Popular interventions to enhance sustained attention in children and adolescents: A critical systematic review

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ARTICLE INFO

Keywords:
- Attention
- Intervention
- Children
- Adolescence

ABSTRACT

There are a myriad of interventions promoting activities designed to help enhance sustained attention in children and adolescents. In this systematic review, we critically evaluate the evidence behind three popular sustained attention training approaches—cognitive attention training, meditation, and physical activity. Seven databases were searched in addition to secondary searches. Cognitive attention training, meditation training or physical activity intervention studies aimed at improving sustained attention (randomised-controlled or non-randomised-controlled designs) in samples of children and adolescents (3–18 years) were included. We screened 3437 unique articles. Thirty-seven studies satisfied inclusion criteria. In general, cognitive attention training (\(n=14\)) did not reliably improve sustained attention. Physical activity (\(n=15\)) and meditation interventions (\(n=8\)) demonstrated somewhat more potential in enhancing sustained attention, but these effects should be considered preliminary and need to be replicated with greater methodological rigour. Cognitive attention training demonstrated very limited transfer to other aspects of attention. Notably, mindfulness training had rather consistent positive effects on selective attention. Across all three intervention types, there was very weak evidence for transfer to other aspects of cognition, behaviour, and academic achievement. The paper concludes with methodological recommendations for future studies to strengthen the evidence base.

1. Introduction

Attention is a cognitive process that is fundamental to learning and functioning (e.g., Lundervold et al., 2017; Slattery et al., 2022). It comprises multiple independent but related components (Raz and Buhle, 2006). Sustained attention (commonly referred to as ‘concentration’ or ‘focus’ in everyday life) refers to the ability to continuously maintain focus on goal-directed activity over time (Sturm and Willmes, 2001). From reading a book to listening to a talk, sustained attention is an elementary cognitive function that underlies more complex forms of attention, such as divided or selective attention, and other cognitive domains, such as memory and learning (Sarter et al., 2001). In the last few years, studies of interventions promoting activities designed to enhance sustained attention and other cognitive functions in children have bourgeoned. In this paper, we review the evidence for three common intervention approaches (cognitive attention training, physical activity, and meditation training) for improving sustained attention in children and adolescents and provide a systematic review of the studies in this field.

1.1. Sustained attention

Sustained attention refers to the ability to maintain focus and engagement to task goals over time, particularly in conditions of monotony and repetition (Unsworth and Robison, 2020). Robertson and colleagues (1997) defined sustained attention as “the ability to..."
self-sustain mindful, conscious processing of stimuli whose repetitive, non-arousing qualities, would otherwise lead to habituation” (p. 747).

An important characteristic of sustained attention is that performance tends to decline over time (called the ‘vigilance decrement’; Parasuraman, 1979). These time-on-task effects have been demonstrated over both long durations (e.g., Mackworth, 1948) and short durations (e.g., Gillberg and Akerstedt, 1998). Another important aspect of sustained attention is that attention fluctuations from moment-to-moment. Sustaining an appropriate amount of attention is critical for task performance, but our ability waxes and wanes. Sustained attention fluctuates between ‘in the zone’ periods of low response variability and higher accuracy and ‘out of the zone’ periods of higher response variability and lower accuracy (Esterman et al., 2013, 2014). At any given moment, our capacity to sustain attention is determined by a dynamic interplay between cognitive factors, motivation factors, emotional factors, and arousal factors (McAvinue et al., 2015). Lapses in sustained attention can occur from a deficit in any one or a combination of these factors, which cause the individual to disengage from the task at hand.

A number of separate neural and neurophysiological networks have been linked to sustained attention. These include the default network, the frontoparietal network, the salience network, and the locus coeruleus norepinephrine system (Buckner and DiNicola, 2019; Langner and Eickhoff, 2013; Petersen and Posner, 2012; Sridharan et al., 2008). The default mode network is a large-scale brain system, which includes the medial prefrontal cortex, precuneus and posterior cingulate, lateral temporoparietal cortex and medial temporal lobe. This system tends to be active during periods of rest and/or periods of internally-directed thought (e.g., mind wandering) and ‘deactivated’ during externally-oriented sustained attention tasks (Buckner and DiNicola, 2019). The right frontoparietal network plays an important role in the cognitive control of sustained attention (Petersen and Posner, 2012). This network demonstrates increased activity during externally-directed sustained attention tasks and decreased activity with time on task (Coull et al., 1996; Paus et al., 1997). Thus, when sustained attention is externally directed, the frontoparietal network is typically activated, while the default mode network is typically deactivated. The salience network, which includes the insula, amygdala, dorsal anterior cingulate and the frontal poles detects salient information (e.g., information related to emotion and reward; Seeley et al., 2007) and maintains the focus of attention on relevant stimuli for further processing by regulating activity within other networks (Sridharan et al., 2008). It is thought that the salience network engages the frontoparietal network to focus on goal-directed activity (Sridharan et al., 2008). In addition to these neural networks, the locus coeruleus norepinephrine system plays a critical role in sustained attention, subserving arousal. The system has widespread connections to the frontoparietal and salience networks (Unsworth and Robison, 2017). Optimal locus coeruleus norepinephrine activity is thought to reduce background noise and increase signal-to-noise ratios, ensuring greater processing of target stimuli (Esterman and Rothlein, 2017). This is consistent with the Yerkes Dodson Law, which proposes that any task will have an optimal level of arousal below and beyond which performance will decrease (i.e., there is an inverted-U relationship between arousal and task performance; Yerkes and Dodson, 1908).

Sustained attention develops through childhood and into adulthood with a period of accelerated development occurring in early and middle childhood (approximately 6–9 years; Betts et al., 2006; Lewis et al., 2017; Lin et al., 1999; McAvinnie et al., 2012; Yan et al., 2018). The ability to sustain attention is a key factor influencing children’s academic achievements (e.g., Steinmayaer et al., 2016). However, poor sustained attention is a relatively common problem in childhood (Döpfner et al., 2008) and certain neurodevelopmental disorders and learning disorders are characterised by deficits in sustained attention. Attention problems at school entry (age 5–6 years) have been shown to predict success in reading and mathematics at the end of primary school (age 11–12; Duncan et al., 2007) and at the end of formal schooling (age 17; Breslau et al., 2009). Moreover, problems with attention have been shown to undermine traditional academic interventions (e.g., tutoring; Rabiner and Malone, 2004) and early attention problems have even been shown to predict graduation from high school (Pingault et al., 2011). Given the importance of sustained attention in childhood, the possibility of training sustained attention (i.e., improving the ability to pay attention in typically developing children and ameliorating sustained attention deficits in children with neurodevelopmental conditions) has received considerable interest and several training methods have been employed. Currently, there are a myriad of attention training interventions promoting activities designed to help enhance sustained attention.

1.2. Approaches for improving sustained attention

Two broad approaches for improving attention have been identified: cognitive attention training and state training (Tang and Posner, 2009).

Cognitive attention training involves the repetitive practice of a cognitive task thought to exercise neural networks related to attention (Posner et al., 2015). This type of training is often called attention training, cognitive training, network training or brain training. Cognitive attention training focuses on improving the cognitive control aspect of sustained attention involving the frontoparietal network with the practice of tasks designed to exercise this system. The alternative approach, state training, involves practice designed to develop a brain state that is thought to influence attention and other networks (Posner et al., 2015). This type of training may also involve networks but does not include cognitive tasks designed to specifically train an attentional network (Posner et al., 2015). A range of methods have been suggested for training a brain state that promotes attention: physical activity and meditation are two examples of state training approaches (Posner et al., 2015; Tang and Posner, 2009). State training methods likely put the brain and body into an optimal state for sustaining attention. Physical activity likely primarily targets sustained attention via physiological arousal though may also target cognitive control when the kind of exercise involves a requirement for continued focus on goal-directed stimuli. Meditation training likely targets both physiological and cortical arousal. It may also work through the salience network, calming the emotions and enabling a reappraisal of what should be attended to, and the frontoparietal network, maintaining focus on certain stimuli while excluding others. In practice and school settings, cognitive attention training, meditation and physical activity are among the most popular intervention approaches for enhancing ‘concentration’ or ‘focus’. A recent commentary on behavioural interventions for cognitive enhancement highlighted the need for well-defined and precise terminology to describe interventions and intervention outcomes (Green et al., 2019). To date, the lack of precision in the literature precludes a definitive conclusion on whether cognitive attention training, meditation and physical activity enhance sustained attention capacity. The current review provides a fine-grained critical analysis of these sustained attention training interventions and attempts to answer that question.

1.3. Cognitive attention training

In recent years, cognitive attention training has been a common intervention approach for targeting children’s sustained attention (e.g., Rapport et al., 2013). The premise of training is that the repetitive practice of a specific task leads to improvements in the underlying neural network linked to the task (i.e., the frontoparietal network), which enhances the cognitive function(s) underpinned by the targeted neural network (Kerns et al., 1999; Tann et al., 2013). The objective is that these improvements would be sustained on a long-term basis. It is posited that if one’s sustained attention capacity increases, then performance in other cognitive or behavioural domains that are related to sustained attention should also increase (Peng and Miller, 2016). Several
cognitive attention training programmes claim to train sustained attention in children (e.g., Pay Attention!, Aixtent, Attention Process Training), including some commercialised programmes (e.g., Tali Train, BrainTrain). Typically, training requires children to practice videogame-like attention tasks (among other tasks) delivered via computers or tablets with adaptive procedures (training task difficulty is automatically adapted to an individual’s level of performance) and reward systems to encourage motivation. It is widely accepted that practice on any cognitive task leads to improved performance on those same activities (Ratz et al., 2018), but the extent to which those improvements matter for other untrained tasks (e.g., academic achievement) is a matter of ongoing debate (Shipstead et al., 2012).

In a selective meta-analysis, Peng and Miller (2016) investigated the effects of cognitive attention training programmes on attention and other cognitive outcomes (all non-trained academic and cognitive measures) in populations of ADHD, learning difficulties and typically developing individuals. The results indicated that training improved performance on attention measures (objective and subjective combined) compared to controls with a medium effect size (Hedges’ g = .25) and transferred to measures of far transfer (Hedges’ g = .24). The findings led the authors to conclude that “attention is a malleable construct” (p. 83). However, the term ‘attention’ is a broad category and has limited descriptive value. This is because attention is not a unitary construct but rather comprises several distinct components (Raz and Buhle, 2006).

Thus, training may generate different effects on the various components of attention (e.g., sustained attention, selective attention, divided attention). The pertinent question is then: What aspect or aspects of attention are amenable to cognitive attention training? Notably, these findings are in direct contrast with an earlier review by Rapport et al. (2013) which found no significant effects of training targeting attention on attention outcome measures in children and adolescents with ADHD (i.e., no evidence of near transfer) though only 6 attention training studies were included.

1.4. Meditation

Another widespread approach for enhancing sustained attention in children is meditation, particularly mindfulness meditation (e.g., Posner et al., 2015). Mindfulness has been defined as “the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment” (Kabat-Zinn, 2003, p. 145). During mindfulness practice meditators typically select a point of focus (e.g., the breath) and direct their attention to that point over time (Bishop et al., 2004). If one’s mind wanders from the point of focus, thoughts or sensations are acknowledged and further processing is inhibited as attention is directed back to the point of focus (Bishop et al., 2004). Mindfulness training may improve children’s self-regulation as it targets both top-down (controlled) and bottom-up (automatic) processes (Zelazo and Lyons, 2012). That is, the effortful regulation of attention that is key to mindfulness practice trains children’s cognitive control (e.g., sustained attention is required to maintain awareness of the present moment) while simultaneously modulating potential bottom-up influences on self-regulation (e.g., arousal and motivation). These bottom-up influences interact with top-down pathways in complex ways to facilitate the recruitment of top-down processes (Zelazo and Lyons, 2012).

Recently, Mak et al. (2018) reviewed the efficacy of mindfulness-based interventions for improving attention and executive function in children and adolescents aged 5–18 years. The studies recruited children/adolescents that were typically developing, diagnosed with ADHD, orphans, in correctional schools/institutions or had reading difficulties. The authors found that out of 13 studies, 5 studies demonstrated a significant positive effect of training on at least one measure of attention or executive function; however, only one study found a positive effect of mindfulness on sustained attention (assessed using the Test of Variables of Attention).

1.5. Physical activity

Physical activity is another popular approach for enhancing sustained attention in children (e.g., Posner et al., 2015). Empirical and meta-analytic studies have shown broad effects of chronic physical activity on children’s cognition, including attention (e.g., Vazou et al., 2019). Several mechanisms have been proposed to explain the effects of physical activity on cognition. From a neurophysiological perspective, it is posited that exercise stimulates the synthesis and release of neurotransmitters such as norepinephrine, dopamine and serotonin which may improve cognitive functioning (Best, 2010; Moreau and Conway, 2013). The synthesis and release of norepinephrine is particularly important for sustained attention as it regulates the arousal factors that are required for maintaining optimal sustained attention (Sarter et al., 2001). The positive effects of exercise on sustained attention may also be attributed to increases in neuro-trophins such as brain-derived neurotrophic factor (Gottman et al., 2007; Hillman et al., 2008), which play a critical role in hippocampus functioning, synaptic plasticity, neurogenesis, and neuroprotection (Gottman et al., 2007). However, recently, some researchers (e.g., Diamond and Ling, 2016) have argued that cognitively engaging physical activity (e.g., physical activity that requires the allocation of attention and cognitive effort) is more beneficial for cognition than ‘mindless’ or ‘simple’ physical activity (e.g., physical activity without a cognitive component). Physical activity that is cognitively engaging (e.g., basketball, which requires children to focus their attention, scan the environment, anticipate the behaviour of teammates/opponents and so on) may have more of an effect on attention than physical activity with low cognitive engagement (e.g., running). This is because physical activity with a cognitive component is assumed to activate multiple mechanisms simultaneously (Best, 2010). Thus, this type of physical activity may impact arousal factors and top-down systems of attentional control underlying sustained attention.

In a recent meta-analytic review, de Greere and colleagues (2018) investigated the effects of long-term physical activity on multiple cognitive domains, including attention (selective, divided and sustained attention), executive functions (inhibition, working memory, cognitive flexibility and planning), and academic performance (mathematics, spelling and reading) in children aged 6–12 years. However, only one study examined the effect of long-term physical activity on attention, which used a measure of selective attention and found a large positive effect (Hedges’ g = 0.90). Notably, no studies focused on sustained attention or divided attention. Overall, there were small-to-moderate positive effects on several cognitive domains as well as on academic performance but there was no significant effect for each subdomain of academic performance (mathematics, reading and spelling). The authors noted larger effects for cognitively engaging physical activity compared to aerobic physical activity.

1.6. Criteria for evaluating approaches for improving sustained attention

Unfortunately, various methodological issues are prevalent in the literature evaluating the impact of behavioural interventions for cognitive enhancement (Green et al., 2019). In an excellent review, Simons et al. (2016) found insufficient evidence for the benefits of cognitive training on real-world cognition after finding major methodological shortcomings in published studies. The authors recommend a set of best practices for cognitive training interventions and use these standards to evaluate intervention studies cited on the websites of various cognitive training companies. These standards included adequate sample sizes, pre-registration, active control groups, matched groups at baseline, random assignment, outcome measures fully reported and analysed, outcome measures different to the trained task and blind assessors when using subjective outcomes (for more detail, see Simons et al., 2016). While Simons et al. (2016) focused specifically on cognitive training studies, these criteria are relevant for any intervention study aiming to enhance cognitive capacity. In this review, we
evaluate the quality of scientific evidence for each intervention study for enhancing sustained attention using these standards.

