Updates in technology-based interventions for attention deficit hyperactivity disorder

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Purpose of review
Technological advancement has led to the development of novel treatment approaches for attention deficit hyperactivity disorder (ADHD). This review aims to review recent studies which employ the use of technology to treat ADHD, with particular focus on studies published during a 1-year period from February 2019 to February 2020.

Recent findings
Most recent studies involved children aged 12 years and below. Interventions included cognitive training through games, neurofeedback and a combination of several approaches. More novel approaches included trigeminal nerve stimulation and brain–computer interface, and studies had utilized technology such as X-box Kinect and eye tracker. There was a shift towards delivering intervention at home and in school, enabled by technology. The study outcomes were variable and mainly included executive functioning measures and clinical ratings. These interventions were generally safe with few reported adverse events.

Summary
Technology has enabled interventions to be delivered outside of the clinic setting and presented an opportunity for increased access to care and early intervention. Better quality studies are needed to inform on the efficacy of these interventions.

Keywords
attention deficit hyperactivity disorder, attention training, cognitive training

INTRODUCTION
Attention deficit hyperactivity disorder (ADHD) is among the most prevalent child psychiatric conditions [1–4]. This neurodevelopmental disorder can persist into adulthood and result in significant adverse health and psychosocial outcomes including higher incidence of comorbid mental health disorders, occupational difficulties and marital conflicts; hence ADHD is associated with significant burden [5–7]. Pharmacological and psychosocial interventions are the main evidence-based approaches [8–11]. However, due to the limitations associated with these treatments including undesirable side effects, an intense level of commitment and unclear long-term benefits, alternatives which are effective, safe and cost-efficient are needed [12–14].

Understanding the pathophysiology of ADHD is necessary to enable the search for other intervention approaches (Fig. 1). Although stimulant and non-stimulant medications correct the underlying neurochemical (catecholamine) deficit, neuroimaging studies have helped identify affected brain networks in ADHD. These include the ventral attention, frontoparietal, default mode and visual networks [15]. ADHD has long been associated with executive function deficits including organization, working memory and inhibition [16,17]. Cognitive training could reducing these deficits by strengthening key neural networks, leading to overall functional improvement [18,19]. Neurofeedback therapy targets electroencephalogram (EEG) abnormalities such as excessive cortical slowing and increased theta waves (with corresponding reduced beta-theta ratios), another reflection of the underlying network abnormalities [20–23]. Neurofeedback therapy has been shown to strengthen the brain’s attentional circuits [24].
Others have examined the use of physical exercise which can lead to neuroplastic changes and neurophysiological changes such as increased levels of fronto-striatal catecholamines [25,26].

Technological advancement has led to more specific adaption of intervention options for ADHD. Indeed, progress in technology has reduced the reliance on mental health professionals to administer intervention and allowed for a more cost-effective and flexible delivery of treatment [27]. In their review of technology-based care for ADHD, Benyakorn et al. [28] categorized the use of technology into direct care provision (e.g. computerized cognitive training) and supporting care provision (e.g. health information technology). It is critical to fully understand the emerging evidence around the domains of ADHD difficulties in which technology has been applied to address, describe associated key findings, as well as identify any limitations. This rapid review will provide an update to the current empirical base by identifying research involving technology for treating ADHD, with particular focus on the preceding 1-year period.

**METHOD**

Studies were identified through a systematic search across the following electronic databases: PsycINFO and MEDLINE. The search terms used were (attention deficit hyperactivity disorder) in combination with (intervention, programme, treatment, training, therapy) and (computer, Internet, technology, video, online). The respective terms with truncation were first searched and subsequently combined using Boolean searching. Specific key words were also identified in empirical articles arising from the initial search, and further searches utilized combinations of the following search string: neurofeedback OR electroencephalogram OR transcranial-magnetic OR brain OR executive function OR cognition OR virtual reality OR augmented reality.

A study was deemed to be suitable for inclusion if it met the following criteria:

1. Examined the effectiveness of a technology-based intervention for ADHD,
The intervention was tested on both children and/or adults with ADHD,

The intervention was directed to improve primary ADHD symptoms (e.g. impulsivity, inattention),

Written in English,

Published in a peer-reviewed journal (dissertations, book chapters were excluded),

Published between February 2019 to February 2020.

The second author with the help of her intern independently reviewed the included abstracts according to the inclusion criteria outlined above. Any further duplication of studies and/or data was removed. Discrepancies were discussed, and the first author was consulted where appropriate. The full text of studies that met the selection criteria were then retrieved, and reviewed by the authors to ensure their relevance. Figure 2 illustrates the search and inclusion process.

