Classroom interventions targeting sensory processing and executive functions of school-aged children: A systematic review comparing and contrasting different intervention approaches.

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Abstract

Sensory processing (SP) and executive functions (EF) are popular intervention targets to improve primary school children’s academic performance and classroom behavior. In this review, we systematically reviewed studies investigating the effectiveness of classroom interventions for SP and EF, distinguishing three main intervention approaches: 1) implicit training, 2) metacognition and/or strategy use, and 3) external aids and/or modifications. Four electronic databases (i.e. PubMed including MEDLINE, PsycINFO, CINAHL and ERIC) were searched. Additionally, studies were identified in reference lists of included studies and previous literature reviews in the field. In total, 258 empirical studies were included. Only data from 132 studies with a moderate to strong quality rating were extracted and described. Results suggest that targeting components of SP/EF mainly leads to improvements in domains of functioning where the trained functions or the learned strategies are relevant. While implicit training mainly improves cognitive performance related to the training, metacognition and/or strategy instruction has the potential to beneficially impact academic performance and/or behavior in areas where the learned strategies are applicable. External aids show promise for clinical populations (e.g. ADHD). For future research, it is essential to clarify when interventions work and for whom they are (most) effective, to provide useful, evidence-based recommendations for future studies as well as to educational practitioners.

Keywords: sensory processing, executive function, intervention, children, primary school
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In a primary school classroom, children are already expected to organize their work, focus their attention and be flexible in their thinking. In this context, both children’s sensory processing (SP) abilities and executive functions (EFs) are of concern to teachers since they are thought to underlie successful classroom functioning (defined as academic performance and classroom behavior) (Ahmed, Tang, Waters, & Davis-Kean, 2018; Dunn, 2007; Jacob & Parkinson, 2015; Meltzer, 2007; Morgan, Farkas, Hillemeier, Pun, & Maczuga, 2018). SP is defined as the way in which children detect, process and manage sensory information (Dean, Little, Tomchek, & Dunn, 2018). EF is an umbrella term for cognitive functions underlying purposeful, goal-directed behavior (Anderson, 2002; Diamond, 2013; Miyake et al., 2000). To support children’s SP and EF in the classroom, a large number of interventions have been developed and are enthusiastically used by parents, educational professionals and school practitioners with the ultimate aim to optimize children’s classroom functioning (Jacob & Parkinson, 2015). These interventions vary greatly in their main target (i.e. different aspects of SP and/or EF, to be described below) and in their approach (i.e. ranging from computerized training programs offering children exercises, to teaching learning strategies and supplying external aids). However, there is currently no comprehensive overview of available interventions to support EF and SP, specifically in the classroom. The main aim of the present article was to systematically review available studies into interventions directed at EF and SP. To identify the most promising approach for improving academic performance and classroom behavior, we compare three main intervention approaches: 1) implicit training, 2) metacognition and/or strategy use, and 3) external aids and/or modifications.
1.1 Definitions of SP and EF

SP is characterized by a combination of detecting incoming stimuli and the behavioral response towards them (Dean et al., 2018; Dunn, 2007; Little, Dean, Tomchek, & Dunn, 2017). Incoming stimuli can originate from an external source (e.g. a sound made by an animal) or from the own body or mind (e.g. a bodily sensation or a distracting thought). Both registering stimuli and responding to them are thought to be best represented on a continuum: the registration threshold ranges from low (i.e. quickly registering many stimuli) to high (i.e. slow to detect stimuli), while responses vary between passive (i.e. reacting to stimuli when they appear) and active (i.e. actively increasing or decreasing exposure to stimuli) (Dean et al., 2018; Dunn, 1997). SP abilities are important for children in a classroom context to be able to control their attention, i.e. to focus on the task at hand, while ignoring other stimuli such as internal thoughts or external sensory stimuli.