1.7. The current review

The current review updates and expands previous reviews by examining popular intervention approaches (cognitive attention training, physical activity, meditation) for specifically improving sustained attention in a single paper. We focused on two main questions:

1) Do interventions designed to enhance sustained attention improve performance on sustained attention tasks? If so, what intervention methods are most effective?

2) Do interventions designed to enhance sustained attention improve performance on other cognitive tasks (e.g., executive functions, academic outcomes) and behavioural measures (e.g., ADHD symptoms)?

Question 1 addresses whether attention training interventions are effective in improving performance on sustained attention tasks. Examining whether cognitive attention training, exercise and meditation improves performance on measures of sustained attention is of theoretical importance because it provides insight into whether sustained attention is malleable. Question 2 addresses transfer to other cognitive, academic and behavioural domains. This question is particularly relevant for practitioners, teachers, and applied researchers designing interventions targeting real-world outcomes/clinically relevant outcomes. To answer these questions, we synthesise studies of cognitive attention training, physical activity and meditation that aim to improve sustained attention in children and adolescents. We then discuss evidence for improvements in sustained attention and other aspects of cognition/behaviour from these attention training approaches and identify whether sustained attention and other cognitive/behavioural skills can be enhanced. Lastly, we make recommendations for future research.

2. Method

The protocol for this review was registered with PROSPERO: CRD42020193922.

2.1. Search strategy

The following bibliographic databases were systematically searched on June 19, 2020: EMBASE (via Elsevier), Medline (via Ovid), Medline (via EBSCO), APA PsychInfo (via EBSCO), The Cochrane Library (via Cochrane Library), Web of Science Core Collection (via ISI), and PubMed (via National Library of Medicine). The search strategy took the following form: (terms for physical activity) or (terms for meditation) or (terms for cognitive attention training) and (terms for sustained attention) and (terms for training). No time restrictions were placed on the search strategy. Supplementary searches were also performed. A grey literature search was conducted via Open Grey and the references of included studies/relevant systematic reviews were hand searched for studies. Where possible, authors of registered trials, protocol papers, conference proceedings were contacted to identify any unpublished studies. Searches were updated on June 5, 2021, using the same search strategy as the original search. The reproducible searches for all database searches are available at https://osf.io/8m2nh/. All identified studies were loaded into EndNote.

2.2. Eligibility criteria

Studies meeting the following criteria were included: a) randomised or non-randomised studies that compared an intervention group and at least one control group, b) intervention designs with a stand-alone cognitive attention training / physical activity / meditation programme aiming to enhance sustained attention capacity (studies had to describe a specific aim to improve attention or sustained attention), c) samples of children or adolescents aged 3–18 years (this age range was chosen to broadly capture the years characterised by development of sustained attention capacity), including typically developing children and children with neurological conditions / neurodevelopmental disorders / learning difficulties, d) the intervention was delivered over more than one session, e) employed at least one cognitive measure of sustained attention. Multi-domain training programmes (e.g., interventions training sustained, selective and divided attention) could also be included. Multiple papers based on the same study were compiled and included. For example, if multiple manuscripts reported data from the same trial, they were compiled and included for full evaluation. Studies were excluded when: a) samples comprised psychiatric patients (psychiatric groups can have sustained attention difficulties for a variety of reasons other than weaknesses in the cognitive systems underpinning sustained attention and, thus, were excluded from the review to make the groups more comparable), b) pre- and post-data for sustained attention was not reported or different measures of sustained attention were used at pre- and post-test, c) they were written in a language other than English, d) training effectiveness in enhancing sustained attention capacity could not be established due to explicit multicomponent interventions (this is because their design does not permit determining the effect of each stand-alone intervention, examples of such interventions were cognitive attention training + physical activity or cognitive attention training + strategy-based training or mindfulness training + parent training) or e) they examined the attention training technique (used for treating repetitive negative thinking) or attention bias modification training (used to modify attention bias to threat).

2.3. Screening

Following de-duplication in EndNote, the titles and abstracts of all studies were screened. Screening was conducted using Rayyan software. An initial sample of 10% were independently screened by two reviewers (ES, EOC) to ensure consistency in the screening process (n = 260). Inter-rater reliability was high (Cohen’s Kappa = 0.86). The remaining studies were single screened by ES. Where the title and abstract met the criteria (or if this was unclear), the full text article was retrieved and screened. Full-text screening was undertaken by ES and a random sample of articles (10%) was checked by another reviewer (EOC). Any disagreements between the reviewers regarding study eligibility were resolved through discussion and consensus. A second reviewer (EOC) was consulted if study eligibility was unclear at any stage. The screening process is graphically represented in Fig. 1.

2.4. Data extraction

Data from the included studies were extracted by ES and entered into an Excel spreadsheet. Under the following headings: publication details, methods, number of participants, participant characteristics, intervention, comparator, setting, statistical analyses, outcomes, results and other.
2.5. Quality assessment

The PEDro scale was used to assess the quality of all included full text studies. ES completed quality assessment. The scale is widely used to rate the methodological quality of clinical trials included in systematic reviews across health and medical research (Cashin and McAuley, 2019). This scale was chosen because it can be used to evaluate many different types of study designs (e.g., RCT, cluster RCT, crossover RCT). It comprises 11 items assessing external validity (item 1), internal validity (items 2–9) and statistical reporting (items 10–11). Items are rated yes (1) or no (0). A total score is computed by adding the ratings of items 2–11. Scores range from 0 to 10 with higher scores indicating greater methodological quality. Total PEDro scores are included in Table 3 (see Appendix A for each study’s ratings on individual items).

3. Review and discussion

In this section, we summarise the results of studies evaluating three popular intervention approaches (cognitive attention training, meditation, physical activity) for enhancing sustained attention and discuss whether certain methodological concerns apply. The evaluation of methodology is based on criteria outlined by Simons et al. (2016), which is described in the section ‘Criteria for Evaluating Approaches for Improving Sustained Attention’ (see Introduction). Table 1 provides the details of the 37 studies included in the review and Table 2 lists the relevant measures included in each study. Table 3 indicates the extent of positive effects on sustained attention and other cognitive/behavioural/academic outcome measures. In the table, we use colours to represent whether the intervention yielded 1) positive effects with few methodological concerns (dark blue), 2) positive effects with significant methodological concerns (striped blue), 3) no effects with few methodological concerns (dark yellow) or 4) no effects with significant methodological concerns (striped yellow).

3.1. Summary of intervention study results

An overview of each study can be found in Appendix B.

3.1.1. Cognitive attention training studies

In total, fourteen studies examined cognitive attention training in children and adolescents. Eight of these studies (1, 3, 4, 6, 7, 10, 13, 14) reported at least one positive near transfer effect to a measure of sustained attention; however, of these, five studies (1, 7, 10, 13, 14) had serious methodological limitations. Six studies (2, 5, 8, 9, 11, 12) found no statistically significant effects of training on sustained attention.

Three studies with few methodological limitations (3, 4, 6) reported statistically significant improvements in sustained attention following training. Study 3 found that the AKL-TO1 programme designed to train attention and cognitive control led to improvements in sustained attention, assessed using the TOVA Attention Performance Index, in a sample of children with ADHD (N = 348; Kollins et al., 2020). This study has many strengths (e.g., randomised design, large sample size, active control, prospective registration, participants with deficits in cognitive attention, between group statistical comparisons) and provides the strongest evidence for an improvement in sustained attention following cognitive attention training. Study 4 reported that the Tali Train attention training group demonstrated greater improvements in sustained attention from baseline to follow up compared to the passive control group (Kirk et al., 2019). In this study, typically developing children (N = 107) were cluster randomised to the training group, active control, or passive control. The Tali Train group completed adaptive game-based exercises designed to train sustained, selective, and executive attention. The active control completed non-adaptive game-based exercises that required minimal attention skills. Notably, there was no improvements in sustained attention in the intervention group relative to the active control group. That is, the active control who received no cognitive attention training demonstrated improvements in sustained attention. Thus, this study provides limited evidence that cognitive attention training is effective in improving sustained attention. Study 6 found that participants (N = 129) who received NeuroTracker training demonstrated improvements in sustained attention, assessed using d prime scores from the Conners’ Continuous Performance Test 3, compared to participants in both the active and passive control groups (Tullo et al., 2018). However, it is worth noting that an improvement was reported on only one outcome (d prime) out of several possible outcome variables on the CPT-3. Therefore, considering the inconsistent findings and methodological weaknesses of the studies evaluating cognitive attention training, the evidence supporting cognitive attention training for improving sustained attention is sparse.

Seven studies (1, 4, 5, 8, 11, 13, 14) examined near transfer effects to other measures of attention (e.g., selective attention, divided attention). Four of these studies (1, 4, 8, 14) found evidence for such effects on...
Table 1
Characteristics of intervention studies.

| ID | First Author | Year | Sample (N) | Age (years) | % Male | Place | Design | Intervention (n) | Setting | Duration (minutes) | Comparator (n) | Follow up |
|----|--------------|------|------------|-------------|--------|-------|--------|-----------------|---------|-------------------|--------------|-----------|
| 1  | Nejati       | 2021 | ADHD (N = 30) | 8-14 | 53% | Iran | RCT (2) | Program for Attention Rehabilitation & Strengthening (PARS; n = 15): Adaptive, non-computerised tasks targeting sustained attention, selective attention and shifting attention. | Hospital | 600–750 min (12-15 sessions over 4-5 weeks) | 1. Passive control (n = 15) | 6 weeks |
| 2  | Slattery     | 2021 | Typically developing (N = 36) | 9-11 | 50% | Ireland | Cluster RCT (2) | Keeping Score! (n = 18): Training was based on sustained updating and required participants to silently keep score while playing table tennis. | School | 270 min (18 sessions over 6 weeks) | 1. Active control (n = 18): Same as the training group except the score was called out by the researcher as each point was won. | 6 weeks |
| 3  | Kollins      | 2020 | ADHD (N = 348) | 8-12 | 71% | United States | RCT (2) | AKL-T01 (n = 180): Adaptive, video game-based exercises designed to train to attention and cognitive control administered via a tablet. | Home | 500 min (20 sessions over 4 weeks) | 1. Active control (n = 168): Online activities that required participants to spell as many words as possible, by connecting letters in a game-like grid. | 6 months |
| 4  | Kirk         | 2019 | Typically developing (N = 107) | 5-9 | 61% | Australia | Cluster RCT (3) | Tali Train (n = 39): Adaptive, tablet-based exercises designed to train sustained, selective, and executive attention. | School | 500 min (25 sessions over 5 weeks) | 1. Active control (n = 35): Non-adaptive, tablet-based exercises that required minimal attention. 2. Passive control (n = 33) | 24 weeks |
| 5  | Bikic        | 2018 | ADHD (N = 70) | 6-13 | 84% | Denmark | RCT (2) | ACTIVATE™ Cognitive Training (n = 35): Computerised exercises designed to train multiple cognitive functions. | Home | 1920 min (48 sessions over 8 weeks) | 1. Passive control (n = 35) | 6 months |
| 6  | Tullo        | 2018 | Neurodev disorders (N = 129) | 6-18 | 71% | Canada | RCT (3) | 3D Multiple Object-Tracking Paradigm, NeuroTracker (n = 43): Adaptive training designed to train visual attention including sustained and selective attention. | School | 105 min (15 sessions over 5 weeks) | 1. Active control (n = 43): Computer game 2048. 2. Passive control (n = 43) | 6 months |
| 7  | Bikic        | 2017 | ADHD (N = 18) | 15.6 (0.99) | 75% | Denmark | RCT (2) | Scientific Brain Training (n = 9): Adaptive computerised programme designed to train multiple cognitive functions. | Home | 1050 min (35 sessions over 7 weeks) | 1. Active control (n = 9): Non-adaptive version of Tetris. | 6 months |
| 8  | Kirk         | 2016 | IDD and attentional difficulties (N = 76) | 4-11 | 60% | Australia | RCT (2) | Tali Train (n = 38): See study 1 for description. | Home | 500 min (25 sessions over 5 weeks) | 1. Active control (n = 38): See study 1 for description. | 3 months |
| 9  | Mishra       | 2016 | ADHD (N = 31) | 12 (1.9) | 93% | India | RCT (2) | Online Neuroplasticity Targeted Remediation of Attention Deficits in Children (UNTRAC; n = 21): Online adaptive exercises that either focused on attended-signal training or distractor-suppression training. Exercises trained sustained attention, working memory and response inhibition. | Home | 1800 min (60 sessions over 6 months) | 1. Active control (n = 10): Played the Hoyle puzzle game online. | 3 months |
| 10 | Sarzyńska    | 2017 | Typically developing (N = 54) | 8 | 43% | Poland | CT (2) | Adaptive computerised tasks designed to train multiple attentional functions (n = 30) | NR | 300 min (10 sessions) | 1. Active control (n = 24): Adaptive computerised tasks that targeted problem solving | (continued on next page) |
Table 1 (continued)

| ID  | First Author     | Year  | Sample (N) | Age (years) | % Male | Place           | Design               | Setting      | Duration (minutes) | Comparator (n) | Follow up                  |
|-----|------------------|-------|------------|-------------|--------|-----------------|-----------------------|--------------|--------------------|----------------|----------------------------|
| 11  | Schrief-Elsdon   | 2017  | Low SES    | 7–13        | 80%    | South Africa    | CT (3)                | School      | 900 min (20 sessions over 10 weeks) | 1. Active control (n = 5); Played physical games like hopscotch. 2. Passive control (n = 5) | –                           |
| 12  | Rueda            | 2012  | Typically developing | 64.7         | 54%    | Spain           | RCT (2)               | School      | 450 min (10 sessions over 5 weeks) | 1. Active control (n = 18). Watched cartoons. | 2 months                    |
| 13  | Tucha            | 2011  | ADHD       | 10.9        | 69%    | Germany         | RCT (2)               | NR          | 360 min (8 sessions over 4 weeks) | 1. Active control (n = 16) Adaptive non-computerised visual perception training. | –                           |
| 14  | Kerns            | 1999  | ADHD       | 7–11        | 57%    | Canada          | CT (2)                | School or lab | 480 min (16 sessions over 8 weeks) | 1. Active control (n = 7): Played computer games. | –                           |
| 15  | Bauer            | 2020  | Typically developing | 11.76 (3.40) | 30%    | United States   | RCT (2)               | School      | 1440 min (32 sessions over 8 weeks) | 1. Active control (n = 16): Computerised coding programme. | –                           |
| 16  | Mishra           | 2020  | History of neglect | 10–18       | 60%    | India           | Cluster RCT (3)       | After school group | 900 min (30 sessions over 6 weeks) | 1. External attention intervention (n = 15): Adaptive computerised exercises from brainhq.com targeting focused attention, divided attention, selective attention and working memory. 2. Passive control (n = 43) | 1 year for behaviour and academic measures) |
| 17  | Tarrasch         | 2018  | Typically developing | 8–11        | 50%    | Israel          | CT (2)                | School      | 450 min (10 sessions over 10 weeks) | 2. Passive control (n = 3) | –                           |
| 18  | Kiani            | 2017  | Females with ADHD symptoms | 13–15 (0.53) | 0%     | Iran            | RCT (2)               | NR          | 720 min (8 sessions over 8 weeks) | Passive control (n = 15) | –                           |
| 19  | Wimmer           | 2016  | Typically developing | 10.80        | 47%    | Germany         | CT (3)                | School      | Approx. 2700 min (25 sessions over 18 weeks) | 1. Active control (n = 8): Concentration skills training 2. Passive control (n = 10) | –                           |
| 20  | Ricarte          | 2015  | Typically developing | 6–13 years | 54%    | Spain           | RCT (2)               | School      | 450 min (30 sessions over 6 weeks) | 1. Passive control (n = 45) | –                           |
| 21  | Leonard          | 2013  | Imprisoned youth | 16–18 years | 100%   | United States   | Cluster RCT (2)       | Prison      | 750 min (Approx. 10 sessions over 3–5 weeks) | 1. Active control (n = 117): Cognitive perception training | –                           |
Table 1 (continued)

