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Reviews

Current State and Model for Development of Technology-Based Care for Attention Deficit Hyperactivity Disorder

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Abstract

***Introduction:** Care (i.e., evaluation and intervention) delivered through technology is used in many areas of mental health services, including for persons with attention deficit hyperactivity disorder (ADHD). Technology can facilitate care for individuals with ADHD, their parents, and their care providers. The adoption of technological tools for ADHD care requires evidence-based studies to support the transition from development to integration into use in the home, school, or work for persons with the disorder. The initial phase, which is development of technological tools, has begun in earnest; however, the evidence base for many of these tools is lacking. In some instances, the uptake of a piece of technology into home use or clinical practice may be further along than the research to support its use. **Methods:** In this study, we review the current evidence regarding technology for ADHD and also propose a model to evaluate the support for other tools that have yet to be tested. **Results:** We propose using the Research Domain Criteria as a framework for evaluating the tools' relationships to dimensions related to ADHD. **Conclusion:** This article concludes with recommendations for testing new tools that may have promise in improving the evaluation or treatment of persons with ADHD.*

Keywords: *behavioral health, e-health, mHealth, technology, pediatrics*

Introduction

Attention deficit hyperactivity disorder (ADHD)[1] is the most common childhood neurodevelopmental disorder, with a prevalence of ~5%.[2] Pharmacological intervention[3] is the most common treatment for ADHD[4,5]; it is successful in most instances, although it does not always cause symptom reduction.[6] Parents and treatment providers are interested in nonpharmacological interventions with or without medication.[7,8] Furthermore, nonpharmacological interventions delivered through technology may be appropriate for children with ADHD who have an insufficient response to medication or who cannot tolerate its side effects.[9]

This article reviews current evidence-based technology (i.e., programs, Web sites and devices) and proposes a model to implement new technology for ADHD care. It also reviews technologies that may potentially address challenges associated with ADHD, as well as how they fit the proposed model. This article uses the Research Domain Criteria (RDoC) as a framework to present potential uses of consumer technologies.[10]

Evidence-Based Technology in ADHD Care—Direct Patient Care

Due to increased usage of consumer technologies (e.g., smartphones), technology-based psychological interventions are now easily accessible. Given the flexibility, availability, and cost effectiveness of computerized therapies,[11] these interventions may be an effective form of ADHD care. However, translation of technological interventions from the laboratory to the home is limited by a lack of evidence-based studies regarding use in the community. In addition, most technologies with potential benefits for ADHD care were developed for the general population, so there is the added necessity of testing them specifically for persons with ADHD.

Computerized working memory training (CWMT) is one area where technology has been specifically assessed for ADHD. CWMT has generally been shown to improve WM capacity for individuals with ADHD,[12,13] but generalizability to other cognitive domains has remained controversial.[14] Two randomized controlled studies showed improvement in parent-rated ADHD symptoms following CWMT.[15,16] However, one randomized, controlled double-blind study showed that use of CogMed®, a leading CWMT program, reduced off-task behavior during an academic task, but did not affect parent-rated ADHD symptoms.[17] In addition, a meta-analysis[18] on seven CWMT studies that applied evidence-based treatment criteria[19] showed mixed findings regarding generalization effects. Another recent meta-analysis from the European

ADHD Guidelines Group[20] also concluded that CWMT improved WM, but did not change ADHD symptoms or academic performance.

In contrast, evidence for computerized progressive attentional training (CPAT), which is a novel technology that trains users in orienting of attention and in improving sustained, selective, and executive attention, appears promising. A randomized controlled CPAT efficacy study[21] found significant improvement in children with ADHD on both academic tests and behavior ratings of inattention and hyperactivity–impulsivity. However, no follow-up study has been conducted to demonstrate the long-term efficacy of CPAT.

In addition to CPAT and CWMT, self-monitoring is beginning to accrue a base of evidence. Actigraphy, which measures movement, may assist those with ADHD to monitor their fidgeting behavior by providing feedback on its frequency and intensity.[22] A small pilot study[23] of two children with ADHD showed that limb monitoring (through Nintendo's Wiimote®) combined with vibration feedback increased awareness of inappropriate behavior and improved inhibitory control over movement. Clearly, studies with larger samples are needed to verify these results.

