heart rate data collection function in CASTT to detect forthcoming emotional outbursts similar to the smart wristband by McHuge et al. (McHugh et al., 2010) as presented in the related work section. McHugh et al. (McHugh et al., 2010) relied on the child to perform a breathing exercise without any in-situ support or guidance, however CASTT could utilize the smartphone to provide guidance by for example a smartphone version of ChillFish where the breathing pattern is derived directly from the heart rate monitor. In this way, CASTT could provide assistance for people with conduct disorders or a high degree of emotional outbursts. Furthermore, by focusing on detecting stress levels, CASTT could trigger a modified ChillFish application as a discrete way to lower individuals’ stress level.

In general, CASTT is an example of wearable technology that captures physical and physiological activities why all disorders that has a certain activity or physiological pattern could therefore potentially be relevant application areas for CASTT.

11.5.2 MOBERO potentials beyond the ADHD domain

As the negative consequences of poor sleep (e.g., executive functioning (Gruber et al., 2011), daytime sleepiness (Dewald et al., 2010; Gruber et al., 2011), mood (Dahl, 1996), and school performance (Dewald et al., 2010)) applies to all children, MOBERO is naturally not limited to children with ADHD. Today, daytime sleepiness among children and teenagers has become a major international health concern (Fallone et al., 2002), some even argue that we live in a sleep-deprived society (Gerber, 2014). Healthy bedtime habits are an incredibly effective way to improve sleep quality, why MOBERO will also be beneficial for children and families beyond the ADHD domain. Thus, I sincerely hope that future HCI researchers will continue to explore the potentials for computing technologies to improve children’s sleep, and I will argue that MOBERO as presented in this dissertation could also be beneficial for neurotypical children.

11.6 Summary

In this chapter, I have provided reflections upon working as an HCI researcher within the highly unexplored domain of assistive technologies for children with ADHD. I have discussed how the ADHD Design Framework, interdisciplinary collaborations with ADHD domain professionals, and frequent iterations and evaluations of prototypes in real world contexts are important factors for designing technologies for the ADHD domain. In addition, I have argued how CASTT, ChillFish, and MOBERO advance state-of-the-art technology for the ADHD domain. Finally, I have provided perspective for how CASTT and MOBERO can be used beyond the ADHD domain.

In the next chapter, I will give a practical example of how my work can be used outside the ADHD domain by presenting the ChillFish Hospital research experiment (Paper A).
In this chapter, I will give a brief account of Paper A by presenting the ‘ChillFish Hospital’ research experiment. This is an example of how the presented design process and the ChillFish prototype can be used to provide assistance beyond the ADHD domain.

The ChillFish Hospital research experiment illustrates that techniques developed for the ADHD domain do have more generic fields of application beyond ADHD. This research experiment was initiated after an assistant professor from the psychology department heard me presenting ChillFish’s abilities to facilitate calming breathing exercises. She immediately saw potentials in using ChillFish to calm down children without mental disorders for example when they are temporarily stressed during blood drawing procedures (with which she had previous research experience).

12.1 Motivating The ChillFish Hospital Research Experiment

Blood sampling is among the most frequent medical procedures in the treatment and diagnosis of a variety of diseases. However, the procedure is often associated with fear, worries, and anxiety for children, they might even physically resist the procedure. Existing pharmacological and non-pharmacological treatments exist and can to some degree limit pain and improve patient experience e.g., (Carter et al., 2010; Krauss and Green, 2006). One of the most widely used non-pharmacological treatments is distraction, and while the function of distraction is not entirely understood, there is evidence that distraction can improve the patient experience during painful procedures (Kleiber and Harper, 1999). In addition, breathing exercises of various types have also been explored as active distraction techniques and have been found to be an effective method to reduce stress in both parents and children during painful medical procedures (Manne et al., 1990).

Existing research within the HCI domain has shown positive results in using technology to reduce anxiety and pain for children in pediatric hospital contexts (Aghel Manesh et al., 2014; Beran et al., 2013; Lu et al., 2011; Ullrich et al., 2016). However, the research has often been carried out in controlled lab studies outside the hospital context. The ChillFish Hospital research experiment advance the related work on assistive technology for the pediatric hospital domain by investigating the potential benefits of
distractions that combine a biofeedback game with breath-based relaxation techniques for children who undergo stressful blood drawing procedures in a hospital setting.

12.2 The ChillFish Hospital Design Process

As argued in chapter 11, establishing an understanding of the target domain is important when designing assistive technologies. Therefore, contextual inquiries (Holtzblatt and Beyer, 2014) were conducted in a hospital pediatric phlebotomy department as further described in Paper A. From these initial studies, appropriate design strategies and technological opportunities and requirements were identified as advocated for in chapter 11. Two main findings from this process emerges as briefly covered below (and in more detail in Paper A).

12.2.1 Designing Distraction for both Children and Parents

Similar to the MOBERO research experiment, findings from the initial empirical studies suggested that it would be beneficial to design technologies that could both distract the child and parent. From the conducted observations and interviews it was found that parents often failed to distract or calm down their child during the blood sampling procedure, and in several cases the parent made their child more nervous, as they themselves were nervous and unable to hide this fact from their child.

12.2.2 Ensuring Hygienic and Sterile Handling of Technology

Conducting studies in a hospital context naturally requires strict hygienic guidelines. Unfortunately, the original ChillFish prototype could not be used for studies in a hospital context, as objects that are part of hospital procedures should be either disposed or sterilized after use. Thus, the ChillFish controller was redesigned as described below in 12.3.

12.3 Changes to the Original ChillFish Prototype

Due to the hygienic and sterile requirements of evaluating technology in a hospital context, we had to make refinements to the original ChillFish prototype presented in chapter 9.

The biggest change compared to the original prototype was the development of a bespoke silicone sensor to measure breath rate. This silicone sensor is based on the physics of a pendant vane flow meter (Pendant vane flow meter, 1956) in which the deflection of an object immersed in the flow of a fluid results in a corresponding change in a display indicator (Paper A). Our silicone sensor incorporates all of the complex components of a moving vane flow meter into a single solid piece of silicon, allowing for contactless sensing of breath as further described in Paper A.

![Figure 12-2: a) assembled ChillFish controller as used by the participants; b) the top layer of bricks removed, the interior of the ChillFish controller reveals the electronic components; c&d) electronic components removed from the LEGO brick body.](image)
12.4 ChillFish Hospital Study Design

As a first step in evaluating ChillFish in a hospital blood sampling context, we designed a preliminary study with a total of 20 children divided into two groups: Passive distraction (watching a video) and active distraction (playing ChillFish) as shown in Table 12-1 and further described in Paper A.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Age</th>
<th>Gender</th>
<th>No. of previous blood samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active distraction</td>
<td>M = 9.4</td>
<td>3 Male</td>
<td>M = 39</td>
</tr>
<tr>
<td></td>
<td>SD = 1.6</td>
<td>7 Female</td>
<td>SD = 48</td>
</tr>
<tr>
<td>Passive distraction</td>
<td>M = 7.9</td>
<td>5 Male</td>
<td>M = 14</td>
</tr>
<tr>
<td></td>
<td>SD = 1.9</td>
<td>5 Female</td>
<td>SD = 10</td>
</tr>
</tbody>
</table>

Table 12-1: Participant information

Children were randomly assigned to either of the conditions after the child and parent had completed a set of questionnaires related to their expectations to the upcoming blood sampling procedure as seen in Table 12-2 and further elaborated in Paper A.

<table>
<thead>
<tr>
<th>Data collection</th>
<th>Data collection time</th>
<th>Collected information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glasses Fear Scale*</td>
<td>B + A (before + after)</td>
<td>Child fear before / experienced fear</td>
</tr>
<tr>
<td>Faces Pain Scale*</td>
<td>B + A</td>
<td>Child expected / experienced pain</td>
</tr>
<tr>
<td>Visual Analog Scale*</td>
<td>B + A</td>
<td>Parent proxy assessments of their child’s expectations / experiences</td>
</tr>
<tr>
<td>Visual Analog Scale*</td>
<td>A</td>
<td>Parent reported self-experienced discomfort during the procedure</td>
</tr>
<tr>
<td>Level of Difficulty and Effect</td>
<td>A</td>
<td>MLT assessment of degree of procedure difficulty and effect of intervention.</td>
</tr>
</tbody>
</table>

Table 12-2: An overview of the data collected as part of the ChillFish study. *Clinically validated.

Children in the passive distraction condition were asked to watch a video of fish in an aquarium and children in the active distraction condition were asked to play the ChillFish biofeedback game. In both conditions the intervention (video and ChillFish) ran from a tablet placed on a stand in the blood drawing room as seen in Figure 12-1. After the blood draw procedure, children, parents, and the Medical Laboratory Technologists (MLT), who drew the blood, completed questionnaires’ as summarized in Table 12-2.

12.5 Findings from the ChillFish Hospital Study

Based on the qualitative and quantitative data analysis described in Paper A, I will in the following give a brief account of selected findings from the ChillFish Hospital research experiment.

Both the passive and active distraction conditions showed a positive effect on both the children’s and parents’ experience with the blood drawing procedure, and most parents
would recommend both distraction techniques to a friend (passive 78%, active 89%), but with a slightly higher rate for the active distraction (ChillFish).

In addition, parents in the ChillFish condition reported their child’s pain to be lower than expected, suggesting that ChillFish was effective in distracting and calming the child during the blood drawing procedure.

Though we did not see significant effects in the children’s reported fear or pain (see Figure 12-3), we however see a positive tendency towards ChillFish being more effective in reducing fear and pain compared to the control condition as further discussed in Paper A.

![Child fear and pain](image)

**Figure 12-3: Child reported fear and pain before and after the blood drawing procedure**

When looking at the qualitative findings, we found that the passive distraction was used differently than we had intended. Instead of being just a passive distraction, the MLTs and parents turned the video (of fish in an aquarium) into an active distraction by engaging and asking the child questions about the movie e.g., “Do you think we will see a small shark?”, “How many fish are there right now?” and “Can you find Nemo?” (Paper A). We therefore in a way ended up comparing two active distraction conditions against each other, however, these are the kind of unexpected and uncontrollable ‘issues’ that happens during experiments in the wild.

The last finding I will highlight is that the provided distractions were not efficacious for all children. From analysis of observations of the blood draw procedures three patient types emerged, and especially one of the emerged patient types (the ‘highly anxious child’) did not seem to benefit from either the video or ChillFish condition as further discussed in Paper A.

### 12.6 Summary

This chapter has illustrated how the general principles behind the ADHD Design Framework (i.e., understand the target domain, develop design strategies, and explore technological opportunities) and my reflections upon designing successful technologies for the ADHD domain (e.g., involve subject matter experts in the design process) showed to be highly applicable and effective outside the ADHD domain. Furthermore, I provided a brief account of Paper A by presenting core steps and findings related to the
design process. Finally, I showed that ChillFish was associated with improvements in the blood drawing procedure and had a positive impact on the children’s fear and pain during the procedure.
13 Conclusions and Future Work

Assistive technologies for people with ADHD have long been an underexplored research domain within HCI. However, through the research conducted as part of this dissertation, I have found that assistive technology shows much potential in empowering children with ADHD and their families. Though the presented research has only scratched the surface of possibilities in the area of assistive technology for the ADHD domain, the presented ADHD Design Framework and the three research experiments show promise that future research within this domain hold enormous potentials for empowering people with ADHD to cope with their deficits.

In this final chapter, I will first conclude dissertation by summarizing the main contributions by addressing the six research questions in this dissertation, where after I will end my dissertation with directions for future work.

13.1 Main Contributions from the Conducted Research

The aim of this dissertation has been to explore the opportunities for empowering children with ADHD through assistive technology. Over the last three years I have conducted theoretical and experimental explorations in order to address the research objectives of this dissertation presented in chapter 1. My research has been driven by a genuine interest and desire to empower children with ADHD and to investigate how technology can assist in achieving this goal. I will therefore in the following address each of six the research questions in this dissertation.

How can HCI researchers analyze and conceptualize the mental disorder domain of ADHD, in order to create the foundation for designing assistive technologies for this domain? Over the chapters 5, 6, and 7, I introduced the ADHD Design Framework, which was based on findings and insights from combined analysis of HCI and ADHD literature, numerous empirical studies, hands-on training, and collaborations with a wide range of subject matter experts. The ADHD Design Framework consists of three components: 1) An analysis and identification of central deficits and challenges frequently associated with ADHD; 2) five design strategies that address these identified deficits and challenges; and 3) a design space that identifies technological opportunities for designing novel assistive technologies for the ADHD domain. Thus, I will argue that the ADHD Design Framework provides a foundation for HCI researchers to design and explore the many uncharted areas within the domain of ADHD assistive technology. Furthermore, as discussed in chapter 11, I argue that these activities are also highly relevant and applicable for research on assistive technology for other domains than ADHD.

How can assistive technologies be designed to assist children with ADHD in handling their central deficits and challenges? In chapter 8, 9, and 10, I respectively presented the research prototypes CASTT, ChillFish, and MOBERO that each addresses core deficits and challenges associated with ADHD. These three research prototypes build upon the foundation provided by the ADHD Design Framework, which ensured that central ADHD deficit and challenges were addressed and appropriate design strategies chosen. In addition, as discussed in chapter 11, the involvement of subject
matter experts (e.g., psychologists, child psychiatrists, teachers, ADHD medical researchers) in the design process also added significant contributions to the design of both technological prototypes and evaluation studies. Finally, rapid and iterative development of prototypes was valuable in both the design process with subject matter experts and in evaluating these in real world context with children with ADHD.

**How can assistive technologies assist children with ADHD sustain attention in real-world contexts?** The CASTT research experiment addressed this research question in chapter 8. The first part of the *ADHD Design Framework* (chapter 6) highlights situations where many children with ADHD find it especially challenging to sustain attention. These situations include transitioning between activities and engagement in challenging and low motivation tasks like homework assignments. Having identified situations where children with ADHD struggle to maintain attention, the design strategies presented in the second part of the *ADHD Design Framework* (chapter 7) provide two design strategies that might be successful in assisting children with ADHD sustain attention. The first applicable design strategy is to provide structure for the child, as this helps the child stay focused and refocus on activities during/after attention lapses (chapter 6.1). The second applicable design strategy is to use rewards and praise to keep the child motivated doing challenging tasks (chapter 6.2). Together, these elements of the *ADHD Design Framework* are beneficial for designing assistive technologies to assist children with ADHD to sustain attention in real-world contexts.

**How can assistive technologies assist children with ADHD better regulate emotions?** This research question was addressed by the ChillFish research experiment presented in chapter 9. From the initial analysis of the ADHD domain (chapter 4.2) that included observations in classrooms and following psychologists in schools, I identified that some children with ADHD easily get emotionally upset and furthermore find it hard to calm down afterwards. This is also documented in the broader ADHD literature and identified in the *ADHD Design Framework* in chapter 6. Often, the current practice in schools is to remove the child from the classroom and wait for him to calm down, however, from the hands on training at Center for ADHD, I found that breathing exercises are effective in calming down and relaxing children and adults (further documented in Paper D). Thus, one way to use assistive technology to assist children with ADHD to better regulate their emotions is to assist them in performing calming breathing exercises (as ChillFish does). The smart watch prototype by McHugh et al. (McHugh et al., 2010) relied on teaching children to use breathing exercises, however using the rewards strategy from the *ADHD Design Framework* (chapter 6.2) might be more suitable for children with ADHD, especially if the child is already upset. The ChillFish research experiments showed that combining a biofeedback game with a breathing exercise is an effective way to calm down and reduce stress in both adults and children with ADHD.

**How can assistive technologies assist children with ADHD and their families to establish healthy bedtime routines and improve sleep quality?** This research question was addressed by the MOBERO research experiment in chapter 10. As identified in the *ADHD Design Framework*, sleep deficits and parent frustrations around bedtime are very common in families of children with ADHD (chapter 5.5). From the interdisciplinary design process in the MOBERO research experiment it was found that establishing healthy bedtime routines were often paramount to improving sleep quality for children with ADHD. As ADHD is highly heritable, parents of children with ADHD
might also suffer from ADHD, which can make it difficult for parents to provide the structure needed to establish a healthy bedtime routine. Thus, a design strategy for designing assistive technologies related to sleep and children with ADHD is to design technology for family dynamics by including assistance for parents as well as children (chapter 6.3). Furthermore, utilizing the rewards and praise design strategy (chapter 6.2) in the MOBERO research experiment had a positive effect on the children by motivating them to maintain consistent bedtime routines.

What potentials do interactive technologies hold as a supplement to traditional treatment methods for ADHD and other mental disorders? In addressing this research question, I will argue that it is important that HCI researchers do not see assistive technology as a replacement for existing and well-documented traditional treatments as pharmaceutical treatments or parent training programs. Instead, technology should be seen as a supplement to existing treatment strategies and (maybe in the future) the diagnostic process. Similarly, assistive technology should not replace teachers, child psychiatrists, psychologists, or parents, instead the ambition of technology should be to assist these people in providing even better care for the child.

Returning to the research question, a major quality compared to traditional treatment strategies is that assistive technology can provide everyday support to people with ADHD, caregivers, parents, and teachers – which existing treatments simply cannot provide. Assistive technology offers an opportunity to provide personalized assistance unique to each child, without side effects followed by traditional treatment strategies that many patients with ADHD experience today (chapter 2.2).

Having addressed the six research questions and summarized the contribution of the presented research, I will end this dissertation by presenting directions for future work.

13.2 Future Work

In this dissertation I have explored the greatly unexplored domain of ADHD assistive technologies. However, this domain still holds many interesting and novel research opportunities and in the following I will present potential directions for future work.

13.2.1 Future work on the ADHD Design Framework

The ADHD design framework is to the best of my knowledge the first of its kind for the ADHD domain. The ADHD Design Framework provides an initial foundation for HCI researchers to design assistive technologies for the ADHD domain and future work should therefore investigate new design strategies to facilitate designing even better technologies for the ADHD domain. Also, the ADHD Design Space should continuously be updated with future research within this domain. Furthermore, as a critical amount of new research is added to the design space, both the technological and the ADHD impairments dimension should be further divided into more fine-grained categories to allow for continued identification of new unexplored spaces.

13.2.2 CASTT future work

Based on the findings from the CASTT research experiment (Paper E), advancements in sensor technology since the original CASTT study, and the unexplored spaces in the ADHD Design Space (chapter 7), I see especially two interesting directions for advancing the research on CASTT: 1) Improve the existing CASTT prototype and conduct further studies to evaluate the impact of the CASTT assistive intervention and
2) focus on capturing sensor data that can provide ADHD domain professionals with new insights into the condition.

Since I conducted the CASTT experiments in 2013, the advancements within sensor technology have resulted in commercial products such as wristbands and smart watches with embedded activity and physiological sensors that can now be tailored and used to assess stress and attention level. This technological advancement combined with designing the assistive intervention to run on a smart watch instead of a smartphone would make a new version of CASTT even more discrete and eliminate chances of stigmatization (chapter 6.4.).

As an alternative to use CASTT to provide real-time attention assistance, the medical collaborators in the CASTT research experiment see great potential in capturing objective activity and physiological data from children with ADHD in order to gain new insights into the conditions of ADHD.

13.2.3 ChillFish future work
ChillFish has shown to be both effective in providing a calming effect and in improving blood sampling procedures in hospitals. Therefore, interesting next steps for ChillFish could be to evaluate it with families of children with ADHD. Besides assisting the child to calm down after emotional outburst, ChillFish could be used prior to bedtime to assist the child in calming down and thereby be better prepared for bed. Another potential for future work would be to use ChillFish as a tool that children (and adults) can use to calm down in stressful situations.

13.2.4 MOBERO future work
Based on positive findings from the MOBERO study, future work on MOBERO could both contribute with novel research to the HCI community and provide even better support for families of children with ADHD (and families with neurotypical children). Below, I will present potential directions for future work on MOBERO.

Investigate usage and impact over time through a longitudinal study
In the presented MOBERO research experiment (chapter 10), I have shown that MOBERO is associated with improvements in the child’s sleep quality, parent frustration, child’s independence, and a reduction in parent rated ADHD symptoms. However, it is unclear what the effect would have been had the families used MOBERO over a longer period of time. The existing research most similar to MOBERO Lullaby (Kay et al., 2012) and SleepTight (Choe et al., 2015) were evaluated for 14 days and four-weeks respectively. Currently, longitudinal studies of assistive technologies are underexplored with HCI - especially for assistive technologies related to sleep and the ADHD domain. Longitudinal studies could limit potential novelty effects and provide insights into how users adopt the technology over time.

Specifically, future research could investigate how and if the value of rewards delivered by technology reduces over time. In the MOBERO research experiment, both virtual and physical rewards were used as a way to explore differences between virtual and tangible rewards (as presented in chapter 10 and Paper C), however feedback from parents was mixed; most parents agreed that the tangible rewards motivated their children, and they argued that these rewards would continue to motivate them as the reward system allowed for changing the actual reward each week. In contrast, feedback on the virtual rewards was more mixed; some parents reported that it only motivated the child for a few days while others said that the child was still very motivated by the
rewards at the end of the study (14 days). Future research could therefore investigate the implications of different types of rewards for children (with ADHD) on task engagement.

Utilize machine learning to transform MOBERO into a CCD assistive technology
MOBERO is currently categorized as a MIIS (Manually interacted with information and services) technology in the ADHD Design Space, however by adding sleep tracking and machine learning capabilities to MOBERO, it can capture and analyze sleep data in order to provide personalized sleep assistance to the users, making MOBERO a CCD (Manually interacted with information and services) technology.

An example of future work could be called MOBERO v2.0. MOBERO v.2.0 is similar to MOBERO in focusing on improving sleep habits. However, in addition to the original MOBERO system, MOBERO v2.0 also captures and analyzes the child’s sleep patterns. The result of the sleep analysis is presented to parents together with insights into their child’s sleep habits and recommendations for improvements. A scenario could be that MOBERO v2.0 detects that a child’s bedtime has been fluctuating too much throughout two weeks. MOBERO v2.0 therefore informs the parents about this unhealthy habit together with information about the implications of this unfortunate behavior (e.g., impaired school performance and executive functioning (Cortese et al., 2009)) together with suggestions for how to change this behavior (for example consistent bedtime routines). In this way, MOBERO v2.0 would be an example of an assistive technology for the ADHD domain that can be categorized within the ‘Services for personal reflection’ subcategory of the CCD category in the ADHD Design Space.