| ID  | First Author       | Year  | Sample (N) | Age (years) | % Male | Place             | Design    | Intervention (n)                                                                 | Setting | Duration (minutes) | Comparator (n) | Follow up |
|-----|--------------------|-------|------------|-------------|--------|-------------------|-----------|--------------------------------------------------------------------------------|---------|-------------------|----------------|-----------|
| 22  | Napoli             | 2005  | typically developing (N = 228) | 1st-3rd graders (age NR) | 53%    | United States      | RCT (2)   | attentional and response modification elements of mindfulness meditation.        | School  | 540 min (12 sessions over 24 weeks) | 1. Active control (n = 144) completed “reading and other quiet activities”. | –         |
|     |                    |       |            |             |        |                   |           | Attention Academy (n = 114): Exercises included paying attention to breath, movement activities and sensory stimulating activities. |         |                   |                |           |
|     |                    |       | Physical Activity | 9.2      | 49%    | Netherlands       | Cluster RCT (3) | 1. Aerobic exercise (n = 221): Activities designed to target moderate-to-vigorous intensity while avoiding high cognitive demands. The focus was on highly repetitive and automated exercises (e.g., running, squats). | School  | 1680 min (56 sessions over 14 weeks) | 1. Passive control (n = 430) | –         |
| 23  | Meijer             | 2021  | typically developing children (N = 891) |            |        |                   |           | 2. Cognitively demanding exercise (n = 240): Team games or exercises that required complex movement and dealing with changing task demands. |         |                   |                |           |
| 24  | Cherriere          | 2020  | Diagnosis of Charcot-Marie-Tooth disease (N = 9) | 7–12 years | 22%    | Canada            | CT (2)    | 1. Dance (n = 5): Various dance forms (African-contemporary, jazz, break dance, and tap) with the goal of addressing the specific clinical needs of the children. Dance forms were chosen for their particular emphasis on musical rhythm and the inclusion of complex motor movements. | NR      | 1200 min (20 sessions over 10 weeks) | 1. Passive control (n = 4) | –         |
| 25  | Duarte             | 2020  | typically developing children (N = 66) | 12–14 years | NR     | NR                | Cluster RCT (3) | 1. Qigong (n = 22): Qigong integrates movement and breathing exercises that require and induce a special kind of mental state of ‘awareness’ or ‘attention’. This group performed the White Ball Qigong exercise, according to the Heidelberg Model of Traditional Chinese Medicine. | School + home | 40 min (8 sessions over 4 weeks) | 1. Active control: Performed a sham Qigong (n = 22). 2. Passive control (n = 22) | –         |
| 26  | García-Hermoso     | 2020  | typically developing (N = 170) | 8–10 years | 57%    | Chile             | Cluster RCT (2) | Active Start Intervention (n = 100): Physical games that focused on group cooperation. | School  | 1200 min (40 sessions over 8 weeks) | 1. Passive control (n = 70) | –         |
| 27  | Hedayatjoo         | 2020  | Hearing deficits (N = 36) | 7–12 years | 44%    | Iran              | RCT (2)   | Balance training (n = 18): Completed various balance exercises. | School + home practice | 540 min (12 sessions over 4 weeks) | 1. Passive control (n = 18) | –         |
| 28  | Månsson            | 2019  | ADHD and ADHD symptoms (N = 130) | 10–14 years | 85%    | Denmark           | CT (2)    | Target shooting (n = 64) | Shooting range | NR (sessions were approx. 60 min; 1 session per week for 6 months) | 1. Passive control (n = 66) | –         |
| 29  | Buchele Harris     | 2018  | typically developing (N = 116) | 4–5th graders (age NR) | 49%    | United States     | Cluster CT (3) | Coordinated-bilateral physical activity (n = 31): Exercises involved bilateral body movement and participants wore fitness trackers. | School  | 120 min (20 sessions over 4 weeks) | 1. Fitness tracker only group (n = 29) 2. Passive control (n = 56) | –         |
| 30  | Rezaei             | 2018  | ADHD (N = 21) | 7–14 years | NR     | Iran              | RCT (3)   | Yoga (n = 7): Yoga and relaxation exercises. | NR      | 1080 min (24 sessions over 8 weeks) | 1. Neurofeedback intervention (n = 7) 2. Passive control (n = 7) 1. Passive control (n = 25) | –         |
| 31  | Chou               | 2017  |            | 78%       | Taiwan | CT (2)            |          |                                                                                  |         |                   |                |           |

(continued on next page)
| ID | First Author | Year | Sample (N) | Age (years) | % Male | Place | Design | Intervention (n) | Setting | Duration (minutes) | Comparator (n) | Follow up |
|----|--------------|------|------------|-------------|--------|-------|--------|----------------|---------|-------------------|---------------|-----------|
| 32 | Sabel        | 2017 | Childhood brain tumour survivors (N = 13) | 7–16 years | 46%    | Sweden | Cross-over RCT (2) | Active video gaming (Nintendo Wii) | Home    | 1500–1800 min (5 sessions over 10–12 weeks) | 1. Passive control | –        |
| 33 | Gallotta     | 2015 | Normal weight and obese children (N = 230) | 8–11 years | NR     | Italy  | Cluster RCT (3) | 1. Coordinative physical activity (n = 83): Focused on improving coordination and dexterity of participants. 2. Traditional physical activity (n = 78): Focused on endurance, strength, flexibility exercises and circuit training for cardiovascular health. | School  | NR (2 1 hour sessions per week over 5 months) | 1. Passive control (n = 69) | –        |
| 34 | Zach         | 2015 | Typically developing (N = 123) | 4–5 years | 51%    | Israel | Cluster CT (3) | 1. Orienteering (n = 44) 2. Dance (n = 40) | School  | NR (9 weekly sessions) | 1. Passive control (n = 39) | –        |
| 35 | Spitzer Study 1 | 2013 | Typically developing (N = 44) | 12.72 | 63%    | Germany | Cluster CT (2) | Activities like basketball, soccer, and dance (n = 24). | School  | 1080 min (36 sessions over 4 months) | 1. Passive control (n = 20) | –        |
| 36 | Spitzer Study 2 | 2013 | Typically developing (N = 148) | 12.36 | 61%    | Germany | Cluster CT (2) | Games that could be played with 3–4 members on each team (n = 55). | School  | 900 min (30 sessions over 3 months) | 1. Passive control (n = 33) | –        |
| 37 | Verret       | 2012 | ADHD (N = 21) | 7–12 years | 90%    | Canada | CT (2) | Activities such as basketball, soccer, and tag (n = 10). | School  | 1350 min (30 sessions over 10 weeks) | 1. Passive control (n = 11) | –        |

Note. RCT = randomised controlled trial, CT = controlled trial, Neurodev = neurodevelopmental, IDD = intellectual and developmental disabilities, NR = not reported, MBSR = mindfulness-based stress reduction.
### Table 2

| ID | First Author | Year | Objective Outcomes | Subjective Outcomes |
|----|--------------|------|--------------------|---------------------|
| 1  | Nejati        | 2021 | 1. Sustained attention: Persian Attention Registration Test (3 measures) | | |
|    |              |      | 2. Selective attention: Stroop Test (4 measures) | | |
|    |              |      | 3. Attention shifting: Trail Making Test (2 measures) | | |
|    |              |      | 4. Inhibitory control: Go/No-Go Test (3 measures) | | |
|    |              |      | 5. Working memory: 1-Back Task (2 measures) | | |
| 2  | Slattery     | 2021 | 1. Sustained attention: Vigil, Cerberus and Sustained Attention to Response Task subtests (TEA-Ch; 3 measures) | | |
|    |              |      | 2. Short-term memory: Forward Span subtest WISC-V (1 measure) | | |
|    |              |      | 3. Working memory: Digit Span Backward subtest WISC-V and the Operation Span and Symmetry Span subtests of the Adaptive Composite Complex Span (3 measures) | | |
| 3  | Kollins      | 2020 | 1. Sustained attention: TOVA (1 measure) | | |
|    |              |      | 2. Working memory: CANTAB-Spatial Working Memory test (8 measures) | | |
|    |              |      | 3. Inhibitory function: TOVA (1 measure) | | |
| 4  | Kirk         | 2019 | 1. Sustained attention: Simple reaction time (TEA-Ch; 1 measure) | | |
|    |              |      | 2. Executive attention: SART (TEA-Ch; 1 measure) | | |
|    |              |      | 3. Visual selective attention: Balloon Hunt + Hide & Seek Visual (TEA-Ch; 2 measures) | | |
|    |              |      | 4. Auditory selective attention: Hide & Seek Auditory (TEA-Ch; 1 measure) | | |
|    |              |      | 4. Verbal working memory: Backward Digit Span (AWMA; 1 measure) | | |
|    |              |      | 5. Visuospatial working memory: Odd One Out (AWMA; 1 measure) | | |
|    |              |      | 6. Numeracy: Test of Early Mathematics Ability (1 measure) | | |
| 5  | Bikic        | 2018 | 1. Sustained attention: Rapid Visual Information Processing | | |
|    |              |      | 1. ADHD symptoms: ADHD Rating Scale IV (parent/teacher; 1 measure) | | |
|    |              |      | 2. ADHD symptoms: ADHD Rating Scale (CANTAB; 3 measures) | | |
|    |              |      | 2. Executive function behaviour: BRIEF (parent/teacher; 22 measures) | | |
|    |              |      | 3. Functional behaviour: Weiss Function Impairment scale (parent; 1 measure) | | |

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Table 2 (continued)

| ID | First Author | Year | Objective Outcomes | Subjective Outcomes |
|----|--------------|------|--------------------|---------------------|
| 10 | Sarzyńska    | 2017 | 2. Response inhibition: TOVA (1 measure) 3. Short-term memory: Spatial Capacity Task (1 measure), Verbal Capacity Task (1 measure) 4. Executive function: Stroop Colour and Word Interference Test (1 measure) | 1. Attention: d2 Attention test (7 measures) 2. Intelligence: Raven’s Progressive Matrices (1 measure) |
| 11 | Schrieff-Elson| 2017 | 1. Sustained attention: Score! (TEA-Ch; 1 measure) and Numbers Forward (CMS; 1 measure) 2. Selective attention: Sky Search (TEA-Ch; 3 measures) 3. Attentional control: Opposite Worlds and Creature Counting (TEA-Ch; 3 measures) 4. Divided attention: Sky Search DT (TEA-Ch; 1 measure) 5. Inhibition/switching: Inhibition NEPSY-II (1 measure) and switching NEPSY-II (1 measure) 6. Working memory: Numbers Backwards (CMS; 1 measure) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 12 | Rueda        | 2012 | 1. Attention: ANT (3 measure) 2. Delay gratification: Delay of gratification task (4 measures) 3. Decision making: Children gambling task (2 measures) 4. Intelligence: K-BIT (2 measures) | 1. Sustained attention: CPT (3 measures) 2. Selective attention: Conjunctive Search task (6 measures) |
| 13 | Tacha        | 2011 | 1. Tonic alertness (TAP; 2 measures) 2. Phasic alertness (TAP; 2 measures) 3. Vigilance (TAP; 3 measures) 4. Selective attention (TAP; 3 measures) 5. Divided attention (TAP; 3 measures) 6. Flexibility (TAP; 2 measures) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 14 | Kerns        | 1999 | 1. Auditory sustained attention: Attention Capacity Test (1 measure) 2. Visual sustained attention: Underlying Task subtest 14 (1 measure) and Children’s CPT (2 measures) 3. Selective attention: Underlying Task subtest 2 and 4 (1 measure) 4. Planning/attention: Mazes subtests WISC-III (1 measure), Digit Span | Inattention/impulsivity: ADDES (parent/teacher; 2 measures) |
| 15 | Bauer        | 2020 | 1. Sustained attention: SART (1 measure) 2. Response inhibition: SART (1 measure) 3. Seed of response: SART (2 measures) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 16 | Mishra       | 2020 | 1. Sustained attention: Test of Variables of Attention (1 measure) 2. Interference resolution: Flanker Test (1 measure) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 17 | Tarrasch     | 2018 | 1. Sustained attention: CPT (3 measures) 2. Selective attention: Conjunctive Search task (6 measures) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 18 | Kiani        | 2017 | 1. Sustained attention: CPT (1 measure) 2. Impulsivity: CPT (1 measure) 3. Working memory: Digit Span and Letter-Number Sequencing subtests of the WISC-V (5 measures) 4. Inhibition: Stroop-Word-Colour Interference Test (1 measure) 5. Planning: Tower of London Test (1 measure) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 19 | Wimmer       | 2016 | 1. Sustained attention: Vigilance test (3 measures) 2. Cognitive flexibility: Reversible Figures task and WCST-64 (2 measures) 3. Inhibition: Stroop Color Word Interference Test (2 measures) 4. Information processing: Recognition task and Visual Search task (7 measures) | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |
| 20 | Ricarte      | 2015 | 1. Sustained attention/eye-hand coordination speed: TMT Part A (1 measure) 2. Mental flexibility: TMT Part B (1 measure) 3. Focused attention: Perception of Differences Test-Faces (1 measure) 4. Memory span/ | 1. ADHD symptoms: ADHD-RS IV (caregiver; 2 measures) 2. Academic performance: APRS (teacher; 1 measure) |

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| ID  | First Author | Year | Objective Outcomes | Subjective Outcomes |
|-----|--------------|------|--------------------|---------------------|
| 21  | Leonard      | 2013 | 1. Attentional networks (alerting, orienting, conflict monitoring): ANT (9 measures) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 22  | Napoli       | 2005 | 1. Sustained attention: Score! subtest, Walk Don’t Walk subtest and Code Transmission subtest (TEA-Ch; 1 measure) 2. Selective attention: Sky Search and Map Mission (TEA-Ch; 1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 23  | Meijer²      | 2021 | 1. Attention/sustained attention: ANT (5 measures) 2. Verbal short-term/working memory: Digit Span Task (2 measures) 3. Visuospatial short-term/working memory: Grid Task (2 measures) 4. Inhibition: Stop Signal Task (1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 24  | Cherriere    | 2020 | 1. Sustained attention: Score! subtest (1 measure) and Score DT subtest (1 measure; TEA-Ch) 2. Short-term memory/attention: Letter Number Sequencing Test (WISC-R; 1 measure) 3. Short-term memory/attention/hand-eye coordination: Coding Test (WISC-R; 1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 25  | Duarte       | 2020 | 1. Attention/concentration: d2 Test of Attention (5 measures) 2. Concentration: d2 Test (1 measure) 3. Selective attention: d2 Test (1 measure) 4. Academic grades: Mathematics performance (1 measure) and language performance (1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 26  | García-Hermoso| 2020 | 1. Concentration: d2 Test (1 measure) 2. Selective attention: d2 Test (1 measure) 3. Academic grades: Mathematics performance (1 measure) and language performance (1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 27  | Hedayatjoo   | 2020 | 1. Attention/sustained attention: Persian Form of the CPT (1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (4 measures) |
| 28  | Månsson      | 2019 | 1. Inattention/hyperactivity/impulsiveness: Qb Test (4 measures) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (parent/teacher; 2 measures) |
| 29  | Bachele Harris| 2018 | 1. Sustained attention/selective attention/concentration: d2 Test of Attention (5 measures) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (parent/teacher; 2 measures) |
| 30  | Rezaei       | 2018 | 1. Sustained attention/impulsivity: CPT (4 measures) 2. Attention/concentration/maths: Arithmetic Test (WISC-R; 1 measure) | 1. ADHD symptoms: ADD-H Comprehensive Teacher Rating Scale (parent/teacher; 2 measures) |