EF can be conceptualized as response inhibition, working memory and cognitive flexibility (Diamond, 2013; Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000). Response inhibition is needed to withhold prepotent or automatic responses when inappropriate for the context at hand (Diamond & Ling, 2016; Huizinga et al., 2006; Jacob & Parkinson, 2015; Miyake et al., 2000). Working memory can be defined as temporarily cognitively maintaining and manipulating information (Baddeley & Hitch, 1974; Jacob & Parkinson, 2015). Finally, cognitive flexibility is the ability to shift attentional focus between mental sets and tasks (Anderson, 2002; Miyake et al., 2000). These three core EFs are, in turn, thought to underlie more complex EFs such as reasoning, planning and organizing (Anderson, 2002; Diamond & Ling, 2016). EF are essential for children to follow a teacher’s instructions in the classroom, adapt to new tasks and situations and working towards a goal (e.g. completing an assignment).
1.2 The relation between SP and EF

SP and EF and thereby the interventions targeting them are rooted in different disciplines such as neuropsychology, educational psychology and occupational therapy. Therefore, they are often described and investigated as if they were separate, unrelated concepts. However, SP and EF seem to be highly correlated in both typically developing school-aged children and children with a neurodevelopmental disorder (Romero-Ayuso et al., 2018) and problems with SP and EF often co-occur, for example in children who have been diagnosed with a neurodevelopmental disorder, such as an autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD) or a learning disability (such as dyslexia or dyscalculia) (Adams, Feldman, Huffman, & Loe, 2015; Anguera et al., 2017; Yochman, Alon-Beery, Sribman, & Parush, 2013). When examining various models and definitions of SP and EF, these two constructs do not only seem to correlate and co-occur, but even show extensive overlap when considering what is called ‘detecting stimuli’ and ‘responding to stimuli’ in SP terms, and ‘response inhibition’ in EF terms (Anderson, 2002; Dunn, 1997; Posner, Rothbart, Sheese, & Voelker, 2012). Supporting this proposed overlap between SP and EF, neurobiological studies have shown that behavior suggestive of suboptimal detection of and response to stimuli (e.g. touching objects around them) shares neurodynamic mechanisms with insufficient response inhibition as seen in tasks used to assess EF (Koziol, Budding, & Chidekel, 2011; Middleton, 2003). Together, this evidence indicates that SP and EF are not as distinct as suggested by the largely separate disciplines focusing on these two concepts.

Behaviorally and in the context of a classroom, it is virtually impossible to clearly attribute certain behaviors to either SP or EF. For example, a child wobbling in his or her seat during a math test could be a behavioral response to a lack of incoming sensory stimulation as described in SP models (e.g. trying to enhance attention by increasing sensory stimulation) or a sign of failing response inhibition as defined by EF models (e.g. not being able to withhold
wobbling even though it is not appropriate in the current context). Therefore, in the present review, we did not separate interventions based on the discipline of origin (i.e. SP or EF), but rather based on the specific cognitive function (e.g. attentional control) that is targeted with the intervention (see Figure 1).

**Figure 1. Overlap between sensory processing and executive functions**

![Overlap between sensory processing and executive functions](image)

1.3 Prior research on the effectiveness of interventions

Previous studies have indicated that attentional control, response inhibition, working memory and cognitive flexibility, as well as higher-order EF such as planning, reasoning and organizing, are significant predictors of (long-term) academic performance (Ahmed et al., 2018; Jacob & Parkinson, 2015; Morgan et al., 2018), making them a popular target for classroom interventions. A common way of categorizing such interventions is by intervention target, i.e. the cognitive function at which the intervention is directed. A recent meta-analysis making use of this way of categorizing showed that interventions directed at, for instance, inhibition (including attentional control and response inhibition), working memory and cognitive flexibility are mainly effective in improving performance on tasks that also rely on the specific cognitive function targeted by the intervention (Kassai, Futo, Demetrovics, &
Takacs, 2019). There was no convincing evidence that interventions for one cognitive function also led to improvements in other cognitive functions.