Furthermore, MOBERO v2.0 could also occupy the other CCD subcategory ‘Services for research’, if it allowed for sharing sleep data with researchers or the child’s psychiatrist. In Denmark (like many other European countries), a child psychiatrist is required to investigate if poor sleep habits could be the root reason for a child’s behavior problems (as poor sleep is associated with ADHD-like symptoms as described in chapter 5.5) prior to diagnosing the child with ADHD. Today, the child psychiatrist examines this by asking parents to complete a sleep diary of their child’s sleep for two or more weeks, however, as identified in the MOBERO research experiment, the accuracy of these sleep diaries can be doubted, which my interviews with child psychiatrists also supported (Paper C).

Thus, future research on capturing and analyzing sleep data hold potentials both as a supplement to the existing diagnostic process and for improving children’s sleep.

13.3 Epilogue
The work presented in this dissertation has aimed to explore how assistive technology could empower children with ADHD. Through the development of an ADHD Design Framework and several technological research experiments this dissertation has illustrated the rich potentials for using technology to assist people with ADHD. However, I believe that the presented research has merely scratched the surface, and that there is a lot more research and development to undertake within assistive technologies for mental disorders like ADHD and beyond. I therefore sincerely hope that the presented work can be used by and inspire future researchers to design assistive technologies for this interesting and relevant ADHD domain!

So Long, and Thanks for All the Fish!
Part II - Publications
In this chapter, the paper ‘Calming Children When Drawing Blood Using Breath-based Biofeedback’ is presented. This paper has been submitted for review.

Calming Children When Drawing Blood
Using Breath-based Biofeedback

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Abstract
Blood sampling is a common and necessary procedure in the treatment and diagnosis of a variety of diseases. However, it often results in painful and stressful experiences for children. Designed together with domain experts, ChillFish is a breath-controlled biofeedback game technology with bespoke airflow sensor that aims to calm children during blood sampling procedures. An initial randomized controlled trial was conducted in which 20 children aged 6-11 were assigned to one of two conditions involving either passive distraction (watching a video) or active distraction using the ChillFish prototype. Medical staff rated ChillFish significantly more useful in facilitating the blood sampling procedure compared to passive distraction. Qualitative feedback from patients, parents, and medical staff identified aspects that impact the acceptance of breath-based active distraction. Our study highlights the potential of non-pharmacological assistive technology tools to reduce fear and pain for children undergoing painful or stressful medical treatment.

Author Keywords
Children, assistive technology, hospital context, medical, blood drawing, blood test, biofeedback, game, calming, relax, field study, tangible computing, RCT, in the wild.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI):

14.1 Introduction
Blood sampling is among the most common medical procedures, and is often associated with anxiety, fear, worries, and even physical resistance from children. Medical staff can employ pharmacological techniques such as local anesthetic gel to reduce pain at the site of skin puncture, or increasingly invasive measures including physical restraint or sedation (Krauss and Green, 2006). Non-pharmacological treatments have been explored as they reduce resources required from the medical staff, are usually simple to implement and do not carry the potential health risks of sedation (Carter et al., 2010). These include reduction of pain through the application of cold compress at the injection site, emotional comfort through human touch, vibrotactile stimulation (Baxter et al., 2011) or massage. Distraction is also a frequently used cognitive coping strategy that is intended to redirect the attention of the child toward a stimulus or engage the child actively in a task other than the procedure in order to diminishing the capacity to attend to painful stimuli, resulting in reduction of pain, distress, and anxiety (DeMore and Cohen, 2005). While the function of distraction is not completely understood there
is mounting evidence that it can improve the patient experience during painful procedures. Research has explored the use of passive distraction techniques, e.g. where the child is presented with music or a video during the procedure with successful results; or active distractions, e.g. asking the child to play an interactive game (Minute et al., 2012) or more physical tasks such as blowing soap bubbles (Sparks, 2001). Breathing tasks have gained attention because the activity itself could calm the child and stabilize the quick shallow breathing often associated with anxiety. Research has examined breathing exercises (French et al., 1994), which seem to assist in calming the child and muscle relaxation, making it easier and less painful to use the needle to take the blood sample.

While techniques of active or passive distraction have been shown to be beneficial for children, medical researchers have claimed that not all work well in every situation and that caregivers should therefore have various techniques and strategies available for each patient (Winskill, 2008). Considering the fast-pace hospitals and the need for sanitary controls, attractive options would be simple, cheap and easy to use.

In this paper, we present a study that compares breath-based biofeedback and videogame technology for active distraction to reduce anxiety and pain during medical pediatric procedures. We present a bespoke airflow sensor suitable for use in a medical context. Based on an initial Randomized Controlled Trial (RCT) study in a hospital context we provide insights into how active and passive distraction techniques impact the blood draw procedure.

14.2 Background and Related Work

There are broadly three categories of research that inform our work: pediatric health technologies, stress-relieving biofeedback applications, and medical studies of various distraction strategies within the pediatric health domain.

14.2.1 Existing Technologies for the Pediatric Health Domain

Designing hospital technologies is not new within HCI (Bardram, 2004; Stisen et al., 2016), and several technologies for pediatric health have also been presented (Beran et
al., 2013; Jeong et al., 2015; McCarthy et al., 2015; Mott et al., 2008; Ullrich et al., 2016). However, most studies have either been early stage feasibility studies conducted in controlled lab settings (Aghel Manesh et al., 2014; Lu et al., 2011; Ullrich et al., 2016) and/or have focused on other pediatric health contexts than blood drawing e.g., rehabilitation (McCarthy et al., 2015) or burn injuries (Miller et al., 2010; Mott et al., 2008).

The work most related to ours includes mediPuppet (Lu et al., 2011) and MEDi (Aghel Manesh et al., 2014; Beran et al., 2013, 2015). mediPuppet is an interactive and comforting companion that aims to help children to feel more relaxed and comfortable during medical procedures (Lu et al., 2011). It is a tangible prototype comprising an Android smartphone embedded into a ‘puppet’ made of foam board, which allows the child to interact with a ‘procedure game map’ by scanning QR codes (Lu et al., 2011). mediPuppet was evaluated in a lab study, and preliminary findings suggest that the participating children (aged three to five) treated the puppet as a real person that they became attached to (Lu et al., 2011).

More related to our work is MEDi (Aghel Manesh et al., 2014; Beran et al., 2013, 2015) a humanoid robot that utilize cognitive behavioral strategies to mitigate pain and distress of children during their annual flu vaccination (Aghel Manesh et al., 2014; Beran et al., 2015). During the vaccination procedure, MEDi sat on a table in front of the child and several times asked the child to perform certain actions like e.g., blowing ‘dust’ off toy objects in front of the robot. The use of pre-programmed distraction strategies was associated with significantly less pain and distress in both children and parents.

14.2.2 Various Uses of Calming Biofeedback Applications

Research on stress reducing biofeedback applications have shown promising results in reducing stress in both adults and adolescents (Harris et al., 2014a; MacLean et al., 2013; Moran et al., 2016; Moraveji et al., 2011; Parnandi et al., 2014). However, within the HCI community the use of biofeedback to distract or calm down users in a hospital setting has received less attention. As we highlight later in this paper, designing for and conducting evaluations in a hospital context requires interventions to be sterile and in most cases there is not time for a patients to put on the special equipment required to detect breath or respiration in many of the existing stress relieving biofeedback applications (Harris et al., 2014a; MacLean et al., 2013; Moraveji et al., 2011; Parnandi et al., 2014).

14.2.3 Distraction Strategies used in Pediatric Health Care

Distraction is one of the most widely used non-pharmacological pain management techniques during medical procedures because it can be a simple and fast way to reduce pain, stress, and anxiety (Kleiber and Harper, 1999). Blood sampling procedures are often performed with little pain and in many cases completed quickly, however, during the procedure, the medical staff orchestrates a very complex situation managing the behavior of the child and parents while at the same time manipulating the medical equipment needed to draw the blood. Various challenges arise as the medical technician finds a suitable vein through sight or palpation, potentially seeks additional vein punctures to attain proper flow, changes sample vials and removes the needle when complete. The child may disturb the process by moving or resisting physically. Coping strategies for children dealing with medical procedures such as venipuncture vary—
some children prefer to watch the process while others prefer avoidance strategies, with cognitive distraction being the most widely adopted approach (Peterson, 1989). Many of the commonly used distraction techniques in pediatric care require either active or passive involvement (Koller and Goldman, 2012). Passive distraction techniques associated with reduced pain include watching an animation clip (Yoo et al., 2011), listening to music or watching television (Fanurik et al., 2000). In active distraction, the patient is engaged in a task that requires action in the form of physical activity or frequent responses to stimuli. Examples range from special cards that medical staff can use to prompt answers from patients (Sahiner and Bal, 2016), playing a console game or active participation with a digital companion (Miller et al., 2016).

Breathing tasks of various types have been explored as active distraction techniques. Results suggest reduced anxiety and pain during medical treatments. Manne et al. reported that inflating a balloon was an effective method in reducing the family’s and the child’s stress (Manne et al., 1990). Gupta et al. showed that children’s pain levels were significantly lower in a balloon inflation group than in the control group (Gupta et al., 2006). French et al. taught children to blow out during immunizations as if blowing bubbles, resulting in significantly reduced levels of pain behaviors (French et al., 1994). In another study using party blowers, Blount et al. found that the use of the breath based distraction was helpful for children coping with the pain of immunization (Blount et al., 1992). In their study, a 10-12 minute training session with parents and children was required to prepare the children for exhaling during the needle insertion.

Existing HCI research has shown positive results in utilizing distraction techniques as a way to reduce anxiety and pain for children in hospital. Researchers within the HCI and medical domains have shown that breathing techniques and biofeedback are able to reduce stress and anxiety. However, investigations have been carried out in controlled lab studies or outside the hospital context. In this paper, we extend this related work by investigating the potential benefits of distractions that combine breath-based relaxation therapy and engaging digital games for children who undergo stressful blood draw procedures.

14.3 Design Process - Designing Technologies for the Hospital Context

In this section we present our design process. We used a contextual inquiry (Holtzblatt and Beyer, 2014) inspired approach to understand the hospital context we were designing for, gather specifications for the ChillFish prototype, and identify requirements needed to conduct evaluations in a hospital.

During the initial design process, we spent three days at a hospital pediatric phlebotomy department. We observed numerous blood tests of children of all ages and conducted interviews with Medical Laboratory Technologists (MLT), specialized professionals who take the blood samples, focusing on understanding their work practices, current strategies for calming children, and the challenges and opportunities for using and evaluating technological interventions in the pediatric phlebotomy department. In this early phase of the study, we interviewed two MLTs, the head of the pediatric phlebotomy department and one hospital clown whose role is to engage with children and raise their spirits. In addition, we also interviewed and observed several children and their parents, focusing on their expectations and experiences before (in the patient
waiting room), during, and after the blood draw procedure. In the later part of the design process we had several meetings and interactions with an infection control nurse, who had to approve our prototypes and our (hygienic) procedures for handling the evaluation of ChillFish. As part of this approval, we received training and detailed instructions on how to assemble and handle the ChillFish prototypes and proper handling and interactions during the blood draw procedure with the children.

Below, we highlight two findings from our design process that we found especially relevant when designing technologies to be used during blood drawing procedures in a hospital context.

14.3.1 Designing Distractions for both Children and Parents

From analysis of our findings from our design process at the hospital, we learned that the MLTs frequently used distractions. These distractions were mostly verbal, like e.g., asking the child about hobbies, sports, or siblings, and had the purpose of calming the child and distracting them from the blood drawing. However, in our discussions with MLTs and a hospital clown, all emphasized that it was important not to introduce any technology that would fully immerse the child (e.g., virtual reality) during the blood drawing procedure, as the needle prick could then come as a shock. This could be very an unpleasant experience and could cause the child to abruptly (re)move her arm, which could result in a needle accident.

In addition, many of the MLTs commented that parents often failed to distract and calm their child during blood drawing. In fact, parents often made that their child more nervous, as they themselves were nervous and unable to hide it from their children. We observed numerous situations that supported this. For example, we often observed that parents were holding their child’s hand, and though the child were told to look away, the parent was looking at the needle, and squeezed the child’s hand harder and harder as the needle came closer to the arm, causing the child to “feel” the forthcoming pain, and thus become nervous. Thus, technologies for blood drawing procedures should be engaging and able to distract both the child and the child’s parent(s) during blood drawing procedures.

14.3.2 Ensuring Hygienic and Sterile Handling of Technology

Without a doubt, the most challenging and time consuming task in this project was designing ChillFish to pass the hospital’s hygiene requirements, especially because our target patient group includes children who might suffer from various health issues or receiving medical treatments, which could negatively impact their immune systems.

From our meetings with the infection control nurse we learned that objects used as part of a hospital procedure should either be disposable (single use items) or able to be sterilized after use. We therefore had to explore options for sensing breath that would meet the requirements described in the next section. The final solution involved a contactless breath detecting silicone module that could be sterilized after each patient. All electronics are shielded from contact and therefore could be reused without the risk of transferring infection. Although 3D printing a controller was an option, the surface would need to be smooth enough to be cleaned with an antibacterial wipe as required by the infection control nurse. The use of LEGO bricks in the tangible ChillFish controller presented smooth surfaces, but due to the separate pieces these could not be easily cleaned after use. An option suggested by the infection control nurse would be to
completely disassemble and wash all parts in a special medical autoclave machine, which uses high temperature and pressure to sterilize instruments. We were offered training in using the autoclave machine, however for the purpose of our study we instead built 50 ChillFish controllers so that we could dispose of each LEGO model after use with plenty of extra controllers for pilot testing and refinements. Both the MLTs and the infection control nurse argued for a toy-like form factor. The consensus among the MLTs was that vivid colors would be appealing for children and would stand out in the sterile context. This is supported by research that suggests decorative choices impact the acceptance of the equipment by children. For example, chemotherapy patients experienced significantly lower levels of anxiety and needle phobia when the needles and hypodermic syringes were decorated to appear as a butterfly or with sparkly stickers that might be appealing to children (Kettwich et al., 2007).

14.4 The ChillFish System

We now introduce ChillFish, a breath-based biofeedback game designed to distract and calm down children and their parents during blood sampling procedures. The system builds upon work presented in (Sonne and Jensen, 2016a) where a similar 2D game is used. However, the breath-based biofeedback controller uses another breath-sensing technique and has been designed to meet hygiene and safety demands.

14.4.1 The ChillFish Biofeedback Game

The ChillFish biofeedback game runs on an Android tablet and is implemented using the Unity Game Engine (“Unity - Game Engine,” 2016). The gameplay is based on an underwater 2D side-scrolling world, where the objective is that the player character (a puffer fish) has to collect as many starfish as possible as seen in Figure 14-3. The vertical position of the player character is controlled by inhaling or exhaling through the mouthpiece on the physical controller shown in Figure 14-2a. The starfish are
positioned in a sine wave pattern, so that to collect as many starfish as possible, the player has to follow a slow-paced breathing pattern similar to the ones used in well documented relaxing breathing techniques (Jerath et al., 2006b; Song and Lehrer, 2003).

14.4.2 Technical Description of Tangible ChillFish Controller

Although various technologies can sense respiration (see (AL-Khalidi et al., 2011) for an overview), most are very expensive and require bulky equipment, which would not be suitable in the pediatric phlebotomy clinic. The tangible ChillFish controller is built from LEGO bricks to resemble a fish as seen in Figure 14-2 and contains two analog light sensors, a white LED backlight module, an RFDuino microcontroller, two LiPo batteries, and a custom made silicone sensor as described below. Together, these electronic components can reliably detect when the child breathes in or out through the straw at the front of the controller. This information is transmitted via a wireless Bluetooth 4.0 connection to the tablet running the ChillFish biofeedback game, where the information either moves the player character upwards or downwards depending on the child’s breath.

14.5 Bespoke Silicone Sensor

In order to measure breath rate, it would be possible to use cumbersome and expensive medical equipment. However, this study points toward the feasibility of creating a simple medical device that could work in the clinic and perhaps become a personal coping technology for use outside the hospital setting. Aside from cost, medical spirometers and respiration devices further inhibit the patient and often cover the mouth and nose, which could result in a more restricted feeling contributing to stress. Furthermore, the precision achieved with more expensive sensors is not needed to measure general inhalation behaviors. To the best of our knowledge, sensing the airflow from breath with a contactless sensor has not been done in previous work aside from expensive medical equipment. The sensor we developed is based on the physics of a pendant vane flow meter (Pendant vane flow meter, 1956) in which the deflection of an object immersed in the flow of a fluid results in a corresponding change in a display indicator. Our design incorporates all of the complex parts of a moving vane flow meter into a single solid piece of silicone. The design, development, and additional performance characteristics of the sensor will be detailed in a separate forthcoming article, but we present overview of the sensor and how it enables testing in the hospital context. The child breathes through a 1cm diameter straw protruding from the fish which forces air through the silicone sensor, which causes an opaque silicone pendant vane to move in the direction of the airflow and partially blocks the light directed toward two analog light sensors mounted to a PLA plate beside the silicone body (see Figure 14-5d). When the child inhales, the internal vane moves toward the mouth and blocks the frontmost light sensor as shown in Figure 14-4.

When the child exhales, the pendant vane moves in the other direction partially blocking the rearmost light sensor. When there is no airflow, the pendant vane returns to the center position and does not block either light sensor.

Two Adafruit GA1A12S202 log-scale analog light sensor breakout boards were cut in half to reduce the size and were affixed to a custom PLA sensor plate as shown in Figure 14-5e. The sensor plate provides two openings that collect light directs it to each
sensor. A custom PLA plate was designed to hold a white LED backlight module, which directs the cast light through the silicone piece toward the sensor plate.

![Diagram of sensor setup]

**Figure 14-4:** Cross-section drawings of the silicone sensor with pendant vane moving according to airflow during respiration.

Food-safe Bluesil 3428 RTV silicone was used with platinum catalysts resulting in a durable rubbery final product. We utilized transparent catalyst for the body and white catalyst for the pendant vane. The transparency of the block allows light from the LED backlight to pass through, yet some of the light is blocked by the white silicone pendant vane. This drop in light level is detected by the two light sensors (see Figure 14-5f,g).

The fabrication of the silicone pendant vane sensor follows an approach that has become popular in the field of microfluidics in that a special mould is created about which silicone is cast and then the mould is removed leaving a complex form that is only possible through an investment casting process (Saggiomo and Velders, 2015).

![Fabrication process diagrams]

**Figure 14-5:** Silicone moving pendant flow sensor parts include: a) rearmost and b) frontmost column of light emitted from the c) LED backlight, which pass through the d) cast silicone, striking the e) sensor plate, f) front most and g) rear most analog light sensor.

**Figure 14-6:** Overview of the fabrication process. a) silicone with opaque white catalyst injected into 3D printed ABS negative b) prepared negatives are placed in the mould frame c) silicone with transparent catalyst is poured into mould frame d) after silicone has cured, mould frame is cut to access individual cast pieces e) each cast piece is trimmed to remove excess silicone f) after acetone bath has removed ABS negatives, LED light shone through the resulting piece reveals the shadow cast by the internal pendant.
The casting involves a double-shot process using two colors of catalyst. To begin, a small amount of the 3428 mixture was prepared with the white catalyst and placed into a sterile 5ml medical syringe fitted with an 18 gauge 40mm long hypodermic needle and injected into the void of the ABS negative as shown in Figure 14-6a. Before the white silicone was set, a large batch of silicone was prepared with transparent catalyst and is poured into a mould frame to a depth of approximately 2 cm. The previously prepared ABS negatives were placed in a mould frame (Figure 14-6b), additional transparent silicone was poured into each of the mould sections (Figure 14-6c). After 16 hours of curing time, the mould frame was cut and removed (Figure 14-6d) yielding the silicone blocks with the ABS negative embedded as shown in Figure 14-6e. The ABS negative was removed using repeated cycles of acetone bath and cotton swabs. The silicone was then washed with washing up liquid and a brush, then placed into a bath of boiling water and soaked in ethanol to complete the sterilization process. The result is a single block of silicone with embedded pendant vane as shown in Figure 14-6f.

14.6 The ChillFish Study Design

We conducted a randomized controlled trial with 20 child participants who were assigned to one of two conditions: the ChillFish active distraction technique for improving the blood draw procedure compared with standard passive distraction provided by watching a video. The ChillFish condition involved playing the breath-based ChillFish biofeedback game during the blood drawing procedure. The control condition presented a video of an aquarium. In both conditions, video elements were presented on a tablet positioned on a stand next to the child (see Figure 14-1). Prior to beginning the study, ethical clearance was granted by the regional ethics committee. Participants received no reimbursement for participating in the study.

Our hypothesis was that active distraction provided by the ChillFish breathing technique would result in better patient and clinician experiences during venipuncture and blood sampling procedures, compared to the control condition.

14.6.1 Questionnaire Measures Used

Glasses Fear Scale

The Glasses Fear Scale is a variation of the Visual Analog Scale designed for making children self-assess their fear (Cavender et al., 2004). The Glasses Fear Scale consists of a visual representation of six cylinders (glasses). The first cylinder is empty meaning no fear, and the remaining five cylinders is filled with increasing amounts of fear. The last (sixth) cylinder is completely filled meaning most fear. The cylinders are assigned a value from 0 (no fear) to 5 (most fear). Children reported their level of fear before and immediately after the blood draw procedure.

Faces Pain Scale-revised

The Faces Pain Scale-revised is a self-assessment tool used to assess the intensity of a child’s pain (Cavender et al., 2004). The Faces Pain Scale consists of a facial scale with six faces, where no pain and worst possible pain are the extremes and the remaining four faces are in between these two. The children reported the level of pain they expected to experience from the blood draw procedure and the pain they actually experienced.
Visual Analog Scale (VAS)

The Visual Analog Scale is an instrument that measures continuous factors. It has been validated through various studies (Aitken, 1969; Gift, 1989). The VAS is a 10cm horizontal line. The parents marked on the line the point that they felt represented their answer, and the score (Manne et al., 1990) on the VAS was determined by measuring in centimeters from the left on the line to the point that the parent marked.

Parents were asked to mark, how worried their child was before the blood test on a VAS with the endpoints “Not worried” to “Most worried”. The parents also rated their own level of worry before the blood test. In addition, parents were asked to mark, how painful they expected the blood test to be for their child on a VAS with endpoints “No Pain” to “Worst possible pain”. After the blood test, parents reported their assessment of how much fear and pain the child experienced during the blood test using VAS with the endpoints “No fear” to “Most fear”, and “No pain” to “Worst pain”. The parents reported their own level of discomfort during the blood test using a VAS with the endpoints “No discomfort” to “Worst discomfort”.