**SUMMARY OF MAIN FINDINGS**

In all, 15 studies fulfilled all the selection benchmarks and were included. The majority of the identified studies offered treatment for young persons' between the age of 5–17 years old \((n = 14; 93.3\%)\). These interventions were offered through a variety of technology-assisted modalities. Duration and intensity of the treatment differed across the studies. Table 1 presents a detailed summary of the characteristics of the identified studies.

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**Figure 2.** Information about study screening, selection and inclusion.
## Table 1. All eligible studies identified during systematic review

| Source | Treatment condition and sample size | Age range in years (M) | Intervention format | Primary outcome measure and selected secondary outcomes | Outcome at follow-up |
|--------|-------------------------------------|------------------------|---------------------|------------------------------------------------------|----------------------|
| Kollins et al. (2020) | 1: AKLT01 (n = 180) 2: Control (n = 168) | 8–12 (1: 9.7; 2: 9.6) | Tablet-based, 20 sessions over 4 weeks | TOVA Attention Performance Index | 1 > 2 |
| Benzing and Schmidt (2019) | 1: Exergame intervention (n = 28) 2: Wait list Control (n = 23) | 8–12 (1. 10.63) | X-box Kinect, 24 sessions over 8 weeks | 1. Simon task 2. Modified Flanker Task 3. Colour span backward task | 1. 1 > 2 2. 1 > 2 3. 1 > 2 |
| Bioulac et al. (2019) | 1: Neurofeedback 2: Methylphenidate | 7–13 | Home-based neurofeedback | 1. Clinician ADHD RS IV total score | NA (study protocol) |
| Capodieci et al. (2019) | Intervention in 2 groups: 1: ADHD (n = 12) 2: Typically developing (n = 15) | 6–8 (1. 7.25; 2. 7.2) | Visuospatial WM and metacognition training (group + individual) | 1. Backward Corsi Blocks test 2. Go/No-Go task | 1. 2 > 1 2. 2 > 1 |
| Davis et al. (2019) | 1: Executive function training 2: Placebo | 8–12 (1. 10.6; 2. 10.5) | WM, inhibition and cognitive flexibility training | Near transfer: CBTT, Stop task, TMT Far transfer: DBDRS, BRIEF | 1 = 2 |
| Fontes et al. (2020) | 1. Time-estimation task exposure (n = 11, crossover) 2. Control (n = 11, crossover) | 20–30 (22.4) | Mobile app for time estimation task, 15 min/day × 30 days | ADHD-APA, Behavior data, EEG | 1 > 2 |
| Garcia-Baos et al. (2019) | 1. RECOGNeyes, eye tracker version 2. RECOGNeyes, mouse version Total N = 28 | 8–15 (11.05) | Laptop game, 9 sessions over 3 weeks | BGaze system game attention assessment tasks | 1 > 2 |
| Groeneveld et al. (2019) | Neurofeedback + heart rate variability biofeedback + psychoeducation (n = 100) | 6–17 (10.6) 18–51 (32.1) | 30 Sessions by trained EEG technicians | ASEBA AD/H T score | Post < pre |
| Lim et al. (2019) | 1: BCI-based attention training (n = 85) 2: Wait list control (n = 87) | 6–12 (8.6) | 24 Sessions over 8 weeks, by trained therapists | ADHD Rating Scale | 1 > 2 at 8 weeks |
| McGough et al. (2019) | 1: Trigeminal nerve stimulation (n = 32) 2: Sham (n = 30) | 8–12 (10.4) | Nightly over 4 weeks | ADHD Rating Scale | 1 > 2 at 4 weeks |
| Minder et al. (2019) | 1: CT (n = 31) | 8–14 (10.5) | 10–12 weeks | Conners-3 by 1. Parents 2. Teachers | Parents: post > pre Teachers: post = pre |
| Oliveira Rosa et al. (2019) | 1: CT + stimulant (n = 10) 2: Control + stimulant (n = 10) | 8–13 (1: 10.9; 2: 11.9) | Computerized ACTIVATE, 48 sessions over 12 weeks | Executive function tasks | 1 = 2 |
| Rajabi et al. (2019) | 1: Neurofeedback + CT (n = 16) 2: Wait list (n = 16) | 1: (10.2) 2: (10.05) | 30 Sessions over 10 weeks | 1. IVA 2. Conners Rating Scales-Revised | 1: 1 > 2 2: 1 > 2 |
| Sluiter et al. (2019) | Self-monitoring intervention (n = 7) | 9–12 (10.1) | 6-Week observation | 1. Observed off-task behaviour 2. Teacher reported task behaviour | 1: Post > pre 2: Post = pre |
| Smith et al. (2019) | 1: IBBS (n = 13) 2: TAU (n = 16) | 5–9 (7.14) | CT, physical exercise, behaviour management | ERP measures of attentional control | 1 > 2 |