Effectiveness of interventions may be strongly influenced by the intervention approach, i.e. the way in which cognitive functions are targeted by the intervention (Bierman & Torres, 2016; Morrison & Chein, 2011; Rabipour & Raz, 2012; von Bastian & Oberauer, 2014). Based on previous reviews and studies in various populations (Morrison & Chein, 2011; Resch, Rosema, Hurks, de Kloet, & van Heugten, 2018; van der Donk, Hiemstra-Beernink, Tjeenk-Kalff, Van Der Leij, & Lindauer, 2015) we distinguish three main intervention approaches. The first approach, implicit training, consists of repeated practice of exercises frequently directed at one specific cognitive function. These interventions are often computerized and have frequently been placed in a game-like context, such as adventure games. Well-known implicit training interventions are Cogmed, Braingame Brian, RehaCom and Jungle Memory. Over recent years, much attention has been paid to one specific type of implicit training: computerized working memory training. Multiple systematic reviews and meta-analyses across various populations (including typically developing children, children with ADHD, and children with learning disabilities) have examined the evidence for this intervention approach (Melby-Lervåg, Redick, & Hulme, 2016; Peijnenborgh, Hurks, Aldenkamp, Vles, & Hendriksen, 2016; Rapport, Orban, Kofler, & Friedman, 2013). Common conclusions from these studies are that computerized working memory training leads to improvement on the trained tasks, but transfer (i.e. improvement in other areas than the training) to other tasks or other domains of functioning is limited or non-existent. While the evidence thus seems to indicate that there are no significant, wide-ranging benefits of computerized working memory training, there are significant gaps in our knowledge related to whether implicit interventions targeting functions other than working memory (e.g. response inhibition or cognitive flexibility) or other intervention approaches are more effective.
A second intervention approach is directed at metacognition and/or strategy use. This approach is focused on explicitly instructing and guiding children’s thinking. Metacognition training provides strategies in an overarching way, teaching children to ‘think about their thinking’ and how to approach tasks in general (e.g. first read the instructions carefully). The strategy use component is directed at explicit instruction how a specific task can be approached, such as rehearsing a sequence of numbers to remember them better (strategies). An example is the Self-Regulated Strategy Development (SRSD) approach to teach writing skills (Harris, Graham, & Mason, 2003) or Meichenbaum’s self-instruction method (Goodman & Meichenbaum, 2017). Inherently to learning a new strategy or skill is a certain amount of practice. Interventions with a metacognition and/or strategy use approach are therefore also likely to include repeated practice, but differ from implicit training interventions in their metacognitive component. To our knowledge, there is currently no overview of studies into effectiveness of this intervention approach for a wide range of cognitive functions, i.e. attentional control, response inhibition, working memory, cognitive flexibility and higher-order EF.

The final intervention approach that can be distinguished are external aids and/or external modifications. External aids support children’s attentional control, response inhibition, working memory or cognitive flexibility with various materials and devices, e.g. headphones to filter noise or mobile applications to support working memory (Wilson et al., 2009). Alternatively, external modifications can be applied to the environment (e.g. adjust the ambient sound) to support one or more of the cognitive functions. While previous reviews are available focusing on the effects of specific external aids (e.g. weighted vests), it is currently unclear how effective they are compared to other intervention approaches.

All three approaches are suitable to apply in a classroom setting. However, it is currently unclear whether these intervention approaches are differentially effective in
improving attentional control, response inhibition, working memory, cognitive flexibility and higher-order EF, as well as classroom functioning (i.e. academic performance and classroom behavior) of primary school children. In the present review, we examine whether the three intervention approaches, when directed at attentional control, response inhibition, WM or cognitive flexibility, are effective in improving these cognitive functions and/or associated areas of functioning such as academic performance and classroom behavior. Additionally, we examined the effects of the various intervention approaches on higher-order EF such as planning, organizing and reasoning.

1.4 Influences on intervention effectiveness

When examining effectiveness of intervention approaches, it is important to take into account potentially influential factors. For example, cognitive intervention models state that the developmental level (i.e. age) of a child should be taken into account when applying or investigating an intervention, since this may influence intervention effectiveness (Limond, Adlam, & Cormack, 2014). In line with this, computerized implicit working memory training as described above seems to be more effective (i.e. greater improvements in verbal working memory performance immediately after training as well as on the longer term) for children with learning disabilities age 10 and older (Peijnenborgh et al., 2016). Given the impact of such factors, the present review also includes studies explicitly investigating potential influential factors on the effectiveness of interventions.

2. Methods

A systematic review was designed and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Liberati et
al., 2009; Moher, Liberati, Tetzlaff, & Altman, 2009). The review protocol was approved by NRO (Nationaal Regieorgaan Onderwijsonderzoek; Netherlands Initiative for Education Research; ID: 405-18-637) and was registered in PROSPERO (International prospective register of systematic reviews, ID: 99883) before screening studies for inclusion.

