Attention Deficit Hyperactivity Disorder (ADHD) is the most prevalent childhood psychiatric condition, with estimates of more than 5% of children affected worldwide, and has a profound public health, personal, and family impact. At the same time, a multitude of adults, both diagnosed and undiagnosed, are living, coping, and thriving while experiencing ADHD. It can cost families raising a child with ADHD as much as five times the amount of raising a child without ADHD (Zhao et al. 2019). Given the chronic and pervasive challenges associated with ADHD, innovative approaches for supporting children, adolescents, and adults have been engaged, including the use of both novel and off-the-shelf technologies. A wide variety of connected and interactive technologies can enable new and different types of sociality, education, and work, support a variety of clinical and educational interventions, and allow for the possibility of educating the general population on issues of inclusion and varying models of disability.

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Research Advances in ADHD and Technology
Synthesis Lectures on Assistive, Rehabilitative, and Health-Preserving Technologies

Editors
Ronald M. Baecker, University of Toronto
Andrew Sixsmith, Simon Fraser University

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ABSTRACT

Attention Deficit Hyperactivity Disorder (ADHD) is the most prevalent childhood psychiatric condition, with estimates of more than 5% of children affected worldwide, and has a profound public health, personal, and family impact. At the same time, a multitude of adults, both diagnosed and undiagnosed, are living, coping, and thriving while experiencing ADHD. It can cost families raising a child with ADHD as much as five times the amount of raising a child without ADHD (Zhao et al. 2019). Given the chronic and pervasive challenges associated with ADHD, innovative approaches for supporting children, adolescents, and adults have been engaged, including the use of both novel and off-the-shelf technologies. A wide variety of connected and interactive technologies can enable new and different types of sociality, education, and work, support a variety of clinical and educational interventions, and allow for the possibility of educating the general population on issues of inclusion and varying models of disability.

This book provides a comprehensive review of the historical and state-of-the-art use of technology by and for individuals with ADHD. Taking both a critical and constructive lens to this work, the book notes where great strides have been made and where there are still open questions and considerations for future work. This book provides background and lays foundation for a general understanding of both ADHD and innovative technologies in this space. The authors encourage students, researchers, and practitioners, both with and without ADHD diagnoses, to engage with this work, build upon it, and push the field further.

KEYWORDS

Attention Deficit Hyperactivity Disorder, ADHD, human-computer interaction, cognition, social interaction, social skills, education, disability, human development, interactive technologies, user experience, mobile computing, shared active surfaces, tabletop computing, virtual reality, multi-sensory environments, augmented reality, sensors, wearable computing, robots, robotics, natural user interfaces, natural input, tangible computing, tactile computing, eye tracking, behavioral intervention
Franceli L. Cibrian:
To Armando, Rome, and Francisco

Gillian R. Hayes:
To Steve, Warner, and William

Kimberley D. Lakes:
To Dr. Francis Crinella and James, Emma, Micah, and Elijah
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Attention Deficit Hyperactivity Disorder (ADHD) is the most prevalent childhood psychiatric condition, with worldwide prevalence estimates of 5% and 7.2% (Polanczyk, et al., 2014; Thomas et al., 2015), and profound public health, personal, and family impacts. In 2013, in a European setting estimate that the average total ADHD-related costs ranged from €9,860 to €14,483 per patient and annual national costs were between €1,041 and €1,529 million (M) (Le et al., 2014). In the U.S. in 2000, a study estimated that the excess cost of ADHD was $31.6 billion (1.6 billion was for the treatment; $14.2 billion for healthcare cost and $3.7 billion was for the work loss) (Birnbaum et al., 2005; Doshi et al., 2012). In the Republic of Korea, the total economic burden of ADHD was US$47.55 million, which accounted for approximately 0.004% of Korean gross domestic product in 2012 (Hong et al., 2020). Given the international differences in the medical care system, it is difficult to generalize a global cost and there is not a lot of data about the burdensome costs from countries of the Global South; still, the burden may be similar or greater, although it may not be recognized to the same extent.

At the same time, a multitude of adults are living, coping, and thriving while experiencing ADHD, both diagnosed and undiagnosed. Given the chronic and pervasive challenges associated with ADHD, innovative approaches for supporting people with ADHD across the lifespan have been engaged, including the use of both novel and off-the-shelf technologies. A wide variety of connected and interactive technologies can enable new and different types of sociality, education, and work, support a variety of clinical and educational interventions, and allow for the possibility of educating the general population on issues of inclusion and varying models of disability. These technologies are used for traditional mental health care, such as diagnosis and assessment, as well as addressing the primary mental health concerns of ADHD, including cognition and attention. We intentionally engage a variety of technologies beyond this, however. Notably, we explore behaviors that can put people with ADHD in conflict with those without ADHD and discuss how technologies can support self-regulation and management of behavior to fit cultural and societal norms and social engagement with those without ADHD. We also explore technologies most concerned with promoting the pragmatic outcomes of academic, work, and daily lives. Our goals are to describe both a broad base of existing and emerging technological approaches as well as the large scope of potential opportunities and challenges in the space of ADHD that future technologies could address.

Since 2004, research papers describing potential applications of technology to ADHD have increased dramatically; the ACM Digital Library (2019, https://dl.acm.org/) indicated that
from 2004–2019 the numbers of publications focused on ADHD and technology increased exponentially, with the fastest growth occurring in the last ten years. As scientific interest has grown, commercial interest has developed even more rapidly. Many commercial products are currently available on the market, advertising clinical benefits to individuals with ADHD and their families. The efficacy of these products, however, is largely unknown.