Evidence-Based Technology in ADHD Care—Support for Providers and Systems

Other evidence-based studies support the effectiveness of health information technology (HIT) and Telemental Health in improving the quality of ADHD care.[24] Even though these technologies provide support to the general medical community, many studies show specific benefits to ADHD care. HIT includes electronic health records (EHRs), which are an effective tool in improving the quality of ADHD care.[24] A survey of pediatricians showed that EHRs with ADHD-specific templates improved effectiveness in diagnosis, treatment, and documentation of ADHD by prompting clinicians to assess for and record ADHD symptoms.[25] A multisite study showed that pediatricians were highly satisfied with myADHDportal®, which is another ADHD-specific HIT, and would recommend it to their peers.[26] This online platform integrates several quality improvement features for healthcare providers, including a wizard for mapping patient flow and a guide for the Plan-Do-Study-Act cycle.[27] It increased the rate of implementation of American Academy of Pediatrics-recommended care practices and improved the quality of ADHD care in community-based settings.[28]

Telemental health may improve child and adolescent psychiatric care,[29] especially in underserved populations. Among children and adolescents with ADHD, there are many recent randomized controlled trials supporting the effectiveness of telemental health in both pharmacological[30,31] and behavioral[31,32] interventions. For example, teleconferencing allows parents to train remotely in ADHD behavioral interventions. Parents who learned intervention skills through videoconferencing versus face-to-face training had equal improvement on symptoms and parental disciplinary practice and were equally satisfied with both formats.[33]

In summary, several positive results suggest that technology can target cognitive domains that are frequently affected in ADHD (e.g., working memory); however, stronger evidence is needed to support far-transfer effects and behavioral generalization. Evidence for provider-specific tools is stronger, although these tools require more tests showing successful integration and maintenance in community practice. Fortunately, developers are creating consumer technologies that might be useful in ADHD care at a rapid pace. Even though these technologies have minimal evidence to support their effectiveness, we hypothesize that they are potentially effective for ADHD care.

ADHD RDoC Construct

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM),[1] impairing and developmentally inappropriate levels of inattention and/or hyperactivity and impulsivity are the key behavioral symptoms associated with ADHD.[34] While the DSM was developed based on clusters of clinical symptoms, it is less informed by objective neuroscience findings to identify etiology.[35] In contrast, the National Institute of Mental Health launched RDoC using a domain-based framework related to specific functions of behavior.[10] The goal of RDoC is to relate fundamental domains of behavioral functioning to underlying neurobiological components, conceptualized as disorders in brain circuitry.[36,37] RDoC is not a diagnostic system, but rather a structure for organizing research findings[10] related to mental health; its goal is classifying how behaviors and symptoms, which may appear in multiple diagnostic categories, relate to genes, molecules, circuits, and systems. Following the neuroscience framework proposed by Baroni and Castellanos,[34] ADHD is conceptualized within six RDoC domains: 1) reward-related processing; 2) inhibition; 3) sustain attention; 4) timing; 5) arousal; and 6) emotional lability. This framework can help categorize the electronic tools that have been developed for ADHD and may lead to more precise assessment and treatment.

Model to Implement Technology in ADHD (Tech Model)

Previous sections discussed the evidence base of technological care for ADHD, concluding that it is promising, but needs more research to grow. In this section, we propose a theoretical model for implementation and evaluation of technological interventions that target particular RDoC domains. We will first discuss the difference between training and support technologies; next, we will present these technologies within the RDoC domains organized into three components: (1) schedule setting; (2) difficulty matching; and (3) immediate feedback. We refer to this framework as the "Tech Model."

An important distinction in ADHD intervention technology is between training and support. Training repeatedly exposes a user to a task to improve ability. An example is Cogmed, a CWMT program. Support facilitates a skill while the technology is in use. An example is EHRs, which prompt providers to assess for common ADHD problems. This distinction is not a dichotomy; however, technologies exist on a continuum. Actigraphy, for instance, both trains and supports. While using an actigraph, a user receives motion feedback, leading to better inhibitory control. In addition, continued actigraph usage yields internalization of motion feedback, decreasing motion levels after the session. Training technologies develop skills that persist after use; in contrast, support technologies increase skill level during use, so skill improvement through support depends on usage frequency. Ideally, support technologies will also reinforce continued usage, helping users develop fluency and comfort with the technology itself.