MLT assessed level of difficulty and effect of intervention

The MLT rated after the blood draw procedure on a 5-points Likert scale the level of difficulty of the blood drawing from 1 “Unproblematic” to 5 “Very problematic”. In addition, the MLT scored the usefulness of the intervention (ChillFish/control) on a 5-point Likert scale from “Very Useful (it made a big positive impact)” to “Not at all useful (it made a big negative impact)”.

14.6.2 Participants

We recruited 20 children and their parents to participate in our study. Our inclusion criteria included that the participants should be children aged between six and eleven already scheduled to have a blood sample taken at the hospital, and accompanied by parents who were able to read and speak LANGUAGE BLINDED FOR REVIEW. Table 2 provides an overview of the participants.

<table>
<thead>
<tr>
<th>Data collection</th>
<th>Data collection time</th>
<th>Collected information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glasses Fear Scale*</td>
<td>B + A (before + after)</td>
<td>Child fear before / experienced fear</td>
</tr>
<tr>
<td>Faces Pain Scale*</td>
<td>B + A</td>
<td>Child expected / experienced pain</td>
</tr>
<tr>
<td>Visual Analog Scale*</td>
<td>B + A</td>
<td>Parent proxy assessments of their child’s expectations / experiences</td>
</tr>
<tr>
<td>Visual Analog Scale*</td>
<td>A</td>
<td>Parent reported self-experienced discomfort during the procedure</td>
</tr>
<tr>
<td>Level of Difficulty and Effect</td>
<td>A</td>
<td>MLT assessment of degree of procedure difficulty and effect of intervention.</td>
</tr>
</tbody>
</table>
14.6.3 Procedure

The child and the accompanying parent were informed about the project in the waiting room prior to the blood sampling. If the child and parent fitted the inclusion criteria, they were invited to participate in the study. Both had to give oral consent to participate, and the parent also had to provide written consent. The child and parent then completed the questionnaire as seen in Table 14-1. The parent was also asked to provide background information about the child (age, number of previous blood samples etc.). After answering these questions the child was randomly assigned to either active or passive distraction, at which point was introduced respective technology. A researcher joined the patient in the room in order to collect information about the blood draw procedure and the interactions with the technology. The researcher did not initiate any interactions with the child, parent or MLT during the procedure.

After the blood sampling procedure, the child, parent, and MLT answered short questionnaires (see Table 14-1). In addition, families were afterwards asked to participate in semi-structured interviews about their experiences with the blood test and the intervention.

Children and parents were only informed about the condition they were assigned to. Similarly, the MLTs were introduced neutrally to the two study conditions. None of MLTs from this study were involved with or knew about the earlier described design process.

Data Analysis

All included participants completed the measures before the blood sampling procedure. One child assigned to the ChillFish condition was extremely anxious and physically resisted the blood draw procedure and was deemed by the MLT to be in a state unsuitable for safe blood draw procedures. Therefore, only nine families in the ChillFish group completed the measures. Due to the low sample size, and therefore low statistical power in this study, a non-significant p-value does not necessarily indicate the absence of an effect (Sullivan and Feinn, 2012). Thus, to estimate the magnitude of the difference between the conditions the effect size was reported in all analyses. An effect size of $r=0.1$ indicated a small effect, $r=0.3$ a moderate effect, and $r=0.5$ a large effect.

Glasses Fear Scale and Faces Pain Scale Processing

Glasses Fear Scale and the Faces Pain Scale measures from before and after the blood sampling procedure for both conditions (ChillFish/control) were compared with two-tailed Mann–Whitney $U$ tests.

### Table 14-2: Participant information

<table>
<thead>
<tr>
<th>Condition</th>
<th>Age</th>
<th>Gender</th>
<th># of previous blood samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active distraction</td>
<td>M = 9.4, SD = 1.6</td>
<td>3 Male, 7 Female</td>
<td>M = 39, SD = 48</td>
</tr>
<tr>
<td>Passive distraction</td>
<td>M = 7.9, SD = 1.9</td>
<td>5 Male, 5 Female</td>
<td>M = 14, SD = 10</td>
</tr>
</tbody>
</table>
MLT Level of Difficulty and Effect Processing

A two-tailed Mann–Whitney U test was used to compare the MLT’s assessment of the level of difficulty of the blood draw between the two conditions. Similarly, a two-tailed Mann–Whitney U test was used to compare the MLT’s assessment of the level of usefulness of the intervention between the two conditions.

Differences in self-reported and parent-reported scores between conditions.

Differences between the conditions reported on Glasses Fear Scale, the Faces Pain Scale, and Visual Analog Scales were compared with two-tailed Mann–Whitney U tests.

14.7 Quantitative Results

The results of the data analysis showed general positive effects of both distraction conditions, and most parents would recommend the distraction technique to a friend (passive 78%, active 89%). Children easily understood and engaged with the ChillFish game collecting points by navigating the fish through controlled breathing even during the longer and more complicated blood draw procedures. Both conditions involved blood draw procedures of similar complexity, rated by the MLTs as ChillFish condition (Mdn = 3; neutral) and control condition (Mdn = 2; somewhat unproblematic), z = 0.79, p = 0.59, r=0.12.

As shown in Figure 14-7, the parents in the active distraction condition reported higher levels of fear before the procedure and expected their children to experience more pain compared to the passive distraction condition. The differences between the conditions were not significant and with small effect sizes for all measures except the parents’ rating of their own level of worry, where parents in the active condition rated a significant higher level of worry (Z=2,35, p=0.02, r=0.58). These results indicate that the random allocation to the conditions did not balance potential differences between the groups, which may have affected the differences between the conditions. The parents in the ChillFish condition had more worries before the blood test and rated their children to be more anxious before the test compared to parents in the passive distraction condition. As shown in Figure 14-8, this was not the case when children
rated their own level of fear before the blood test, where children in both conditions reported similar level of fear before the blood test.

14.7.1 Higher MLT-rated effect from using ChillFish
There was a significant improvement in responses to the MLT-reported answer to the question “On a scale from 1-5, how useful did you experience the ChillFish/Tablet Movie distraction under the blood sampling you have just completed” between the ChillFish condition (Mdn = 2: useful - made a positive difference) and the control condition (Mdn = 3: Neutral - did not make any difference), $z = -2.04$, $p=0.02$, $r = 0.55$.

14.7.2 Parents Report Less Pain than Expected in the ChillFish Condition
The level of pain both parents and children expected before the blood test was not comparable to how painful the blood test procedure actually was rated. Both children and parents in the ChillFish condition overestimated the painfulness of the procedure before the blood test when compared to the actual level of pain during the procedure. When compared to the parents in the passive distraction group the parents in the active distraction group reported a significantly lower level of pain during the procedure than they were expecting. This difference was statistically significant ($p=0.04$) and with a moderate effect size ($z=-2.00$, $p=0.04$, $r=0.46$). This result indicates that the procedure was not as painful as expected for the ChillFish condition. The difference between the children’s expected and actual pain was not statistically significant and showed a small effect size ($z=-0.94$, $p=0.35$, $r=0.22$).

14.7.3 Positive Effects of ChillFish on Parent-reported Child Pain and Fear
The use of the active distraction (ChillFish) during the blood test had a larger effect compared to the passive distraction on the children’s experience of fear and pain. As shown in Figure 14-8 children in the active distraction condition reported less fear and pain during the blood test compared to children in the passive distraction condition. However, the difference did not reach a significant level and showed small effect sizes ($z=-1.08$, $p=0.45$, $r=0.17$ and $z=-0.76$, $p=0.28$, $r=0.25$, respectively).

Due to the difference in rated level of parental worry before the procedure, analyses between ratings of the child’s fear and pain were conducted controlling for this difference. After adjusting for parental level of worry before the procedure, there were still no significant differences between the conditions on child-reported level of fear and pain ($F(1,16)=0.98$, $p=0.34$, partial eta squared= 0.06, $F(1,16)=0.01$, $p=0.99$, partial eta squared = 0.001). For the parent report of the child’s fear and pain during the procedure there were moderate differences between the conditions when controlling for their pre-procedure parental worry. Parents in the active distraction condition rated their child’s level of fear and pain lower. The differences were moderate but not statistically significant ($F(1,16)=1.23$, $p=0.28$, partial eta squared=0.07, $F(1,16)=1.26$, $p=0.28$, partial eta squared=0.07, respectively). These results indicate that when controlling for the differences in parental worry between the conditions the parents experienced a positive effect of the ChillFish distraction on their children’s level of fear and pain.
14.8 Qualitative Results

Analysis of the qualitative data further supports the quantitative findings that show positive benefits of the ChillFish condition. After one of the procedures in the ChillFish condition, the mother said to her child (T13): “You did not even cry this time!” Afterwards, the mother told us that this was the first time that the daughter had not resisted or cried during a blood sampling procedure (the mother had, prior to the blood test reported that her child had experienced 20 blood tests). We experienced similar positive sentiment from a parent of another ChillFish participant in which the father handed back the completed questionnaire and asked if the technology could be made available for his child during their child’s next blood draw procedure. The video condition did not elicit any specific comments from the parents yet was found to be received positively. We now examine more closely how the distraction conditions functioned in the real world context and appropriated during the procedures.

14.8.1 The MLTs and Parents Turned the Passive Distraction Condition into an Active Distraction Condition

In our study we were surprised to observe that both parents and the MLTs in almost all 10 cases in the passive distraction condition turned the passive distraction (a side scrolling aquarium movie) into an active distraction. In most cases the MLT would soon after the child had sat down ask a question related to the movie e.g., “Do you think we will see a small shark?” or “How many fish are there right now?”. In this way, the MLT turned the passive distraction into an active distraction where the MLT (and sometimes also the parent) would continuously ask questions about the aquarium movie to distract the child.

14.8.2 Three Emergent Patient Types

From a combined analysis of the child-reported Glasses Fear Scale questionnaire, our observations of the blood drawing procedure, and follow up interviews with MLTs three main patient types emerged: 1) ‘Not afraid’, 2) ‘Semi afraid’, and 3) ‘Highly anxious’.

The children in the ‘not afraid’ group reported no fear (score = 0) in the Glasses Fear Scale questionnaire completed prior to the blood sampling procedure. These children
were very independent, did not express worry before or during the blood draw, and did not pay any attention to the passive distraction condition. Instead, several of the children preferred to follow along in the preparations and the actual blood drawing.

The children in the ‘semi afraid’ group reported Glasses Fear Scale scores between 1 and 3. These children benefitted from distractions, and a few even had their own existing coping strategy (smartphone game, teddy bear etc.). They were generally worried about the pain and somewhat influenced by environment and other stressors.

The ‘highly anxious’ children in our study (we had three) all reported a score of 5 (most fear) on the Glasses Fear Scale. This group might include children with needle phobias. From our observations, these children did not seem to exhibit an exaggerated level of fear in the waiting room, however as soon as they entered the blood drawing room, they instantly became very anxious and often refused even simple requests like walking to the chair or rolling up their sleeves. In our study, an extra MLT was called in to assist, however in all cases the parent ended up having to physically restrain the child in order to get the blood sample. However, in one of our cases, the child exhibited so much resistance that the MLT could and would not try to draw the blood due to the risk of a needle accident. These children seemed pay too much attention the needle and the expected pain.

14.8.3 Distraction was not Efficacious for all Children
For several of the children in our study the degree of distraction provided by the two conditions was not enough to distract them from their fear of the needle. These children included all of the children in in the highly anxious’ group and several from the ‘semi afraid’ as discussed above.

In these situations, the child would only engage in the intervention for a short while and would continuously return their attention to the procedure, resulting in a vicious cycle of increasing anxiety. From our observations, neither the passive or active condition had any effect on these children, which was also supported in the MLTs questionnaire responses in these situations. The first time we observed such a situation we asked the MLT if she believed that a hospital clown could have assisted the child to calm down to which she responded “No. In situations like these, there is nothing to do”. In these situations the blood drawing procedure often required an extra MLT to assists, and if this did not help, the parent and the extra MLT together had to physically restrain the child in order to draw the blood (if the parent approved of this). However, as we experienced with one of the patients, two adults cannot always physically restraint the child enough to allow for a blood sample as the child might fight.

14.8.4 Differences in Social Interactions
A review of the formal characteristics of the distraction techniques used in this study reveals similarities and key differences. We describe how the participants responded to the distraction techniques to illustrate in what ways the treatments affected the social interactions between the patient, parent, and MLTs.

In both interventions, the technology became a shared focal point and provided a hook or a “ticket to talk”, which engaged the MLTs, patients and parents. Both in the ChillFish and the control condition, we observed that the MLTs and the parents used the interventions to distract the child as exemplified by a patient’s mother saying “Can you
“find Nemo?” and by a MLT saying “how many starfish have you got now?”. Furthermore, parents from both conditions afterwards commented that positive effects of both conditions included distraction.

In both conditions we observed that MLTs and parents often engaged with the interventions to encourage the distraction of the child. In the ChillFish condition, this engagement was limited to cheering for and instructing the child to inhale and exhale, while the aquarium video provided many opportunities to engage the child in discussion, for example asking if s/he had seen that new fish, counting the fish together, or asking specifically about one of the fish, as the MLT asked, “Did you see a yellow fish yet? What do you think the yellow fish is doing?” Although the game provided a challenge requiring the child to actively engage and navigate the fish, there was a lack of additional texture and details for encouraging conversation.

14.9 Discussion

14.9.1 Using Technology to Support Different Patient Types

In the following, we will discuss implications for the design of technologies in the hospital context suited for the three patient types identified previously.

We learned that children in the ‘highly anxious’ group did not benefit from either distraction condition. According to Thurgate and Heppell, children with a high level of anxiety need special treatment in order to avoid developing or reducing their needle phobia (Thurgate and Heppell, 2005). Thurgate and Heppell developed a three-step approach for overcoming needle phobia that focused on relaxation, control, and graded exposure (Thurgate and Heppell, 2005). Children that assess their own fear to be four or greater (on a 10-point scale) should, according to Thurgate and Heppell undergo their three-step approach to overcome their anxiety and support positive experiences with medical procedures involving needles.

The ChillFish condition was designed to both distract and assist the child to perform a relaxing breathing exercise. However, according to Thurgate and Heppell’s findings, one possible reason that children in the ‘highly anxious’ group did not benefit from the either of the interventions was that they were delivered too late.

Currently, HCI research on pediatric technology is mainly focused on interventions for the waiting room (e.g., (Lu et al., 2011; Ullrich et al., 2016)) and interventions during the medical procedure (e.g., (Aghel Manesh et al., 2014; Bucolo et al., 2006; McCarthy et al., 2015). However, as suggested by Thurgate and Heppell, taking a more holistic approach when designing for the pediatric hospital domain might be more appropriate. This is supported by a recent medical study which found that a combination of a calming intervention in the waiting room and an intervention during the medical needle procedure was significantly more effective than any of the two separately (Miller et al., 2016).

Though little HCI work has taken a holistic approach to the patient experience of pediatric procedures, our findings and related work suggest that allowing for personalized treatment of the child according to their anxiety level can improve the effectiveness of the distractions / interventions and reduce child anxiety.
14.9.2 Active Distraction Provided Soft Physical Restraint

There were key differences in the ways the distractions affected the bodily experiences of the children. In both conditions, the same tablet was used for onscreen content, and it was placed next to the child away from the needle insertion arm. This encouraged children’s heads to be oriented away from the needle insertion point. In the ChillFish condition, however, there were a few additional influences on the body that were not present for the video condition. The ChillFish controller required the children to place their mouth on the breathing tube, which reduced the opportunities for the child to speak. In the passive distraction condition, the children could speak freely or cry out when the needle was inserted. Furthermore, the ChillFish condition had a direct influence on the children’s breathing and encouraged a breathing pattern that has been shown to be relaxing for children (Jerath et al., 2006b; Song and Lehrer, 2003), whereas the video condition involved no guidance for the breathing behaviors. Considering the impact of the two distraction types, our findings highlight a tension created with the videogame related to control and the body. In the blood draw experience, the child has been brought to the hospital by the parent where they have reduced control over their body and the related testing. By playing the ChillFish game, the child must remain oriented to the screen, and must generally remain still in order to breathe through the controller. The result is that the child does not move away from the needle and does not resist the procedure. It may be that the child engages with the game and while giving up control of their own body, they can control something—the video game. Passive distraction on the other hand, offers little physical control to the child except from opting out entirely. Providing a feeling of situational and bodily control has been shown in the literature to improve the experience and emotional state of children (Thurgate and Heppell, 2005).

14.9.3 The Influence of Parents on Procedures

As we identified in our initial design process and the literature (Thurgate and Heppell, 2005), parental worry and anxiety is transferred to the child. In both conditions we saw that parents actively engaged in the distractions and that they would recommend the intervention to others, suggesting that the parents found both interventions to be an improvement to the blood sampling procedure independent of their own anxiety level. As noted previously, the MLTs claimed that parents either build confidence for their child or can easily transfer their anxiety. Although we did not see this transfer to children, we did however encounter one family where both the mother and father accompanied the child to the hospital and their coping strategy was to have the calm father accompany the child during the procedure. They explained that the mother would easily upset the daughter due to her own anxieties related to needles. We hope that this draws attention to designing for the complex family dynamic.

14.9.4 Limitations

We now discuss and evaluate several aspects of this study that present possible limitations. These include limited information on patient health history, number of study participants, the breadth and granularity of logged data, the design of the distractions, and environmental factors in the hospital setting. We now discuss how these might affect the validity of the contribution.

Participants in the study varied in terms of medical history, which might have affected the response to the distraction techniques. Based on the wide range of previous blood tests from 1 to 150, it is apparent that the participants are living with a range of
conditions and as the head of the phlebotomy department noted, this means that stage of diagnosis, medications prescribed, and treatments vary from child to child. While future studies can target more narrow segments of the blood clinic patients, the breadth of the current study serves to illustrate the diverse experiences of child patients and has provided insights into the further refinement of breathing based distraction games. Furthermore, the number of patients included in the study follows sample sizes for exploratory medical research on children undergoing venipuncture and injections (Dahlquist et al., 2002; Gold et al., 2006; Koller and Goldman, 2012; Manne et al., 1990; Wolitzky et al., 2005) and was sufficient to understand initial responses to breath-based biofeedback games.

This study examined responses to two forms of distraction using self-reported data, however we did not gather physiological data such as heart rate or skin conductance. While these measures could provide additional insights to the patient experience in larger sample sizes, these measures would require additional equipment attached to the child, which might negatively impact the child’s fear for the upcoming procedure. Instead, the findings from the presented study provide insights into the responses to distraction technologies.

14.9.5 Conclusion

In this work, we presented an initial RCT study to investigate potential benefits of distraction techniques that combine breath-based relaxation exercises and digital games for children who undergo stressful blood draw procedures. Our study was conducted in a pediatric hospital context involving 20 children aged between 6 and 11 and their families. Participants were randomly assigned to either a passive or an action distraction condition involving watching a video or actively playing the breath-based ChillFish game, respectively. We developed a bespoke breath sensor embedded in a tangible controller to satisfy the demands of safety and infection control of the hospital. Our findings show that the use of ChillFish was associated with an improvement in the blood draw procedure and showed positive impact on the child’s pain and fear during the blood test. The medical laboratory technicians rated the active distraction provided by ChillFish significantly more helpful than passive distraction. Based on our qualitative analysis we identified aspects that impact the acceptance of breath-based active distraction and highlighted three emergent patient profiles. This research highlights the potential of non-pharmacological assistive technology tools to reduce fear and pain for children undergoing painful or stressful medical treatment.
In this chapter, the paper ‘An Assistive Technology Design Framework for ADHD’ is presented. The paper is accepted for publication in Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction, OzCHI ’16.

An Assistive Technology Design Framework for ADHD

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Abstract
In this paper, we present a design framework for ADHD assistive technologies that aims to give researchers grounding in the background research on the condition, to provide a lingua franca, and to highlight potential research directions for HCI researchers within assistive technology. The design framework couples ADHD patient challenge areas to technological opportunities and it provides a set of practical design strategies for developing successful assistive technologies for people with ADHD. The framework is based on empirical studies, ADHD research, and related work on assistive technologies. We map existing assistive technologies and potential new research efforts to the framework concepts. This way we show how it is used to support and advance the research and development of novel assistive technologies for the ADHD domain.

Author Keywords
Design; children; adults; ADHD; assistive technologies; interventions; design framework; mental disorders; health.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

15.1 Introduction
HCI researchers have recently explored and demonstrated the potential of using technology to assist and empower patients with a broad range of mental health conditions (e.g. (Fage et al., 2014; Hirano et al., 2010b; Kientz et al., 2013; Milne et al., 2014)). However, to date there has been limited attention on the development of technologies to support people with Attention Deficit Hyperactivity Disorder (ADHD), despite ADHD being the most prevalent reported mental health diagnosis for children and teens (Perou et al., 2013). In comparison with other disorders like autism spectrum disorder (ASD) (Abdullah and Brereton, 2015; Cramer et al., 2011; Hirano et al., 2010b; Kientz et al., 2013) and bipolar disorder (Bardram et al., 2013), there has been far less research on assistive technologies for the ADHD domain. Yet the potential long-term consequences of ADHD are many, including social and academic impairments (Massetti et al., 2008), low self-esteem (Wehmeier et al., 2010), and increased risk of criminal conviction (Dalsgaard et al., 2013). Important early research (e.g., Pina et al. (2014); Weisberg et al. (2014)) has primarily focused on technological
exploration rather than on guidelines for designing assistive technologies for this domain.

In this paper, we seek to provide researchers within assistive technology and related HCI communities with a design framework for discussing and developing novel assistive technologies for people with ADHD. Our design framework is grounded in an analysis of the ADHD literature, related technology development for people with ADHD, as well as other conditions and lessons learned from our work within this field. The design framework comprises two parts: 1) two taxonomic dimensions: a technology dimension and an ADHD symptom dimension; and 2) A set of practical design strategies. For 1), the technology dimension introduces three approaches, which each relates to the functionality the assistive technology provides: 1. Manually Interacting with Information and Services (MIIS); 2. Automatically Executing Services (AES) based on in-situ analysis of contextual information, and 3. Capturing Contextual Data (CCD) for later retrieval. The ADHD dimension in the design framework spans five categories that all relate to how ADHD impacts the quality of life of people with ADHD (Faraone et al., 2015). From plotting related work into the design framework, we identify several unexplored opportunities for assistive technologies for the ADHD domain. We illustrate with existing systems and potential research efforts how the design framework can be used to advance existing technologies, and provide an example of how we have used the design framework in our own design process.