Limited reviews of the scientific literature surrounding ADHD and technology use do exist and are included in this book. Every day, people with ADHD and their families, co-workers, friends, and teachers are adapting and adopting interactive technologies in novel ways not cataloged by any researchers. Thus, this review does not attempt to make clinical recommendations nor provide a comprehensive examination of all technology use surrounding ADHD. Rather, this volume focuses on describing current research—technological, social-behavioral, and medical—in the broad spaces of ADHD assessment, diagnosis, treatment, and self-determination.

Each of the authors of this book has worked with and/or taught people with ADHD of all ages for years. We come to this work as researchers, clinicians, educators, family members, and friends of people with ADHD. Additionally, we have sought and incorporated feedback from people with ADHD, including both children and adults, throughout our time working on this manuscript and are grateful for their lived experiences, which have informed this book. Our intention with this book is to help readers understand ADHD as both a medical and sociological construct and provide a broad review of the research literature that demonstrates the role technology has served to this point. Finally, we hope through this work to identify some gaps, biases, and challenges that we as a community have yet to overcome.

This book provides an overview of the historical and state-of-the-art use of technology by and for individuals with ADHD with deep dives into a subset of research to further illustrate the trends we see in the space. We take both a critical and constructive lens to this work, noting where we have made great strides and where there are still open questions and considerations that must be engaged. This book provides background and lays foundation for a general understanding of both ADHD and innovative technologies in this space. We encourage students, researchers, and practitioners, both with and without ADHD diagnoses, to engage with this work, build upon it, and push the field ahead in order to support the needs of children, adolescents, and adults with ADHD.

1.1 THE EVOLUTION OF ADHD AS A DIAGNOSTIC CATEGORY

The historic 1980 revision of the *Diagnostic and Statistical Manual of the American Psychiatric Association* (DSM-III, 1980) introduced the diagnostic categories of Attention Deficit Disorder without (ADD) or with Hyperactivity (ADDH). These categories replaced the prior diagnostic category of hyperkinetic reaction of childhood (DSM-II, 1978). The DSM-III diagnostic criteria
described symptoms of inattention, impulsivity, and hyperactivity. Subsequent revisions to the manual (e.g., DSM-IIIR, DSM-IV 1994, DSM-5) expanded on these categories and symptoms. Today, the DSM-5 diagnosis of ADHD falls within the broader grouping of Neurodevelopmental Disorders, a grouping of conditions that emerge during early development. DSM-5 diagnostic criteria are grouped as either inattention or hyperactivity-impulsivity symptoms. The earlier term “ADD” is no longer applied; rather, the DSM-5 uses the diagnosis of ADHD, which can be specified as “Combined presentation” (six or more symptoms of inattention and six or more symptoms of hyperactivity-impulsivity have been present for at least six months), “Predominantly inattentive presentation” (sufficient inattention symptoms are present but hyperactivity-impulsivity symptoms do not meet the threshold), or “Predominantly hyperactive/impulsive presentation” (symptoms of hyperactivity-impulsivity meet the threshold, but symptoms of inattention do not).

The DSM-5 provides examples of how inattention and hyperactivity-impulsivity impair daily functioning. Symptoms of inattention can include having difficulty focusing on a task, failing to attend to details, demonstrating disorganization, lacking persistence, losing things, and forgetting to do things. Symptoms of hyperactivity often include fidgeting, having difficulty remaining in place, and extreme restlessness. Impulsivity can be exhibited by acting without thinking, talking excessively, interrupting others, and having difficulty waiting in line. The DSM-5 requires that these difficulties interfere with functioning to meet the threshold for diagnosis and that alternative explanations for these difficulties are considered and ruled out.

Researchers (e.g., Swanson, Wigal, and Lakes, 2009) have described attention and behavioral control (the ability to regulate behavior and control one’s impulses) as occurring across a spectrum, noting that individuals with ADHD fall at an “extreme” on the spectrum and exhibit impairment in daily functioning. In other words, attention and self-regulation are exhibited to some degree in all persons. Some demonstrate very strong abilities to pay attention and sustain attention over a long period of time, while others struggle to do so. Likewise, some individuals display impressive levels of self-control, while others appear to have very little self-control and frequently display impulsivity. These cognitive and behavioral skills have been described as critical to success in life. In a rigorous longitudinal study, Moffit et al. (2011) followed nearly 1,000 children from birth into adulthood and concluded that self-control predicted physical health, substance dependence, personal finances, and criminality, producing a gradient that indicated that as self-control improved, corresponding outcomes improved as well. Their study continues to have important implications for society at large, as well as individuals with ADHD who struggle with self-control: improving self-control can improve outcomes across a wide range of domains (health, education, wealth, and citizenship). A large body of evidence in the field of ADHD research similarly demonstrated that difficulties with self-control are associated with poor educational, occupational, and social outcomes. Collectively, this research highlights the importance of improving treatment and providing ongoing support
for individuals with ADHD who struggle to control attention and behavior, as it suggests that the long-term impact on outcomes can be meaningful and substantial.