*Physical Activity*

| ID  | First Author | Year | Objective Outcomes | Subjective Outcomes |
|-----|--------------|------|--------------------|---------------------|
| 31  | Chou         | 2017 | 1. Sustained attention/selective attention: Visual Pursuit Test (2 measures) 2. Discrimination: Determination Test (2 measures) | 1. Execution of Activities of Daily Living: AMPS (clinician; 2 measures) |
| 32  | Sabel        | 2017 | 1. Sustained attention: Conners’ CPT II (1 measure) 2. Disinhibition: Conners’ CPT II (1 measure) 3. Mean reaction time: Conners’ CPT II (1 measure). 4. Selective attention: Map Mission (1 measure) 5. Visual attention: Visual Scanning (D-KEFS; 1 measure) 6. General working memory: Digit Span WISC-IV (1 measure) 7. Verbal working memory: Auditory Consonant Trigrams (1 measure) 8. Immediate memory: RAVLT (1 measure) 9. Complex word span: RAVLT (1 measure) 10. Simple span: Spatial span (WNV; 1 measure) 11. Complex spatial span: Spatial span (WNV; 1 measure) 12. General spatial working memory: Spatial span (WNV; 1 measure) 13. Verbal learning: RAVLT (1 measure) 14. Immediate recall: RAVLT (1 measure) 15. Delayed recall: RAVLT (1 measure) 16. Information: WISC-IV (1 measure) 17. Copying capacity: Rey Complex Figure Test (1 measure) 18. Copying time: Rey Complex Figure Test (1 measure) 19. Immediate recall: Rey Complex Figure Test (1 measure) 20. Delayed recall: Rey Complex Figure Test (1 measure) 21. Recognition: Rey Complex Figure Test (1 measure) 22. Psychomotor processing speed/ | 1. Execution of Activities of Daily Living: AMPS (clinician; 2 measures) |

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selective attention, though two of these studies (1, 14) had serious methodological limitations. Study 4 and Study 8 examined the efficacy of the Tali Train programme in typically developing children (4) and children with IDD (8). Study 4 reported that the passive control group made greater gains in auditory selective attention (assessed using the Hide and Seek Auditory subtest from the TEA-Ch) from baseline to post-training compared to the intervention group (Kirk et al., 2019). In contrast, Study 8 reported that the intervention group showed significantly greater improvements in selective attention (assessed using the Visearch task from the Wilding Attention Battery) from baseline to post-training and from baseline to 3-month follow up compared to the active control group (Kirk et al., 2016).

These contradictory findings highlight the influence of the task used to assess study outcomes (i.e., intervention effects may depend on the task used rather than on enhanced capacity). Moreover, it also highlights that potential intervention effects may depend on the sample of participants selected (i.e., enhancing capacity in children with developmental cognitive deficits vs improving capacity in typically developing children). Two other studies reported improvements in other aspects of attention. Study 13 reported improvements in divided attention and alternating flexibility following training though this study had methodological limitations, including a small sample size and no correction for multiple comparisons despite a large number of pairwise comparisons (Tucha et al., 2011). Study 11 reported improvements in the intervention group in attentional control; however, the group comprised five participants (Schrief-Elson et al., 2017). Considered collectively, these studies at best provide limited evidence for the efficacy of cognitive attention training in improving other aspects of attention.

Twelve studies (1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 14) examined far transfer effects (i.e., any other cognitive, academic, or behavioural measure). Eight studies report far transfer; effects varied considerably across studies. Studies reported improvements in working memory (1), planning (5, 14), IQ (12), decision making (12), ADHD symptoms (4, 9), interference (9), inhibition (1, 9, 11, 14), numeracy (8) and academic efficacy (14). Some studies reported far transfer effects in the absence of reliable near transfer (e.g., 4). These effects are difficult to explain in the absence of improvements in the trained cognitive abilities. That is, effects of training on measures of far transfer are typically seen as dependent on increases in cognitive capacity. Thus, in these studies, far transfer effects are likely not attributable to the training component of the intervention and may be due to non-specific factors or factors unrelated to the intervention. Alternatively, a theoretical account of why/how cognitive attention training improves performance on measures of far transfer in the absence of near transfer is required to explain these findings.

3.1.2. Meditation studies

Eight studies examined meditation training in children and adolescents. All of these studies investigated mindfulness-based interventions. Five studies (15, 16, 17, 19, 21) reported positive intervention effects on at least one measure of sustained attention. Though these results are encouraging, all meditations studies had methodological/statistical issues (e.g., small sample sizes, non-randomised designs, no correction for multiple comparisons, no long-term follow up). Out of the 8 meditation studies, five studies (17, 19, 20, 21, 22) examined the impact of training.

### Table 2 (continued)

| ID | First Author | Year | Objective Outcomes | Subjective Outcomes |
|----|--------------|------|--------------------|---------------------|
| 33 | Gallotta     | 2015 | 1. Sustained attention/concentration: d2-R test of attention (3 measures) | 1. Study behaviour: Teacher’s List for Social and Studying behaviour (10 measures) |
| 34 | Zach         | 2015 | 1. Attention: MOXO Continuous Performance Test (4 measures; sustained attention, timing, impulsivity, and hyperactivity) | 2. Spatial perception: Reproduction of Patterns (CMR; 4 measures) |
| 35 | Spitzer Study 1 | 2013 | 1. Sustained attention: d2 test of attention (4 measures) | 1. Study behaviour: Teacher’s List for Social and Studying behaviour (10 measures) |
| 36 | Spitzer Study 2 | 2013 | 1. Sustained attention: d2 test of attention (4 measures) | 1. Study behaviour: Teacher’s List for Social and Studying behaviour (10 measures) |
| 37 | Verret       | 2012 | 1. Auditory sustained attention: Score (TEA-Ch; 1 measure) | 1. Behavioural problems: CBCL (parent and teacher; 22 measures) |
|     |              |      | 2. Visual search: Sky search (TEA-Ch; 1 measure) |                     |
|     |              |      | 3. Divided attention: Sky Search (TEA-Ch; 1 measure) |                     |
|     |              |      | 4. Response inhibition: Walk/Don’t Walk (TEA-Ch; 1 measure) |                     |

Note. TEA-Ch = Test of Everyday Attention for Children, BRIEF = Behavioural Rating Inventory of Executive Function, SART = Sustained Attention to Response Task, WISC = Wechsler Intelligence Scale for Children, TOVA = Test of Variables of Attention, SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behaviour, AWMA = Automated Working Memory Assessment, CANTAB = Cambridge Neuropsychological Test Automated Battery, CPT = Continuous Performance Test, WATT = Wilding Attention Battery, TEMAS = Test of Early Mathematics Ability, PPVT = Peabody Picture Vocabulary Task, PAT = Phonological Abilities Test, WMRS = Working Memory Rating Scale, DBC = Developmental Behaviour Checklist, CMS = Children’s Memory Scale, NEPSY = Developmental Neuropsychological Assessment, ANT = Attention Network Test, K-BIT = Kaufman Brief Intelligence Test, TAP = Test Battery for Attentional Performance, ADDIES = Attention Deficit Disorder Evaluation Scale, APRS = Academic Performance Rating Scale, WCST = Wisconsin Card Sorting Test, TMT = Trail Making Test, SDQ = Strengths and Difficulties Questionnaire, D-KEFS = Delis-Kaplan Executive Function System, RAVLT = Rey Auditory Verbal Learning Test, WNV = Wechsler Nonverbal Scale of Ability, COWAT = Controlled Oral Word Association Test; AMPS = Assessment of Motor and Process Skills, CMB = Cognitive Modifiability Battery, CBCL = Child Behaviour Checklist.

* Principal components analysis was performed on all measures to derive composite scores. Six components were extracted: 1) information processing and control (information processing speed, lapses of attention and motor inhibition), 2) interference control (speed and accuracy of interference control), 3) attention accuracy (accuracy of alerting attention and spatial orientation), 4) visuospatial working memory (visuospatial working memory and visuospatial short-term memory), 5) verbal working memory (verbal working memory and verbal short-term memory), and 6) attention efficiency (speed of alerting attention and spatial attention to information).
on other measures of attention. Four of these studies reported positive effects on other aspects of attention / other indices of attention, including overall attention performance (ANT % correct; 21), selective attention (conjunctive visual search task; 17; visual search task; 19; TEA-Ch; 22). These findings suggest that mindfulness training may be particularly helpful for improving selective attention. Five studies examined other outcomes (16, 18, 19, 20, 22), out of which four studies reported positive effects on aspects of cognition and/or behaviour (ratings of attention or hyperactivity; 16, 18, 20, 22). However, it is difficult to ascertain far transfer effects due to the small number of far transfer measures employed in studies and these measures varied across studies. Overall, these studies provide some promising evidence for the efficacy of mindfulness in improving attention.

3.1.3. Physical activity studies
Fifteen studies examined the impact of a physical activity intervention. Physical activity interventions included yoga, target shooting, Nintendo Wii, coordinated-bilateral physical activity, and traditional physical activity. Eleven of these studies reported improvements in sustained attention following physical activity interventions (24, 25, 27, 28, 29, 30, 31, 33, 34, 36, 37). One of the most promising of these was Study 33, which used a cluster-randomised parallel group design to examine the impact of traditional physical activity, coordinative physical activity, and a passive control on sustained attention (d2-R test;
Gallotta et al., 2015). Improvements between groups were analysed by comparing pre-to-post absolute difference and percentage difference. A main effect of group was found on three measures. Post hoc tests indicated that traditional physical activity led to an improvement in processing speed compared to the coordinative group, while coordinative physical activity led to improvements in concentration and % error scores relative to both the traditional physical activity and control group (exact \( p \) values not reported just \( p < .05 \)). The other ten studies had several limitations including non-randomised designs (e.g., 24, 28, 29, 31, 32, 34, 35, 36, 37), significant differences between the groups at baseline on some outcome measures that were not controlled for (e.g., 28, 29), passive controls only (e.g., 27, 30, 31, 34) and small sample sizes (e.g., 24, 27, 30, 37), which complicate the interpretation of intervention effects. Overall, while exercise-based interventions demonstrate some potential, further, more rigorous research is required to definitively determine the efficacy of physical activity in improving sustained attention.

3.2. Issues that impact the comparison of studies

Many methodological factors complicate the comparison of study results. In this section, we summarise these factors and explain the impact of these issues on findings. Across studies there was large variability in study types and designs (randomised vs non-randomised studies, active vs passive control groups), sample characteristics, training characteristics, experimental protocols, construct measurement, and statistical analyses and reporting. It is our hope that this analysis will result in better methodology and reporting in future attention training research.

3.2.1. Study types and designs

It is possible to differentiate between four broad types of intervention studies for cognitive enhancement: 1) feasibility studies (identify the feasibility of an intervention), 2) mechanistic studies (demonstrate an intervention’s mechanisms of action), 3) efficacy studies (determine whether the intervention results in the desired effect under controlled circumstances) and 4) effectiveness studies (determine whether an intervention results in the desired effect under real-world settings/clinical practice; Gartlehner et al., 2006; Green et al., 2019). Each type of study is characterised by different goals, which impacts the methodological approaches employed and the conclusions that can or should be drawn from the study (for detailed review, see Green et al., 2019). Note, in practice studies may not neatly fall into these categories or may overlap multiple categories. Many studies in this review seemed to identify as either an efficacy study (2, 3, 4, 5, 6, 8, 14, 16, 21, 33) or effectiveness study (13, 17, 18, 30); six studies clearly identified as a feasibility or pilot study (7, 9, 19, 24, 32, 37). Notably, in most instances the precise type of study being conducted was not clear (e.g., 1, 10, 20, 22, 25, 26, 31). This was particularly the case for meditation and physical activity studies. As such, we would like to echo the call of Green et al. (2019) for more precise terminology at the outset of a paper so that studies can clearly be distinguished, and the methodology employed evaluated relative to the type of study being conducted.

An important consideration in the design of any intervention study is the selection of a control group or groups. The adequacy of a control group depends on the type of intervention study being conducted and its underlying research question. In an efficacy study, an appropriate control is identical to the intervention group except for the “active” ingredient (i.e., an active control group; Simons et al., 2016). If an efficacy study does not employ an active control, then differences between the intervention and control group could account for any observed improvements (Simons et al., 2016). In an effectiveness study, a passive control (no-contact control or treatment-as-usual) may be more appropriate to align with the study’s aims (i.e., measure the extent of improvement under real-world conditions; Green et al., 2019). Participants in these control groups simply complete pre- and post-assessments. In a feasibility study, a passive control may be appropriate as the aim of this study, as the name suggests, is to demonstrate feasibility (Green et al., 2019). However, of the six feasibility or pilot studies, three studies also aimed to evaluate the efficacy of their respective interventions (7, 9, 32). Thus, it is important to consider the study goals when evaluating the control groups. From the ten studies that seemed to identify as efficacy studies in this review, seven studies included active control groups (2, 3, 4, 6, 8, 14, 21). Two of these studies included both an active and passive control group (4, 6). The inclusion of both an active and passive control group can aid in the interpretation of study results (Green et al., 2019). From the four studies that seemed to identify as effectiveness studies, three studies included passive control groups (17, 18, 30). Three out of six feasibility/pilot studies included active controls (7, 9, 19; Study 19 included both an active and passive control group). Notably, in several studies there were some differences between the intervention and control groups on outcome measures prior to the intervention (e.g., 17, 28, 29) which complicates the interpretation of intervention effects. Additionally, some studies did not randomly allocate participants to groups (e.g., 17, 28, 31). Group differences on variables other than those of interest might drive or suppress any effects seen in these studies (Simons et al., 2016).

3.2.2. Sample size

Many studies had small sample sizes, which make the results less reliable. Some intervention groups consisted of 15 or fewer participants (e.g., 1, 7, 11, 16, 24, 30). This is problematic as a study with a small sample size is likely to produce an exaggerated effect size, misrepresenting the strength of an intervention (Button et al., 2013). Large sample sizes provide stronger and more reliable evidence about the efficacy of an intervention (Redick et al., 2015). It has been recommended that intervention studies should include pre-test and post-test data for a minimum of 20 participants per group (Redick et al., 2015; Simmons et al., 2011). Twenty studies satisfied this criterion (out of 37 studies). The type of intervention study being conducted may also influence decisions around optimal sample size. For example, it has been suggested that efficacy and effectiveness studies require larger sample sizes than feasibility studies (Green et al., 2019). Further sample size considerations may include practicalities or factors that may limit sample size such as whether a study requires costly neuroimaging outcomes in addition to behavioural outcomes.

3.2.3. Construct measurement

Studies used a wide range of tasks to measure sustained attention. Common tasks included the Conners’ Continuous Performance Test, the Test of Everyday Attention for Children, the d2 Test of Attention and the Attention Network Test. Typically, multiple variables were extracted from each task such as errors of omission, errors of commission, reaction time and reaction time variability. Some studies used questionable variables other than those of interest might drive or suppress any effects seen in these studies (Simons et al., 2016).
to measure (Redick et al., 2015). Moreover, single tasks can be very sensitive to similarities with training regimens and impacted by a component of the intervention despite no change in the underlying ability (Moreau, 2021). A more convincing demonstration of intervention effects is achieved by using multiple different measures of the target construct, which can be used to create a composite score or latent variable for analysis (Moreau et al., 2016). However, while this may be aspirational, it is important to recognise that the use of multiple measures may not always be possible to achieve in a given study or may prove problematic if, for example, differences in the psychometric properties of the measures makes their combination dubious. It is also important to note that when interventions include multiple outcome measures of an underlying construct, and report only one significant effect, claims of improvement are much more ambiguous (Moreau et al., 2021).