2.1 Eligibility criteria

Studies were included when they met the following criteria: (1) The investigated intervention was mainly directed at the different components of SP and/or EF (see search terms); (2) The intervention targeted EF and/or SP directly, not by targeting another area of functioning (e.g. physical activity, eating lunch); (3) The intervention under investigation was not specifically directed at academic skills (e.g. reading strategies), since outcomes of these interventions may not reflect effects of changes in cognitive functions but rather changes in the academic skills themselves (Jacob & Parkinson, 2015). For the same reason, interventions requiring adaptations of the complete classroom curriculum (e.g. Tools of the Mind (Diamond, Barnett, Thomas, & Munro, 2007) were excluded; (4) The examined intervention was suitable as a classroom intervention and could be provided by a classroom teacher or another school professional. Studies into interventions requiring extensive therapist or medical training (e.g. pharmacological interventions) or expensive materials (e.g. neurofeedback training) were excluded. 5) The intervention included active participation by the child as a core element. More specifically, interventions consisting mainly of parent-training or professional education for teachers were excluded; (6) Studies investigating adaptations of a task or task instructions (e.g. dynamic assessment) or an intervention delivered in a single session (except for external aid and/or modifications) were excluded; (7) Participants were aged 4 to 12 years. This is in line with the (primary) school system in the Netherlands (i.e. the country of origin of the authors of the present review). Studies examining children with a wider age range were included when
the mean age of the study sample was between 4 and 12 years; (8) Participants were children that are likely to be encountered in a regular primary school, i.e. typically developing children or children with one of the common neurodevelopmental disorders (i.e. attention deficit hyperactivity disorder, autism spectrum disorder, or specific learning disability with impairment in reading, writing or mathematics); (9) The study was an empirical study (i.e. not a review) designed as a randomized controlled trial (RCT), a controlled clinical trial or a quasi-experimental (controlled) pretest-posttest study; (10) The study was published as a peer-reviewed journal article (i.e. not a book chapter, doctoral dissertation or conference abstract).

2.2 Information sources

The electronic databases PubMed including MEDLINE, PsycINFO, CINAHL and ERIC were searched on June 22nd, 2018. To stay up to date with new articles in relation to our search terms added to the databases, we created e-mail alerts for each database. Therefore, the present systematic review encompasses articles published and included in the above-mentioned databases before November 1st, 2018. Additionally, reference lists of all articles included in the present review as well as of relevant previous meta-analyses or reviews were examined.

2.3 Search

Search terms were formulated for 1) ‘SP and/or EF’ and 2) ‘intervention’ and consisted of a combination of main terms and Medical Subject Headings (MeSH) or Thesaurus terms. Search terms were based on previous systematic reviews into relating topics, suggestions from experts in the field, and the help from a research information specialist affiliated with the University Library of Maastricht University. Searches were limited to studies concerning children meeting our criteria regarding age range and to studies published in English or Dutch. No date restrictions were used. We excluded specific types of publications such as interviews.
and newspaper articles. Main search terms and the full electronic search for the PubMed database including MeSH terms and search limits are shown in Supplementary Material 1.

2.4 Study selection

The articles were reviewed by two raters (i.e. the first author and one of two well-trained research assistants during title and abstract screening, and the first and last author during full-text selection) to determine inclusion eligibility. In case of doubt, the other authors were consulted.

2.5 Data collection process, data items and synthesis of results

Data were extracted by the first author, the last author was consulted in case of doubt. The following information was collected whenever available: (1) study characteristics, i.e. authors, year of publication, country of study, study design, and sample size; (2) participant characteristics, i.e. age, gender and diagnostic status (e.g. typically developing or having been diagnosed with a neurodevelopmental disorder); (3) intervention characteristics, i.e. target cognitive function, approach (i.e. implicit training, metacognition and/or strategy use, external aids and or external modification, and/or a combination of two or more of these components), control intervention (if applicable), setting, duration and intensity; (4) results of statistical analyses in terms of effects on cognitive functions and other areas of functioning (e.g. academic performance and classroom functioning). For all outcomes, attention was paid to potential differences in the short-term (e.g. immediately after an intervention) and the long-term (e.g. weeks/months/years after the intervention) effect(s) of the interventions.