Despite a wealth of research and attention, ADHD remains in many ways a misunderstood condition, especially for women and girls. Researchers, clinicians, and the broader public have shifted to some degree on the notion of ADHD as something that debilitates to something that differentiates. Sabrina Park, writing in 2019, chronicled 11 women with ADHD whom she described as “thriving:” including actress Emma Watson who also graduated from Brown University and served as a United Nations Goodwill Ambassador, vocalist Solange Knowles who lamented people’s perceptions of her before her diagnosis, Olympic gold medalist Simone Biles, and even a YouTuber who created a “Hot to ADHD” informational channel (Park, 2019). Entrepreneur magazine similarly chronicled ADHD success stories, such as JetBlue Airways founder Devid Neeleman and Virgin Group founder Richard Branson (Belanger, 2017). That article references research in which Wiklund et al. (2016) studied 14 entrepreneurs previously diagnosed with ADHD, noting that impulsivity can be a major driver of entrepreneurial action, and hyper-focus can spur such action to consequences. Regardless of these specific cases or potential benefits to ADHD, we acknowledge that much of the western world is incompatible with the cognitive and behavioral profile of ADHD. Thus, in this work, we explore technologies that seek to support people with ADHD in learning to accommodate the environment around them as well as technologies that seek to change the environment to accommodate them. As Harvey Blume (1998) noted, “Neurodiversity may be every bit as crucial for the human race as biodiversity is for life in general. Who can say what form of wiring will prove best at any given moment?”

1.2 THE EVOLUTION OF “TECHNOLOGY” IN MENTAL HEALTH

Although the vast majority of technology profiled in this book is more recent, it was worth understanding to some degree the origins of the notion of the use of technology in mental health. This has, in many ways, tracked the use of technology in other parts of healthcare, but the trends are distinct in interesting ways, with a much stronger emphasis on self-instruction and home care than physical health trends.

In the 1970s, as hospitals and other health systems computerized, mental health also began to include computerization. For example, Johnson and Williams (1975) described an “on-line computer technology” for mental health admissions. This simple system collected psychological, social, and physical information that could then be used for clinical decision-making. Other systems would follow, and some have even been adopted and put into widespread clinical use. And yet, many of our systems still rely on paper and pencil, particularly for smaller practices. A 1976 review of the
state of the art in computers and mental health care delivery (Johnson, Giannetti, and Williams, 1976) predominantly described large-scale data collection and clinical decision support systems.

As in other areas of healthcare, it would take the advent of personal computing to push the notion of technology in mental health into more mainstream practice. An instructional book, complete with included CD-ROM from the late 1990s, describes “practical advice” for even the most “technophobic” clinicians and researchers (Rosen and Weil, 1997). Yet, even then, much of the literature from this time period focus on screening and assessment (e.g., Munizza et al., 2000; Puskar et al., 1996; Stein and Milne, 1999) and computerized decision-support (e.g., Knight, 1995) as opposed to using technology directly for treatment, which was still an emerging area of research (e.g., Budman, 2000; Huang and Alessi, 1998; Riemer-Reiss, 2000). A focus, then as now, was on the notion of treating patients and providing support services at a distance.

In more recent years, the notion of technology for mental health, and for ADHD in particular, has gained enough mainstream interest that a myriad of smartphone “apps;” games for computers, phones, and even in Virtual Reality; and other approaches have become commonplace. Some of this is driven by innovative clinicians, by people with ADHD themselves, and by friends and family members of people with ADHD, making the effects disparate and hard to measure. Several reviews of these technologies and their evidence exist (e.g., Batra et al., 2017; Grist, Porter, and Stallard, 2017; Hansen, Broomfield, and Yap, 2019; Hollis et al., 2017; Michel, Slovak, and Fitzpatrick, 2019; Torous et al., 2018). These explorations can point us toward a variety of future directions with creative solutions and points to the need for more empirical research (e.g., Comer and Myers, 2016; Firth et al., 2018; Ralston, Andrews, and Hope, 2019). Such research also highlights risks and obstacles to technological approaches (e.g., Bhuyan et al., 2017) but cannot yet, in most cases, provide solid extensible guidance and recommendations.

Technology and ADHD have a complicated relationship. While researchers, clinicians, and educators have sought to use technologically enabled approaches to support people with ADHD, others have sought to detect a potential connection between the rise in use of computerized technologies and ADHD itself (e.g., Visser et al., 2014; Beyens et al., 2018). Despite the widespread problematizing by the scientific community of claims that screen and media use cause a wide range of psychiatric disorders (Odgers and Jensen, 2020; Stiglic and Viner, 2019), these myths continue to be perpetuated by both the popular press and an increasingly limited number of researchers (e.g., Twenge et al., 2018). These claims are problematic in part due to their limited statistical power but largely due to the implicit ableism and offensive nature of claims that assert technology has “destroyed a generation” (Twenge, 2017) largely related to claims that this new generation has and makes different choices than was true of prior generations, particularly in relation to independence and social engagement. By asserting that ADHD is caused by screen time and media use (e.g., Tamana et al., 2019, Rosenblatt, 2019) and that, therefore, all children should have such screens removed from their lives or have greatly reduced access (Twenge and Campbell, 2018), we implicitly
assert that living with ADHD is worse than living without educational opportunities, connectivity to remote social opportunities, and connection to the larger culture. We are writing this book at a particular moment in time, during COVID-19 stay-at-home orders and subsequent social distancing, and this experience reinforces the deeply problematic nature of staking these claims that are not backed in science and that contribute to bias and problematic policies.

Further challenging reviews and thoughts about Mental Health Technology, and specifically those for use surrounding ADHD, is the use of the word “technology” itself by the interdisciplinary mix of people working in this space. Some clinicians and mental health researchers use the word technology to mean concepts, such as when Swift and Levin defined “empowerment” as an emerging mental health technology (Swift and Levin, 1987). In this case, they were referring to the feeling of power and competence as well as the modification of the structural conditions to invoke these feelings. In this case, and others like it, the authors appear to be using the term technology to describe any tool. Similarly, Byrnes, and Johnson (1981) use the term technology to describe a new process. At the far other end of the spectrum, for many computer scientists and engineers, technology is an evolving concept, and the term itself is difficult to pin down at times, describing only digital or electrical solutions and at others more traditional tools, such as paper as technology. This concept grows murkier when one considers the publication and funding realities of research in the information and computer sciences, in which only new radically cutting-edge solutions are considered worthy of scientific exploration. In this case, the word technology may often be preceded by “novel” or “innovative.”