3.2.4. Statistical issues

Studies typically included multiple outcomes and tested multiple comparisons. A considerable implication of multiple statistical tests in one study is that the significance level of the study may need to be adjusted to control for the family-wise error rate (Bender and Lange, 2001). For example, in a study when two outcomes are analysed independently at \( \alpha = .05 \), the probability of finding at least one false positive significant result increases to 0.098 (Vickerstaff et al., 2019). Many studies did not correct for multiple comparisons / correct \( p \) values for multiple outcomes (e.g., 8, 13, 14). Reporting results without correcting for multiple comparisons can inflate the rate of false-positive results, introducing erroneous results into the literature (Simons et al., 2016). It is likely that some of these intervention effects would not have been statistically significant had \( p \)-values been corrected for multiple comparisons. However, there is a lack of consensus in the literature about when it is appropriate to correct for multiple comparisons (e.g., Li et al., 2017; Parker and Weir, 2020). The decision to correct for multiple comparisons may be influenced by the type of study being conducted (e.g., exploratory vs confirmatory studies). That is, the cost of a false positive result in a confirmatory study is much greater than an exploratory study, which occurs at the initial phase of development and will be tested in further studies (Li et al., 2017; Parker and Weir, 2020). A second weakness identified within the group of studies reviewed related to the inferential statistics used. Some studies (e.g., 19) reported significant improvements in the intervention group but failed to adequately compare improvement in the intervention group to improvement in the control group. A difference in significance between the intervention and control group (i.e., the training group shows significant improvement compared to the control group. A difference in significance between the intervention and control group must be done.

3.2.5. Different interventions and durations

Many different types of interventions were employed across studies within each attention training category. In the case of cognitive attention training studies, 10 different interventions were evaluated across 14 studies, with only two interventions being evaluated twice; Tali Train and Pay Attention!. Training programmes trained an array of attentional/cognitive functions (though all aimed to train sustained attention). Some primarily targeted attention functions (e.g., Tali Train, AixTent, Pay Attention!), while others targeted attention and other cognitive functions (e.g., ACTIVATE™, Scientific Brain Training). This variability was evident for meditation studies; all studies examined mindfulness training, but studies employed different mindfulness-based interventions. This was also true for physical activity interventions studies, which investigated a range of interventions such as target shooting, dance and yoga. Interventions varied on many other dimensions (computerised vs in-person, type of instructions, training durations, settings, etc.). In relation to training duration, studies used a highly disparate amount of training durations. For example, cognitive attention training studies varied from 105 to 1920min. Some training durations were spaced across time (e.g., 6 months), while others took place within a short time frame (e.g., 4 weeks). Thus, many factors may influence whether one benefits from an intervention; however, these characteristics are often not examined. Moreover, very few researchers endeavour to replicate a training study. To really understand the effectiveness of an intervention, replications must be done.

3.2.6. Sample characteristics

There was some variability in study populations within and across intervention types. It is possible that intervention effects may vary across populations, for example, due to differences in baseline sustained attention performance. That is, some research suggests those with poor baseline performance may benefit the most from training (compensation effects), while other research suggests that those with high baseline performance benefit the most (magnification effects; for review see, Katz et al., 2021). In the cognitive attention training studies reviewed, seven studies (1, 3, 5, 7, 9, 13, 14) examined the impact of training in children/adolescents with ADHD; five studies (2, 4, 10, 11, 12) had typically developing participants and two other studies looked at children/adolescents with other neurodevelopmental conditions (6, 8). The two most promising cognitive attention training studies (3, 6) included neurodevelopmental samples. Study 3 examined the impact of training in participants with ADHD and Study 6 examined the impact of training in participants with various neurodevelopmental disorders. Notably, Study 3 specifically included a sample of participants with deficits in cognitive attention. All meditation studies included participants that could be categorised as typically developing (note, Study 16 included participants with a history of childhood neglect). Most physical activity studies included typically developing participants (23, 25, 26, 29, 33, 34, 35, 36); four studies had ADHD samples (28, 30, 31, 37), while three studies had other samples (i.e., Charcot-Marie-Tooth disease, hearing deficits and childhood brain tumour survivors). The studies reporting the positive effects of physical activity on sustained attention included typically developing samples (25, 29, 33, 34, 36), ADHD samples (28, 30, 31, 37) and samples of children with Charcot-Marie-Tooth disease (24) and hearing deficits (27). However, in the current review, it is difficult to ascertain the potential effects of study populations on meditation and physical activity intervention effects due to methodological limitations evident across studies. Age is another important factor that may influence the impact of each intervention (Katz et al., 2021). This is because childhood and adolescence is a critical period for sustained attention development and cognitive maturation. Many studies included in this review had a wide age range (16 out of 37 studies had an age range \( \geq 5 \) years), which spanned more than one period of development across childhood and adolescence. Note, 13 studies did not report an age range. Across all intervention types, most studies examined participants in middle childhood and early adolescence (7–14 years; cognitive attention training 8 out of 14, meditation training 4 out of 8, and physical activity 13 out of 15). Intervention effects may differ across and within studies due to age, but this is difficult to examine here due to the wide and overlapping age ranges. Taken together, it is possible that attention
training interventions targeting sustained attention may work differently at different ages or with different populations; however, these factors were too variable among the studies included in this review to be analysed systematically.

3.2.7. Pre-registration and data analysis plans

In recent years, there has been an increasing emphasis on the pre-registration of study protocols and data analysis plans in psychology. However, very few recent studies were prospectively registered. Of the 29 studies published since 2015, 13 studies were registered but only 5 of these studies were registered prior to data collection. Prospective pre-registration is essential for research transparency and credibility.

4. Overall discussion

The present review provides a fine-grained critical analysis of popular attention training interventions specifically targeting sustained attention in children and adolescents. Findings varied within and across the different intervention approaches. The current evidence indicates that cognitive attention training does not reliably improve the capacity to sustain attention in children and adolescents. In contrast, the evidence for mindfulness training and physical activity (with a cognitive component) is somewhat more promising though these effects should be considered preliminary and need to be replicated with greater methodological rigour (i.e., pre-registration, larger samples, randomised designs, active control groups and multiple measures of sustained attention).

For other measures of attention, cognitive attention training demonstrated very limited transfer. Physical activity studies rarely assessed such measures. Notably, mindfulness training had rather consistent positive effects on selective attention. Across all three intervention types, there was weak evidence for transfer to other aspects of cognition, behaviour, and academic achievement. A number of positive effects of cognitive attention training on far transfer measures were reported (e.g., ADHD symptoms); however, some of these effects were found in the absence of near transfer, which is theoretically challenging to explain. In the case of mindfulness and physical activity, it is difficult to ascertain transfer to other cognitive, academic and behavioural measures due to the small number of such measures employed in these studies and the measures employed varied considerably across studies.

The primary focus of research in this area has been whether these interventions work rather than why they might work. The mechanisms of improvement are hypothesised to be different across each intervention type reviewed here. Cognitive attention training focuses on improving the cognitive control aspect of sustained attention using the repetitive practice of a cognitive task designed to exercise the frontoparietal network. Physical activity likely targets sustained attention via physiological arousal factors but may also target cognitive control when the activity requires focus to be continuously maintained on goal-directed stimuli. Finally, mindfulness training likely targets arousal factors (cortical and physiological arousal), emotional factors (calming the emotions and enabling a reappraisal of what should be attended to), and cognitive factors (maintaining continuous focus on certain stimuli over time) implicated in sustained attention. Thus, in theory, physical activity and mindfulness training offer the most potential for enhancing sustained attention because they target multiple factors underlying one’s capacity to sustain attention. However, notably, none of the reviewed physical activity or mindfulness studies included a follow up testing occasion. As a result, it is unclear whether these interventions produce potential long-lasting effects. Given that these interventions largely work upon the systems which influence sustained attention (i.e., arousal & salience networks) rather than the sustained attention system itself (i.e., frontoparietal network), and given that they likely typically function to modulate sustained attention, it is possible that enduring effects are unlikely. Frequent engagement in these interventions may be necessary to modulate sustained attention when needed or as a matter of routine. However, this is an open research question which needs to be determined by future research.

This is a timely review with many strengths (e.g., inclusion of multiple interventions to enhance sustained attention, critical analysis and recommendations to improve the evidence base). However, it is important to acknowledge its weaknesses. Only 10% of title and abstracts/full text articles were screened by two reviewers. This was done due to limited time and resources. While single screening has been used in other recent systematic reviews in the health and medical research field (e.g., Gram et al., 2019; Sato et al., 2021), this approach can miss more eligible studies than double screening (Waffenschmidt et al., 2019). Best practice is for the screening process to be conducted by two independent reviewers (Garliebner et al., 2020). Moreover, only one reviewer completed data extraction and quality assessment. It is recommended that more than one reviewer extract data and complete quality assessment to minimise errors and reduce potential bias (Boutron et al., 2022; Li et al., 2022). In the current review, dual screening, data extraction and quality assessment would have strengthened our results and conclusions.

5. Conclusion

We found limited evidence that it is possible to train children’s ability to sustain attention. Cognitive attention training did not reliably improve sustained attention capacity. The evidence for mindfulness training and physical activity was somewhat more promising though these effects should be considered preliminary. Moving forward, mediation training and physical activity intervention studies should adhere to best methodological practices in order to determine the true effect of these interventions on sustained attention. These practices include use of prospective pre-registration and data analysis plans, more precise terminology around the type of intervention study being conducted, randomised designs, adequately powered sample sizes, matched groups at baseline, an appropriate control group aligned to the aims of the study, multiple measures of sustained attention and long-term follow up.

Declarations of interest

None.

Data availability

Data will be made available on request.

Appendix A

See Table A1.
Table A1
PEDro scores for each intervention study.

| Cognitive Attention Training | Eligibility Criteria | Random Allocation | Concealed Allocation | Baseline comparability | Blind Subjects | Blind Therapists | Blind Assessors | Adequate Follow up | Intention-to-treat | Between-group comparison | Point estimates / variability | Score |
|------------------------------|----------------------|-------------------|----------------------|------------------------|----------------|-----------------|-----------------|-------------------|-------------------------|-----------------------------|-----------------|------|
| Nejati (2021)                | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 1                       | 1                          | 1               | 4    |
| Slattery et al. (2021)       | 1                    | 1                 | 0                    | 1                      | 1             | 1               | 1               | 1                 | 1                       | 1                          | 1               | 7    |
| Kollmeier et al. (2020)      | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 1                       | 1                          | 1               | 8    |
| Kirk et al. (2019)           | 1                    | 1                 | 1                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 8    |
| Bikic et al. (2018)          | 1                    | 1                 | 1                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 8    |
| Tullo et al. (2018)          | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 6    |
| Bikic et al. (2017)          | 1                    | 1                 | 1                    | 1                      | 1             | 1               | 1               | 0                 | 1                       | 1                          | 1               | 9    |
| (Kirk et al., 2016)          | 1                    | 1                 | 1                    | 1                      | 1             | 0               | 0               | 1                 | 0                       | 0                          | 1               | 10   |
| Mishra et al. (2016)         | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 1               | 0                 | 0                       | 1                          | 1               | 7    |
| Sarzyńska et al. (2017)      | 0                    | 0                 | 0                    | 0                      | 1             | 0               | 0               | 1                 | 0                       | 0                          | 1               | 4    |
| Schrieff-Elson et al. (2017) | 1                    | 1                 | 1                    | 1                      | 0             | 1               | 0               | 1                 | 0                       | 0                          | 1               | 7    |
| Rueda et al. (2012)          | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 6    |
| Tucha et al. (2011)          | 0                    | 1                 | 0                    | 1                      | 1             | 0               | 0               | 0                 | 0                       | 1                          | 1               | 5    |
| Kerns et al. (1999)          | 1                    | 0                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 0                       | 1                          | 0               | 4    |
| Meditation Training          |                      |                   |                      |                        |               |                 |                 |                   |                          |                             |      |
| Bauer et al. (2020)          | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 0                       | 0                          | 1               | 6    |
| Mishra et al. (2020)         | 1                    | 1                 | 1                    | 1                      | 1             | 1               | 1               | 0                 | 1                       | 1                          | 1               | 8    |
| Tarrasch (2018)              | 1                    | 0                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 0                       | 1                          | 1               | 4    |
| Kiani et al. (2017)          | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 6    |
| Wimmer et al. (2016)         | 0                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 1                       | 1                          | 1               | 4    |
| Ricarte et al. (2015)        | 0                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 6    |
| Leonard et al. (2013)        | 0                    | 1                 | 0                    | 1                      | 1             | 1               | 0               | 0                 | 0                       | 1                          | 1               | 5    |
| Napoli et al. (2005)         | 0                    | 1                 | 0                    | 0                      | 1             | 0               | 0               | 1                 | 0                       | 1                          | 1               | 4    |
| Physical Activity            |                      |                   |                      |                        |               |                 |                 |                   |                          |                             |      |
| Meijer et al., 2021          | 0                    | 1                 | 1                    | 1                      | 0             | 0               | 0               | 1                 | 0                       | 1                          | 1               | 6    |
| Cheriere et al. (2020)       | 1                    | 0                 | 1                    | 0                      | 0             | 0               | 0               | 0                 | 1                       | 1                          | 1               | 5    |
| Duarte et al. (2020)         | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 0                       | 0                          | 1               | 3    |
| García-Hermoso et al. (2020) | 1                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 6    |
| Hedayatjoo et al. (2020)     | 1                    | 1                 | 1                    | 1                      | 0             | 0               | 0               | 2                 | 0                       | 0                          | 1               | 4    |
| Månsson et al. (2019)        | 1                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 4    |
| Buchele Harris et al. (2018) | 0                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 0                       | 1                          | 1               | 3    |
| Rezaei et al. (2018)         | 0                    | 1                 | 0                    | 1                      | 0             | 0               | 0               | 0                 | 0                       | 0                          | 1               | 1    |
| Chou and Huang (2017)         | 1                    | 0                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 0                       | 1                          | 1               | 3    |
| Sabel et al. (2017)          | 1                    | 0                 | 0                    | 1                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 1               | 5    |
| Gallotta et al. (2015)       | 1                    | 1                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 0                       | 0                          | 1               | 1    |
| Zach et al. (2015)           | 0                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 0                 | 1                       | 0                          | 1               | 2    |
| Verret et al. (2012)         | 1                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 0                       | 0                          | 1               | 3    |
| Spitzer and Hollmann (2013)   | 0                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 0               | 2    |
| Study 1                      |                      |                   |                      |                        |               |                 |                 |                   |                          |                             |      |
| Spitzer and Hollmann (2013)   | 0                    | 0                 | 0                    | 0                      | 0             | 0               | 0               | 1                 | 1                       | 1                          | 0               | 3    |
| Study 2                      |                      |                   |                      |                        |               |                 |                 |                   |                          |                             |      |
Appendix B. Summary of Each Study

Study 1: Nejati (2021)

Children with ADHD aged 8–14 years were randomly assigned to a training (n = 15) or passive control group (n = 15). The training group received a programme for attention rehabilitation and strengthening (PARS) over 4–5 weeks. The programme targeted sustained attention, selective attention and attention shifting using non-computerised activities. Both groups completed assessments of sustained attention (Persian Attention Registration Test; 3 measures), selective attention (Stroop Test; 4 measures), attention shifting (Trail Making Test; 2 measures), inhibitory control (Go/No-Go Test; 3 measures) and working memory (1-Back Task; 2 measures) before and after the intervention. The results showed significant group × time interaction effects for some measures including omission errors (p = .001, $\eta^2 = .424$) and commission errors (p = .014, $\eta^2 = .218$) on the Persian Attention Registration Test, incongruent stage speed (p = .041, $\eta^2 = .163$) and the selective attention index (p = .036, $\eta^2 = .170$) on the Stroop Test, go reaction time (p = .013, $\eta^2 = .097$) and no-go accuracy (p = .021, $\eta^2 = .196$) on the Go/No-Go Test, and accuracy (p = .016, $\eta^2 = .211$) on the 1-Back Test. This study had several methodological limitations including no correction for multiple comparisons (at least 14 different variables analysed), a passive control and a relatively small sample size.