15.2 Background

ADHD is a persistent neurodevelopmental disorder. It is the most prevalent mental health disorder in children and adolescents aged 3-17 (Perou et al., 2013), with a worldwide prevalence of approximately 5% and affecting approximately 3% of adults (Faraone et al., 2015). ADHD is characterized by inattention, hyperactivity/impulsivity, or both, and thus has three presentations: 1. predominantly inattentive; 2. Predominantly hyperactive/impulsive; and 3. combined inattentive hyperactive/impulsive. The causes of ADHD are debated, and are outside the scope of this paper. However, as the heritability of ADHD is 70-80%, genetics is considered to be an important factor (Biederman and Faraone, 2005; Faraone et al., 2015).

In the US and Australia, ADHD is diagnosed according to the Diagnostic and Statistical Manual, Fifth Edition (DSM-V) (DSM-V, 2013), whereas in most of Europe, ADHD is diagnosed according to the International Classification of Diseases-10 (ICD-10) as a hyperkinetic disorder (HKD) (World Health Organization, 1992). The ICD-10 diagnostic criteria are more restrictive than those of the DSM-V, which has sometimes been misinterpreted as suggesting that ADHD is more common in the US (Biederman and Faraone, 2005).

Traditional ADHD treatments include prescribed medication and cognitive behavioral interventions. The National Institute of Health and Care Excellence (“Attention deficit hyperactivity disorder | introduction | Guidance and guidelines | NICE,” 2015) suggest that parent-training and education should be used as the first options in treatment, and prescribed medication as a second option. Though medication is shown to significantly improve ADHD symptoms for some, there are potential downsides, including: 1) Side effects of medication like sleep problems (Storebø et al., 2015), stomach pains, dysphoria and growth delays (Faraone et al., 2015); 2) Treatment of symptoms rather
than the underlying condition, such that when medication stops ADHD symptoms reappear; and 3) No significant improvement in academic achievement (Chacko et al., 2014). A 2015 meta review analyzing the effect of the most common drug (methylphenidate) in the treatment of ADHD found that it “may improve teacher-reported ADHD symptoms, teacher-reported general behavior, and parent-reported quality of life among children and adolescents diagnosed with ADHD” (Storebø et al., 2015). However due to the low quality of the underpinning evidence, the magnitude of these effects cannot be certain (Storebø et al., 2015).

Behavioral therapy programs like the parent training program ‘The Incredible Years’ (Webster-Stratton and Jamila, 2003) have shown to reduce parent-reported ADHD symptoms. Most parent training programs include the following five core elements: 1) promoting play and a positive relationship; 2) giving praise and rewards for positive behavior; 3) providing clear rules and clear commands; 4) consistent and calm consequences for unwanted behavior; and 5) organizing the child’s day to reduce the chances of tensions (National Collaborating Centre for Mental Health (Great Britain) and NCCMH, 2013).

### 15.2.1 Common challenges for people with ADHD

In this section we document some of the challenges people with ADHD experience according to the three presentations of the ADHD diagnosis. However, it is important to remember that ADHD is a highly heterogeneous disorder and thus it manifests and affects people to varying degrees.

People with ADHD with a high degree of inattention are often described as “daydreamers”. They commonly experience challenges in paying and sustaining attention as well as shifting attention between activities (DSM-V, 2013). Consequently, they often appear not to be listening, struggle to follow through on instructions, have difficulties organizing tasks, are easily distracted, and often lose things. Furthermore, they often avoid tasks that require continued concentration and can be forgetful (DSM-V, 2013).

People with hyperactive/impulsive presentation often struggle to control their actions, which can be misunderstood as them being rude or in children willfully disobedient (DSM-V, 2013). They often experience difficulties with activities like remaining seated, waiting in line or engaging in activities quietly. Children with ADHD often blurt out answers, run or climb in inappropriate situations and places, experience extreme restlessness, talk a lot, and intrude or interrupts others (DSM-V, 2013). People within the combined presentation (inattentive and hyperactive/impulsive) experience a combination of both of the above sets of challenges.

People with ADHD often also struggle with transitions between activities and with perceiving time (Sonne and Grønbæk, 2015). Furthermore, ADHD is associated with sleep problems: a meta-analysis found that children with ADHD had significantly higher bedtime resistance, sleep onset difficulties, night awakenings, difficulties with morning awakenings and sleep disordered breathing compared to children without ADHD (Cortese et al., 2009).

As a consequence of challenges caused by their disorder, children with ADHD typically experience issues in interacting with parents and teachers (Storebø et al., 2014). ADHD is also associated with impaired academic performance (Massetti et al., 2008), emotional dysregulation (Shaw et al., 2014), and to significantly affect children’s quality of life: in one study, 70% of third graders with ADHD reported that they had no
close friends (Wehmeier et al., 2010). In addition to issues caused as a consequence of the core deficits of ADHD, further challenges may arise from comorbid disorders as more than 80% of people with ADHD have one additional psychiatric disorder, and more than 50% have two additional disorders (Wehmeier et al., 2010).

Faraone et al. (Faraone et al., 2015) presented five general quality of life impairments associated with ADHD: 1) ‘Social disability’ relates to poor social skills, poor peer/family relationship, and parenting problems; 2) ‘Academic and occupational failure’ relates to e.g., underachievement, special education needs, and grade repetition in childhood and adolescence; and e.g., unemployment and lower socioeconomic status in adulthood; 3) ‘Health problems and psychiatric co-morbidities’ category relates to e.g., disruptive behavior, specific learning disabilities, executive dysfunction, and speech and language disorders; 4) ‘Psychological dysfunction’ relates to e.g., emotional dysregulation, lack of motivation, low self-esteem; and from adulthood suicidal ideation, suicide attempts, and suicide; and 5) ‘Risky behaviors’ relates to e.g., accidents, injuries, and unplanned pregnancies.

15.3 Related Work on Assistive Technologies

We now present related work on assistive technology for the ADHD domain grouped according the three technology approaches in our design framework (see Table 15-1).

<table>
<thead>
<tr>
<th>System</th>
<th>Type of System</th>
<th>Context</th>
<th>Target User Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOBERO</td>
<td>Manually interacting with information and services (MIIS)</td>
<td>Home</td>
<td>Children + Parents</td>
</tr>
<tr>
<td>TangiPlan</td>
<td>MIIS</td>
<td>Home</td>
<td>Children</td>
</tr>
<tr>
<td>ChillFish</td>
<td>MIIS</td>
<td>Home/School</td>
<td>Children</td>
</tr>
<tr>
<td>TimeTimer</td>
<td>MIIS</td>
<td>Home/School</td>
<td>Children + adults</td>
</tr>
<tr>
<td>CogoLand</td>
<td>MIIS</td>
<td>Home</td>
<td>Children</td>
</tr>
<tr>
<td>CogMed</td>
<td>MIIS</td>
<td>Home</td>
<td>Children</td>
</tr>
<tr>
<td>ParentGuardian</td>
<td>Automatically executed services based on in-situ analysis of context information (AES)</td>
<td>Home</td>
<td>Parents of children with ADHD</td>
</tr>
<tr>
<td>Smart wristwatch</td>
<td>AES</td>
<td>School</td>
<td>Children</td>
</tr>
<tr>
<td>SmartPen</td>
<td>AES</td>
<td>School</td>
<td>Children</td>
</tr>
</tbody>
</table>

Table 15-1: Overview of the limited related work on assistive technologies for the domain of ADHD.

15.3.1 Existing MIIS technologies

MOBERO (Sonne et al., 2016c, 2016a), TangiPlan (Weisberg et al., 2014), ChillFish (Sonne and Jensen, 2016a), and TimeTimer (“Time Timer,” 2016) are all examples of manually interacted with information and service (MIIS) systems that provide assistance in specific contexts. MOBERO is a smartphone system that assists children with ADHD
and their families in establishing healthy morning and bedtime routines, by providing structure and rewards (Sonne et al., 2016c). Through a two-week baseline period followed by a two-week intervention period, Sonne et al. found that use of MOBERO was associated with lower parental frustration levels during morning and bedtime routines and increased parent-rated child independence, based on daily assessments from parents during both baseline and intervention periods (Sonne et al., 2016c). Furthermore, through validated clinical questionnaires a 16.5% reduction in parent-rated ADHD core symptoms like an improvement in sleep quality was identified (Sonne et al., 2016c). Similar to MOBERO, TangiPlan is designed to assist children with ADHD to complete their morning routines (Weisberg et al., 2014). TangiPlan is only used by the child, and uses tangible connected objects to represent the morning activities the child has to complete. ChillFish (Sonne and Jensen, 2016a, 2016b) is different to MOBERO and TangiPlan as it does not provide assistance for a specific routine. Instead, it is a calming biofeedback game, where by breathing through a tangible LEGO fish the child controls a virtual puffer fish in a virtual underwater world (Sonne and Jensen, 2016a). The goal of ChillFish is to collect as many starfish as possible, which is achieved by performing a calming breathing exercise (Sonne and Jensen, 2016a). TimeTimer is a commercial product that is available in wristband, mobile phone app and physical device versions, which all assist the person in staying focused by visualizing the time remaining on a task. In addition to people with ADHD it is also claimed to be beneficial for others such as those with ASD.

CogoLand and CogMed are two other examples of MIIS systems, which in contrast to MOBERO, TangiPlan, ChillFish, and TimeTimer focus on training core ADHD deficits. Lim et al. (Lim et al., 2012) investigated the effect of the neurofeedback game CogoLand on children’s ADHD symptoms. The gameplay is based on an avatar in a 3D world, which has to complete a race as fast as possible. The speed of the avatar is controlled by the child’s level of concentration, which is measured using an electroencephalography (EEG) headband (Lim et al., 2012). 20 children with ADHD participated in an experiment that ran for 24 weeks, and eight weeks into the experiment the results showed a drop in ADHD symptoms (Lim et al., 2012). Similarly, Cogmed is a research based PC application that trains the child’s working memory (“Cogmed Working Memory Training,” 2015). Though working memory and neurofeedback interventions have shown promising results, the effect of these studies are inconsistent and often based on small populations making definitive conclusions hard to draw (Chacko et al., 2014).

15.3.2 Existing AES technologies

When looking at related work within the AES category ParentGuardian (Pina et al., 2014) is maybe the best known example. ParentGuardian provides situ parental behavioral therapy (PBT) cues for parents of children with ADHD, in order to support parents to better manage stressful situations. The ParentGuardian system uses changes in skin conductance, measured by an electro dermal activity wristband, to estimate the stress level of the parent. When a high level of stress is detected, the parent is prompted with a combined textual and visual reflective strategy on their smartphone and on a peripheral display to remind them to use PBT strategies (Pina et al., 2014). Pina et al. found that in situ cues could assist parents to remember to use the PBT strategies during moments high stress (Pina et al., 2014).
An example of an AES system for the school context can be found in the smart wristband prototype by McHugh et al. (McHugh et al., 2010) who investigated if a watch connected to a heart rate belt could assist children to avoid emotional outbursts in school. By analyzing sensor data from the heart rate belt, the system detects an approaching emotional outburst, and alerts the child to use self-calming techniques to prevent it. McHugh et al. found their system to be useful in assisting children to calm down without the need of help from parents or teachers (McHugh et al., 2010). Similarly, the Smart Pen prototype by DePrenger et al. (DePrenger et al., 2010) is designed to detect concentration lapses during reading in school and redirect the child’s attention back to the reading task. Via an embedded 3-axis accelerometer and a machine-learning algorithm, the Smart Pen is able to recognize reading patterns. The Smart Pen discretely reminds children to resume reading by either lighting a small LED or vibrating.

More recently we have seen both CASTT (Sonne et al., 2015b) and BlurtLine (Smit and Bakker, 2015) as examples of wearable AES systems. CASTT collects movement and physiological data and uses it to assist children with ADHD to regain attention in critical school situations. Development on CASTT is ongoing (Sonne et al., 2015b), however preliminary evaluations in four different schools have been conducted with positive outcomes (Sonne et al., 2015b). BlurtLine (Smit and Bakker, 2015) is also a wearable prototype system designed for children with ADHD to be used in school contexts. It relies on an interactive chest strap that monitors the wearer’s breathing pattern to predict and prevent a child with ADHD from blurt (impulsive speaking behavior). When a forthcoming blurt is detected, BlurtLine alerts the child though tactile feedback. The ability to detect potential blurs was evaluated with adults in a controlled setting with positive results (Smit and Bakker, 2015). However, to date BlurtLine has only been evaluated with one child with ADHD in a school context.

Even though limited, the prior work show great promise for assistive technologies within the ADHD domain. However, existing research has focused on isolated systems, and does not provide directions for further research on how to design technology for the ADHD domain. In this paper, we present a design framework for ADHD assistive technologies that aims to give researchers grounding in the condition, to provide a lingua franca, and to highlight unexplored research directions. In addition, we also present practical design strategies for developing successful assistive technologies for people with ADHD.

15.4 Exploring the ADHD Domain Through Designing and Evaluating Prototypes

Though four design projects we have conducted several empirical studies including: 1. More than 50 hours (2.5~3.0 hours each week for 20 weeks) of experience working with and taking care of children with ADHD, while their parents received parent training at the Center for ADHD in Aarhus, Denmark; 2. Weekly one-hour training and discussion sessions with two psychologists working at the Center for ADHD for 25 weeks; 3. 11 hours of observations in clinics with follow up interviews with child psychiatrists and psychologists; 4. Shadowing two psychologists during their observations of children being investigated for ADHD in school contexts for two full days; 5. Extensive classroom observations of children with ADHD (2nd ~ 5th grade) in addition to interviews with seven teachers from four different elementary schools and
two pedagogues, who all had extensive experience working with children with ADHD; 6. Several ideation workshops with teachers, pedagogues and ADHD domain professionals; 7. Five hours of in the wild studies with 11 children with ADHD in 4th – 5th grade in three schools in order to evaluate a wearable system; 8. A four-week study with 13 children with ADHD and their families evaluating the effect of a mobile assistive technology to assist the families in establishing healthy morning and bedtime routines; and 9. An evaluation of a biofeedback game for children with ADHD at a summer camp. Therefore we have extensive experience in working with people who have ADHD and ADHD domain professionals in design assistive technologies.

15.5 Design Framework: Technology and ADHD Challenges Dimensions

We now present our design framework for assistive technologies for the ADHD domain. The design framework consists of two dimensions as seen in Figure 15.1. The technological dimension (the y-axis) relates to the question of how an assistive technology provides assistance. The ADHD dimension (the x-axis) relates to the challenges and quality of life impairments associated with ADHD.

![Figure 15.1: The design framework for assistive technologies for the ADHD domain. The ADHD challenge dimension relates to the quality of life impairments associated with ADHD. Existing assistive technologies are plotted in the design framework according to their categories.](image)
15.5.1 The technological dimension

The first approach in the technological dimension is manually interacted with information and services (MIIS), which covers technologies that are manually triggered or interacted with. The two MIIS subcategories further divide into technologies for assistance in context and technologies for training. The first subcategory covers systems that provide real time assistance in specific situations like TangiPlan (Weisberg et al., 2014), whereas the second subcategory relates to systems that aim to support a long term improvement in ADHD symptoms like CogoLand (Lim et al., 2012).

The second category automatically executing services based on in-situ analysis of context information (AES) comprises context aware technologies (cf. (Dey et al., 2001)) that analyze captured data and use this to provide in-situ assistance to the user. Examples in the ADHD domain include ParentGuardian (Pina et al., 2014), CASTT (Sonne et al., 2015b), and BlurtLine (Smit and Bakker, 2015).

The third category covers context aware technologies that capture contextual data for later retrieval (CCD), but that do not automatically act on the users’ behalf. We have divided this category into two subcategories based on whom the data is captured for: services for research and services for personal reflection. Later in the paper, we present CCD technologies from related domains.

15.5.2 The ADHD challenge dimension

In order to situate our design framework in the ADHD domain the ADHD dimension contains five general categories of challenges and impairments associated with ADHD taken from the Nature paper by (Farão et al., 2015): ‘Social disability’, ‘academic and occupational failure’, ‘health problems and psychiatric co-morbidities’, ‘psychological dysfunction’, ‘risky behaviors’. We introduced these categories in the ‘Common challenges for people with ADHD’ section above.

15.6 Investigating the Unexplored Space in the Design Framework

Looking at the design framework in Figure 15-1, we see that the CCD category is the only category in the technological dimension that contains unexplored spaces, indicating a gap in the existing research on assistive technologies for the ADHD domain. However, assistive technologies for other patient groups suggest that CCD technologies do hold potential for assisting patients as illustrated below.

15.6.1 Examples of CCD technologies from related domains

MONARCA (Bardram et al., 2013) is an assistive technology designed for people with bipolar disorder and can be categorized as a CCD system. MONARCA collects, analyzes, and presents subjective and objective data in order to provide bipolar patients and clinicians with insights into the parameters influencing the nature of the patient’s disorder (Bardram et al., 2013). Thus, MONARCA would be placed in both of the CCD sub-categories: services for research and services for personal reflection on the technological dimension in our design framework. In addition, many technologies within the domain of personal informatics can also be categorized within the CCD category. For example, Lullaby (Kay et al., 2012) is a capture and access system that assists users in improving their sleep environment and includes a range of sensors including light, audio, motion, and temperature (Kay et al., 2012). Data from these sensors are visualized on a tablet, and support the user to learn about optimal conditions for their sleep. Furthermore, Lullaby provides users with the functionality to explore their recorded sleep and environmental data together with video recordings for further
reflection about their sleep behaviors (Kay et al., 2012). Thus, Lullaby can also be categorized as a CCD system (in the services for personal reflections sub-category) in our technology dimension.

Although we found no current CCD technologies for the ADHD domain, we believe that this type of system holds significant potential. Capturing objective data from people with ADHD related to e.g., sleep, stress and mental wellbeing, could provide new insights into how these are related. This would allow scientists to develop new insights about ADHD based on detailed studies of large populations (similar to the StudentLife study (Wang et al., 2014), which analyzed how various contextual factors predicted GPA in a population of college students), and supporting individuals with ADHD in reflecting on and gaining insight into their own conditions – an approach that has been popularized in HCI as personal informatics (Li et al., 2010).

Based on the above investigation of the unexplored spaces within our design framework and the successful examples of CCD systems in related domains, we encourage researchers to explore, design, and develop ADHD assistive technologies with CCD functionality. Furthermore, looking at the unexplored spaces in the ADHD dimension, we see that no existing technologies are currently categorized within the ‘risky behaviors’ category. We are not aware of existing technologies from other domains targeting risky behaviors, making such technologies truly unexplored. In the next section we describe how the design framework can be used to identify opportunities for future research within both explored and unexplored spaces.

15.7 Using the Design Framework Dimensions to Identify Opportunities for Future Research

Below we will show how our design framework can be used to identify new opportunities for novel research on technologies for the ADHD domain by both advancing existing excellent research as well as establishing completely new technologies.

15.7.1 Expanding existing research

As the first example of how our design framework can be used to generate new research, we will look at BlurtLine (Smit and Bakker, 2015), which is categorized within the intersection of the AES and Health problems and psychiatric co-morbidities categories. The proposed design framework provides a visual overview of the opportunities for identifying new research directions for BlurtLine. For example, BlurtLine could be extended with the ability to capture data (e.g., time, date, school subject, location, current teacher, minutes into class etc.), analyze, and present these blurt data to teachers and/or researchers, which would then categorize BlurtLine as a CCD system. This functionality could allow the child, parents and teachers to investigate if certain conditions trigger the impulsive speaking behavior, which could then be mitigating by the teacher. Thereafter, the effect of this change of actions could be evaluated by analyzing the captured sensor data providing an objective measure of the effect of the intervention.

CASTT is another example where the design framework could be used to identify future research directions. If CASTT was expanded with logging functionality to capture physical activity data from the individual, it could provide this data as a service
for research, which could then be used by e.g., a child psychiatrist in the diagnostic process as a way to objectively quantify the hyperactivity in people with ADHD. Another opportunity for expanding the functionality of CASTT could be to look for patterns in how and when the child loses his concentration, and visualize these data for teachers, as a way for them to get feedback and reflect upon how e.g., different teaching techniques or methods affect the child with ADHD. In this way, CASTT would be categorized within the services for personal reflection subcategory of the CCD category.

Having highlighted how our design framework could be used to provide new directions for two existing research technologies, we now illustrate how it can also be used to generate ideas for new research projects, by using an example of our own ongoing research on assistive technologies for the ADHD domain.

15.7.2 Creating new research approaches

As presented, children with ADHD have significantly higher bedtime resistance, sleep onset difficulties, and sleep disordered breathing compared to children without ADHD (Cortese et al., 2009). These challenges are related to the Health problems and psychiatric co-morbidities category in the design framework. From the existing technologies plotted in the design framework we see that there is an unexplored space for CCD technologies in the Health problems and psychiatric co-morbidities category. Having decided on the domain and type of technology, a design process with health professionals and users was initiated. Based on our interdisciplinary design process and inspired by existing work within the ADHD domain (Sonne et al., 2016c), related work on sleep technologies (Choe et al., 2011; Kay et al., 2012), and research on sleep (Cortese et al., 2009), we created a vision for a future research project called SleepAssist to extend the MOBERO project. SleepAssist can be categorized as a technology that provides services for personal reflection within the CCD category. SleepAssist should utilize a sleep sensor placed under the child’s mattress to capture information about the child’s sleep habits. If SleepAssist detects that the child’s bedtime varies too much throughout a week, the parents would be notified about this unhealthy habit together with information about the potential implications of this behavior i.e., increased inattention, disruptive behavior, and decreased executive functioning (Cortese et al., 2009). Moreover, SleepAssist suggests to parents how to improve their child’s sleep habits. In addition to provide services for personal reflection, SleepAssist could also provide services for research: the sleep data could be shared with e.g., a child psychiatrist. In Denmark and many other countries, a child psychiatrist has to investigate if poor sleep habits could be the root cause of a child’s behavior, as part of the ADHD investigation. This process involves asking parents to complete a sleep diary. However, as we have previously reported, the accuracy of such sleep diaries can be doubted (Sonne et al., 2016c). Thus, a technology that captures objective sleep data could hold the potential to be a supplement to the existing diagnostic process. Similarly, using a sleep monitoring system prior to and after medication might also provide medical researchers with new insights into the effects of ADHD medication on sleep.

Furthermore, from the framework we see that no technologies exist within the assistive technology literature that specifically target “risky behaviors” for people with ADHD. There is therefore an opportunity for researchers to target these behaviors: for example, a CCD system for personal reflection might help someone with ADHD to identify
behavior patterns that lead to injuries and to take steps to mitigate them, or an AES system might analyze contextual factors to give someone with ADHD a warning.

In this section, we have shown how the design framework can be used to expand the functionality of existing assistive technologies for the ADHD domain, and we have also provided an example from our own ongoing research on how the design framework can be used early in a design process to guide the development of novel research on assistive technologies for the ADHD domain.