Thus, both support and training technologies should train users. We propose that technologies include the following three components to maximize training potential (Fig. 1). First, after an initial assessment, the technology sets explicit goals and schedules. Since ADHD has a broad spectrum and a heterogeneous manifestation,[38] baseline symptom severity should be assessed to determine the degree of improvement needed. In addition, training duration must account for set goals so that users can train regularly. Individuals with ADHD are better at achieving smaller subgoals rather than larger goals set farther away.

Second, the technology matches difficulty to the user's skill. Following Csikzentmihalyi's flow theory,[39] difficulty level is optimal when it matches a user's skill level; this produces better concentration and more engagement.[40] Technology should match difficulty to skills for individuals with ADHD, which increases focus and enjoyment.

Third, the technology gives immediate feedback about performance. Convincing individuals with ADHD to practice consistently is challenging due to their significant motivational deficits. Immediate positive reinforcement can encourage task completion. When the user errs, immediate feedback leads to early correction. Technology should also track and present progress in an understandable way so that users stay aware of their performance and gain more from continuous use. In addition, technology can support variable ratio reinforcement

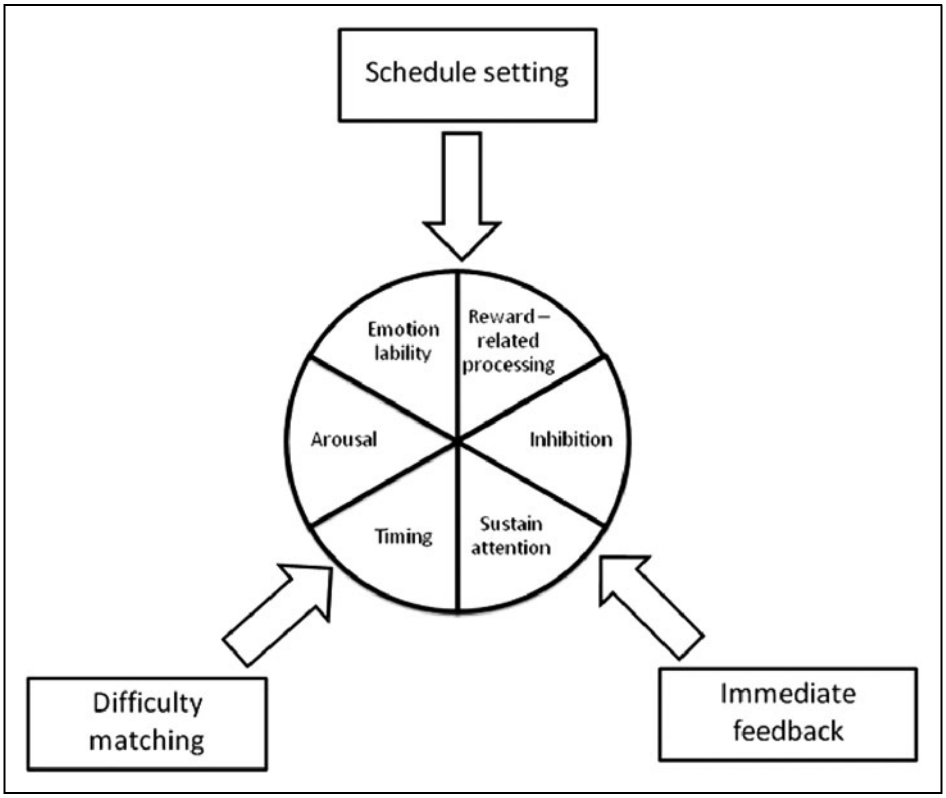

Fig. 1. Tech model following ADHD RDoC construct. This figure displays the three suggested components of the tech model that developers should consider when designing intervention technology for ADHD. These three components take into account the needs relevant to ADHD symptomatology. Schedule setting includes goal and time setting to address issues with task completion and time management. Difficulty matching includes adapting to the individual's current level of functioning and should change as the person's behavior changes; immediate feedback is salient and occurs as close as possible in time to when the behavior is emitted. The inner circle displays subcomponents based on constructs from the RDoC associated with ADHD that should be used to assess how well current technologies and future products are responsive to ADHD symptomatology. ADHD, attention deficit hyperactivity disorder; RDoC, Research Domain Criteria