ADHD-APA, Attention Deficit Hyperactivity Disorder Scale-Adult and Adolescent Version; BRIEF, Behavior Rating Inventory of Executive Function Questionnaire; CBTT, Corsi block tapping task, stop task; CT, cognitive training; DBDRS, disruptive behaviour disorder rating scale; EEG, electroencephalogram; ERP, event-related potential; IBBS, integrated brain, body, and social; IVA, integrated visual and auditory continuous performance; TAU, treatment as usual; TMT, trail making task; TOVA, test of variable attention; WM, working memory.
Digital interventions and serious games

With today’s connected youth, cognitive training through games may be more engaging [29–33]. Termed ‘serious games’ due to their training purpose rather than for entertainment, these digital games for ADHD can train several cognitive domains [34]. They can also incorporate biofeedback, virtual reality and augmented reality to facilitate mastery and transfer effect to untrained domains and ultimately, to daily life situations [35–38]. Such digital training has been shown to lead to EEG changes in the prefrontal cortex [39]. Reviews of previous studies on serious games for ADHD had cited concern regarding the limited quality of most studies [40,41].

Kollins et al. [42] reported their large randomized, double blind, parallel-group, controlled trial involving 346 children aged 8–12 years. The intervention programme was a home-based digital game with cognitive training components involving attention control and set shifting, within built real-time adaptive mechanism to personalize the training level. Although there was evidence of effective attention control (i.e. near transfer effect) post-intervention, these skill set was not generalized to new contextual settings (far transfer effect).

Studies have examined metacognitive therapy in adults with ADHD [43]. To enhance far transfer skills, Capodieci et al. [44] incorporated metacognitive elements such as active reflection and promotion of self-awareness to the working memory training tasks. Their open-label study suggested that both children with ADHD and typically developing children showed some transfer effect to other executive functions after intervention, with the ADHD group showing improved behavioural rating.

Cognitive therapy may be more beneficial for a subgroup of children with ADHD, especially those with more severe executive function deficit [45–48]. Dovis et al. tested this hypothesis in their placebo-controlled study to elucidate the effect of pretraining executive function as a moderator of outcome of a gamified home-based 5-week training programme. However, those with poorer pretraining working memory and inhibition did not benefit more [49].

In an interesting study conducted in a classroom setting, teachers delivered the gamified attention training to students aged 5–9 years. Compared with the control groups, students in the intervention group showed improved attention and hyperactivity ratings, even at 6 months’ follow-up, although there were no cognitive or academic gains [50]. Although the study did not specifically enrol children with ADHD, it represents an opportunity for upstream school-based intervention.

Earlier studies have shown that cognitive training results in increased activation in related brain regions [51,52]. In their functional MRI study of children with ADHD, de Oliveira Rosa et al. [53] found that those who received cognitive training and stimulant medication showed greater activation of the right fronto-parietal brain areas that mediate sustained attention after intervention, compared with those who received nonactive computerized intervention with stimulant medication. This added further evidence that cognitive training could normalize neural circuits in children with ADHD.

Future cognitive training programmes should involve several cognitive domains, be personalized to the individual needs and ability, include components to increase engagement as well as promote transfer of skills to daily tasks. Delivering interventions at home and in school can increase access to intervention and promote upstream intervention.

Neurofeedback and related therapy

Standard neurofeedback treatment protocols include sensori-motor rhythm neurofeedback, theta/beta neurofeedback and slow cortical potential neurofeedback [54]. Though many studies have reported positive results, reviews have highlighted the need for better quality studies, need to examine longer term efficacy and the lack of standardized training for therapists [55–59].

An alternative approach is Z-score neurofeedback which is less studied [60]. Groeneveld et al. [61] combined Z-score neurofeedback and heart rate variability training (biofeedback) in their study involving both adults and children with clinical and subclinical ADHD symptoms. They reported improvement in behavioural symptoms and normalization of EEG postintervention.

A novel brain computer interface-based intervention used machine learning technique to develop a unique algorithm utilizing the entire EEG spectrum, with feedback and training activities incorporated into a game [62–64]. Academic tasks were included to promote skills transfer. Their large randomized wait-list control trial involving 172 children aged 6–12 years diagnosed with ADHD found the effect size of the intervention was small, based on blinded clinician ratings [65]. A subgroup of the children underwent neuroimaging, which revealed that those with improved behavioural rating tended to exhibit increased functional network reorganization, especially within the salience/ventral attention network [66].

As we move towards personalized medicine, further research can uncover predictors of positive
response to neurofeedback [67]. Technology advancement has boosted the ease of programmed home-based neurofeedback treatment, removing the need for therapist training [68]. For instance, the multichannel EEG cap has now been replaced by the more user-friendly headband utilizing much fewer channels. One study to look out for is Bioulac’s head-to-head clinical trial comparing a novel home-based neurofeedback intervention with long-acting methylphenidate [69].