15.7.3 Limitations of the Design Framework

Having filled the design framework in Figure 15-1 with examples of existing work may give a misleading impression of no need for novelty in designing assistive technologies for areas of the design framework where research already exists. However, the examples CASTT (Sonne et al., 2015b) and SmartPen (DePrenger et al., 2010) are only example of AES technologies within the academic and occupational failure category. Thus there is still an open design space for further research on assistive technologies in this area. The five categories in the ADHD dimension are broad, and as more assistive technologies for the ADHD domain are being developed, it might make sense to create separate sub-categories for the categories in the ADHD dimension related to the specific challenges and impairments people with ADHD experience. Nevertheless, we think that the current “level of detail” in the design framework can provide HCI researchers with a starting point for designing assistive technologies and it also enables a way to discuss and categorize assistive technologies for the ADHD domain.

15.8 Design Framework: Strategies for HCI Research within the ADHD Domain

We have presented our design framework and shown how it can be used to identify new research directions for assistive technologies for the ADHD domain. The HCI field lacks design strategies that support researchers in transitioning from the theory/idea phase to successfully develop and deploy assistive technologies for the ADHD domain. In this section we present practical design strategies for developing assistive technologies for the ADHD domain that are inspired by research on ADHD, our own empirical studies, and existing practices that people with ADHD, ADHD professionals, and teachers use to limit and cope with some of the common challenges that people with ADHD experience. Finally, we discuss strategies for maximizing the impact of research on ADHD assistive technologies.

15.8.1 Provide structure to facilitate activities

Structure is beneficial for people with ADHD, as they are more likely to succeed in completing tasks if they occur in a predictable pattern. Empirical studies of families with children with ADHD found routines and structure to be the most important factor in supporting daily family life (Firmin and Phillips, 2009). Furthermore, a core element in parent training is to organize and structure the child’s day as this reduces the chances of tensions. One of the most common existing practices to assist in establishing healthy routines is to use printed charts or checklists, which the person with ADHD can rely on to complete specific routines. However, parents of children with ADHD can experience two key challenges that make it hard for them to provide the needed structure. First, due to the high heritability of ADHD, the parents might themselves experience challenges in creating and providing the needed structure (Firmin and Phillips, 2009). Second, paper-
based chart often do not motivate the child and are easily mislaid, damaged and forgotten, resulting in an abandoning of the chart-based system (Sonne et al., 2016c).

15.8.2 Minimize distractions
Attention deficit is one of the core characteristics of ADHD. Thus, it is beneficial to limit external distractions in order to prevent people with ADHD from losing attention. In school, extra work is done to limit distractions in order to assist the child in staying focused on school tasks, such as seating the child in the front of the class or providing head to reduce distracting sounds in appropriate situations. This poses a challenge for researchers, as technology itself can be seen as a distraction for the child. Care should therefore be taken in any technological intervention to avoid unnecessary distractions. For instance, when sleep assistance such as MOBERO (Sonne et al., 2016c) introduces technology just before bedtime, it needs to be carefully investigated for potential distraction effects.

15.8.3 Encourage praise and rewards
Praising and rewarding a child or a teenager with ADHD is a core element in parent training as this promotes desired behaviors (National Collaborating Centre for Mental Health (Great Britain) and NCCMH, 2013). Often parents and teachers use a chart based system where the child collects stars or stickers for performing certain activities (e.g. brushing teeth) or behaving in a certain way that the parents or teachers want to encourage (e.g. do not yell at the teacher or other pupils during class) (Sonne and Grønbæk, 2015). However, as parents of children with ADHD experience increased levels of stress (Harpin, 2005), they can find it challenging to remember to praise and reward their child (Pina et al., 2014). Furthermore, as children with ADHD are often very reward driven (Sonne and Grønbæk, 2015), researchers can use and explore opportunities for using rewards in assistive technologies as a way to encourage children to perform certain activities or behavior, e.g., Sonne et al. reported that rewards were an important and deliberate part of their design (Sonne et al., 2016c).

15.8.4 Integrate and report standardized ADHD measures
An important factor to maximize the impact of research on ADHD assistive technologies is to include relevant measures in the study design and report these in an appropriate way. A similar discussion has recently been started within the ASD assistive technology community (Carter and Hyde, 2015), and here we briefly discuss key factors that are relevant to integrate and report in studies with people with ADHD in order to maximize the impact of the conducted research.

First, we propose that researchers should assess and report standardized scores of the severity of ADHD symptoms. This is critical as: 1) it ensures that the patients in the study are representative of the general population of patients with ADHD; 2) it provides transparency; 3) such standardized measures are already used within the existing medical and physiological domains (both as inclusion criteria and efficacy of treatment); and 4) it allows researchers to evaluate the size of the effect associated with using their technology, based on a standardized scale. This also provides opportunities for comparison to traditional treatments and (future) technology based interventions.

Within HCI research, only Pina et al. report that they used a standardized rating scale (though only used as an inclusion criterion) (Pina et al., 2014). Pina et al. report that they lowered the cut-off values “for the sake of the exploratory study” (Pina et al., 2014).
2014), however critically failed to report how many of their participants actually had an ADHD score within the normal ADHD range. This missing information makes it impossible for the reader to judge if the ParentGuardian system was evaluated with children with ADHD, or children with mild ADHD-like symptoms.

Second, we argue that it is important to report whether the participants receive any medical treatment during the evaluation due to the natural effects of these treatments (e.g. lowering ADHD symptoms), which could confound any effects attributable to the intervention. To date only the work on TangiPlan has mentioned this issue (Weisberg et al., 2014). In particular, children who receive changes to their dose of medication shortly before or during an evaluation period, should be excluded from the study, as adjusting the dose can have several side effects that might affect the evaluation of an assistive technology.

Finally, we agree with Klasnja et al.’s argument that evaluations of novel technologies which focus mostly on qualitative findings are fundamental (Klasnja et al., 2011), especially as this field of assistive technologies for the ADHD domain is still in its infancy. Gaining insights into setting up studies, unexpected outcomes, unique challenges etc. are critical for informing credible research. The HCI community is a natural context for interdisciplinary research teams to explore and report promising technologies for the ADHD domain that can later be followed up with randomized controlled trials. Thus, it is both important to focus on qualitative findings that can bring the field forwards, but also to include quantitative (standardized) measures so that these novel technologies can be taken to the next stage in the medical evaluation.

15.9 Conclusion

We have presented a design framework for ADHD assistive technology that is solidly grounded in empirical studies, ADHD research, and related work on assistive technologies. The framework consists of: 1) conceptual dimensions to couple technologies to ADHD challenges, and 2) a set of practical design strategies for developing successful assistive technologies for people with ADHD. The design framework gives researchers grounding in the condition, provides a lingua franca, and highlights unexplored research directions within assistive technologies for the ADHD domain. By mapping existing and potential new research to the design framework, we have demonstrated how it can be used to support and advance the research and development of novel assistive technologies for the ADHD domain.
16 Paper C - Changing Family Practices with Assistive Technology: MOBERO Improves Morning and Bedtime Routines for Children with ADHD

In this chapter, the paper ‘Changing Family Practices with Assistive Technology: MOBERO Improves Morning and Bedtime Routines for Children with ADHD’ is presented. The paper is published in Proceedings of the 34th Annual ACM Conference on Human Factors in Computing Systems, CHI ’16.

Changing Family Practices with Assistive Technology: MOBERO Improves Morning and Bedtime Routines for Children with ADHD

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Abstract
Families of children with Attention Deficit Hyperactivity Disorder (ADHD) often report morning and bedtime routines to be stressful and frustrating. Through a design process involving domain professionals and families we designed MOBERO, a smartphone-based system that assists families in establishing healthy morning and bedtime routines with the aim to assist the child in becoming independent and lowering the parents’ frustration levels. In a two-week intervention with 13 children with ADHD and their families, MOBERO significantly improved children’s independence and reduced parents’ frustration levels. Additionally, use of MOBERO was associated with a 16.5% reduction in core ADHD symptoms and an 8.3% improvement in the child’s sleep habits, both measured by standardized questionnaires. Our study highlights the potential of assistive technologies to change the everyday practices of families of children with ADHD.

Author Keywords
Children; attention deficit hyperactivity disorder; ADHD; sleep; mobile; assistive technology; mental health; routines; behavior change.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

16.1 Introduction
In recent years, HCI researchers have demonstrated the potentials of using interactive technologies to assist people with various deficits and disorders (Bardram et al., 2013; Kientz et al., 2013; Tanuwidjaja et al., 2014). However, only few examples of research within the HCI community have been reported on assistive technologies for the Attention Deficit Hyperactivity Disorder (ADHD) domain (although see (Pina et al., 2014; Sonne et al., 2015b; Zuckerman et al., 2015)). ADHD is the most prevalent mental health diagnosis among children aged 3–17 (Perou et al., 2013) with a worldwide prevalence of approximately 5% among children and adolescents (Polanczyk et al., 2007). As a consequence of the difficulties caused by the ADHD disorder, such as inattention, hyperactivity, impulsivity and behavior problems, there is a significant burden on those affected, their families and society (Harpin, 2005). Traditional ADHD treatments include prescribed medication (Hechtman and Greenfield, 2003), cognitive training (Klingberg et al., 2005) and parent training (Anastopoulos et al., 1991).
In this paper, we present a supplementary technology-based approach to support families of children with ADHD. Our aim is to assist the family in establishing effective morning and bedtime routines, as these situations can be particularly stressful and frustrating for parents of children with ADHD (Cortese et al., 2009; Firmin and Phillips, 2009; Segal, 1998; Weisberg et al., 2014). Furthermore, an effective bedtime routine is important, as sleep deprivation affects the child’s executive functions and manifests in more hyperactivity and inattention, poorer concentration, disruptive behaviors and poor school performance (Cortese et al., 2009; Dewald et al., 2010). Through a design process involving parents of children with ADHD and ADHD domain professionals consisting of two child psychiatrists, three psychologists, and three medical researchers we developed a Morning and Bedtime Routines smartphone system (MOBERO – see Figure 16-1) in order to investigate our hypotheses that mobile technologies can lower the parents’ frustration level during their child’s: 1. morning; and 2. bedtime routines; assist the child to become more independent during 3. morning and 4. bedtime routines; and 5. improve the child’s sleep habits. We report on a four-week study of MOBERO with 13 children with ADHD and their families. Quantitative results showed that MOBERO was associated with a significant increase in the parents’ rating of their child’s independence level, a decrease in parental frustration during the child’s morning and bedtime routines and more consistency in the times the child went to bed. In addition, we discovered a significant improvement in both parent-rated ADHD symptoms and the child’s sleep habits. Qualitative data from interviews with the families support our quantitative findings, and further provide insights into their use and experience of MOBERO, including some unexpected negative effects related to rewards and tailoring.

Figure 16-1: Top: MOBERO. Bottom: A child explaining and showing his rewards collected from using MOBERO in a two-week study (Permission to use photo granted by parents).
16.2 Background and Related Work

To understand the ADHD domain, we provide a background to the ADHD diagnosis, the challenges families with ADHD experience and the effects of unhealthy sleep habits. We then position our work within related work on assistive technologies to support habits and routines.

16.2.1 Attention Deficit Hyperactivity Disorder (ADHD)

ADHD is childhood-onset neurodevelopmental disorder with a worldwide prevalence of approximately 5% among children and adolescents (Polanczyk et al., 2007). In addition to the behavioral challenges mentioned above, ADHD is associated with impaired academic performance (Goldman LS et al., 1998; Massetti et al., 2008), difficulties in interacting with parents and teachers (Storebø et al., 2014), increased risk of criminal convictions in adulthood (Dalsgaard et al., 2013; Mannuzza et al., 2008) as well as increased mortality (Barbaresi et al., 2013). Furthermore, it has been shown to significantly affect children’s quality of life (Wehmeier et al., 2010): for example in one study 70% of third graders with ADHD reported that they have no close friends (Wehmeier et al., 2010).

ADHD is a controversial diagnosis, although most researchers argue that it is valid (Biederman and Faraone, 2005). Rather than taking a side in this debate, we designed MOBERO to provide support for specific challenges associated with the disorder.

16.2.2 Routines and Frustrations in Families with ADHD

Studies have found that parents of children with ADHD find morning and bedtime routines especially challenging and stressful (Firmin and Phillips, 2009; Segal, 1998). This is also supported by additional studies, showing that children with ADHD exhibit more bedtime resistance than those without (see (Cortese et al., 2009) for a review). Furthermore, studies of parental coping strategies have found that techniques such as structure, routines and rewards are effective in assisting the child during morning routines (Firmin and Phillips, 2009). Many of the challenges these families experience are compounded by ADHD, as some of the effects of the disorder include challenges in/with: handling transitions between activities; low self esteem; perceiving time; remembering a sequence of instructions; sustained attention; disruptive behavior; and lack of motivation (Harpin, 2005). In addition, ADHD is often seen to co-exist with other disorders (e.g. conduct disorder), which can cause additional deficits and challenges.

16.2.3 The Importance of Adequate Sleep for Children

Adequate sleep is especially important for the developing child (Dewald et al., 2010), as insufficient sleep and poor sleep quality negatively impact school performance (Dewald et al., 2010). Sleep is central in ADHD, as the disorder is often linked to abnormal sleep. Children with ADHD may have difficulties in getting to bed and falling asleep and may have irregular sleep patterns. These challenges tend to worsen problems with hyperactivity, inattention, difficulty in concentrating, disruptive behaviors, and poor school performance (Cortese et al., 2009). Consistent bedtimes have shown to improve sleep (Cassels, 2013); however as children with ADHD exhibit bedtime resistance, set bedtimes can be difficult to implement.
16.2.4 Technologies that Support Habits and Routines

A number of HCI researchers have explored opportunities to use technology to support healthy sleep routines (see (Choe et al., 2011) for an overview). An example is ‘Lullaby’, which tracks sleep and environmental parameters like temperature and noise level, supporting adult users in creating optimal sleep conditions (Kay et al., 2012). Another example is ‘ShutEye’, which attracts attention to activities (e.g. drinking coffee) that might improve or worsen sleep via an ambient representation on the user’s mobile phone (Bauer et al., 2012). The most recent example is ‘SleepTight’ (Choe et al., 2015), a mobile-phone based system that investigates how to lower the burden of manually tracking sleep, as automatic tracking of sleep reduces the user’s engagement and awareness, which are critical elements for behavior change.

In contrast to technologies to support sleep for healthy adults, there has been very limited research on assistive technologies for the ADHD domain. ‘ParentGuardian’ is a system that delivers in situ parental behavioral therapy cues to parents of children with ADHD in situations of stress (Pina et al., 2014). High stress levels are detected through a wrist worn device, triggering reminders on mobile phones and a glanceable display of coping strategies. Another example of a system that provides real-time feedback is ‘CASTT’ (Sonne et al., 2015b), which is designed to support children with ADHD in sustaining attention in the classroom. The system most related to our research is ‘TangiPlan’, a tangible interface designed to improve executive functioning for children with ADHD during their morning routines (Weisberg et al., 2014; Zuckerman et al., 2015). TangiPlan consists of multiple tangible objects each representing a task (e.g. get dressed) and through an array of LED lights, the child is informed about the remaining time to complete the task. A paper prototype of TangiPlan was evaluated with three users (Weisberg et al., 2014) and later a 3D printed model was evaluated with two users (Zuckerman et al., 2015) with positive feedback. However, TangiPlan, CASTT and ParentGuardian are all designed for the individual and not the family. Slovák et al. (Slovák et al., 2015) highlight the importance of including parents when designing technologies to support social and emotional skills training for children. An example from outside the ADHD domain that does involve parents in supporting the child is TalkBetter, which provide in situ cues to the parents of children with language delay (Hwang et al., 2014). TalkBetter consists of two mobile phones, one for the child and one for the parents, and based on analysis of the conversation, it triggers auditory feedback to the parents like “Please talk more slowly” and “Please do not interrupt your child” (Hwang et al., 2014).

Several technologies that try to establish or change behavior have been studied like Fish’n’Steps (Lin et al., 2006) and UbiFit Garden (Consolvo et al., 2008a, 2008b), which both encourage people to be more active. Even though most behavior change applications are designed for adults, some have been designed specifically for children (Arteaga et al., 2010; Kim et al., 2011). However, Stawarz et al. criticize many existing behavior change applications (both commercial and within HCI research) for not being theoretically grounded in habit formation theory (Stawarz et al., 2015), limiting their ability to support long term change.

We introduce a novel approach as the first to focus on bedtime routines for children with ADHD by building upon existing research on adult sleep technologies, and focus on how technologies might improve the sleep of children. Furthermore, we contribute to the very limited work on assistive technologies for ADHD by designing for the family...
instead of only the individual. Finally, we expand existing work on behavior change technologies by developing to support the whole family in order to support the child in changing their daily practices.

16.3 Designing with Parents and Professionals

In this section we present our design process and describe how ADHD professionals and families influenced the design of the MOBERO system and the user study. Our design process included two pilot studies with two families with children with ADHD and ADHD professionals (three psychologists, two child psychiatrists and three medical doctors and researchers from the ADHD domain). The two families were recruited through the Center for ADHD, Aarhus, Denmark, which offers parent-training programs for parents of children with ADHD. The initial concept and prototype of MOBERO were established through meetings and workshops with the ADHD professionals and was designed to be playful, lightweight and to provide structure for families of children with ADHD in providing support for bedtime routines only. The first family evaluated the prototype for four weeks and then the second family used it for three weeks. The parents were encouraged to contact us during the evaluation if they had suggestions for improvement or general feedback. After each pilot study, we conducted a one-hour semi structured interview with the family addressing their experiences with MOBERO. The feedback from the first family was incorporated into the version of MOBERO tested with the second family, and in collaboration with the ADHD professionals we agreed on changes that ended up constituting MOBERO. Below, we highlight findings from our design process that changed our initial concept and prototype.

16.3.1 Designing for the Family instead of the Individual

Our initial goal was to improve the sleep quality for children with ADHD through the use of technology, as poor sleep negatively affects the child (Cortese et al., 2009; Dewald et al., 2010). However, in contrast to existing technologies focusing on changing sleep habits for adults (e.g. (Bauer et al., 2012; Choe et al., 2015; Kay et al., 2012)), we learned from the ADHD professionals that we should not design for the individual child because of the importance of family dynamics in establishing routines. However, as ADHD is highly heritable (Biederman and Faraone, 2005; Wehmeier et al., 2010), the parents might themselves have challenges in providing the structure needed to create a consistent bedtime routine. Therefore, we ended up designing MOBERO for the whole family by including routines for both parents and children.

16.3.2 Identifying the need for Additional Support Modules

One week into the first pilot study the family contacted us and asked if we could extend MOBERO to include morning routines too, as they also had challenges getting their child ready for school in the morning. As frustrating mornings both affect children and parents, we decided to expand the functionality of MOBERO by integrating a morning module into the system. Furthermore, we had planned to use a paper based sleep diary (which child psychiatrists normally ask parents to complete as part of the ADHD investigation) to evaluate MOBERO’s impact on the child’s sleep quality. However, the pilot studies taught us that the families often forget to complete the sleep diary (cf. (Choe et al., 2015)). To encourage engagement in the evaluation, we developed the Daily Assessment Application (DAA) as a digital version of the sleep diary with a built in notification system that would remind the parent to report data daily. The DAA also
allowed us to assess the accuracy of the reported data, as we logged when the parents made entries in the app.

16.3.3 Creating Valuable Rewards

Both parents and ADHD professionals emphasized that rewards are an effective motivator for children with ADHD, a claim supported by both the HCI and ADHD literature (cf. Consolvo et al., 2008a; McInerney and Kerns, 2003). In order to explore the effects of different kinds of rewards, we incorporated two kinds into MOBERO: virtual medals for completing morning routines in predetermined durations and a physical fluorescent star for completing all bedtime routines (see Figure 16-1) that the child could place on a laminated reward sheet. The reason for choosing a physical reward was two-fold. First, as many children with ADHD often have developed low self-esteem (Harpin, 2005), one of the ADHD professionals explained that a physical acknowledgment could work as a manifestation of the child’s achievement and success, that would be visible to themselves and their family and friends. Second, the fluorescent stars were part of another reward. The placeholders for the fluorescent stars were in three groups on the A4 rewards sheet, and for each group there was a space where the child could draw the reward that this group of stars should unlock (see Figure 16-1). Originally, we intended to provide the family with small presents like e.g. LEGO Mini Figures. However, one of the ADHD professionals suggested that the reward should be used for family activities like playing a game or building LEGO together. Therefore, the families were encouraged to choose rewards that involved parent-child activities inspired by the Incredible Years parent training program (Webster-Stratton and Jamila, 2010) used at the Center for ADHD, Aarhus, Denmark. Child-directed play draws from social learning theory and provides a foundation for building positive child-adult relationships and strengthening the ties between child and parents (Webster-Stratton and Jamila, 2010).

16.4 The MOBERO System

MOBERO was installed on a LG Nexus4 Android- smartphone that was provided to the families during the study. Both MOBERO modules (morning and bedtime) were developed to assist the child in becoming more independent in daily routines and to reduce the parent frustration level. We attempted to achieve this by establishing and supporting routines for both the child and the parents.

16.4.1 MOBERO Bedtime Routines

The MOBERO bedtime module includes activities for both the child and parents to complete (see Figure 16-2)

1. 15 minutes before the set bedtime, MOBERO notifies the parents to begin their bedtime routines for the child. The auditory notification keeps ringing until the parents either snooze it or start their activities. Having pressed the start button, the parents see a short list of activities for them to complete in order to prepare for their child’s sleep, e.g. ventilate their child’s bedroom.

2. When the parents have completed their activities, a countdown view displays the remaining time until the child should initiate her bedtime routine.

3. A visual list representation with both pictograms and text provides an overview of the activities that make up the child’s bedtime routine. A dedicated view for an activity is shown when it is selected.

4. The last activity in the MOBERO bedtime module is a reward in the form of a physical luminous star, which the child can place on a laminated A4 rewards sheet.
16.4.2 MOBERO Morning Routines

The MOBERO morning module is designed to assist children with ADHD to complete their morning routines from when they wake up until they leave home for school. The module contains three general views (see Figure 16-3):

1. A visual list representation of the morning routines;
2. A view for each activity with a textual description of the routine, a pictogram representing the routine, a circular visual timer indicating the time elapsed/remaining that is connected to a representation of the expected reward (numbers of medals)
3. A final view showing the total number of collected medals during the morning routines.