Table 1. Summary of Potential Technologies Following Attention Deficit Hyperactivity Disorder Research Domain Criteria Constructs and Tech Model

ADHD RDoC CONSTRUCT	TECHNOLOGY	TYPE	SETS SCHEDULES?	MATCHES DIFFICULTY TO SKILL?	GIVES FEEDBACK?
Reward-related processing	Epic Win®	Support			X
Inhibition	MotivAider®	Training		X	
Sustain attention	Lenovo® emotion analytics software	Support			X
Timing	Task Manager Applications 30/30®, Due® Task Timer®, RescueTime®	Support	X		
Arousal	Brain Works®	Support			
Emotion lability	Zones of Regulation®	Training			X
Working memory	Cogmed®	Training	X	X	X

ADHD, attention deficit hyperactivity disorder; RDoC, research domain criteria.

scheduling, which is an effective strategy of behavioral modification in ADHD.

In the next section, within the Tech Model framework, we discuss existing technology targeting RDoC deficits and some possible improvements. Table 1 summarizes how well these technologies match RDoC for ADHD and the Tech Model.

ADHD RDoC Construct and Tech Model

REWARD-RELATED PROCESSING

The RDoC classification scheme includes the construct of reward-related processing, which is impacted in ADHD.[34] Individuals with ADHD have an altered response to reward that is reflected in impaired motivation.[41–47] This processing dysfunction is likely associated with alterations in the dopamine system.[48] Those with ADHD are more likely to choose smaller-sooner over larger-later rewards,[49,50] highlighting the salience of immediate feedback in engaging them. One hypothesis is that a lack of dopamine drives them to seek activities that stimulate dopamine release (e.g., video games).[51]

Gamification[52] is a technique used to increase motivation and interest by adding game play elements. Gamified tasks dispense badges, points, and levels to reward participants for meeting goals; this framework is similar to reward charts, which are widely used in ADHD behavioral modification. To our knowledge, there are no gamified programs specifically designed for ADHD behavioral modification and no studies have evaluated the effectiveness of gamified programs, but there are many behavioral reinforcement apps that we hypothesize will be effective at increasing motivation in ADHD.

EpicWin® (www.rexbox.co.uk/epicwin) is a gamified technology that might help users with ADHD overcome their tendency to focus on immediate rewards. It is a support technology that uses tropes from role-playing games to increase the fun of using a task management system. When a user checks off a task, EpicWin rewards the user with experience points. The user's avatar gains levels, rare items, and increased abilities when the user accrues enough experience. By giving immediate feedback, EpicWin implements the Tech Model's third component.

INHIBITION

Children with ADHD underperform in tasks that require inhibitory control.[53–55] Challenges with inhibitory control may underlie symptoms of hyperactivity, impulsivity, and inattention.[56,57] One technique that may help individuals with ADHD improve focus and inhibitory control is self-monitoring,[58–60] which teaches an individual to become aware of a behavior with the goal of reducing its frequency.[61] Self-monitoring through tactile[62] and verbal[63] prompts has been shown to improve academic and on-task behaviors in children with ADHD. Thus, technology for self-monitoring may lead to improved response inhibition. For example, MotivAider®,[64] a small electronic device, may help users maintain focus by providing a tactile prompt (vibration) to renew attention at various time points so that users inhibit responses to distractions. Small pilot studies have shown that MotivAider can increase on-task behavior in children with autism[65] or ADHD,[66] and in students attending special education classrooms.[67] MotivAider implements the second component of the Tech Model; schedules can be matched to the user's skill level and it can vibrate at a customizable fixed or variable rate.

SUSTAINED ATTENTION

Sustained attention,[34] a common challenge in ADHD, is the ability to maintain attention over time.[68] Interestingly, some studies suggest that repeated presentation of distractors temporarily enhances the performance of those with ADHD on attentional tasks, possibly by optimizing arousal.[69,70] Thus, technologies that systematically present distractors may target distractibility symptoms in ADHD. Lenovo® emotion analytics software[71] is a support technology that may improve sustained attention in the actual classroom. It tracks student attention by recognizing facial gestures and graphing data on a real-time monitor. With this information, teachers can determine when to take corrective actions that may in turn improve student attention. This software provides continuous monitoring of facial gesture data, although the functional relationship between facial gestures and attention requires future exploration. Lenovo's software may improve sustained attention in the classroom for students with ADHD by providing immediate feedback on student's individual performance, which is consistent with the third component of the Tech Model.