1.3 OTHER RELEVANT ADHD AND TECHNOLOGY REVIEWS

This book is not the first effort to catalog research related to ADHD and technology in some form or another. However, prior reviews published in scientific journals have primarily focused a specific form of technology and its impact on targeted outcomes in ADHD. For example, Powel et al. (2017) focused on the ten most popular smartphone applications targeting children and young people with ADHD or their caregivers and noted the lack of an evidence base for the applications, as well as concerns about their utility and inadequate privacy/security features. They observed that once an application had been purchased and downloaded, there was little opportunity for feedback on utility; participants interviewed in their research identified a range of limitations in the available products, suggesting that they had fallen short when it came to addressing patient, family, and clinician needs. Powel et al. (2018) conducted a second review of 14 studies focused on technologies designed to encourage and support self-management for individuals with ADHD. They noted that although the research indicated some promise for technology to support self-management of ADHD-related difficulties, research was limited by small sample sizes, weak outcome measures, and limited integration of psychoeducation. As another example, in a recent preprint, Hussain
As we describe in Chapter 4, for example, hundreds of journal articles and several systematic and meta-analytic reviews have been published addressing computerized cognitive training (e.g., attention training using a computer program designed to look like a video game) for individuals with ADHD. These works have contributed to a growing understanding of how technology may or may not ameliorate ADHD symptoms and improve outcomes. Our intent in this book is to take a broader perspective and describe a wider range of technologies that have been addressed in prior individual reviews. When relevant to a particular chapter, we cite those other review articles and hope that readers may engage with those works as they find them useful and relevant to their own work.

This book also is not meant to include every article ever written about ADHD in relation to technology or technology in relation to ADHD. For one, the book would never be complete as research is ongoing and growing in this space. More importantly, however, scientific journals are the appropriate space for systematic reviews or structured meta-reviews and meta-analyses, such as those described in the previous paragraph. This book is meant, instead, to lay out an intellectual space. The hope of this approach, as has been in true in many volumes in this series, is three-fold. First, we seek to educate and support scholars choosing to move into this area. Second, this book should inspire others to build on, critique, and update the exciting advances we overview here. Finally, this book can serve as a resource for those in the industry looking to develop a new product or modify an existing one to provide a better user experience for someone with ADHD, to enable people with ADHD to make their own content and products or to develop new assessment, diagnostic, and therapeutic tools.

1.4 STRUCTURE OF THIS BOOK

This book is organized by functional domain within the broader context of living with ADHD. While we do not focus on any particular age group, that organization means that some chapters are more likely to focus on children while others may be more centered around the adult experience. We begin in the next chapter with a description of our initial structured literature review and the themes used to classify the literature in that review. This classification scheme runs throughout the book and provides the backbone for the remaining chapters. Chapter 3 focuses on the diagnosis and assessment of ADHD, a series of tools and approaches that cross many of these functional domains. Chapter 4 focuses on cognition and attention and includes a discussion of tools developed to train these skills in individuals with ADHD. In Chapter 5, we focus on social and emotional skills, including the experiences of both children and adults. In Chapter 6, we review tools to support behavior management and self-regulation. Chapter 7 is dedicated to academic skills and so is heavily tied to the experience of childhood schooling as well as higher education. By contrast,
the next chapter, Chapter 8, highlights the role of technology in supporting everyday life skills and employment and is thus more focused on the experiences of young adults and adults. Chapter 9 describes technologies to support and improve motor skills, physical access, and physical behaviors. Finally, we conclude with a discussion of where we are headed as a field and what opportunities may lie ahead. Of course, many projects overlap in categories and so can be found in multiple chapters. Likewise, points from the discussion are relevant to detailed portions of the individual chapters as well. Thus, readers may wish to begin with the discussion, read detailed chapters of interest, and return to the final chapter again.

Within each chapter, we describe the background of the experience of ADHD as related to the overall topic of that chapter. In these cases, we highlight both strengths and challenges, indicating the ways in which technology can help people with ADHD to improve their life experiences, ways that technology might help people without ADHD to be supportive and inclusive, and ways in which the currently available technological solutions do not appear to be effective. Finally, we close each chapter with some indication of the conclusions we can draw from inspecting this literature together and the future directions the field might wish to pursue.
CHAPTER 2

Methods and Classification Scheme

In this chapter, we provide a description of the methods we used to identify and analyze interactive technology research included in this book. Based on the existing work of Kientz et al. (2019) in classifying papers in the broad space of interactive technologies for autism, we modified their classification scheme to help categorize each technology approach. This approach is particularly appealing in that it is both descriptive and explanatory. Using this framework, we have been able to trace the history and evolution of this research within specific technology verticals. This approach then provides a roadmap for future research by showing both where the field is headed and where it perhaps could or should be with some appropriate intervention by researchers, practitioners, product developers, or even funding bodies.

2.1 METHODS

Given the rapid growth rate in this area of research, the ambiguous definition of technology, and the rapid changes in clinical and educational practice, as in the Kientz et al. volume that was focused on autism, we do not represent this work as a complete review of the literature but rather an overview of the preponderance of evidence for and open questions about various technological approaches. Notably, there are numerous off-the-shelf, open-source, and commercial products that serve similar needs, either explicitly or through appropriation and adaptation. We intentionally exclude applications from popular media, such as games for children with ADHD found in the Apple App Store or on Google Play. These marketplaces are rich with different applications, but in general, they are beyond the scope of this book unless they have been studied in the scientific literature. Given our focus on research, this book is limited to research projects and research-validated products with some mention of other non-research products when particularly relevant.