In both the MOBERO bedtime and morning modules the order of the routines cannot be changed by the child, thus they have to complete them in the order that is shown. However, the routines might not be identical from one day to another, as the child might have different routines on certain days (e.g. remember gym clothes every Thursday). The specific routines were chosen by the parents as they know their child’s routines the best, but most included the same “backbone” routines e.g. put socks on, get dressed, eat breakfast, brush teeth, pack backpack and put jacket, shoes, and bike helmet on.

Having presented the two MOBERO modules we now introduce our study.

16.5 The MOBERO User Study

We conducted a four-week study with 11 families and 13 children with ADHD in order to investigate our hypotheses that MOBERO could lower the parents’ frustration level during their child’s: 1. morning; and 2. bedtime routines; assist the child to become
more independent during 3. morning and 4. bedtime routines; and 5. improve the child’s sleep habits. We were also interested to see if MOBERO had an effect on the parent-reported ADHD symptoms as well as the child’s sleep habits, both evaluated though the use of standardized questionnaires. Furthermore, we wanted to investigate the qualities and challenges that families with children with ADHD experienced using MOBERO to establish healthy morning and bedtime routines. Prior to beginning the study, ethical clearance was granted by the regional ethical committee. The families did not receive any payment for participating in the study.

16.5.1 Overview of Dependent Variables

Table 16-1 provides an overview of the collected data.

<table>
<thead>
<tr>
<th>Data collection</th>
<th>Collected information</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAA</td>
<td>Child bedtime, sleep time, wake up time and parent assessment of frustration and child independence.</td>
</tr>
<tr>
<td>ADHD-RS</td>
<td>Child ADHD symptoms.</td>
</tr>
<tr>
<td>CSHQ</td>
<td>Child Sleep Habits.</td>
</tr>
<tr>
<td>Screening questionnaire</td>
<td>Parent assessment of frustration and conflicts, and insights into family routines.</td>
</tr>
</tbody>
</table>

Table 16-1: An overview of the data collected as part of our four-week MOBERO study.

16.5.2 Questionnaire Measures

The Daily Assessment Application (DAA)
The purpose of the DAA was to collect daily parent assessments. Therefore, the DAA notified the parent once a day to report: 1. the child’s wake-up time; 2. their bedtime; 3. their sleep time; the parent’s rating of the child’s independence during 4. morning- and 5. bedtime routines; and their own frustration level during the child’s 6. morning and 7. bedtime routines. Questions were all reported through a five-item Likert scale (strongly disagree - strongly agree). Furthermore, DAA included an option for parents to write comments they found relevant to report.

ADHD Rating Scale-IV (ADHD-RS)
ADHD-RS is a validated tool used in ADHD diagnosis to measure the severity of symptoms and to evaluate the treatment efficacy in children and adolescents with ADHD (Faries et al., 2001). As ADHD in Denmark is diagnosed accordingly to the International Classification of Diseases 10 (ICD-10) as a Hyperkinetic conduct disorder (World Health Organization, 1992), we use the version of the ADHD-RS modified to match the ICD-10 diagnostic criteria. Thus, the version of ADHD-RS used in our study contained a total of 26 questions, with 18 covering the core diagnostic ADHD symptoms of inattention, hyperactivity and impulsivity in addition to eight questions covering symptoms of conduct disorder, which is the most common comorbidity with ADHD. We used ADHD-RS to select families for our study and to evaluate the treatment efficacy of MOBERO on the children’s ADHD symptoms.

Children’s Sleep Habit Questionnaire (CSHQ)
The CSHQ is a validated parent reported sleep screening survey specifically designed for school-aged children (Owens et al., 2000), which consist of 35 questions conceptually grouped into eight subscales: ‘bedtime resistance’, ‘sleep onset delay’, ‘sleep duration’, ‘sleep anxiety’, ‘night wakings’, ‘parasomnias’, ‘sleep-disordered
breathing’ and ‘daytime sleepiness’. We used the CSHQ to evaluate the treatment efficacy of MOBERO on the child’s sleep habits and sleep quality, by comparing CSHQ before and after our study.

16.5.3 Participants
The participating families were recruited through the Center for ADHD (eight), through a child psychiatrist (six), and by word of mouth (two). A total of 16 families signed up for participation, but only 11 families were selected to participate based on our inclusion criteria, which were: 1. the families should reply ‘often (two to four times a week)’ to at least two statements in a screening questionnaire on how often they experienced conflicts/frustration around their child’s morning/bedtime routines; and 2. The child should be clinically diagnosed with ADHD or under investigation for ADHD and have an ADHD-RS score within the ADHD range (World Health Organization, 1992); 3. Children should not be below the age of six; and 4. Children should not have a condition other than ADHD as the primary diagnosis.

Of the 11 families included, two had two children who both met the inclusion criteria. Thus, a total of 13 children participated in the study. The 13 children (four female) were aged between six and 12 (average age = 9.3). The mean parent-rated ADHD-RS score was 39.18 (inattention and hyperactivity/impulsivity) and 11.69 (behavior). All individual ADHD-RS scores were in the range expected from gender and age stratified normative data scores for children clinically diagnosed with ADHD (Szomlaiski et al., 2009). Seven children received medication as part of their ADHD treatment; however, no changes were made to the medication dosage during the MOBERO study. Furthermore, as none of the children had recently started on medication or had made changes to their medication, the effect of medication should not impact the findings in our four-week study. On the contrary, for the children receiving medication the effect of MOBERO might be lower due to its effect on core ADHD symptoms.

16.5.4 Procedure
The user study was divided into a two-week baseline phase and a two-week intervention phase. Prior to the baseline phase, families completed the ADHD-RS and CSHQ questionnaires. All families were asked to participate for two weeks in each phase, however due to variance in scheduling visits, most families experienced the phases as longer than two-weeks.

MOBERO baseline period
On the first day of the baseline phase, we visited the families and conducted a short interview about their experiences with their child’s ADHD diagnosis. They were then introduced to the study design and the parents were instructed in the use of the DAA, and encouraged to use it every day during the baseline and intervention phases. Halfway through the baseline period, the parents were contacted by email and asked to list the specific morning and bedtime routines they would like to have in their version of the MOBERO system.

MOBERO intervention period
After the approximately two-week baseline phase, we returned to the families and introduced them to MOBERO. The families were then encouraged to incorporate MOBERO into their daily morning and bedtime routines for the remaining two weeks of the study. We furthermore informed the parents that we could update MOBERO.
over-the-air, and emphasized that they should not hesitate to contact us if they wanted to make changes to their routines.

After the intervention phase, we visited the families to conduct an approximately one-hour semi-structured interview about their experiences with MOBERO. Additionally, the parents were asked to complete the online ADHD-RS and CSHQ questionnaires.

16.5.5 Data Analysis

Parent rated frustration levels and child independence processing
As we did not assume the same number of DAA entries between families, we took the median values for each child for the parent rated frustration levels and child independence for both the baseline and intervention periods, so that all children accounted equally in each category. Measures for the baseline and intervention periods were compared with two-tailed Wilcoxon Signed Rank tests.

Parent rated bedtime and sleep time processing
From the parent reported bedtime, sleep time, and wakeup time we calculated the child’s sleep delay and the total sleep time, where sleep time refers to the time the child fell asleep and sleep delay refers to the duration between bedtime and sleep time. As we did not assume the same number of entries between families, we took the mean value for each question for each child so that all children account equally in each category. Measures for the baseline and intervention periods were compared with two-tailed paired t-tests.

Questionnaire Processing
We used a two-tailed paired t-test on the ADHD-RS scores to evaluate the treatment efficacy of MOBERO on the child’s ADHD symptoms. Similarly, a two-tailed paired t-test was used to evaluate the efficacy of MOBERO on the CSHQ.

Interview processing
The audio-recorded interviews were recorded, transcribed and analyzed in Danish and thematically analyzed (Braun and Clarke, 2006). Selected sentences were translated into English for presentation. Names were changed and personal information was removed to preserve anonymity.

16.6 Results

16.6.1 Higher Child Independence from Using MOBERO
There was a significant improvement in responses to the daily parent-reported answer to the question “[The child’s name] was independent during the morning routines?” between the baseline (Mdn = 3: neutral) and intervention (Mdn = 4: agree) phases, \( z = -2.28, p<0.05, r = 0.45 \). Similarly, the response to “[The child’s name] was independent during the bedtime routines?” improved between the baseline (Mdn = 3: neutral) and the intervention phases (Mdn = 4: agree), \( z = -2.02, p<0.05, r = 0.40 \) as seen in Figure 16-4. Our qualitative analysis supports the quantitative findings as exemplified by Simon’s mother “Before we started this, we should almost be giving him shoes on every day - ‘Who will help me?’ It has not at all been like that - he has just done it. Even putting his lunchbox in his bag he has just done it.”
16.6.2 Parents Report Lower Frustration During Their Child’s Morning and Bedtime Routines

Parents’ reported frustration level during the morning routines reduced between the baseline (Mdn = 3: Neutral) and the intervention (Mdn = 2: Disagree) phases, z = 2.76, p<.01, r = 0.54. Similarly, parent reported frustration levels around the child’s bedtime reduced between the baseline (Mdn = 3: Neutral) and intervention (Mdn = 2: Disagree) phases, z = 2.52, p<.05, r = 0.49. This is supported by our qualitative findings as we see a similar pattern exemplified by comparing how Brian’s parents described their bedtime routines prior to the study “There is a yelling and screaming from all sides, even from ours, up until the last half hour before he [Brian] sleeps or is in his bed [...]. (Interviewer) How does this make you feel? (Mother) Super frustrated. We have of course often been very sorry when putting him to bed, and mad, and frustrated and yes. (Father) When you first come downstairs, you simply just collapse. (Mother) There have been times when I almost did not have the strength to put him to bed [...]”, to how they described it when using MOBERO “[...] we’ve got calmer and better evenings, and it has been pleasant to tuck him in. There have been more loving and quiet moments than conflict, and it’s really nice”. Another example is from Søren’s mother “It has often been a struggle [to get the child to wash his hands]. But now, well it is on the phone, so now it is no problem (laughing)”.

![Graph showing the distribution of daily parent responses to questions about their child’s level of independence during morning (top) and bedtime (bottom) routines.](image)

16.6.3 Improvements in the Parent Rated ADHD symptoms

We observed a 16.5% drop in the traditional ADHD-RS score (i.e. ‘inattention’, ‘hyperactivity’ and ‘impulsivity’) between baseline (M=39.4, SD=5.4) and intervention (M= 32.9, SD=5.5) periods, t(12) = 2.59, p<.05, Cohen’s d=0.73, suggesting that using MOBERO was associated with an improvement in the children’s ADHD symptoms.

Looking at the ADHD-RS subcategories separately, there was a 20.1% reduction in the inattention score between baseline (M=21.46, SD=4.67) and intervention (M=17.15,
SD=4.81), \( t(12) = 2.63, p<.05 \) Cohen's \( d=0.73 \), suggesting that MOBERO was associated with an improvement in children’s ability to attend to tasks. In the hyperactivity/impulsivity subcategory, there was a 12% reduction between baseline (M=17.92, SD=5.72) and intervention (M=15.77, SD=6.19). However, this difference was not significant \( t(12) = 2.63, p>.05 \), Cohen's \( d=0.57 \), suggesting that MOBERO was not associated with improvements in the children’s hyperactivity / impulsivity.

As our version of ADHD-RS included eight additional questions related to conduct disorder, we additionally identified a 26.3% reduction in the ‘behavior’ score between baseline (M=11.96, SD=5.34) and intervention (M=8.61, SD=6.04), \( t(12) = 3.68, p<.01 \), Cohen's \( d=1.02 \), suggesting that MOBERO was associated with an improvement in children’s behavior.

16.6.4 MOBERO Improves the Child’s Sleep Habits

Comparing the CSHQ scores before and after the MOBERO study, we see an significant improvement (8.3%) from a mean CSHQ score of 58.62 (SD=10.87) to 53.77 (SD=8.27), \( t(12) = 2.43, p<.05 \), Cohen's \( d=0.67 \). Furthermore, we see a positive change in seven of the eight CSHQ subscales: ‘bedtime resistance’, ‘sleep duration’, ‘sleep anxiety’, ‘night wakings’, ‘parasomnias’, ‘sleep-disordered breathing’ and ‘daytime sleepiness’. However, we saw no improvement for the ‘Sleep Onset Delay’ subscale. This is consistent with the parents’ descriptions of their child’s ability to fall asleep during the intervention phase “Well, he still has difficulties falling asleep” (Michael’s dad) and “It is not because he falls asleep earlier” (Simon’s mother). Interestingly, six families improved the CSHQ score related to the child’s need to move to another bed (e.g. the parents’) during the night, which is also exemplified by Ryan’s father “[...] before, [Ryan] stayed in his own bed once a week, now I experience it as it is almost diametrically opposed, now it’s once a week he comes down to us – at most.”

16.6.5 Positive Effects on Bedtime Consistency

Though we see a positive tendency in bedtime consistency (see Figure 16-5), we did not find a statistically significant change in bedtimes between baseline and intervention phases, \( t(10)=1.9, p=.08 \). Furthermore, we did not find significant changes between the baseline and intervention for sleep time \( t(10)=1.5, p>.05 \) or sleep delay \( t(10)=0.3, p>.05 \) which are consistent with our analysis of the CSHQ.
16.6.6 Visualizing Time can be a Double Edged Sword

Most parents emphasized that the visualization of time in MOBERO (see Figure 16-2 and Figure 16-3) was very useful for the children as it kept them on track during the morning and bedtime routines: e.g., “It has become easier for him to see it [time]. Before I used the hands of a clock to show him, now it is just so much more clear to him” (Simon’s mother) and “The fact that he can see the time passing [in MOBERO] is much better for him than seeing the pointer move. It has made a world of a difference for him, no doubt about it, and he also says that himself.” (Anders’ mother). However, visualizing the time also caused unexpected outcomes. First, several families reported that the child had to get used to the time element, which caused some issues such as one family explaining how their child hardly had time to say goodnight “[...] he hardly had time for a hug because he had to rush and tap it [MOBERO]” (Anders’ mother). Though the parents mostly told these situations as funny stories, it does indicate the time element in MOBERO caused problems. Furthermore, three families explained that the time element stressed their child as exemplified by Brian’s mother “[...] and then he has to put his clothes on, which always makes him super frustrated because [putting on] the socks are challenging both on time [using MOBERO] and without time, but he has been especially stressed when he had to do it on time” supported by Tom’s parents “[Mother) He told me that he got stressed by the clock. (Father) Yes, that is right, especially when he eats, then he puts the phone away, he does not want to see the time”.

Furthermore, the time combined with the rewards also caused unexpected negative consequences as highlighted by Brian’s mother “It is very often, not in the evening, but in the morning it very often ends up being very much about the medals. It very quickly becomes about doing things as fast as possible, and if the time goes too fast he becomes enormously sad and angry - especially with the clothing [activity] because it was set a little too fast”.

16.6.7 Positive Effects of using Rewards

The rewards during both morning and bedtime routines motivated the child as explained by Sebastian’s dad saying “[...] but I also think that we should not be afraid to say that the reward in the end is the motivational factor, he has put great pride in putting the stars up [before bedtime]”, which is also supported by Rebecca and Owen’s mother “[...] the reward system and the [fluorescent] stars certainly means something”.

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Figure 16-5: Boxplot of the parent reported child bedtime and sleep time for both baseline and intervention period.
Several families empathized that their child did not seem to lose interest in the morning rewards during the intervention period “No, it still keeps him focused. This morning he also just had to see how many points he got, even after 14 days it was interesting for him to see how many points there were.” (Anders’ mother). However, for some children, the virtual rewards in the morning did not motivate them: e.g. “I don’t think that Fiona experienced the [virtual] medals as the same rewards as she does with the [physical] stars […]. The stars are clearly more motivating […]. She can see them when she goes to bed, and she is very proud when she earns a star [...].” (Fiona’s mother). Most parents suggested that the physical reward in the evening would always be interesting for their child, as it supports the opportunity to change the reward, e.g. “I think that it [the bedtime reward system] will always work if you make sure that you agree on a different thing [rewards]. I believe that would work in a longer period because we have previously in periods done that with the reward board over several months. Then we have just exchanged the tasks or rewards and that has worked fine for motivating him” (Brian’s mother).

16.6.8 Children do not Question Routines in MOBERO

Several parents reported that activities/requests that previously would have resulted in conflicts between the child and parent were eliminated by MOBERO: e.g., “Because it is on the phone he accepts the sequence completely” (Brian’s mother). The parents also mentioned that specific activities that previously had been impossible to ask of the child, were now simply completed without question: e.g., “I do not have to tell him to wash his hands. Before, he did not want to and there would be a bloody fight if he had to wash his hands – and now he also just does that” (Simon’s mother); and “He sort of just accepts that we have now ventilated his room and he does not get angry in the same way when he needs to go to bed” (Brian’s mother). These statements support the quantitative results that show that parents experienced less frustration when using MOBERO. Furthermore, it also indicates that the parents did not only become less frustrated because their child became more independent, but also because the children seemed to accept the sequence of routines on the phone, limiting the discussions.

16.6.9 The Children Integrated MOBERO into Their Routines

The parents reported that their child embraced MOBERO very quickly and that it became a help for the child to comprehend the activities around the morning and bedtime routines exemplified by “In some way he is now more aware of the flow, and it does not come as a shock for him every day that he has to brush his teeth.” (Brian’s mother) supported by Anders’ mother “I definitely believe that he feels he has more control”. Furthermore, several of the parents reported that their child was very aware of the phone and established a connection to MOBERO e.g. “He has talked about it [MOBERO] and he has remembered the phone if we forgot it ‘Where is the phone? We can’t start without it.’ […]” (Brian’s mother). Another example of this was: “He also wanted to bring it with him [to his grandparents], he has also been a little proud of it” (Simon’s mother) and Ander’s mother explained that Ander wanted it on his own iPad: “He asked if he could get it [MOBERO] on his own iPad, because then it was sort of closer to him […]”. Ander’s mother also told us that Ander’s the previous day had said “He think today is the worst day in his life because you come and pick up the phone”.

16.6.10 MOBERO Helped the Children Feel More Responsible

Asking the parents about the qualities of MOBERO compared to a similar paper based system, we learned that the children found it engaging in a way a piece of paper was
not: e.g., “Also, it [a paper-based tool] is not involving in the same way, I mean, a piece of paper appeals to something for adults right?” (Otto’s mother) supported by Ander’s mother “So, for him it [technology] is a world he knows and one that he thinks is fun”. Furthermore, technology also makes the child feel more responsible “He feels a responsibility in that it is he who is controlling the smartphone in another way than a child can take responsibility of a piece of paper.” (Otto’s mother). Furthermore, the parents’ also highlighted elements in MOBERO that would not be possible to do with a piece of paper, such as assisting the child in transitions between tasks “I have made pictograms for him and things like that […] but with regards to getting from A to B and making that [transition] smooth, it is clear that the paper can’t do that […]” (Simon’s mother). Several families also emphasized the interactive time and reward element in MOBERO as motivating for the child, though as mentioned in one of the previous subsections this also caused challenges “[...] Even though there have been some conflicts in relation to the rewards they also encourage him because he is competitive and he does not get that from a piece of paper” (Brian’s mother). According to the ADHD professionals, many children with ADHD are naturally drawn to “screens” due to the high level of stimulation; and that “screen-time” often seems to be a reward in itself. Finally, many families stressed to us that a physical piece of paper would disappear or get destroyed as exemplified by Ryan’s mother: “We have tried several different charts, but after a few days there are torn apart or have vanished. This [MOBERO] is always there, so that is convenient”

16.7 Limitations and Future Work

We want to emphasize that the presented work is not a clinical study, and we do not argue that MOBERO can assist all families with ADHD in the way we experienced in the presented study.

We are furthermore aware, that a limitation in our current work is the relatively low number of participants and the absence of a control condition. However, as children with ADHD are vulnerable users and we are evaluating a novel technology-based approach to assist these children to cope with their deficits, we argue (in line with Klasnja et al. (Klasnja et al., 2011)) that it is more important to first uncover potential problems and understand the use of the technology, than to conduct longer and larger efficacy studies. However, as we did design our study to include a baseline period, we used the families as their own controls, allowing us to compare our quantitative and qualitative data from the baseline period against the intervention period.

To address the concern that our results might be due to the novelty of the intervention, we plan to run a prolonged study with families using an improved version of MOBERO based on findings from this work. This new study will focus on investigating the qualities and challenges families experience from using assistive technologies like MOBERO over several months. If this work is successful, then we will work with colleagues in the medical domain to design a randomized controlled trial of MOBERO.

16.8 Discussion

We have reported the results of a design process involving ADHD domain professionals and parents of children with ADHD, two pilot studies with families, and a four-week structured user study of MOBERO with 11 families and 13 children with ADHD. From
our early design process with ADHD domain professionals we learned that we had to design for the family and not only the child with ADHD, due to the fact that ADHD is highly heritable and many parents might find it hard to provide the structure needed for their child to establish healthy routines. We integrated our findings from our design process and pilot studies into MOBERO and ran a four-week study with 13 children diagnosed with ADHD and their families, to explore how technology can assist in changing family practices around the child’s morning and bedtime routines. We showed that MOBERO was associated with lower parental frustration levels and higher child independence during morning and bedtime routines. Furthermore, based on standardized questionnaires we showed a reduction in ADHD symptoms and an improvement in the child’s sleep habits. Based on our findings from this process, we now discuss implications for the design of technologies to support families with children with ADHD.

16.8.1 Differences Between Virtual and Physical Rewards
As our findings suggest, both the virtual (morning) and physical (bedtime) rewards positively influenced most of the children. The virtual rewards in the MOBERO morning module were based on how fast or slow a child completed an activity and would give the child between one or four medals. These time-based rewards seemed to motivate the child to complete not just certain activities faster or slower, but also to complete activities that would otherwise have caused a conflict. Interestingly, in the cases where the parents reported that their child was not motivated by the virtual rewards, we saw little or no effect in the parent reported data. This suggests that immediate rewards could be a critical part of the success for assistive technologies like MOBERO for children with ADHD. However, time-based rewards could also have the potential to stress and cause defeats; researchers should take care to include ways to tailor the rewards system to the individual child as suggested above.

Furthermore, several parents emphasized their child took pride in putting up the stars and put significant effort into drawing their rewards on the reward sheet. This suggests that the child valued the physical rewards more than the virtual rewards, and that the rewards being physical and visible were important for the child. It may also have been because the physical rewards were not based on how fast the child completed the bedtime routines: the child did not have to stress about completing the routines as fast as possible, which could have made it more difficult for the child to calm down and fall asleep. Finally, the physical rewards were more closely embedded into existing family dynamics, in representing quality time that the child would spend playing with their parents. Further work would be necessary to identify which of these factors contributed most to the greater success of the physical rewards.