TIMING

Individuals with ADHD are commonly impaired in three major timing domains: motor timing; perceptual timing; and temporal foresight.[72] Timing impairments are associated with neurocognitive measures in intelligence, working memory, attention, inhibition, and clinical behavioral ratings.[72,73] Moreover, time perspective and future planning may be related to one's level of devaluing future rewards.[74] Time perspective also impacts one's ability to plan and organize, which are key areas of dysfunction in ADHD.[1] Currently no consumer technology directly targets all three timing domains, but several programs target perceptual timing, which may facilitate the ability to estimate time intervals among individuals with ADHD. These support technologies include task manager apps such as 30/30®, Due®, Task Timer®, and Rescue Time®,[75] which create to-do-lists and explicitly show time spent. Users increase their awareness of time usage and as a result can improve time management skills. Although no study has evaluated these apps for effectiveness in the ADHD population, we hypothesize that they can improve organization. In accordance with the Tech Model's first component, these apps set concrete schedules, but they lack difficulty matching and immediate feedback. As a result, users may lose interest in using them.

AROUSAL

Both hyperarousal and hypoarousal can be found in individuals with ADHD[34]; thus, technologies that can both increase and decrease arousal might be useful in modulating the symptoms of the disorder. One mobile application was designed to regulate arousal is Brain Works® (www.sensationalbrain.com/app). With this technology, a user selects their environment and how they feel (e.g., "slow and sluggish" or "fast and stressed"). Brain Works then prompts the user to choose a strategy (e.g., action songs or ball pass) to help them feel "just right" again. Brain Works is a support technology, and so, its usefulness is related to how often it is used. It does not train the user to repeatedly use the technology or does it implement any of the three components in the Tech Model. As a result, Brain Works may not maintain usefulness for individuals with ADHD in the long run.

EMOTIONAL LABILITY

Mood changes among individuals with ADHD are often characterized by quick transitions to excitability or depression.[76] This lability may be decreased by technologies that train users in emotional regulation. For example, Zones of Regulation® (www.zonesofregulation.com) is a game-based learning tool designed to teach users to recognize and regulate their emotions and responses. Players choose a character and then learn about the four different "zones" of emotions (calm/focused, anger/terror, excited/anxious, and sad/tired). After the explanation of a particular zone, users develop their own "toolbox" of methods to deal with associated emotions. Consistent with the third component of the Tech Model, users answer questions about emotions and receive virtual rewards (e.g., speedier shoes) for correct responses. Devices that may improve emotional stability for parents of children with ADHD are also under development.[77]

Recommendations and Future Directions

Many tools for addressing challenges associated with ADHD are currently available or in development, but the majority awaits testing in randomized placebo-controlled trials. For technologies in the development phase, we recommend designers consider the three suggestions in the Tech Model as they plan their products. In addition, when designing a support technology, we recommend developers take into consideration how difficult it is to maintain the interest of individuals with ADHD in the long term; we hope they will implement the specific steps outlined above to keep users engaged. A full set of recommendations for implementing the Tech Model is beyond the scope of this article. For inspiration, designers might look toward Cogmed, which is an example of a tool that integrates many of the features of the Tech Model. Please see Table 1 for how technologies mentioned in this article fit the Tech Model.

Conclusion

This article discusses evidence-based technology in ADHD, displays a model to select technology for symptoms, and examines existing technologies that target ADHD deficits consistent with RDoC domains. Because most potential technologies were not specifically designed for ADHD care, users may find it valuable to consider the role of technology in treating ADHD through the RDoC construct. In addition, rigorous and sophisticated clinical trial designs are necessary to investigate the feasibility and utility of technologies for the ADHD population. We conclude that currently there are many opportunities to design personalized, precise low-cost tools that have the potential to significantly improve options for evaluating and treating persons with ADHD.

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No competing financial interests exist.

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