We conducted our research for this book in two phases. In the first phase, we conducted a structured literature review using searches in PubMed, ACM Digital Library, and IEEE Xplore for articles published in English from 2004 to June 1, 2020. We witnessed an inflection point in the ACM and IEEE articles, in particular around 2004 (see Figure 2.1). Search terms included: “ADHD,” “Attention Deficit Hyperactivity Disorder,” “treatment,” “digital,” “intervention,” “assistive technology,” “computer intervention,” “computer assisted,” “sensor,” “mobile,” “wearable,” “smartphone,” “tablet,” “robot,” “virtual reality,” “augmented reality,” “neurofeedback,” “working memory training,” “cognitive training,” “internet,” and “web.” We limited results to published
peered-reviewed research papers, excluding research published solely as abstracts or extended abstracts; these research abstracts were excluded during the first phase of screening (Figure 2.2).

Figure 2.1: Chart graphing publications in the ACM and IEEE digital libraries using “ADHD” as the keyword starting in 1991 shows 2004 as a clear point after which the topic began to gain substantial interest to technology and computing researchers. Notably, at time of publication, 2020 is still in progress, hence limiting the numbers of publications available for that year.

We included research articles that used consumer, clinical, and educational technologies. To identify this initial set of literature for the book, we used the PRISMA process for identifying appropriate articles for inclusion (see Figure 2.2, which demonstrates how we identified papers focused on the application of technology to intervention and treatment only).
Once this initial corpus was developed, we broadened our search to include additional conferences and journals and additional topics in an iterative fashion. We checked the reference lists in the papers in our initial corpus and used Google Scholar to scan the papers that cited them. We then analyzed these papers using the classification scheme outlined below. Finally, when we identified holes in the literature through this analysis, we searched again, this time using Google Scholar.
with the broad sets of terms outlined above but expanding to other databases, such as JSTOR and EPIC that are indexed by Google. This process continued iteratively as we developed the text for the book itself. Thus, while we do not compile a comprehensive view across all potential fields that intersect ADHD and Technology, we are confident in our ability to detail the landscape of studies to provide a foundation for scholars interested in expanding research in this area as well as practitioners or developers looking to build on what already has been done.

2.2 CLASSIFICATION SCHEME

We adapted the framework developed by Kientz et al. (2019) to organize the existing literature. This adapted framework consists of five dimensions along which projects can be categorized. Within each dimension, we determined several labels within that dimension that could describe the work, again derived in part from the Kientz et al. framework. Below we describe the five dimensions, along with the associated labels within those dimensions and their operational definitions. In many of these dimensions, it is possible that multiple sub-labels apply. For the purposes of the readability of this book, we categorize them roughly in the most dominant sub-label, noting the overlap, however in Table 2.1.

2.2.1 INTERACTIVE TECHNOLOGY PLATFORM

This category describes the primary platforms, form factors, or delivery mechanisms used by the technology or application.

- **Personal Computers and Web:** Includes applications that use a traditional keyboard, mouse, and monitor, and Internet-based applications that are primarily designed for access via a desktop-based web browser. Can also include laptop-based technologies, but the primary differentiator is those that are intended to be stationary and not mobile.

- **Mobile Devices and Tablets:** Includes applications delivered on cell phones, PDAs, tablets, or other mobile devices intended for personal use. Can be used in multiple environments or anywhere the user goes.

- **Sensor-Based and Wearable:** Includes the use of sensors (e.g., accelerometers, heart rate, microphones, brain-computer interfaces (BCI) etc.), both in the environment and on the body, or computer vision to collect data or provide input.

- **Virtual and Augmented Reality:** Includes the use of virtual reality, augmented reality, virtual worlds, and use of virtual avatars.
• **Robotics**: Includes physical instantiations of digital interactions. Includes both humanoid or anthropomorphic robots and general digital devices that carry out physical tasks. Includes both autonomous robots and those operated remotely by humans.

• **Natural User Interfaces**: Includes the use of input devices beyond traditional mice and keyboards, such as pens, gestures, speech, eye tracking, multi-touch interaction, etc. Interacts with a system rather than just providing passive input. Although this is a term of art for computing researchers, it is not without its critics, as the term “natural” here largely means “not mouse and keyboard” rather than anything that is truly “natural” in the sense of not being artificial, synthetic, or learned.

### 2.2.2 DOMAIN

This category refers to the area of functioning within individuals with ADHD that the technology targets, such as helping with the acquisition of certain skills or addressing particular deficits.

• **Cognition and Attention**: Includes applications designed to improve cognitive skills, including attention, working memory, and other executive functions.

• **Social and Emotional Skills**: Includes technologies designed to improve social skills and peer and family relationships and reduce emotional symptoms, such as anxiety and depression.

• **Behavior Management and Self-Regulation**: Includes applications focused on supporting self-regulation and behavioral approaches, such as technologies to track or deliver token economies.

• **Academic and Organizational Skills**: Includes applications focused on time management, organization, reading, mathematics, and other academic skills.

• **Life and Vocational Skills**: Includes applications or technologies designed to support the development of independent living skills and other specific skills, such as training to support safe driving behaviors.

• **Motor Behaviors**: Includes applications designed address hyperactivity and motor coordination skills, such as tools to help improve fine motor coordination.
2.2.3 GOAL

This category refers to the primary goal of the technology itself. Some technologies related to ADHD are intended to support a diagnostic process or to screen for symptoms of ADHD, whereas others are intended to support or deliver interventions.