Study 2: Slattery et al. (2021)

In this cluster-randomised preliminary study, children aged 9–11 years were assigned to the Keeping Score! attention training group (n = 18) or an active control group (n = 18). Training was based on sustained updating and required participants to silently keep score during an interactive game of table tennis. Both groups completed cognitive assessments of sustained attention (Vigil, Cerberus and Sustained Attention to Response Task subtests of the TEA-Ch2; 3 measures), short-term memory (Forward Span task WISC-V; 1 measure) and working memory (Digit Span Backward subtest of the WISC-5 and the Operation Span and Symmetry Span subtests of the Adaptive Composite Complex Span; 3 measures) at baseline, post-test and 6-week follow up. Parents also completed ratings of executive function behaviour (BRIEF; 4 measures). There were no significant time by group interaction effects for any objective or subjective outcome measure.

Study 3: Kollins et al. (2020)

In this large randomised controlled trial, children with ADHD aged 8–12 years were assigned to a digital intervention group (n = 180) or an active control group (n = 168). Participants in the intervention group received the AKL-T01 programme designed to train attention and cognitive control using video game-based activities at home over 4 weeks. The active control group completed activities that required participants to spell as many words as possible, by connecting letters in a game-like grid. The results showed a statistically significant improvement in the primary outcome, sustained attention, assessed using TOVA Attention Performance Index in the intervention group compared to the control. No intervention effects were found for secondary outcomes, including the Impairment Rating Scale, ADHD-RS-IV (3 measures), Clinical Global Impressions-Improvement and the BRIEF (3 measures). No intervention effects were found for minor secondary efficacy endpoints, working memory (CANTAB-spatial working memory; 8 measures) or inhibitory function (TOVA; 1 measure). Study strengths include a large sample size, a sample of participants with deficits in cognitive attention and prospective pre-registration.

Study 4: Kirk et al. (2019)

Children (5–9 years) were cluster-randomised to the training group (n = 39), active control (n = 35), or passive control (n = 33). The training group completed adaptive game-based exercises from the Tali Train programme designed to train sustained, selective, and executive attention. The active control completed non-adaptive game-based exercises that required minimal attention skills. Sessions were held in school over a 5-week period. All groups were tested on near transfer measures (visual sustained attention, visual/auditory selective attention, executive attention) and far transfer measures (verbal/visuospatial working memory, numeracy, and inattention/hyperactivity) at pre-test, post-test and 6-month follow up. The results indicated the training group made significantly greater improvements in visual sustained attention from baseline to follow up compared to the passive control. In contrast, the passive control group made greater gains in auditory selective attention from baseline to post-training compared to the intervention group. No other effects were found for objective measures. A number of significant intervention effects were reported for rating scale measures. Specifically, the training group demonstrated significantly greater improvements in teacher-rated inattention and hyperactivity from baseline to post-training compared to the active and passive control groups. Parents reported significantly larger improvements in hyperactivity from baseline to post-training compared to the passive control. Improvements were maintained for teacher ratings of hyperactivity at follow up compared to the passive control. The study concluded that classroom-based attention training has select benefits in reducing inattention and hyperactivity but may not promote gains in cognitive or academic skills in primary school children. However, this conclusion is at odds with the underlying rationale of cognitive attention training, as effects of training on behaviour are typically seen as dependent on increases in cognitive capacity. Study strengths include the inclusion of both an active and passive control group, fairly large sample size, long-term follow up and prospective pre-registration.

Study 5: Bikić et al. (2018)

Children with ADHD aged 6–13 years were randomly assigned a training group (n = 35) or passive control (n = 35). The training group completed the computer programme ACTIVATE™ at home. Participants completed 40-minute sessions six days a week for 8 weeks. The programme trained multiple cognitive functions simultaneously, including sustained attention, working memory, speed of information processing, response inhibition, cognitive flexibility, category formation, and pattern recognition. All exercises were adaptive, and the programme included an in-built reward system. The results showed no significant improvements in the primary outcome, sustained attention, or secondary outcomes, executive function/attentional behaviour after 8, 12 or 24 weeks. However, the training group showed significant improvements in one exploratory measure, planning ability, from pre- to post-training compared to the control (p = .006). This effect was maintained at both the 12-week (p = .035) and 24-week (p = .017) follow up.

Study 6: Tullo et al. (2018)

In this randomised-controlled trial, students with neurodevelopmental conditions (6–18 years) were assigned to a training group (n = 43), active control (n = 43) or passive control (n = 43). The training group received NeuroTracker training designed to trained visual attention including sustained and selective attention. Training was adaptive. Participants completed a total of 15 sessions over 5 weeks at school. Sessions lasted 7 min. The active control completed the computer game 2048. Groups were matched on age and two WASI subscales. Sustained attention was assessed using d prime scores from the Conners’ Continuous Performance Test at pre- and post-test. The results showed a significant difference in standardised change CPT-3 d prime scores between the training group and active control (p = .033, d = .524) and between the training group and passive control (p = .048, d = .497). There was no significant difference between the active and passive
controls. Though this study did not assess far transfer or long-term effects, it had a number of strengths including a large sample size, randomised design, and active/passive control groups.

**Study 7: Bikic et al. (2017)**

This double-blind randomised pilot allocated participants to an intervention group (n = 9) or active control (n = 9). The intervention group completed exercises from the Scientific Brain Training programme for 30-minutes five days a week for seven weeks at home. The exercises were adaptive and trained numerous cognitive functions, including sustained attention and working memory. The control group played a non-adaptive version of Tetris. The Cambridge Neuropsychological Test Automated Battery and ADHD rating scale were completed at pre- and post-training. The test battery included measures of sustained attention, processing speed, visual memory, short-term memory, spatial working memory, planning and rule acquisition/visual discrimination/attention shifting. There were no significant differences between the groups on sustained attention (assessed using a Rapid Visual Information Processing task) or any other cognitive/behavioural measure. However, there were some within-group differences from pre- to post-training. In the training group, scores on two sustained attention measures improved, A prime (the ability to detect the target sequence; \( p = .003, d = 1.5 \)) and probability of hit (\( p = .005, d = 1.3 \)). In contrast, the control group improved on one spatial working memory variable (between errors; \( p = 0.042, d = 0.88 \)).

**Study 8: Kirk et al. (2016)**

Results of this single intervention are reported separately in Kirk et al. (2016; attention outcomes; 7 different variables) and Kirk et al. (2017; academic, executive functioning and behavioural/emotional problems outcomes; 20 different variables). In this study, children with a diagnosis of intellectual disability and attentional difficulties (aged 4–11 years) were randomly assigned to receive Tali Train (n = 38) or an active control (n = 38). Outcome measures were completed at baseline, post-training and 3-month follow up. Participants in the training group showed significantly greater improvements in some aspects of selective attention from baseline to post-training (d = 0.24) and baseline to 3-month follow up (d = 0.26) compared to participants in the control group. Training did not have an immediate effect on academic outcomes but participants in the training group showed significantly greater improvements in numeracy skills from baseline to follow up compared to participants in the control (d = 0.15). The training was not effective in improving sustained attention, attention control, cardinality, vocabulary, phonological abilities, inattentive/hyperactive behaviour, working memory behaviour, executive function behaviour or behavioural problems. Although this study had a fairly large sample size and included an active control group, it did not correct for multiple comparisons. Correction for multiple comparisons would have been appropriate as over 20 different variables were investigated. Therefore, the results should be interpreted cautiously.

**Study 9: Mishra et al. (2016)**

In this study, children with ADHD were randomly assigned to an intervention group (n = 21) or active control (n = 10). The intervention group completed adaptive online cognitive exercises that focused on attended-signal training or distractor-suppression training over a 6-month period. The exercises targeted sustained attention, working memory and response inhibition. The active control played the online Hoyle puzzle game. Both groups completed assessments of sustained attention (first 10 min of the TOVA; 1 measure), response inhibition (second half of the TOVA; 1 measure), short-term memory (spatial capacity task and verbal capacity task; 2 measures) and executive function (Stroop Colour and Word Interference Test; 1 measure) at baseline and post-test. Parents rated ADHD symptom severity and clinicians completed the Clinical Global Impression (CGI) of Severity of Illness Scale at baseline, mid-intervention, post-intervention and at a 6-month follow up. The results indicated that change in ADHD symptom severity for the intervention group vs the control group from baseline to mid-/post-intervention did not reach between-group significance but was significant at follow-up (\( p = 0.04, d = 0.36 \)). Within-group ANOVAs applied over the four assessment time points (baseline, mid-, post-, follow up) showed that symptom severity ratings changed significantly in the intervention group (\( p = 0.003 \)) but not in the control group. Nonparametric ANOVA over the four assessed time points did not find a significant effect in the intervention group for CGI but did find a significant effect in the control group (\( p < 0.007 \)). The training group demonstrated statistically significant improvements in response inhibition and Stroop interference compared to the control group. No other effects reached statistical significance.

**Study 10: Sarzyńska et al. (2017)**

Sarzyńska et al. (2017) reported near transfer to sustained attention but no far transfer to fluid intelligence in a sample of 8-year-old children. In this non-randomised study, participants were assigned to an intervention (n = 30) or active control (n = 24) group. The training group completed computerised tasks designed to train multiple attentional functions. The difficulty of the tasks was adjusted according to the child’s performance and a token system encouraged motivation. The control group completed computerised tasks that targeted problem solving and perceptual skills. Both groups completed a total of 10 sessions 2 or 3 times a week. Each session lasted 30 min. Outcome measures of attention (d2 Attention test; 7 different variables) and intelligence (Raven’s Progressive Matrices Test) were completed at baseline, post-test and 3-month follow up (training group only). The results showed significant group × time interaction effects for some d2 variables, including false alarms (\( p = .0003, \eta^2 = 0.06 \)), discriminability (\( p = 0.001, \eta^2 = 0.03 \)) and bias (\( p = .02, \eta^2 = 0.03 \)).

**Study 11: Schrieff-Elson et al. (2017)**

Fifteen low socioeconomic status children aged 7–13 years were assigned to an intervention group (n = 5), active control (n = 5) or passive control (n = 5). The intervention group received the Pay Attention! training programme, which consisted of four non-computerised tasks designed to train sustained, selective, alternating, and divided attention. The active control played physical games like hopscotch. Participants received two 45-minute sessions per week for 10 weeks. Tests of attention, working memory and inhibition were completed before and after the intervention. Training was not effective in improving sustained attention (assessed using the Score! subtest from the Test of Everyday Attention for Children and Numbers Forward from the Children’s Memory Scale) or any other outcome. The active control displayed higher inhibition scores compared to the passive control at post-test (\( p = 0.36 \)). Within-group analyses indicated that the intervention group improved in aspects of selective attention, attentional control and inhibition from pre- to post-test. In contrast, both controls improved in aspects of selective attention. Given the very small sample size, all findings should be interpreted cautiously.

**Study 12: Rueda et al. (2012)**

In this study, 5-year-old children were pseudo-randomly assigned to a training group (n = 19) or control group (n = 18) matched for gender, IQ and flanker inference scores on the Attention Network Test (ANT). The training group completed computerised exercises designed to train tracking, discrimination, conflict resolution, inhibition, and sustained attention. All exercises were adaptive. Training took place twice weekly for 45 min over 5 weeks. The active control watched cartoons. The
following measures were completed at pre- and post-training: ANT, delay gratification task, gambling task and Kaufman Brief Intelligence Test. There were no significant differences between the training and control group in sustained attention (alerting scores from the ANT) or any other cognitive outcome over time (i.e., no significant time × group interaction effects). However, a number of significant differences were found in planned contrast analysis. In the training group, there was a significant improvement in IQ matrices from baseline to post-training and significant improvements in a gambling task from baseline to follow up. Both groups showed significant improvements in some outcome measures from a delay of gratification task from baseline to post-training and baseline to follow up. However, to show a training benefit relative to the control, improvements in the training group must be compared directly to improvements in the control group (time × group intervention effects were not statistically significant).

Study 13: Tucha et al. (2011)

The results from this study are reported in both Tucha et al. (2011) and Lange et al. (2012). Children with ADHD were randomly assigned to an AixTent attention training group (n = 16) or active control (n = 16). AixTent is an adaptive computerised programme designed to trained sustained, selective, and divided attention. Participants completed two sessions a week for four weeks. Each session lasted 1 h. The control group completed visual perception training. The intervention and control groups underwent tests of tonic and phasic alertness, vigilance, selective attention, divided attention, and flexibility before and after training. The training group demonstrated improvements in some aspects of vigilance (commission errors; p = .011, d = 0.59), divided attention (commission errors; p = .002, d = 1.28), and flexibility (commission errors; p = .050, d = 0.84) from baseline to post-training (15 paired t-tests). In contrast, the control group show no changes (15 paired t-tests). At post-training, there was one statistically significant difference between the training and active control in divided attention (commission errors; p = .003) out of 15 comparisons. Differences in ipsative scores (change from pre- to post-assessment) were also calculated for both groups. The training group demonstrated significantly greater ipsative change compared to the control in aspects of vigilance (errors of commission; p = .047) and divided attention (errors of commission; p = .014; 15 comparisons). However, no correction for multiple comparisons was applied despite the large number of pairwise comparisons.

Study 14: Kerns et al. (1999)

In this early influential study, Kerns et al. (1999) reported improvements in sustained attention following training with the Pay Attention! programme in children with ADHD. Participants (aged 7–11 years) were assigned to the intervention (n = 7) group or active control (n = 7). Pay Attention! trained sustained, selective, alternating and divided attention using various non-computerised tasks. All tasks were adaptive, and participants received feedback on their performance. The control group played computer games. Both groups completed 16 30-minute sessions over 8 weeks. Participants in the intervention and control groups underwent cognitive tests (attention, executive function and academic efficacy; at least 13 different variables) and parent/teachers completed ratings of ADHD symptoms. The training group demonstrated improvements in auditory sustained attention (p < .001; Attention Capacity Test), planning (p = .010; Mazes subtest WISC-III), inhibition (p = .005; Day Night Stroop), selective attention (p = 0.15; Underlying Task) and academic efficiency (p = .015) when compared to the control group. No intervention effects were found for sustained attention (Children’s Continuous Performance Test), impulsivity (Matching Familiar Figures Test), freedom from distractibility (Coding and Digit Span subtests WISC-III), spatial ability (Hooper Visual Organisation Test), or inattentive/hyperactive behaviours (Attention Deficit Disorder Evaluation). The authors concluded that attention training interventions “may be a valuable treatment option for improving cognitive efficiency in children with ADHD”. However, given the many methodological concerns (e.g., small sample size, adequacy of the active control, no correction for multiple comparisons (at least 14 between group comparisons conducted), no follow up assessment and no randomisation), this conclusion seems far-reaching.