**Technology-assisted delivery of standard treatment**

Telehealth has been on the rise to improve access to mental healthcare, as communication technology like vide conferencing improves. Synonymous terms include telepsychiatry and telemental health. Telepsychiatry can be an effective way to deliver care for ADHD [70–74]. A review has concluded that telemedicine was cost-effective for children and suggested that research should also be conducted in adults with ADHD [75]. In the pipeline, there is a randomized controlled trial underway to investigate the efficacy of a web-assisted self-help programme for parents of children with ADHD [76].

Mobile apps have been developed to support young persons and their caregivers including parents, teachers and professionals, as well as adults with ADHD [77,78]. Despite the large number of apps available, they may not necessarily match the users’ needs and there has been little research done to properly evaluate them [79,80*].

Biederman’s study found that text messages could significantly improve timely refill of prescriptions in adult patients with ADHD [81]. The use of readily available technology can facilitate more effective delivery of evidence-based intervention and are potential quality improvement projects.

**Multidomain approaches**

Technology can combine the training of multiple domains into a seamless programme. In their randomized waitlist control trial, Johnstone et al. [82] tested a home-based gamified intervention combining working memory, inhibitory control and neurofeedback in 85 children aged 7–12 with clinical and subclinical ADHD. Behavioural improvement did not reach significance and the children became less engaged with further sessions. Similarly, Rajabi et al. [83] studied combined cognitive training and neurofeedback, and their sample improved in behavioural ratings and visual attention, compared with untreated controls. We are likely to see more similar multimodal intervention emerging.

Cognitively engaging physical exercise can increase cognitive performance in ADHD possibly through training the brain regions involved in higher order cognition [84,85]. Benzing and Schmidt [86] developed a home-based ‘exergaming’ intervention and tested the 8-week programme in 51 children aged 8–12 in their randomized waitlist-control study. Utilizing X-box Kinect to control movement, these adaptive games train strength, coordination and endurance, as well as cognitive functions of inhibition, attention and set shifting. The intervention group improved in their executive functions (inhibition, switching, updating), general psychopathology and motor abilities compared with the control group. In their multisite study, Smith et al. [87] combined computerized cognitive training and physical exercises in their intervention, which was delivered in a classroom setting by teachers and therapists. Their behaviour ratings at the end of the study did not differ from the control group which received psychosocial and or pharmacological interventions.

**Other approaches**

Neurostimulation induces longer term changes in brain excitability or neurotransmission through the application of electrical or magnetic stimulation [88*]. Trigeminal nerve stimulation (TNS) can activate higher brain centres through the nerve’s projections, including those involved in ADHD such as the locus coeruleus, thalamus and anterior cingulate cortex [89,90]. The Monarch external TNS System became the first medical device for treating ADHD to receive marketing authorization from the US Food and Drug Administration, based on the study by McGough et al. [91]. They conducted a blinded sham-controlled trial and randomized 62 children 8–12 years old with ADHD to 4 weeks of nightly treatment with active TNS or sham treatment [92*]. The intervention group improved significantly in their behavioural and clinical ratings. Though well tolerated, it remains to be seen if the results can be replicated in other clinical trials, and whether any improvement can be sustained over time.

García-Baos et al. [93*] hypothesized that eye gaze can therefore be a proxy measure for attention and inhibitory control. They designed a computerized game which utilized an eye tracker, to train the child’s visual attention control, to influence the attention network. The intervention group, when compared with the control group playing the same game without the eye tracker, showed improvement
in their impulsivity, reaction time and gaze control. More studies will be needed to support this approach.

Time estimation has recently gained interest, with studies suggesting interval-timing dysfunction being associated with ADHD [94–96]. In their study involving young adults with ADHD, Fontes et al. [97] showed, in their crossover study, that a training programme involving time estimation exposure tasks was promising in improving ADHD symptoms and cognitive function.

Monitoring sensors such as accelerometer and technology such as smartglasses were previously studied [98]. Sluiter et al. [99] used a timer to regularly remind seven students with ADHD in a special needs classroom to monitor their on-task behaviour. Although their observed off-task behaviour was significantly reduced, most of their executive functions did not improve except for inhibition. This approach is not likely to be a primary treatment but may be a tool to aid behavioural management in ADHD.

CONCLUSION

The use of technology has moved intervention for ADHD towards becoming home-based and even school-based, with the potential for individualization of treatment, improved access to care and early intervention. This exciting development is in the right direction towards personalized medicine and population health. The lack of high-quality trials to provide more reliable evidence for the efficacy of most intervention remains a significant challenge. More rigorous studies will be needed to inform us whether technology-based advancement contributes positively towards the accessibility of early intervention as well as the efficacy and challenges of home-based intervention. In addition, a combination of interventional components, and individualization of treatment appears feasible and may be promising.

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Conflicts of interest

The authors’ work was described and referenced within the article.
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