- **Treatment/Intervention:** Includes (1) applications that attempt to improve or produce a specific outcome in an individual with ADHD. May focus on teaching new skills, maintaining or practicing new skills, or changing behaviors; and (2) applications that provide support for caregivers, educators, clinicians, and other professionals to further their understanding of ADHD and intervention strategies or improve their skills as caregivers.

- **Diagnosis/Assessment:** Includes (1) applications that help either screen for ADHD diagnosis in the general population or test for symptoms of ADHD in clinical settings; (2) applications focused on the collection and review of data over time to assess an individual’s learning, capability, or level of functioning. The data collected is intended for end users and/or people caring directly for individuals with ADHD; and (3) applications or projects that use technology in the collection and analysis of data by researchers to understand more about ADHD and its features or characteristics. Tools in this category generally are not yet available for or may not be appropriate or feasible for home or community use.

2.2.4 TARGET END USER

This category focuses on the person or persons who will actually be interacting with the technology itself and are considered the primary users. It does not refer to secondary stakeholders or those who may benefit from the technology but do not actually interact with or use it.

- **Child with ADHD**
- **Adolescent with ADHD**
- **Adult with ADHD**
- **Family Caregiver:** Includes anyone who is not a professional who cares for or supports an individual with ADHD. May include parents, siblings, other family, friends, volunteers, etc.
- **Provider/Researcher:** Includes a paid professional who works with individuals with ADHD. May include teachers, medical professionals, doctors, occupational therapists,
physical therapists, speech therapists, applied behavior therapists, or other allied health professionals. Also includes a person intending to collect data or conduct studies about individuals with ADHD and publish something generalizable about the data. This does not include researchers running a study about technology for an individual, only when the researcher themselves is one of the technology’s primary users.

### 2.2.5 Setting

The care of individuals with ADHD takes place in a number of different settings. This category refers to the settings or locations in which the technology is primarily intended to be used.

- **Home:** The home or personal living space of a person with ADHD and/or their family.

- **School:** A public or private place for educating individuals with ADHD. Includes both schools that specialize in ADHD education as well as general, inclusive classrooms. Could include all levels from pre-school through postsecondary education.

- **Research Lab:** Technology intended for use in a research laboratory under careful observation or that has been tested only in controlled settings.

- **Clinic:** A place of professional practice that is not intended for education, such as a doctor’s office, therapist’s office, or a specialty service provider.

- **Everyday Life:** Including work, transportation, socialization, shopping, and other daily activities.

### 2.3 Applying the Classification Scheme

To illustrate how we applied this framework, here we describe a single paper and how it was classified. Weisman et al. (2018) published a study evaluating the ICON smartphone application and illustrated how innovative technologies could be applied to improve medication adherence, which can be a substantial problem in ADHD treatment. We classified this work as a mobile device (technological platform) that targets organizational skills (domain) in order to support intervention and patient education (goals). The application targeted children and their caregivers (target end users) and was developed for use at home (setting). Also, Table 2.1 includes 68 projects on technologies reviewed for this book and their associated coding within the classification scheme. We chose the 68 papers based on their diversity across specific areas to exemplify the use of the classification scheme.
In the subsequent chapters, we use this framework to describe the approaches to interactive technology research in the ADHD space. Although we adapted the Kientz et al. (2019) framework for this analysis, we structure the rest of the book differently. Where they structured their review based on the technological platform as the primary organizing principle, we instead focus on the domain of concern that the design, technology, and/or research project was developed to address. Subsequent chapters include Diagnosis and Assessment of ADHD Symptoms (Chapter 3), Cognition and Attention (Chapter 4), Social and Emotional Skills (Chapter 5), Behavior Management and Self-Regulation (Chapter 6), Academic and Organizational Skills and Support (Chapter 7), Life and Vocational Skills and Support (Chapter 8), and Motor Behaviors and Physical Accessibility (Chapter 9). Some applications and technologies might fit into more than one of these categories, in which case they are mentioned in both relevant chapters and cross-referenced appropriately.

Within each chapter, we describe the challenges and opportunities of the specific domain as well as the interventions and innovative technologies that have been developed in this space. We describe solutions that have been developed or used by people with ADHD and the ways in which these technologies themselves can be challenging or problematic. Finally, we close with potential future opportunities in this area of research.

Any book will necessarily only provide a review that is a snapshot in time. Both our understanding of ADHD and the technologies we use to support our lives are ever-changing. We hope this book provides a foundation upon which others may build. Additionally, we expect that others can use the methods we outlined above to monitor additional literature as it is published and stay up to date. Finally, we hope that people with ADHD themselves, whether researchers or not, will take up this work, apply to it their lives, and inform our future work with their lived experiences.
### Table 2.1: Coding of 70 projects used to test our classification scheme

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<th>Target End User</th>
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ADHD is highly individualized, with each child, adolescent, and adult expressing symptoms in different ways, with no clear physical test to diagnose the condition. Rather, diagnosis is typically given in response to a series of behavioral observations and reports sometimes combined with neuropsychological assessments and self-report of internal feelings. Many children and adults with ADHD go years or even lifetimes without a formal diagnosis. At the same time, there is growing interest in increasing the rigor of diagnostic procedures as well as the assessment of progress in response to a variety of interventions. These kinds of tests, requiring intensive support from clinical and educational resources, can be difficult to scale, but with the prevalence of ADHD such scale is necessary. Thus, technology offers an opportunity to support human professionals and experts in their diagnostic and assessment work. In this chapter, we first introduce the basics of ADHD diagnoses, followed by the extensive literature on computational approaches to augmenting diagnostic and assessment work.