Study 15: Bauer et al. (2020)

Bauer et al. (2020) found that a school-based mindfulness programme improves aspects of sustained attention in 6th grade students. The study reports a small subset of data (n = 31) from participants who completed an fMRI protocol as part of a larger RCT (N = 96). The programme was designed to train focused attention and change students’ mindsets about their stress over 8 weeks. The control group received coding training which matched the time commitment and engagement of the mindfulness intervention. Sustained attention was assessed using a SART pre- and post-training. The results indicated that the mindfulness group displayed significantly better Go-accuracy scores after the intervention compared to the coding group (p = .01, Cohen’s d = .47). There were no significant differences between the groups in RT variability or No-Go accuracy after the intervention. Given the small sample size and study design (i.e., participants self-selected to take part in the fMRI protocol), the results should be interpreted cautiously.

Study 16: Mishra et al. (2020)

Adolescents with childhood neglect (aged 10–18 years) were cluster randomised to either an internal attention intervention (IAI; n = 15), external attention intervention (EAI; n = 15) or a passive control (treatment-as-usual; n = 15). The internal attention group used the app Meditrai to practice attending to the sensations of their breath. The external attention group completed exercises from brainhq.com designed to train focused attention, divided attention, selective attention and working memory. Participants in both groups completed 30 sessions over 6 weeks. Sessions lasted 30 min. Participants in the intervention and control groups underwent tests of sustained attention (test modelled after the Test of Variables of Attention; response time variability) and interference control (Flanker Test; RT on incongruent trials minus RT on congruent trials) before and after the intervention. Caregivers rated ADHD symptoms at pre-test, post-test and 1-year follow up and teachers rated students’ academic performance after the intervention and at 1-year follow up. There was a significant time × group interaction effect following the intervention for both outcomes, sustained attention (p = .01, η² = 0.17) and interference resolution (p = .03, η² = 0.16). Post hoc within group tests showed that these outcomes improved from baseline to post-training in only the internal attention group (p = .01 and p = .015). There were no significant changes in the external attention group. The passive control showed a significant decline in sustained attention at post-test (p = .03). There was no significant difference between groups in ratings of inattention/hyperactivity at post-training but significant improvements in hyperactivity were found from baseline to 1-year follow up in the internal attention group (p = .005) and from post-test to follow up (p = .038). There was a significant difference between the groups after the intervention on teacher-rated academic performance (p = .04, η² = 0.15), with the paper reporting that the IAI group had high ratings relative to the EAI and treatment-as-usual groups though the results of these pairwise comparisons are not reported.

Study 17: Tarrasch (2018)

Tarrasch et al. (2018) reported that mindfulness training was effective in improving sustained attention in children aged 8–11 years. In this non-randomised study, participants were assigned to mindfulness
training (n = 58) or a passive control (education as usual; n = 43). The training group received 10 sessions of mindfulness-based stress reduction (MBSR) in a group setting. Both groups were tested in a pre- and post-test using a CPT (sustained attention) and Conjunctive Visual Search Task (selective attention). At pre-test, the intervention group demonstrated a significantly higher CPT commissions (p < .05) and Conjunctive Search accuracy (for trials including 8 displays with and without targets, ps < .05) compared to the control. A significant time × group interaction effect for CPT commissions (p < .01, η_p^2 = 0.124) was found with post hoc Tukey’s HSD indicating the mindfulness group demonstrated improvements from baseline to post-training (p < .001, d = 0.89). No effects were found for CPT omissions or RTSD. Some significant improvements were reported for aspects of selective attention from pre- to post-test in both the mindfulness and control groups (dependent on whether the target was included and the number of items in the display). This was a non-randomised study and groups were not equivalent before training on some outcome variables (which were not accounted for in the analyses), which makes the findings difficult to interpret.

**Study 18: Kiani et al. (2017)**

In this study, female adolescents with elevated ADHD symptoms were randomly assigned to a mindfulness training group (n = 15) or a passive control (n = 15). The intervention group received mindfulness training with sessions focusing on attention and the five senses. Sessions were held weekly for 8 weeks. Both groups completed assessments of sustained attention (CPT; 3 measures), working memory (Digit Span subtest and Letter-Number Sequencing subtest of the WISC-IV; 5 measures), inhibition (Stroop Word-Colour Interference Test; 1 measure) and planning (Tower of London Test; 1 measure) at baseline and one-month after the intervention. The results indicated that the mindfulness group demonstrated statistically significant improvements in inhibition (p = .01, η_p^2 = .22) and planning (p = .04, η_p^2 = .15) compared to the control group. No other between group differences were found. Within group analyses indicated that the training group improved on working memory from pre- to post-test (p = .004).

**Study 19: Wimmer et al. (2016)**

Children were assigned to an intervention group (n = 16), active control (n = 8) or passive control (n = 10). The intervention group received MBSR training 25 times over 18 weeks. The active control received concentration skills training. Groups completed a vigilance task, reversible figure task, Stroop Colour-Word Interference task, recognition task, visual search task and the WSCT-64 at pre- and post-test. In the paper, results are reported at p < .10 due to the “small sample size and pilot character of the study”. A number of intervention effects are reported at this significance level; however, only two of these effects are significant at p < .05 (vigilance task accuracy in no-responses and visual search RT in blank trials). The passive control group accuracy in no-responses scores significantly worsened from pre- to post-test (p = .05), whereas the interaction and active control remained unchanged. This finding is interpreted as “partly” confirming the hypothesis that mindfulness and concentration training are associated with improvements in sustained attention. However, it provides very weak evidence of an intervention effect as there was no direct comparison between groups and a decline in performance in the control does not represent a sensible transfer pattern. Regarding RT in blank trials on the visual search task, the mindfulness improved compared to the passive control (p = .02) and the passive control improved compared to the active control (p = .03). Note, children were not randomly assigned to the passive control.

**Study 20: Ricarte et al. (2015)**

Ricarte et al. (2015) found a school-based adaption of the Mindfulness Emotional Intelligence Training Programme improved concentration and immediate auditory-verbal memory in children aged 6–13 years. The intervention group (n = 45) received mindfulness training every day for 6 weeks and was compared to a passive control group (n = 45). Sustained attention (Trail Making Test Part A), focused attention (Perception of Differences Test), mental flexibility (Trial Making Test Part B), concentration (Digit Span subtest WISC-III total score), auditory-verbal memory (Digit Span Forward) and working memory (Digit Span Backward) were compared between the two groups. Immediately after training, the intervention but not the control group showed improvements in concentration (p < .001, η_p^2 = .12) and auditory-verbal memory (p < .001, η_p^2 = .13). No training effects were found for any other cognitive measure. Study strengths include its fairly large sample size and randomised design, but the intervention group likely had a greater expectation of improvement than the passive control.

**Study 21: Leonard et al. (2013)**

This cluster-randomised controlled trial assigned two hundred and sixty-four incarcerated youths (aged 16–18 years) to a cognitive behavioural/mindfulness intervention group or active control. The intervention combined aspects of cognitive behavioural therapy with the attentional and response modification elements of mindfulness meditation. The active control completed cognitive perception training. Both conditions completed 750 min of training in small groups over 3–5 weeks. The ANT was administered pre- and post-training (9 different variables). There was a significant time × group interaction effect for overall ANT performance (% correct; p < .001, η_p^2 = .06). At post-training, scores were significantly higher in the intervention group compared to the control (p = .04, d = 0.30). There was a time × group interaction effect for response variability (p = .02, η_p^2 = .03). At T2, response variability was lower (responses were more stable) in the intervention group compared to the control (p = .02, d = 0.34). No significant effects were found for alerting, orienting or conflict monitoring (RT or % correct).

**Study 22: Napoli et al. (2005)**

Primary school children were randomly assigned to a mindfulness intervention (n = 114) group or control (n = 114). The intervention group completed the Attention Academy Programme designed to help students improve their quality of life through practicing mindfulness. The control group completed “reading and other quiet activities”. Both groups had twelve 45-min sessions over 24 weeks. Sustained attention (TEA-Ch Scorel, Walk, Don’t Walk and Code Transmission subtests), selective attention (TEA-Ch Sky Search and Map Mission subtests) and ADHD symptoms (ACTeRS) were assessed at baseline and post-training. A series of t tests were used to examine pre-to-post-test differences between groups. No intervention effects were found for sustained attention. The mindfulness group demonstrated significant improvements in selective attention (total score from the TEA-Ch; p < .001, d = 0.60) and attentional behaviour (p = .001, d = 0.49). Limitations include the lack of clarity and/or consistency of control activities, no long term follow up and unclear what statistical analyses were conducted (e.g., “paired t-tests (….) between groups”).

**Study 23: Meijer et al. (2021)**

In this cluster-randomised controlled trial, children were assigned to an aerobic exercise group (n = 221), cognitively demanding exercise group (n = 240) or a passive control group (n = 430). The aerobic exercise group consisted of activities designed to target moderate-to-
vigorously while avoiding high cognitive demands. The focus was on highly repetitive and automated exercises (e.g., running, squats, etc.). The cognitively demanding exercise group consisted of team games or exercises that required complex movement, strategic play, cooperation between children, anticipating behaviour and dealing with changing task demands. Both groups received four sessions per week over 14 weeks. Participants completed the ANT (5 measures), Digit Span Task (2 measures), Grid Task (2 measures), Stop Signal Task (1 measure) at baseline and post-test. Principal components analysis was used to derive composite scores. Six components were extracted: 1) information processing and control (information processing speed, lapses of attention and motor inhibition), 2) interference control (speed and accuracy of interference control), 3) attention accuracy (accuracy of alerting attention and spatial orientation), 4) visuospatial working memory (visuospatial working memory and visuospatial short-term memory), 5) verbal working memory (verbal working memory and verbal short-term memory), and 6) attention efficiency (speed of alerting attention and spatial attention to information). The results indicated no statistically significant differences between the two intervention groups and the control group for any of the components. Study strengths include its large sample size and extensive cognitive test battery.

**Study 24: Cherriere et al. (2020)**

In this non-randomised study, children with Charcot-Marie-Tooth disease aged 7–12 years were assigned to a dance group (n = 5) or a passive control group (n = 4). Participants in the dance group received training in various complex dance forms (e.g., jazz, break dance and tap) twice weekly for 10 weeks. Both groups completed measures of sustained attention (Scorel subtest and Score DT subtest of the TEA-Ch) short-term memory (Forward Span subtest of the WISC-IV) and working memory (Backward Span subtest of the WISC-IV) at baseline and post-test. The intervention group demonstrated greater improvements in sustained attention (Scorel subtest; p = .03) compared to the control group. No other between-group effects were statistically significant. Serious methodological limitations include the small sample size and non-randomised design.

**Study 25: Duarte et al. (2020)**

Adolescents aged 12–14 years were cluster-randomised to a Qigong group (n = 22), active control group (n = 22) or passive control group (n = 22). Qigong integrates movement and breathing exercises that require and induce a special kind of mental state of ‘awareness’ or ‘attention’. The Qigong group performed the White Ball Qigong exercise, according to the Heidelberg Model of Traditional Chinese Medicine. The active control group performed a sham Qigong. Both groups performed their respective activities for 5 min, twice a week, over a 4-week period. They were also encouraged to repeat the exercises at home on a daily basis. Participants completed the d2 test of attention at baseline, after two weeks and four weeks of training. The following measures were extracted: total number of items processed (TN), total hits (TH), total number of items minus error scores (TN-E), concentration performance (CP) and fluctuation rate (FR). The Qigong group demonstrated significant improvements in the total number of items processed (TN), total hits (TH), total number of items minus error scores (TN-E) and concentration performance (CP) compared to both the active and passive control groups after four weeks of practice.

**Study 26: García-Hermoso et al. (2020)**

In this cluster-randomised controlled trial, children from schools with low socioeconomic status were assigned to the Active-Start programme (n = 100) or a passive control (n = 70). Participants in the Active-Start programme completed physical games focused on group cooperation. The intensity of the main part of the sessions was moderate-to-vigorous. The d2 Test of Attention (2 measures) and academic performance (numeric grade scores ranging from 7 excellent to 1 not sufficient) were administered. No statistically significant intervention effects were found for concentration (d = .08, p = .535) or selective attention (d = .04, p = .124). However, significant changes were found for language performance (d = .83, p < .001) and mathematics performance (d = .60, p < .001).

**Study 27: Hedayatjoo et al. (2020)**

Thirty-six children with hearing deficits (7–12 years) were randomly assigned to an intervention group (n = 18) or passive control group (n = 18). The intervention group completed balance exercises over a 4-week period. Both groups completed a CPT to assess sustained attention before and after the intervention. The results indicated that the intervention group improved significantly from pre- to post-test on CPT performance (p = .002) though it was not clear what CPT outcome measure was used in the analysis. In contrast, the control group did not significantly improve from pre- to post-test (p = .906). In addition, the pre- to post-test difference was compared between groups and indicated a significant difference between the groups (p = .017).

**Study 28: Månsson et al. (2019)**

In this non-randomised study, children (those with ADHD and those with ADHD symptoms) aged 10–14 years were assigned to a physical activity group (n = 64) or passive control (n = 66). The physical activity group participated in target shooting practice for a period of 6-months (1 h session each week). Participants in both groups completed the cognitive tests of attention QbTest™ (2 sustained attention variables and 2 hyperactivity variables) and parents/teachers completed a rating scale measures of ADHD symptoms (ADHD Rating Scale; 1 variable), behaviour problems (Strengths and Difficulties Questionnaire; 1 variable), and quality of life (KIDSCREEN-27; 1 variable) before and after the intervention. The physical activity group demonstrated greater improvements in the two measures of sustained attention, Qb reaction time variance (p = .013) and Qb omission errors (p = .019), parent-rated ADHD symptoms (p = .024) and parent-rated behavioural problems (p = .027). However, there was a significant difference between the groups at baseline on Qb omissions, which complicates the interpretation of intervention-related improvements in this outcome. Furthermore, it is likely the parents of children in the intervention group likely had a greater expectation of improvement than parents of children in the control group.

**Study 29: Buchele Harris et al. (2018)**

Buchele Harris et al. (2018) concluded that daily brief coordinated-bilateral physical activities (CBPA) can improve attention and concentration in fifth grade students. In this study, participants were assigned to a CBPA training + Fitbit group (n = 31), Fitbit only group (n = 29), or passive control (n = 56). The CBPA group received CBPA breaks (6 min × 5 days) during the school day and were given fitness trackers to wear Monday to Friday over 4 weeks. Sustained attention was assessed pre- and post-training using outcome measures from the d2 Test of Attention (processing speed, focused attention, concentration performance and attention span). At pre-test, the control group had significantly higher processing speed, focused attention, and concentration performance scores than the CBPA and Fitbit only group. Post hoc comparisons revealed significant improvements in the CBPA group in speed (p = .010), focused attention (p = .02), concentration performance (p < .001) and attention span (p < .001) compared to the passive control. There were also significant improvements in the CBPA group in concentration performance (p < .001) and attention span (p = .011) compared to the Fitbit only group. These findings suggest the coordinated-bilateral physical activities may improve sustained...
attention though results should be interpreted cautiously given the many study limitations. Limitations include no randomisation and significant differences between groups at pre-test which were not accounted for in the analyses.

**Study 30: Rezaei et al. (2018)**

In this study, 21 children aged 7–11 years were assigned to a yoga group (n = 7), neurofeedback group (n = 7) or passive control (n = 7). The yoga group consisted of yoga and relaxation exercises. The neurofeedback training consisted of theta/beta training. Both groups received 24 training sessions over 8 weeks. Various measures of attention (7 different variables) were administered before and after the intervention. The authors first compared each intervention group to the control group and then compared the two intervention groups. For the purposes of this review, we only report yoga-control comparisons. In relation to the yoga-control comparison, an ANCOVA (not clear what was controlled for) indicated a significant effect of group on CPT correct detection (p = .001, η² = .878), CPT errors of omission (p = .008, η² = .722), CPT errors of commission (p = .001, η² = .888), WISC number sequencing (p = .004, η² = .772) and WISC Coding (p = .015, η² = .652). The yoga group seemed to demonstrate improvements in all these variables except for CPT errors of commissions, which were lower in the control group. Given the small sample used, the results should be interpreted cautiously.