16.8.2 Assistive Technologies for the ADHD Domain Hold Potential as a Supplement to Existing Treatments
As mentioned in the introduction, traditional ADHD treatments include prescribed medication (Hechtman and Greenfield, 2003). However, we believe that there are interesting and unexplored opportunities for HCI researchers to collaborate with ADHD professionals on developing novel technological solutions that supplement the existing treatments. In our study, seven children received medication for their ADHD disorder; nevertheless, we still saw a positive impact for these families, suggesting that MOBERO did provide an effect medication could not provide. As both our own and the few existing studies (Pina et al., 2014; Sonne and Grønbæk, 2015; Zuckerman et al.,
2015) within the ADHD domain shows, HCI researchers are in a unique position to contribute with alternative solutions for empowering families and children with ADHD. By involving families and ADHD domain professionals into the design process, HCI researchers are able to identify and evaluate opportunities for technological support in specific situations. Our studies show that these technologies can have a substantial impact on families’ everyday life as well as on children’s traditional ADHD parameters. We are aware, that setting up and conducting studies similar to the clinical studies within the medical domain is out of scope for most HCI researches. However, smaller tailored studies and involvement of users and ADHD domain professionals in the early phase of assistive technologies are still relevant for the HCI community as these can provide unique insights that larger studies often cannot provide. These insights are important as they enable researchers to understand the qualities and shortcomings of their application, which can help frame the next development and evaluation phase. We do not argue for using technology instead of medication, nor do we claim that technology can benefit children and families in the same way that traditional treatments do. However, we argue for the possibilities of designing and evaluating assistive technologies as a complement to traditional solutions for families and children with ADHD.

16.8.3 Facilitate Tailoring to Family Contexts
From our evaluations we learned that visualizing time and rewards in the MOBERO morning module was beneficial as it assisted the child to stay on track and made the child complete activities faster (or longer i.e. brushing teeth) than they usually did. However, in a few of the early studies we also observed the opposite effect, that the time and rewards caused stress and frustration for the child. Because we had not made it possible to tailor the time and rewards properly to the child’s capabilities (realistic duration for him to complete specific tasks), we ended up making the child and parents even more frustrated than they were before, and we caused the child to temporarily experience defeat and failure, as he could not achieve maximum points no matter how hard he tried. The benefits of using rewards as a positive reinforcement to motivate people to change behavior have been extensively documented within the HCI community (e.g. (Consolvo et al., 2008a, 2009)). However, to the best of our knowledge, there are not yet any examples within behavior change technologies of positive reinforcement having yielded the opposite effect, as we saw in our study. However, similar scenarios have been found in studies of competitive sports systems, where players or athletes tend to be discouraged and give up if an opponent seems impossible to beat or a goal seems impossible to reach (Jensen et al., 2013; Sonne and Jensen, 2014).

Finally, we learned that every family is different; the ADHD professionals have a saying to support this, “If you have seen one child with ADHD, you have seen one child with ADHD”. Thus technologies to support habit formation for families should support tailoring at least in terms of parameter settings for parents in order to make it possible to adjust, e.g. sequences and timings to fit the child and the specific practices in the family.

16.8.4 Ethical Considerations
It was an ethical challenge to remove MOBERO from the families at the end of the study, as many expressed a high desire to keep it. However, this was research software and not robust or flexible enough to run long term without significant technical support,
which was not possible to provide. All families were aware when volunteering for the study that the deployment would only be for a month. We plan to provide a free version of MOBERO to those families who are interested when we have implemented improvements based on the findings of this study.

16.9 Conclusions

In this paper we presented MOBERO, a smartphone-based system for supporting families of children with ADHD during morning and bedtime routines. MOBERO was designed through the involvement of both parents and ADHD professionals, and was evaluated in the wild with 11 families of children with ADHD over two weeks. Our qualitative findings supported our quantitative findings in that they showed MOBERO significantly reduced the parent’ frustration level and improved the parent rated child independence level. Furthermore, by using standardized questionnaires we saw a significant improvement in the child’s parent-reported ADHD symptoms and the child’s sleep habits. By tailoring and designing technologies for the whole family, we believe that HCI researchers are in a unique position to improve the quality of life for families and children with ADHD by supplementing traditional medical treatments with assistive technology.

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17 Paper D – ChillFish: A Respiration Game for Children with ADHD

In this chapter, the paper ‘ChillFish: A Respiration Game for Children with ADHD’ is presented. The paper is published in Proceedings of the TEI ’16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction, TEI ’16.

ChillFish: A Respiration Game for Children with ADHD

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Abstract
Breathing exercises can help children with ADHD control their stress level, but it can be hard for a child to sustain attention throughout such an exercise. In this paper, we present ChillFish, a breath-controlled biofeedback game designed in collaboration with ADHD professionals to investigate the possibilities of combining breathing exercises and game design. Based on a pilot study with 16 adults, we found that playing ChillFish had a positive effect, helping the participants to reach a relaxed state similar to the one offered by traditional breathing exercises. Further, we analyze the opportunities and challenges of creating a tangible respiration-based controller and use it as a core game mechanic. Finally, we discuss the challenge of balancing engagement and relaxation in physically controlled games for children with ADHD in order to make a game that can be calming and still sustain their attention.

Author Keywords
Games for health, biofeedback, respiration, stress, ADHD, children with ADHD, serious games.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

17.1 Introduction
Children with a mental disorder like e.g. Attention Deficit Hyperactivity Disorder (ADHD) exhibit significantly more resistance around bedtime than children without ADHD (Cortese et al., 2009). Furthermore, children with ADHD also experience emotional outbursts and higher stress levels more often than their peers. For example, in the United States, more than 1 in 3 children with ADHD are reported to have high levels of emotional difficulties, which include poor self-regulation of emotions and problems coping with frustration (Wehmeier et al., 2010). Traditional strategies for overcoming these challenges include medication or asking the child to perform breathing exercises, as slow paced respiration techniques (e.g. (Clark and Hirschman, 1990; Song and Lehrer, 2003)) are well-documented methods to lower an individual’s stress level. Even though existing research within Human Computer Interaction (HCI) on stress reducing biofeedback applications have shown promising results (e.g. (Moraveji et al., 2011; Parnandi et al., 2014)), the existing research has some shortcomings in terms of being used by children with ADHD. First, most of the applications have been designed for adults, e.g. by being desktop applications incorporated in workspaces (Moraveji et al., 2011). Second, most of the existing applications require the user to wear special equipment (Amon and Campbell, 2008; Harris et al., 2014b; “Inner Balance Trainer - HeartMath,” 2016; Lim et al., 2012; Moraveji et al., 2011; Parnandi et al., 2014), which can be hard for children to put on, especially in stressful situations. Third, some projects have been in the form of biofeedback games e.g. (Amon and Campbell, 2008; Parnandi et al., 2014), however,
none of these use respiration as the core game mechanic. Instead they use the effect of respiration as an indirect control of ambient parameters, which can be difficult for children to understand.

Figure 17-1: ChillFish is a calming biofeedback game designed for children with ADHD. ChillFish is controlled by the player breathing into a sensor-mounted LEGO fish.

In this paper, we present ChillFish, a calming biofeedback game designed for children with ADHD (see Figure 17-1). ChillFish is based on an interdisciplinary collaboration with researchers and practitioners from the ADHD domain. As it is often difficult for a child with ADHD to stay focused during regular breathing exercises, ChillFish is designed to retain the child’s attention by combining a breathing exercise with a video game. Thus, it is a novel technological approach for calming children with ADHD down prior to bed, after an emotional outburst or in situations of acute stress. As children with ADHD are a vulnerable and hard to access group, we evaluated ChillFish with 16 adults to investigate the quantitative and qualitative effects of the breath-based interaction and using respiration as the core game mechanic. This study is the pilot study of a series of studies and developments aiming for children with ADHD, however, here we focus only on the feasibility, design and effect of the controlling mechanism.

We start this paper with an overview of related work in biofeedback application and games, followed by a brief description of our design process and the concepts of ChillFish. This is followed by a study of the game that we analyze quantitatively as well as qualitatively. Finally, we discuss challenges in designing respiration games.

17.2 Related Work

In this section, we present existing examples of biofeedback games and digitized breathing exercises that have inspired our work. Biofeedback games use neurological or physiological data as input to control or affect a game. Biofeedback games have been used in various domains from reducing ADHD symptoms through the use of neurofeedback (Lim et al., 2012) to facilitate more enjoyable and competitive workouts by sharing heart rate data between athletes (Sonne and Jensen, 2014). However, biofeedback is not only limited to virtual video games. Broncomatic (Marshall et al., 2011) is a physical installation of traditional bucking bronco (also know as a Rodeo Bull) that has been modified so that the user’s breathing rate modulates the movements of the Broncomatic (Marshall et al., 2011).

As controlling a biofeedback game is very different from traditional games, Nacke et al. investigated how direct and indirect physiological control enhanced the game
interaction of a 2D shooting game, and which physiological sensors worked best for which game mechanics (Nacke et al., 2011). Their study showed that participants found it more engaging to use physiological controls compared to none-physiological controller options. Furthermore, the participants preferred to use physiological sensors that were directly controlled (e.g. breath) compared to physiological sensors that were indirectly controlled (e.g. electroencephalogram (EEG)), as a result of the immediate visual response in the game (Nacke et al., 2011).

Within the ADHD domain, biofeedback (especially neurofeedback) applications have received immense attention as a potential alternative treatment to medication (Amon and Campbell, 2008; Gevensleben et al., 2009; Heinrich et al., 2007). However, these applications either require the child to wear an EEG headset or other equipment like heart rate monitors. Amon and Campbell found that the biofeedback game ‘The Journey to Wild Devine’ could reduce ADHD symptoms in children with ADHD (Amon and Campbell, 2008), however a critique of this study have been raised in (Wright and Conlon, 2009). ‘The Journey to Wild Devine’ is a biofeedback game, where the player has to relax to explore a virtual world. The user’s stress level is detected through sensors on the players fingers that measures heart rate and skin conductance level (Amon and Campbell, 2008), and thus the game is indirectly controlled. Other studies have found issues with children and worn sensors, particularly with sensors on fingers (Knox et al., 2011).

Biofeedback applications designed for adults to reduce stress both include commercial products (e.g. Inner Balance (“Inner Balance Trainer - HeartMath,” 2016) and emWave2 (“emWave2,” 2016)) and various research experiments. Inner Balance uses an ear clip sensor to detect the user’s heart rate variability (HRV), which is a stress indicator, and through an accompanying smartphone application, the user is provided with feedback on how to lower her breathing rate. Similarly, emWave2 is a portable device that measures the user’s HRV and provides a visualization of breathing rate for the user to follow in order to achieve a relaxed state. Researchers have also investigated the use of biofeedback games and applications with the purpose of lowering the user’s stress level. Chill-Out is an example of a research experiment that uses a chest worn respiration sensor as input to adapt the gameplay of a smartphone game (Parnandi et al., 2014). The game’s difficulty level is altered by the breathing rate of the user in order to reward sustained slow breathing. A study showed that Chill-out was more effective in lowering the participants’ physiological arousal level compared to a deep breathing technique and the same game without biofeedback. Another example of a biofeedback game that uses respiration to reduce stress is reported by Moraveji et al. who explored the concept of peripheral paced respiration in a naturalistic workplace setting, and showed that their onscreen visual feedback system helped reduce the participants’ breath rate (Moraveji et al., 2011). Sonic Respiration (Harris et al., 2014b) is an example of an auditory biofeedback system, where the user’s respiration manipulates an audio signal by adding levels of white noise corresponding to the difference in respiration rate from a target respiration rate. Similarly, the Slow Floor uses auditory feedback to support reflection and mindfulness though walking (Feltham et al., 2013).

Several methods for measuring respiration exist, including chest and abdominal movement detection, optical based respiration rate monitoring and airflow based methods (see (AL-Khalidi et al., 2011) for a review). Most HCI biofeedback games use a worn sensor (abdominal or electrocardiogram sensing). An exception is Tennet et al.’s setup (Tennent et al., 2011), where a gas mask mounted with an airflow sensor
measures the player’s breathing pattern and uses this as input in various games. Tennent et al. developed and evaluated five games for their setup; three where respiration was the core game mechanic and two where respiration affected the gameplay. Even though the participants found the interaction engaging in particular games, they also found the gas mask uncomfortable and disturbing (Tennent et al., 2011). It is important to note that Tennet et al. investigated the potentials for using breath as a game controller, and not on reducing stress.

We extend the existing work on biofeedback games and physiological sensing in two ways. First, by focusing on using breath as a core game mechanic in a stress-reducing biofeedback game, we explore challenges and opportunities compared to the traditional ways of using physiological input to affect the gameplay. Second, we focus on a non-worn sensor for controlling a biofeedback game, and investigate the stress-reducing effect and the experience of this type of interaction.

17.3 Designing a Respiration Game Controller

We now describe insights from our design process of designing and developing a breath-based game controller. During the design process, we developed concepts and prototypes, and discussed and evaluated these regularly with ADHD professionals, including a children psychiatrist, two psychologists with ADHD expertise as well as employees at Center for ADHD, Aarhus, Denmark.

17.3.1 Choosing the right respiration sensor

Several techniques exist for detecting respiration e.g. airflow, various vision-based techniques and abdominal movement detection (AL-Khalidi et al., 2011). However, as ChillFish is designed for children with ADHD, it was emphasized by the ADHD professionals that the child should not have to put on any equipment prior to use, as it should be as easy as possible for the child to play the game. An alternative solution is using vision- or thermal-based techniques, however, vision-based techniques require special camera setup to capture abdominal movements (AL-Khalidi et al., 2011), and thermal-based requires special expensive cameras (AL-Khalidi et al., 2011), which limit the widespread use of the system, especially for children. Therefore, we decided to use a thermistor, as it did not have any of the above limitations, like it could also be embedded into a physical device making it easy to initiate the game.

17.3.2 Building a breath-based respiration controller in LEGO

Our physical design process involved an iterative process with semi-functional paper-, cardboard-, fabric- and LEGO prototypes (Mueller et al., 2014). Our first intention was to 3D-print the final controller design, however, our versions of the LEGO–based controller received positive feedback from the ADHD professionals. Thus, we decided to keep the controller in its prototypical LEGO design, as it supported a natural and playful interaction. Another benefit of building the controller in LEGO was that it enabled us to quickly change and enhance the design of the controller. As an example of this, we learned that we had to provide an air hole in the controller in order to avoid condensation within the cavity of fish, as this could affect the electronics. By building the controller in LEGO we could quickly adjust, build and evaluate enhancements in a way we could not otherwise do with e.g. 3D-printing.
We now introduce our respiration-controlled video game, called ChillFish, as a practical example of a breath-based and calming biofeedback game for children with ADHD.

The gameplay is based on an underwater 2D world where a puffer fish (the player character) has to collect as many sea stars as possible in two minutes. The vertical position of the fish character is controlled through inhaling and exhaling through a physical LEGO fish with embedded electronics (see Figure 17-2). When the player breathes into the LEGO fish, the digital character inflates as seen in Figure 17-3 and moves towards the top of the screen and vice versa, as if the player was blowing air directly into the virtual puffer fish. The sea stars are positioned on a path so that the easiest and most comfortable way for the player to collect all of them is to use a slow-paced continuous breath, similar to the breathing exercise “Equal Breathing” or Sama Vritti, i.e. inhaling for 5 seconds and exhaling for 5 seconds continuously.

17.4 The ChillFish Respiration Game

Figure 17-2: Top: The LEGO breath-based game controller. Bottom: The inside of the controller, showing the electronic components.
17.4.1 Implementation

ChillFish is implemented in the Unity Game Engine, and the game controller is built in LEGO and designed as a fish to resemble the main (fish) character. A thermistor connected to an RFDuino is embedded into the LEGO fish, which detect changes in temperature when the player breathes. The sensor values from the thermistor are smoothed and sent from the RFDuino to ChillFish via a Bluetooth 4.0 connection. The movement of the player character is determined by the changes in the incoming sensor values e.g. for each time the change in temperature is larger than a predetermined threshold, the player character moves either up or down, depending on whether cold air is inhaled through the controller or hot air is exhaled into it. By using the change in temperature instead of the absolute temperature, ChillFish requires no calibration and is not affected by the room temperature.

17.5 User Study

As children with ADHD are considered a high-risk group, we decided to conduct a study with adults to preliminary evaluate the game. With this study we want to investigate how ChillFish affects player’s HRV values, as these values can be used as a stress level indicator (Song and Lehrer, 2003). We compare playing ChillFish to doing a relaxation exercise and playing a video game in order to investigate how these activities, separately and combined, impact the player. Furthermore, we want to get insights on how people engage with and experience the interactions with the controller and the game as such, as this can inform changes that needs to be made before conducting a study with children with ADHD.

17.5.1 Participants

16 adults, aged between 25 and 41, participated in our study (14 males, 2 females). The participants were recruited by word of mouth and volunteered to participate.

17.5.2 Procedure

For our study, we decided to use HRV as a quantitative stress indicator, based on previous research documenting the relaxing effects of slow paced respiration exercises (Clark and Hirschman, 1990; Song and Lehrer, 2003) and biofeedback applications (“emWave2,” 2016; Harris et al., 2014b; Parnandi et al., 2014) relying on HRV as a stress indicator as well.
We decided to use a within-subject study design as this typically offers more precise estimates of variations and requires fewer participants than between-subject studies (Hornbæk, 2013). To measure how the participants’ HRV values were impacted by ChillFish and compare it to other activities, all participants carried out a list of activities in a predefined structure:

- Introduction of study (casual conversation). 2-4 minutes
- Play test of ChillFish. 2 minutes.
- Playing Pac-Man. 2 minutes
- Play test of ChillFish. 2 minutes.
- Casual conversation about the games. 2-4 minutes
- Relaxing activity. 2 minutes
- Casual conversation summing up the participants’ experiences with the different games and activities. 2-6 minutes.

The activities were carefully chosen in order to enable us to compare ChillFish to a video game (i.e. Pac-Man), to casual conversations and to a relaxing activity. Pac-Man was chosen as an activity, as it is a classical computer game using traditional and stressful game elements, and we wanted to monitor how such elements affect HRV values. In the relaxing activity, the participants were asked to relax as much as possible, by doing either: 1) a breathing exercise they were familiar with, 2) the aforementioned “Equal Breathing” exercise, or 3) just to do as they wished in order to feel as relaxed and comfortable as possible. We asked the participants to do this exercise to give us a comparison between ChillFish and their own ability to relax and reduce stress. As the relaxing activity measured the participants’ natural ability to relax and had no impact on the game activities, and because of the continuous return to the casual conversation activity, we decided not to counterbalance the order of activities, as we could not identify any possible carry-over effects between ChillFish and the relaxing activity. The different sessions of casual conversation were chosen to function as a baseline for the HRV values, as we believe it indicates the natural HRV of the participants. The conversations seemed to ease and relax our participants, where a moment of staring at a spot, which other studies have used as baseline (Nacke et al., 2011), might be uncomfortable with two observers present.

17.5.3 Data collection and processing

Before the beginning of the study, we equipped the participants with a Polar H7 heart rate belt in order to monitor their HR data (HR and RR-intervals).

We processed the gathered HR data in three steps. First, we deleted duplicates in the data, which occurred in some of the data sets. Second, all data was filtered using a recursive filtering procedure (Karlsson et al., 2012), where RR intervals that differed more than a predetermined limit (50%) from the average of the preceding and proceeding value were removed. Third, we calculated HRV values using the time domain analysis RMSSD (the square root of mean squared differences of successive RR intervals) using a sliding window of 30 beats. RMSSD is a recommended measure for HRV assessment (Task Force of the European Society of Cardiology the North American Society of Pacing Electrophysiology, 1996). For each participant, we normalized their HRV values, as these are affected by various conditions, such as age and aerobic capacity (Lehrer et al., 2007). Finally, we calculated the normalized mean HRV value for each of the eight activities. The results from this analysis are presented in the following section.
Additionally, we video recorded 10 of the experiments in order to capture the participants’ reactions and responses, and we took notes during all the tests. The video recordings and written notes were structured using a coding process, where we identified key concepts from our study. These key concepts were used in an affinity diagram, where we iteratively sorted the concepts in order to derive at a number of dominant themes that we will present in the “qualitative results” section.

17.6 Quantitative Results: Biometric Outcomes

In this section, we present the analysis of the collected HRV values, followed by results, interpretations and insights from the conducted analysis.

As the participants’ HRV values were measured over several activities, we used a univariate analysis of variance (ANOVA) with repeated measures to test for significant differences among the different activities in the data set. To ensure that the data was suitable for an ANOVA, we did a Mauchly's test, which did not show a violation of sphericity ($W(20) = 0.2747, p = 0.764$), thus no corrections were made to the processed data set. The ANOVA determined that at least two of the activities differed significantly in terms of the mean HRV values ($F(6,84)=13.83, p<0.001$, partial $n^2 = 0.71$). Hence a post-hoc Tukey’s pairwise comparison was applied.

The post-hoc analysis showed no significant differences between the three casual conversation activities, indicating that the recorded HRV data is acceptably stable over time, which allows the activities to function as baseline. Even though there is a difference between the baseline activities and the relaxing activity (see Figure 17-4), the difference is not significant. This illustrates that relaxing exercises can be hard to do in certain contexts and without experience, supported by a participant who pointed out the discomfort of relaxing in a setting with two observers present.

![Comparison of mean HRV values between activities](image)

*Figure 17-4: Graph showing the normalized mean HRV values of the participants during the different activities. The error bars indicate the standard deviation.*

The Pac-Man activity resulted in the lowest HRV values of all activities, and was significantly different from all other activities in terms of the participants’ mean HRV values. This indicates that the game elements (e.g. time, score and chase) in Pac-Man
stressed our participants during the two minutes of playing. This is consistent with the participants’ own description of their experiences, as they also felt stressed during the game. Finally, the HRV values in the two ChillFish activities did not differ significantly from the relaxation activity, though the last ChillFish activity was the only of the relaxing activities that differed significantly from the baseline activities. The HRV values in the ChillFish and relaxing activities were very similar, indicating that they have approximately the same physiological impact on a subject, thus we argue that ChillFish have a corresponding impact on a player’s stress level as a relaxation exercise.

17.7 Qualitative Results: Experiencing ChillFish

Sorting, clustering and thematizing our notes and video recordings in an affinity diagram resulted in three main themes: 1) Implications of using respiration as a game controller, 2) game elements and theme impact the calming experience, and 3) game dynamics facilitated reflective experiences. Together these themes capture the main findings from the qualitative part of our study, and we will present these in the following.