3.1 ADHD DIAGNOSIS

No single diagnostic system or procedure for ADHD has been discovered or adopted yet, and a rigorous evaluation process often involves hours of clinician time. Thus, technological tools have been developed to glean diagnostic information useful to clinicians evaluating patients for ADHD. On the one hand, research has often focused on classifying behaviors or physiological data between individuals with ADHD and neurotypical peers. On the other hand, some research has focused on finding patterns among the data to generate symptom profiles of ADHD.

For a number of years, computers have been used to test attention, yielding normative data that can be useful as part of a comprehensive diagnostic evaluation for ADHD. One of the most commonly used technological tools in clinics is the Conner's Continuous Performance Test, currently in its 3rd edition (www.mhs.com/CPT3). This task-oriented computerized test of attention allows the evaluation of an individual's ability to maintain attention across a period of time and produces standardized, normative scores that can help identify difficulties in attention that are sensitive to development. Similarly, the Test of Variables of Attention (TOVA: www.tovatest.com) also tests attention and produces informative scores. Both tests assess attention using an intentionally boring “computer game” designed to evaluate how well an individual can regulate attention over
time. Neither claims to replace a comprehensive diagnosis, but both are widely thought to generate useful information to inform a comprehensive diagnostic assessment.

As digital recording technologies become more pervasive, more robust, and less costly, it should come as no surprise that they are increasingly used to support medical diagnoses of both mental and physical health conditions. Mental health, in particular, has been traditionally difficult to diagnose because few definitive tests exist for certain behavioral health conditions. Recent research projects indicate that diagnoses of ADHD may be greatly enabled and streamlined through automated sensing and monitoring of physical health and observable behaviors, in particular, as they relate to potential co-occurring motor conditions. Additionally, the use of these tools has, in some cases, enabled researchers to rule out such connections from conditions that only appear to co-occur in clinical practice but such connections were not able to be tested rigorously previously. In this section, we describe the extant research in using technology to understand and support the diagnosis of ADHD, including studies that found use of such technologies to be promising as well as those that demonstrated certain behaviors or symptoms either cannot be effectively measured or are not predictive of diagnoses as expected.

3.2 COMPUTATIONAL DIAGNOSTIC AND ASSESSMENT APPROACHES

Three primary approaches have been explored in research attempting to create non-biased diagnostic tests for ADHD. Computational techniques can be used to classify data from brain activity, either EEG or fMRI. Data can also be collected from sensors (on the body, in the environment, or inherent to computational tool use) used during everyday activities and then create computational models that can classify unseen data instances. Finally, some approaches have been focused on designing and developing serious games or environments where users can play and interact. The interactions of the users with the game are analyzed to infer if the user has ADHD or related symptoms.

3.2.1 COMPUTER AND MOBILE PHONE-BASED ASSESSMENTS

Given that ADHD is largely diagnosed by clinician observation and report, parental report, self-report, and behavioral diagnostics, it should be no surprise that one role computation has taken in this process is simply to document, support, and analyze such collected data. Clinical decision support systems (CDSS) (Berner, 2007) can improve healthcare outcomes by facilitating evidence-based medical practice. For example, Kemppinen et al. (2013) studied the implementation of a customized CDSS for adult diagnosis of ADHD, finding that implementation of such a system required the establishment of a standard for the care of adult ADHD patients, enabling quick changes as new information is incorporated into their processes.
Some computerized tests support the patients directly, rather than as part of a clinical decision support structure. For example, MATH-CPT uses an on-screen sequence of simple mathematical questions, which the authors hope can be used to diagnose participants with ADHD. In a study of 303 participants (63 with ADHD), MATH-CPT correctly classified 91.6% of participants, performing better in their study than the Test of Variables of Attention (TOVA) (Rodríguez et al., 2018). QbTest, a computerized continuous performance test, has been shown to reliably differentiate between children with ADHD and those without (Emser et al., 2018; Hult et al, 2018) as well as adults (Bijlenga et al., 2019; Edebol, Helldin, and Norlander, 2013; Emser et al., 2018; Hirsch and Christiansen, 2017; Lis et al., 2010). Similarly, QbCheck was built as an online assessment tool for families who were not able to come into a clinic but wanted some initial screening or assessment for ADHD. In a study with 142 adolescents and adults (69 with ADHD), high convergent validity was observed between QbCheck at home and QbTest (Ulberstad, 2016) in the clinic (Ulberstad et al., 2020). Despite the promise of these results for a notion of automated diagnosis, many researchers have noted that there are just too many limitations inherent to claiming to diagnose a clinical condition without a qualified clinician. Thus, many experts advocate for such tools to provide useful information to the diagnostic process rather than replace it.

Finally, parents are sometimes the target of data collection as part of family and child assessments. For example, Hsieh, Yen, and Chou (2019) examined the relationship between the Parental Smartphone Use Management Scale (PSUMS) and ADHD symptoms, finding that PSUMS accounted well for reactive management, proactive management, and monitoring in relation to parental feelings of self-efficacy. Although PSUMS itself is not delivered via technology, it is a potentially useful tool for clinical practice and parenting groups to understand parental management and point to particular challenge areas around technology use for families. On the other hand, Li and Lansford (2018) used smartphones in the form of ecological momentary assessment (Shiffman, Stone, and Hufford, 2008) to track parents of 184 kindergartners, with and without ADHD, for one week, finding limited relationships between the stress of parenting and variability in harsh parenting behaviors. Inclusion of assessment tools like this into other therapeutic or educational applications for parents may be particularly valuable.