**Study 31: Chou and Huang (2017)**

In this non-randomised study, the intervention group received 8 weeks of yoga with two sessions per week and was compared to a passive control group. Participants were assigned to a yoga exercise intervention (n = 25) or treatment as usual (n = 25). Each yoga session consisted of 10-minutes of stretching and warming up followed by a 20-min yoga activity, which included concentration and balance, improved attention and breath and body awareness, and a 10-min cool down. Both groups completed a sustained attention task (Visual Pursuit Test) and a discrimination task at baseline and within one week of completing the intervention. At post-test, the yoga group showed improvements in sustained attention, Visual Pursuit Accuracy Rate (p = .010, d = .78) and RT (p < .001, d = −1.20) compared to the control. Improvements in the Discrimination task Response Accuracy (p < .001, d = 1.09) and RT (p < .001, d = −1.25) were also found in the yoga group compared to the control group at post-test. Overall, these findings suggest that a yoga exercise intervention may improve sustained attention in children with ADHD; however, the study has many methodological limitations (e.g., non-randomised design, passive control and no long-term follow up for cognitive measures), which restrict the interpretation of results.

**Study 32: Sabel et al. (2017)**

Sabel et al. (2017) found that active video gaming improved motor and process skills but not sustained attention in thirteen childhood brain tumour survivors aged 7–17 years. Participants were randomised to either an intervention or waitlist control group. After 10–12 weeks the groups crossed over. The intervention involved active video gaming using Nintendo Wii (5 days per week) and weekly online coaching sessions for 10–12 weeks. Training had no effect on the primary cognitive outcome measures which included (among others) sustained attention, working memory, long-term memory, information processing speed and executive function. Parallel group analysis indicated that the intervention group demonstrated significantly improved Process scores on the Activities of Daily Living assessment (p = .030), suggesting they became more independent in their daily lives (secondary outcome). However, we cannot draw conclusions about the impact of active video gaming on attention due to the small sample size and cross over design.

**Study 33: Gallotta et al. (2015)**

In this cluster-randomised trial, normal and overweight children aged 8–11 years were assigned to a traditional physical activity group (n = 78), a coordinative physical activity group (n = 83) or a passive control (school as usual; n = 69). The traditional physical activity group primarily focused on endurance, strength, flexibility exercises and circuit training for cardiovascular health. The coordinative physical activity intervention was focused on improving the coordination and dexterity of participants. Interventions were administered in school over 5 months. Both groups completed two 1-hour sessions per week over a five-month period. The d2 Test of Attention was administered at pre- and post-test. Three outcome measures were extracted: items processed, concentration and % errors. Within group analyses indicated that the traditional physical activity group improved in all measures from pre- to posttest and the coordinative physical activity group improved in concentration and % errors. No improvements were found in the control from pre- to post-test. Analyses were also conducted with the absolute variation and the percentage variation (i.e., post-intervention score – pre-intervention score). The traditional physical activity group led to a higher improvement of total number of items processed compared to the coordinative group, while coordinative physical activity led to higher improvements in concentration and % error scores than the traditional physical activity and control group (exact p values not reported).

**Study 34: Zach et al. (2015)**

In this study, class groups (aged 4–5 years) were assigned to a dance group (n = 40), orienteering group (n = 44) or passive control (n = 39). Both intervention groups received 9 weekly sessions. Participants completed MOXO Continuous Performance Test (8 variables) and a spatial perception task (at least 4 variables). Note, two versions of the MOXO CPT task were used in the study. The orienteering group completed an interactive version, while the dance group and control group completed a non-interactive version. A series of ANOVAs comparing the dance to the control group indicated there was a significant time by group interaction effect on CPT attention (p < .05, n² = .062) and CPT impulsivity (p < .01, n² = .126) when the stimuli were accompanied by disturbances (no follow up tests reported). A paired samples t-test indicated the orienteering group improved its performance on the interactive version of the MOXO (Timing; p = .046). A number of significant time × group interaction effects were found for the spatial perception task but again no post hoc tests were reported. Strengths of the study included a fairly large sample size though lack of randomisation, no correction for multiple comparisons and no active control group limit conclusions.

**Study 35: Spitzer and Hollmann (2013; Study 1)**

In this non-randomised study, two sixth grade classes were assigned to an intervention group (n = 24) or passive control (n = 20). The intervention group received three extra exercise lessons (e.g., basketball, soccer, dance) for 30-min during the first hour of the school day over a 4-month period (36 sessions). The control group received education as usual. Participants completed the d2 Test of Attention (4 different sustained attention variables) and teachers completed ratings of social and studying behaviour (10 subscales). Academic grades in maths, German and English were also used as study outcomes. No intervention effects were reported for sustained attention. However, there was a significant interaction effect found for teacher ratings of accurateness while studying (p = .01). The authors reported that scores in the intervention improved after the intervention while scores in the control group decreased (post hoc tests and descriptive results were not reported). There was also a significant interaction effect on German grades. Grades in the intervention group improved at post-test whereas grades in the control group worsened (again post hoc tests and descriptive results
were not reported).

**Study 36: Spitzer and Hollmann (2013; Study 2)**

One-hundred and forty-eight sixth grade children were initially assigned to an intervention or passive control according to class groups. However, one school subsequently dropped out, which resulted in a final sample of 88 children. The intervention group received 30 extra exercise lessons for 30-minutes at the start of the school day. Participants took part in various games that could be played with 3–4 members on each team. This study used the same outcome measures as Spitzer and Hollmann (2013; Study 1). The results indicated a group by time interaction effect on concentration performance (d2 Test of Attention; p = .01). The authors reported that pre-to-post improvement was greater in the physical activity group than in the control (tests and descriptive results were not reported). There was also a significant time by group interaction effect on maths grades. The authors reported that the control group’s grades worsened while the physical activity group’s grades improved (again tests were not reported). In relation to teacher ratings, the authors reported that the “prosocial behaviour of the intervention group changed positively” though again these results were not reported.

**Study 37: Verret et al. (2012)**

In this study, children with ADHD (7–12 years) were assigned to the intervention (n = 10, 9 boys) or control group (n = 11, 10 boys). The intervention group received 30 physical activity training sessions over 10 weeks. Various physical activities were used such as basketball, soccer, and tag. The main objective of each session was to maintain moderate to vigorous intensity. Participants in both groups completed cognitive tests of attention and response inhibition (assessed using the Test of Everyday Attention for Children; 5 different variables) and cognitive tests of attention and response inhibition (assessed using the Study 37: Verret et al. (2012)

(*) Bikic, A., Leckman, J.F., Christensen, T.O., Bilenberg, N., Dalsgaard, S., 2018. Bender, R., Lange, S., 2001. Adjusting for multiple testing

(*) Bauer, C.C., Rozenkrantz, L., Caballero, C., Nieto-Castanon, A., Scherer, E., West, M.

References

*References marked with an asterisk denote studies included in the review. (*) Bauer, C.C., Rozenkrantz, L., Caballero, C., Nieto-Castanon, A., Scherer, E., West, M. R., Mrache, M., Phillips, D.T., Gabrieli, J.D., Whithfield-Gabrieli, S., 2020. Mindfulness training preserves sustained attention and resting state anticorrelation in children with attention deficit hyperactivity disorder. PeerJ. 5. https://doi.org/10.7717/peerj.2883.

(*) García-Hermoso, A., Hormazabal-Aguayo, I., Fernández-Vergara, O., González-Cañas, C., Ramírez-Velez, R., 2020. A before-school physical activity intervention to improve cognitive parameters in children with attention-deficit/hyperactivity disorder. Eur. Child Adolesc. Psychiatry 27 (12), 1563–1574. https://doi.org/10.1007/s00788-018-1159-2.

(*) Bikic, A., Christensen, T.O., Leckman, J.F., Bilenberg, N., Dalgaard, S., 2017. A double-blind randomized pilot trial comparing computerized cognitive exercises to Tetris in adolescents with attention-deficit/hyperactivity disorder. Nord. J. Epidemiol. 54 (4), 343–349. https://doi.org/10.1016/j.dr.2010.08.001.

(*) Bikic, A., Leckman, J.F., Christensen, T.O., Bilenberg, N., Dalgaard, S., 2018. Attention and executive functions computer training for attention-deficit/hyperactivity disorder (ADHD): results from a randomized, controlled trial. Eur. Child Adolesc. Psychiatry 27 (12), 1563–1574. https://doi.org/10.1007/s00788-018-1159-2.

(*) Bikic, A., Christensen, T.O., Leckman, J.F., Bilenberg, N., Dalgaard, S., 2017. A double-blind randomized pilot trial comparing computerized cognitive exercises to Tetris in adolescents with attention-deficit/hyperactivity disorder. Nord. J. Epidemiol. 54 (4), 343–349. https://doi.org/10.1016/j.dr.2010.08.001.

(*) Bikic, A., Leckman, J.F., Christensen, T.O., Bilenberg, N., Dalgaard, S., 2018. Attention and executive functions computer training for attention-deficit/hyperactivity disorder (ADHD): results from a randomized, controlled trial. Eur.
Slattery, E.J., Ryan, P., Fortune, D., McAvinue, L.P., 2021. Evaluation of a School Based Attention Training Programme for Improving Sustained Attention. J. Neurosci. 27 (9), 2349. https://doi.org/10.1523/JNEUROCIS.5857-06.2007.

Shipstead, Z., Redick, T.S., Engle, R.W., 2012. Is working memory training effective. Psychol. Bull. 138 (4), 628–654. https://doi.org/10.1037/a0027473.

Simmons, J.P., Nelson, L.D., Simonsohn, U., 2011. False-positive psychology: undisclosed flexibility in data collection and analysis allows presenting anything as significant. Psychol. Sci. 59 (1), 50–65. https://doi.org/10.2190/ps.2017.01.730.

Sato, Y., Saio, Y., Yoshioka, E., 2021. Work stress and oral conditions: a systematic review of observational studies. BMJ Open 11 (5), e046532. https://doi.org/10.1136/bmjopen-2020-046532.

Schrieff-Elson, L.E., Ockhuizen, J.H., During, G., Thomas, K.G.F., 2017. Attention-based Attention Training Programme for Improving Sustained Attention. J. Neurosci. 27 (9), 2349. https://doi.org/10.1523/JNEUROCIS.5857-06.2007.

Slattery, E.J., Ryan, P., Fortune, D., McAvinue, L.P., 2022. Unique and overlapping contributions of sustained attention and working memory to parent and teacher ratings of inattentive behavior. Child Neuropsychol. 1–23. https://doi.org/10.1080/1072010X.2021.2023112.

Spitzer, U.S., Hollmann, W., 2013. Experimental observations of the effects of physical exercise on attention, academic and prosocial performance in school settings. Trends Neurosci. Educ. 2 (1), 1–6. https://doi.org/10.1016/j.tine.2013.05.002.

Sridharan, D., Levitin, D.J., Menon, V., 2008. A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. Proc. Natl. Acad. Sci. USA 105 (34), 12569–12574. https://doi.org/10.1073/pnas.0800051105.

Steinmayr, R., Ziegler, M., Trauble, B., 2010. Do intelligence and sustained attention interact in predicting academic achievement? Learn. Individ. Differ. 20 (1), 14–18. https://doi.org/10.1016/j.lindiff.2009.10.009.

Sturm, W., Willmes, K., 2001. On the functional neuroanatomy of intrinsic and phasic alertness. Neuroimage 14 (1), 576–584. https://doi.org/10.1006/nimg.2001.0839.

Tamm, L., Epstein, J.N., Peugh, J.L., Nakonezny, P.A., Hughes, C.W., 2015. Preliminary data suggesting the efficacy of attention training for school-aged children with ADHD. Dev. Cogn. Neurosci. 4, 16–28. https://doi.org/10.1016/j.dcn.2012.11.004.

Tang, Y.-Y., Posner, M.I., 2009. Attention training and attention state training. Trends Cogn. Sci. 13 (5), 222–227. https://doi.org/10.1016/j.tics.2009.01.005.

Tarrasch, R., 2018. The effects of mindfulness practice on attentional functions among primary school children. J. Child Fam. Stud. 27 (8), 2632–2642. https://doi.org/10.1007/s10826-018-1075-9.

Tulas, D., Guy, J., Faubert, J., Bertone, A., 2018. Training with a three-dimensional multiple object-tracking (3D-MOT) paradigm improves attention in students with a neurodevelopmental condition: a randomized controlled trial. Dev. Sci. 21 (6), 1–11. https://doi.org/10.1111/des.12670.

Unsworth, N., Robson, M.K., 2017. A locus coeruleus-norepinephrine account of individual differences in working memory capacity and attention control. Psychon. Bull. Rev. 24 (4), 1282–1311. https://doi.org/10.3758/s13420-016-1220-5.

Unsworth, N., Robson, M.K., 2020. Working memory capacity and sustained attention: a cognitive-energetic perspective. J. Exp. Psychol. Learn. Mem. Cogn. 46 (1), 77. https://doi.org/10.1037/xlm0000712.

Vater, C., Gray, R., Holcombe, A.O., 2021. A critical systematic review of the Neurotracker perceptual-cognitive training tool. Psychon. Bull. Rev. https://doi.org/10.1016/j.xinch.2018.12.008.

Vazou, S., Pesce, C., Lakes, K., Smiley-Oven, A., 2019. More than one road leads to Rome: a narrative review and meta-analysis of physical activity intervention effects on cognition in youth. Int. J. Sport Exerc. Psychol. 17 (2), 153–178. https://doi.org/10.1177/1935684218805974.

Verver, C., Guay, M.-C., Berthaume, C., Gardiner, P., Béliveau, L., 2012. A physical activity program improves behavior and cognitive functions in children with ADHD: an exploratory study. J. Atten. Disord. 16 (1), 71–80. https://doi.org/10.1177/1087054710379735.

Vickerstaff, V., Oman, R.Z., Ambler, G., 2019. Methods to adjust for multiple comparisons in the analysis and sample size calculation of randomised controlled trials with multiple primary outcomes. BMC Med. Res. Methodol. 19 (1), 1–13. https://doi.org/10.1186/s12874-018-0758-8.

Waffenschmidt, S., Knelangen, M., Sieben, W., Bühm, S., Pieper, D., 2019. Single versus dual screening for study selection in systematic reviews: a methodological systematic review. BMC Med. Res. Methodol. 19 (1), 1–9. https://doi.org/10.1186/s12874-019-0792-z.

Wimmer, L., Bellingrath, S., von Stockhausen, L., 2016. Cognitive effects of physical exercise on attention, concentration and mood. J. Exp. Psychol. Learn. Mem. Cogn. 42 (6), 1366. https://doi.org/10.1037/xlm0000712.

Yerkes, R.M., Dodson, J.D., 1908. The relation of strength of stimulus to rapidity of habit formation. J. Exp. Psychol. 8 (6), 6–22. https://doi.org/10.1037/h0078328.

Zelechowska, D., Falkiewicz, M., Niedziela, J., Zerne, J., Zelechowska, D., Falkiewicz, M., Niedziela, J., 2014. Data collection and analysis allows presenting anything as significant. J. Exp. Psychol. Learn. Mem. Cogn. 40 (3), 663–670. https://doi.org/10.1037/a0034778.

Zimmer, B., 2010. Do intelligence and sustained attention interact in predicting academic achievement? Learn. Individ. Differ. 20 (1), 14–18. https://doi.org/10.1016/j.lindiff.2009.10.009.