17.7.1 Implications of Using Respiration as a Game Controller

The main part of the participants stated that they enjoyed using “the fish” as input device. However, using a breath-based sensor as direct input to a computer game presents some implications.

Breath as a key press

As mentioned previously, the goal of the game interaction is for the player to get calm through a slow-paced respiration, and even though most of our participants achieved that, the interaction did not afford this for all. Three of the participants explicitly interacted exhaling and inhaling in short breaths, described by one of the participants as “I just saw it as like the input of a key or anything. So I just needed to input something when I wanted to move. And when I didn’t want to move I didn’t input anymore” (P14). Another participant stated that he felt more in control using periodic breaths. However, because of the design of the sensor and the use of changes in temperature to control the player character, it was not possible to get all the sea stars using a periodic tactic, and this caused some frustration for the participant.

Using breath for direct control creates a player-character relationship.

Even though most participants understood the interaction analogy that blowing air into the physical LEGO fish would fill the virtual fish with air, this was not the case for everyone. One participant said, “I love the analogy of the puffer fish, but for me it’s the wrong way around. Like when diving you try to stay at the same level, so you breath in to go a bit higher and breath out to go a bit lower” (P12), and when explained of the idea of blowing air into the fish, she responded, “that’s true. So I just kind of identify with the fish pretty much. So if I had a [physical] fish that actually inflates I could imagine”.

17.7.2 Game Elements and Theme Impacts the Calming Experience

The main part of the participants enjoyed the aesthetics of the game, exemplified by comments like, “It’s a beautiful game” (P7), and, “It’s really cool. A cool idea. I’m not sure what the effect is but it really makes you concentrate on breathing” (P12), indicating that the game’s theme and elements impacted the calming effect.
**Underwater theme supports the breathing exercise**

The underwater theme reflected in the graphics and the sound scape impacted the participants’ perception of the game, as one participant noted, “The underwater theme fits really well” (P5) and another stated, “It’s a really chill track you got for the fish. It’s nice. It’s almost as being scuba diving again” (P15). This indicates that visual and auditory elements play a role in games’ calming effect.

**Game play choices impact calmness**

In our game design process, we deliberately chose to make the game play about eating starfish and not about getting as far as possible without failing, as in e.g. Flappy Birds or Pac-Man. This was embraced by the participants, and exemplified by one participant comparing it to SuperMario, where “you don’t get disappointed if you don’t get all the coins. [...] It doesn’t feel like failing, just because you don’t get all the stars” (P5). Thus, removing the possibility of losing the game facilitates a calmer atmosphere, which supports a reduction of the player’s stress level. However, the participants were aware of their personal performances, as most of them revealed to know their exact score during the follow-up interview.

17.7.3 **Game Dynamics Facilitated Reflective Experiences**

The study indicated that the game offered more than simply calming the participants by impacting their breath. We found that the dynamics of the game made them aware of their respiration and how they responded to the game.

**It’s all about finding the rhythm**

The participants revealed that the best way of playing the game successfully was by getting into a rhythm of a natural calm breath, exemplified by one participant noting that, “it’s all about finding the rhythm” (P5). However, finding the exact rhythm was a challenge in itself, and participants commented that “it’s easy to control, but it’s harder to get the timing right” (P8) and “I tried to do a more smooth movement, and I had some troubles making it fit in the beginning” (P11). The rhythm of breath and the calming effect are closely related, supported by a participant explaining, “if you have the rhythm everything is fine. It’s really relaxing. As soon as you miss one then you like [hyperventilate] or something like that” (P13).

**Reflecting on breathing techniques and tactics**

By playing ChillFish twice the participants got a possibility to reflect upon their breathing technique and tactic. Several participants emphasized that their interaction in the second game was more “natural” (P9) and “smooth” (P11). One participant stated that, “The difference to the second time was really just, I tried to breath out while at the bottom, and I figured out, well okay, breathing out now I need to breathe in, okay. It’s just well timed” (P14), thereby realizing that the game calls for a calm and continuous respiration. Another participant realized the same thing in a hard way, noting that, “I had to figure to inhale and exhale completely. But you can keep blowing even when it’s at the top. In the beginning, I almost suffocated myself, because I just stopped when it was up” (P7). These examples all indicate that the game over time can teach players respiration techniques, partly explaining the difference in HRV values observed between participants first and second ChillFish game as described in the previous section and illustrated in Figure 17-4.
17.8 Discussion

The results presented in the two previous sections show that it is possible to successfully combine breathing exercises and directly controlled video games using a none-worn respiration controller. We showed that our participants HRV values significantly decreased when playing a classic video game, indicating that game elements can cause a stressful situation. Furthermore, we showed that it can be difficult to relax on command, and we were unable to significantly distinguish the relaxing activity to the casual conversations. On the other hand, despite being a video game, ChillFish showed to significantly increase mean HRV values over time compared to casual conversation. This indicate that our participants were more relaxed playing the game, than in any of the other activities, as a result of the breathing-based input, demanding a continuous relaxed breath, the calming underwater theme, and a point system that stresses the player as little as possible. However, the game still has room for improvement and some unexploited possibilities, especially in terms of balancing engagement and relaxation.

With ChillFish we saw how the participants tried different breathing techniques, and how their success was affected by the hint of counter acting. In ChillFish, players got the best result if they continually inhaled and exhaled through the LEGO fish, ultimately causing a relaxed breathing rate. However, what caused our participants to be engaged was 1) their ability to make their own choices, e.g. completely and directly controlling the game with their breath (causing a player-character relationship and a search for rhythm), and 2) the game elements, e.g. points and sounds (causing underwater sensations and leading to calmness). Had we decided to instruct the participants on how to win the game before we started, chances are they would have received it with less enthusiasm, as a result of the limitations in the game’s core mechanics (Salen and Zimmerman, 2004). On the other side, by not instructing them, we risked that players hyperventilated, used periodical blows and tried to force the input through, which is physically impossible. Balancing the difficulty and in-game guidance is especially important when designing games for children with ADHD. If the game is too obvious and easy the child will lose interest and stop doing the underlying breathing exercise, due to the challenges of sustaining attention as characterized by the ADHD diagnosis. Contrary, if the child is in the middle of a stressful situation, chances are that too hard a game will inflict further frustration and make the situation even worse.

Balancing learning, outcome, seriousness and engagement is a well-known challenge in serious, learning and training games, for example explained by Jensen et al. as the challenge of introducing points without reducing relevance (Jensen et al., 2015). Thus, in order to make a respiration game both engaging and relaxing for the player, it is important to assist the player to get the desired breathing rate, without making it too obvious. We believe this can be achieved by using game design techniques, for example by adding additional exciting and challenging elements to the beginning of the game, e.g. different types of stars in varied places, combos, power-ups. By adding these elements, we might be able to create a more engaging interaction experience that we can gradually reduce, so it ends up being a breathing exercise with points, like the current version of ChillFish. However, engaging game elements can also stress the player, as shown in our study during the Pac-Man activities. Another way of approaching the challenge is to focus on visual and auditory elements. The underwater theme in ChillFish calmed the participants in our study and additional attention to these peripheral elements might increase the players engagement without changing the actual
game play, thus maintaining the breathing exercise. This is consistent with Chang’s requirement of providing visual and auditory stimuli for children to dwell on in order to help them during relaxation procedures (Chang, 1991).

In summary, when designing respiration games, it is important to balance the engagement of the game elements, the difficulty of the game and the visual and auditory stimuli, so the player gets relaxed without getting bored or frustrated.

17.9 Future Work

Based on the findings from this study, we have received approval to evaluate ChillFish with children with ADHD. In collaboration with our research partners from the ADHD domain, we have redesigned the study design specifically for children with ADHD.

17.10 Limitations

The main limitation in this work is the lack of children with ADHD as participants in the study. However, as they are a high-risk group, we found it important to investigate the initial qualities and challenges of ChillFish without putting them at any risk or in any discomfort. Another limitation is the use of HRV as a measure for stress. In spite of the frequent use in similar studies, HRV values are affected by the respiration of the subject, and hence breathing exercises will have an effect. However, because breathing exercises have significant positive impact on stress and relaxation, and the use of ChillFish causes a similar or slightly stronger effect on HRV values as breathing exercises, we argue that ChillFish have the same impact on a player’s stress level and feeling of relaxation.

17.11 Conclusion

In this paper, we have presented ChillFish that combines a breathing exercise with game element designed with children with ADHD in mind. A pilot study with adults showed positive effects on the participants’ stress levels in terms of HRV values, compared to other activities. We also presented a qualitative analysis of participants’ experiences with ChillFish, eliciting for example implications of using breath as a core game mechanic, the importance of auditory and visual stimuli and how the game facilitated a reflection of rhythm and breathing techniques. Based on these results and our experiences from designing ChillFish, we discussed the challenge of balancing engagement and relaxation to sustain attention and avoid frustration of players, and children with ADHD in particular. Our work shows that it is possible to combine a breathing exercise with game design and still achieve positive results.
In this chapter, the paper ‘Designing Real Time Assistive Technologies: A Study of Children with ADHD’ is presented. The paper is published in *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction, OzCHI ’15*.

Designing Real Time Assistive Technologies:  
A Study of Children with ADHD

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Abstract
Children with mental disorders like Attention Deficit Hyperactivity Disorder (ADHD) often experience challenges in school as they struggle to maintain their attention. Based on empirical studies conducted in school contexts and together with teachers and ADHD domain professionals, we identified design criteria in relation to three core components (sensing, recognizing, and assisting) for designing real time assistive technologies for children with ADHD. Based on these design criteria, we designed the Child Activity Sensing and Training Tool (CASTT), a real time assistive prototype that captures activities and assists the child in maintaining attention. From a preliminary evaluation of CASTT with 20 children in several schools, we found that: 1) it is possible to create a wearable sensor system for children with ADHD that monitors physical and physiological activities in real time; and that 2) real time assistive technologies have potential to assist children with ADHD in regaining attention in critical school situations.

Author Keywords
Wearable Computing; Assistive Technology; Children; ADHD; Mental Disorder Management; smartphone intervention;

ACM Classification Keywords
J.3: Life and Medical Sciences. Health; C.3 Special Purpose and Application-based Systems: Real-time and embedded systems.

18.1 Introduction
Even though researchers within Human Computer Interaction (HCI) have begun to investigate how technology can assist people with various deficits, little research has focused on technology that supports children with mental disorders. Children with mental disorders often experience difficulties in school (Zentall, 1980). For example, children with Attention Deficit Hyperactivity Disorder (ADHD) exhibit difficulties in interacting with parents and teachers, and furthermore show impaired academic performance compared to their peers (Goldman LS et al., 1998; Massetti et al., 2008). Limited work has been conducted on assistive technologies for children, and the existing work has mostly focused on children with Autism Spectrum Disorders (ASD), e.g. (Hayes et al., 2008, 2010; Hirano et al., 2010a). However, ASD is a very different disorder to ADHD, and therefore technologies for ASD cannot necessarily be used within the domain of ADHD. Thus, the research question being investigated in this work is: How can we design wearable computing systems that can sense and recognize characteristic ADHD behaviors, and in turn assist children with ADHD to cope with their attention deficit in critical school situations?
We report on an exploratory and interdisciplinary process involving teachers, ADHD researchers, psychologists and children with and without ADHD. Based on this process and empirical studies conducted in schools, we designed the Child Activity Sensing and Training Tool (CASTT) prototype. CASTT is a wearable system that monitors physical and physiological activities of children and uses collected data to provide real time assistance to the child. From our studies with nine children without ADHD and 11 children with ADHD, we made a prototype of CASTT as a proof of concept that it is comfortable to wear and shows promise for providing in situ assistance to children with ADHD. Furthermore, we were allowed to test the system in a Wizard of Oz study with one child with ADHD in a school setting.

18.2 Technologies for Children with ADHD

To understand the behavior and challenges that children with ADHD experience in school, as well as to learn about teachers’ techniques and their experiences of including children with ADHD in the classroom, we conducted more than 12 hours of observations and interviews in four different schools. We supplemented our observations of children with ADHD in 2nd - 5th grade with interviews with seven teachers who had extensive experience working with children with ADHD. In addition to our observations and interviews, we collaborated with ADHD professionals, including medical doctors and two psychologists throughout the design process in order to for example discuss our empirical findings and assist in developing the CASTT prototype.

Based on findings from these empirical studies and our previous work within the ADHD domain (Sonne and Grønbæk, 2015), we will now present three core components needed to provide appropriate real-time assistance (i.e. sensing, recognizing and assisting as seen in Figure 18-2) and for each component highlight design criteria relevant for designing real time assistive technologies for children with ADHD in school contexts.
18.2.1 Sensing

Sensing movement activity and physiological states in an unobtrusive way can shed new light on how different factors, e.g. medication, affect children. Technologies for capturing sensor data with high accuracy already exist and have been used in several applications (Pantelopoulos and Bourbakis, 2010). However, existing studies have so far neglected uses for children with ADHD and have been conducted in lab settings (Börger et al., 1999). We address these shortcomings by defining five design criteria for designing a wearable sensor system for children with ADHD in a classroom context:

- **Unobtrusive to wear**: To avoid affecting the child’s behavior, the system should be designed to be unobtrusive to wear.
- **Robust**: The system should be designed to be robust enough to handle tough classroom and school activities.
- **Quick and easy to set up**: To minimize the impact on the child and the class, the system should be easy and quick to put on the child.
- **Avoid stigmatization**: A child with ADHD is vulnerable to harassment and bullying, thus researchers should take care to use devices that do not expose or stigmatize the child further.
- **Real time continuous sensing**: In order to provide reliable recognition and real time assistance, the system should provide real time continuous sensing.

18.2.2 Recognizing

Being able to recognize characteristic behaviors from worn sensors is needed in order to provide in situ assistance. Existing research has shown that it is possible to recognize a variety of human behaviors, e.g. unhealthy computer mouse habits (Sonne and Grønbæk, 2013), posture of children (Harms et al., 2009) and stereotypical motor movements for children with autism (Albinali et al., 2009). In general, activity recognition research looks for characteristic features of sensor data, in order to develop algorithms with reliable recognition of characteristic activity patterns. The features to analyze are highly dependent on the types of activities being characteristic for the domain. As initial steps to achieve recognition of characteristic off-task behaviors in natural school contexts for children with ADHD, we propose the following criteria:

- **Analyze seated conditions only**: Often learning activities in schools require the child to work with various assignments at a desk. In solving these, the child is expected to sit still, thus a high level of physical activity could indicate a low attention level.
- **Detect changes in physiological states**: A sudden change in physiological state could mark critical situations for the child, e.g. a fast increasing heart rate can lead to an uncontrollable emotional eruption (McHugh et al., 2010).
- **Exclude off-seat activity with walk detection**: In order to prevent triggering the assistive component in unintended situations, walk can be used as a delimiter to temporarily disable the assisting component.
18.2.3 Assisting

Assistive technologies that help children with ADHD to rebuild their attention and achieve more in school can have a great positive impact on the prospects for these children. Recently, research and commercial solutions that assist children in coping with their various deficits have emerged. Existing solutions include technologies to train the children’s cognitive capabilities via a home computer (“Cogmed Working Memory Training,” 2015) or while wearing an EEG headset in a lab (Lim et al., 2012). Research into how to assist children in a school context includes helping children maintain their attention while reading (DePrenger et al., 2010) and assisting children to avoid emotional eruptions (McHugh et al., 2010). To address the issue of assisting children with ADHD in a school context, we have identified five design criteria for real time assistive components.

- **Interesting and intuitive:** The type of intervention should be interesting and intuitive for the child in order to gain and sustain his attention.
- **Include rewards:** Including explicit rewards in an assistive system can influence the behavior of the child and enhance the child’s interest in the system itself.
- **Effective and discrete notifications:** The assistive intervention should effectively notify the child while still being discrete enough to not disturb the other pupils.
- **Facilitate termination and provide guidance:** Children with ADHD often have challenges perceiving time and handling transitions between activities. Thus, assistive interventions should provide a natural termination and a clear guidance to what the child should do straight afterwards.
- **Ubiquitous feedback:** Children with ADHD often lose track of their belongings. Therefore, an assistive intervention should preferably utilize the child’s own computer or smartphone.

Having discussed design criteria for the three components of real-time assistive technologies in relation to children with ADHD in school contexts, we now present a technical implementation of these three core components: the CASTT prototype.

18.3 The CASTT Assistive System

CASTT is a wearable prototype designed to provide real time assistance in regaining attention for children with ADHD that is built around the three main components presented above: Sensing, recognizing and assisting.
In terms of sensing, CASTT currently supports up to eight DUL accelerometers (Brynskov et al., 2012), a smartphone, a HR monitor and an EEG headset to sense physical and physiological activities as illustrated in Figure 18-1. However, due to limited space, we only report on accelerometer data in this paper. For recognition, CASTT calculates 42 features for each connected accelerometer in real time on a sliding window of 128 samples with 50% overlap. The 42 different features are adopted from (Figo et al., 2010), and are used to recognize characteristic ADHD off-task lower body excessive motoric behaviors. The variance feature for each sensor is visualized in real time in the CASTT user interface (both real time and cumulative variance). This user interface supports the recognizing component of CASST, as it allows for monitoring of ADHD related features. We are currently implementing a machine-learning algorithm to efficiently recognize these features, but in the studies described, the recognizing is done manually based on feature visualization. The assistive component of CASTT is implemented through a smartphone-based quiz application that triggers simple mathematical quizzes, with the purpose of breaking the child’s inattention and encouraging a return to focus on the task at hand as seen in Figure 18-3.

The smartphone was selected as a platform as most of the children in our observational studies already had one with them in school. Furthermore, we used the built-in vibration functionality as a discrete and known notification technique. The choice of a quiz application was chosen as it includes rewards for correctly answers questions and facilitates a natural termination after a fixed time. To guide the child from the quiz to the task at hand, we implemented a termination screen with three clear instructions as seen in Figure 18-3.

18.4 Evaluating CASTT with Children

In the following, we report on three studies where 11 children with ADHD and nine children without ADHD wore the CASTT prototype during normal school lessons. The participating children came from four different schools and attended either 3rd, 4th or 5th grade. All children had a signed consent form from their parents to participate in the study. All studies were conducted during regular school classes, with no changes to the teaching program. All studies were video recorded for later analysis.
The first study focused on evaluating the unobtrusiveness of CASTT. 11 children (two with ADHD) from a normal school class participated in this study. The duration of the trials in the study varied from 30 to 65 minutes ($m=40.18$, $\sigma=12.09$).

The second study focused on collecting sensor data of characteristic ADHD movement behaviors, and included three girls and five boys (all eight medicated). The duration of the trials in this study varied from 11 to 35 minutes ($m=26.5$, $\sigma=8.94$).

The third study focused on evaluating the CASTT assistive intervention, however due to practical problems in recruiting children with untreated and clear phenotype ADHD to the project, we have so far only conducted one study with one child with ADHD in a real school context. The participating child evaluated CASTT during a 1.5-hour math lecture. A prolonged increased activity level detected by CASTT, together with the present author’s subjective assessment of the child’s attention level was used to decide when and if to trigger the assistive intervention.

18.5 Results and discussion

Analyzing our interviews video recordings, suggests that all sensors, except the EEG headset, were comfortable to wear. A situation that exemplifies this was when a boy walked out of the classroom right after the teacher had announced a short break, taking only the EEG headset off, but forgetting about the HR belt, the DUL sensors and the smartphone. However, using technological devices designed for adults did create initial challenges in our studies. For example, we found that our smartphone (a Samsung Galaxy IV) was too big to fit in some of the children’s pockets, which is why a smaller HTC Hero smartphone was used instead. Furthermore, the HR belt could not be tightened enough to fit all children, a safety pin was used to solve this for small children. In contrast, it was not possible to adjust the EEG to fit the children, as the three children (all without ADHD) who did try the headset reported that it sat too loose on their heads.

Our second study, which focused on collecting characteristic ADHD movement data did not turn out as we expected. First, as our studies were conducted in special schools for children with ADHD, the duration of school activities was limited in time to accommodate the children’s challenges in sustaining attention, resulting in limited data collection. Furthermore, as the children’s school desk spaces were designed to limit distractions from other pupils, we experienced challenges in capturing sufficient sensor and video data of typical ADHD-related movements and behaviors.

From the third study focusing on the assistive intervention we noticed that from the time from when the intervention was triggered until the child had answered the first quiz question, only 15 seconds elapsed. Additionally, from the video recordings, we saw that none of the other children in the class seemed to notice the vibration notification or that the child used the smartphone. These findings indicate that vibration is an effective notification technique, and is appropriate to be used in classroom contexts. The intervention was triggered 11:01AM (40 minutes into the class), and in the time leading up until the triggering event, the boy seemed unable to keep focus and exhibited a high degree of self-stimulating behaviors. Figure 18.4 shows the aggregated variance for all accelerometer sensor data in two-minute intervals from the study. The two green bars indicate the time of the assistive intervention. A few spikes in activity can be seen
earlier than 11:00AM, however these occurred due to natural off-chair activities. Furthermore, as seen in Figure 18-4 the child had a 10-minute low activity period following the assistive intervention, similar to the activity level in the start of the class. Furthermore, the child did return to his math assignment in front of him after the intervention, and the video recordings suggest that he stayed focused on the school task in front of him in the 10-12 minutes following the intervention.

![Figure 18-4: The graph shows the child's activity level during the study of the assisting component in CASTT. The intervention was triggered at 11:01AM (marked with green bars).](image)

Even though promising, more studies are needed before we can draw extensive general conclusions on if and how the assistive intervention can help children with ADHD in a classroom setting. Nevertheless, initial findings show promise for further experiments on real time assistive technologies for children with mental disorders like ADHD.

### 18.6 Conclusion and Future Work

The paper presented, to our knowledge, the first proposal for real time assistive technologies for children with ADHD to cope with the challenges of their phenotype, which has been tested in real world situations. Based on an interdisciplinary collaboration with ADHD domain professionals and multiple in situ studies of children with ADHD, we identified three core components and related design criteria for designing real-time assistive technologies for children with ADHD in school contexts. These were implemented through the CASTT prototype, which was evaluated in schools with 20 children, 11 of whom were diagnosed with ADHD. Our evaluations suggest that it is possible to design wearable technologies for children with ADHD that provide real time sensing of physical activities while being comfortable to wear. Moreover, it shows that a smartphone-based assistive intervention can potentially assist a child with ADHD, who has lost focus on his school assignment, in returning to the assignment.

In the presented work, we have focused on providing a full cycle from sensing through recognition to assisting interventions. However, each of the core components of the assistive technology will be subject to future work in order to develop a full functioning system that can be deployed to children with ADHD. Thus, each of the three core components will be further developed.
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