3.2.2 VIRTUAL AND AUGMENTED REALITY TO ASSESS ATTENTION

Virtual reality (VR) provides an option for creating dynamic, immersive three-dimensional environments in which behaviors can be recorded and analyzed for later assessment more easily and in more detail than in a traditional physical classroom. VR enables the presentation of cognitive tasks that systematically target attention performance, which while only in VR may provide insights into attention performance outside of this environment. Although there are several studies in virtual and augmented reality to assess ADHD (e.g., Fang et al., 2019; Keshav et al., 2019; Knouse et al., 2005;
Silva and Frère, 2011), two main projects have been widely explored, the Virtual Reality Classroom (then called ClinicalVR) and AULA.

The Virtual Reality Classroom has been used to assess the attention of children with ADHD for the last two decades (Rizzo and Buckwalter, 1997; Rizzo et al., 2000, 2003, 2004, 2006). The VR Classroom includes a standard rectangular classroom rendering containing three rows of desks, a teacher’s desk at the front, a blackboard across the front wall, and a virtual teacher who presents as a woman. On the left side, a large window looks out onto a playground with buildings, vehicles, and people. As a tutorial, the virtual teacher instructs the participants to spend a minute looking around the room and point, name observed objects, and then play a quick game. Following the tutorial, participants can play two games, one focused on identifying letters on the blackboard, with or without audio, visual, and 3D audio/visual distracters, and assessment of the virtual teacher’s accuracy at identifying images drawn on the blackboard. The project was revised digital mediaworks, inc. (http://www.dmw.ca/) and called ClinicalVR: Classroom-CPT (Nolin et al., 2016). The system was then adapted to a Unity 3D version (Yeh et al., 2012; Tan et al., 2019).

Several studies have been conducted to test the efficacy and efficiency of the VR Classroom. VR classroom measurements are consistently correlated with traditional measurements (Parson et al., 2007; Pollak et al., 2009), making it a promising place for testing new interventions. However, children with ADHD were more affected by distractions in the VR classroom than those without ADHD (Adams et al., 2009). In the newest version, ClinicalVR, studies show that assessments made by monitoring behaviors are reliable and unaffected by gender, while age is impacted (Nolin et al., 2016). Although there are differences between performing these tests in the virtual environment from a more traditional computerized one, measurements were able to distinguish between children with ADHD and neurotypical children (Negut et al., 2017), provide incremental validity beyond that of teacher and parent report of behavior (Coleman et al., 2019), and add social cues to the assessment (Eom et al., 2019).

Similarly, The AULA Nesplora or just AULA has also been used to assess ADHD in children (Climent and Banterla, 2010). AULA is a virtual school classroom where children used a head-mounted display with movement sensors, earphones, and a single-button switch to interact in the environment. AULA had two main activities: a NO-X paradigm based exercise (i.e., “Press the button when you DO NOT perceive the target stimulus”) and an X paradigm-based exercise (i.e., “Press the button whenever you DO perceive the target stimulus”), that children can play for 20 minutes (Díaz-Orueta et al., 2014). This approach has also been explored using an aquarium environment (Camacho-Conde and Climent, 2020).

Studies have been conducted with children to first correlate AULA measurements with more common and standard Continuous Performance Tests (CPT), confirming the validity between the tests (Díaz-Orueta et al., 2014). AULA was able to differentiate between children with ADHD and without pharmacological treatment for a wide range of measures related to inattention,
pulsivity, processing speed, motor activity, and quality of attention focus (Díaz-Orueta et al., 2014; Iriarte et al., 2016). The cognitive scales used in AULA take into account the virtual environment to better characterize the difficulties encountered by people with ADHD (Areces et al., 2018a), VR is able to classify the impulsive/hyperactive, inattentive behaviors, and combined symptoms (Areces et al., 2018b). AULA predicts current and retrospective ADHD symptoms (Areces et al., 2019), and better differentiates between ADHD and non-ADHD individuals in comparison with the most commonly used CPT, the Test of Variables of Attention (TOVA) (Rodríguez et al., 2018). These results show promise for improving the performance monitoring data collection that many clinicians use to speed their screening, assessment, and even diagnostic work.

Augmented reality has also been explored to assess ADHD symptoms. For example, Empowered Brain is an augmented reality communication aid for children with ASD. In one study of Empowered Brain, seven high school students diagnosed with ASD played Empowered Brain for one week. In this study, Empowered Brain in-game performance correlated with ADHD symptom severity in students with ASD. This was a relatively small sample but showed promise in using tools designed to support children with ASD in simultaneously assessing them for ADHD (Keshav et al., 2019).

3.2.3 COMPUTATIONALLY ASSESSING MOTOR SKILLS

Using systems that children already engage in within their daily lives that increasingly include touchscreens and other computational tools, makes building assessment into the background appealing. For example, Mock et al. (2018) used touch trajectories during a multiple-choice format math test to predict ADHD. For regression of overall ADHD scores, their mean squared error was 0.096 on a four-point scale ($R^2 = 0.567$). They demonstrated classification accuracy for increased ADHD risk appropriate for use alongside other clinical diagnostics but not on its own (91.1%). Although far from being ready to support ADHD clinical work, as of now it has not been tested with people with ADHD, the Snappy App (Young et al., 2014) and its gaming “in the wild” counterpart (Craven et al., 2014) show some promise in terms of measuring ADHD-related symptoms. These approaches are novel and innovative and should be explored further with both children and adults with ADHD diagnoses or who self-report ADHD symptoms and can be diagnosed as part of a rigorous research study.

VR can be a particularly appealing platform for testing motor, spatial, and physical abilities because it can represent a fully controlled large area in a relatively small physical space. Additionally, data collected by wearable sensors and the VR environment itself provide vast amounts of data with which to run diagnostic and research tests. For example, in a study that included 51 children with ADHD, Farran et al. (2019) used a VR spatial navigation task to test hypotheses around co-occurrence...