Given our broad inclusion criteria, we expected, and indeed observed, significant heterogeneity in terms of study designs, participant characteristics, intervention characteristics and outcome measures. Therefore, no statistical analysis of the results was planned. The effects
of the individual interventions were synthesized narratively and integrated per intervention approach.

2.6 Risk of bias within and across studies

The Quality Assessment Tool for Quantitative Studies (Effective Public Health Practice Project) (Thomas, Ciliska, Dobbins, & Micucci, 2004) is recommended by the Consolidated Standards of Reporting Trials (CONSORT) (Moher et al., 2010) to assess risk bias within studies. Eight different domains (i.e. selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs, intervention integrity, and analyses) are judged based on the extent of the presence of bias. Ratings can be ‘strong’, ‘moderate’, or ‘weak’, where a ‘strong’ rating equals a low risk of bias. The tool is suitable for the assessment of randomized trials as well as non-randomized studies and quasi-experimental designs. Interrater agreement for the final rating is excellent, agreement for rating of individual domains is fair (Thomas et al., 2004). To improve consistency between raters, we included the clause that information necessary to rate the different domains had to be provided in the paper or an explicit reference had to be made to a different paper where that information could be found. For example, if the authors did not explicitly make a statement regarding the number of study drop-outs and/or how many participants completed the study, the questions regarding withdrawals and drop-outs were rated with ‘can’t tell’. Similarly, if psychometric properties of outcome measures were not reported or an explicit reference to this information was not made (e.g. “the reliability of the test was sufficient”), the question concerning data collection methods was answered with ‘can’t tell’. Risk of bias of each included study was assessed by two raters: one of these raters was the first author, the other authors each assessed part of the included studies. Disagreements were resolved through discussion or consultation of a third
author. Only studies that were rated as having moderate to strong quality were included in the syntheses of the results.

3. Results

3.1 Study selection

Details concerning the study selection are illustrated in a flow diagram in Figure 2. A total of 47161 unique articles were identified during the first search of the electronic databases on June 22nd, 2018. Additionally, we identified 53 articles from other sources (i.e. previous reviews and meta-analyses, e-mail alerts from the searched databases, and reference lists of other articles). A total of 251 full-texts met all eligibility criteria. Some articles reported on multiple empirical studies, leading to a total of 258 unique studies. Of these, 126 did not meet quality criteria (i.e. overall quality rating was ‘weak’) and were excluded. Finally, 132 studies were included.

3.2 Syntheses of results

Findings for each intervention approach (i.e. implicit training, metacognition and/or strategy use, and external aids and/or external modifications) are described below. We categorized the study outcomes into three main levels: I. Cognitive functions assessed with performance tasks, II. Academic performance, and III. Behavior and other outcomes. A detailed overview per study, containing study characteristics, participant characteristics, intervention characteristics and outcomes, as well as a codebook to clarify the data extraction is presented in the Appendix.

3.2.1 Implicit training. A total of 77 studies investigating implicit interventions were included. Interventions were found for attentional control, response inhibition, working
memory, cognitive flexibility and higher order EF alone, but also for combinations of one or more of these cognitive functions.

**Figure 2. Flowchart for the literature search and the study selection**


3.2.1.1 **Attentional control.** Six studies investigated the effects of six different implicit interventions for attentional control (Mishra, Sagar, Joseph, Gazzaley, & Merzenich, 2016;
Murray, Scott, Connolly, & Wells, 2018; Rabiner, Murray, Skinner, & Malone, 2010; Shaffer et al., 2001; Solan, Shelley-Tremblay, Ficarra, Silverman, & Larson, 2003; Spaniol, Shalev, Kossyvaki, & Mevorach, 2018). Details on these studies can be found in the Appendix Table 1. All had RCT designs, although one study only reported within group changes from pretest to posttest (Solan et al., 2003). Sample sizes ranged between 15 and 101. Three studies included children with ADHD or attentional difficulties, one investigated solely children with ADHD, one included children with ASD and one examined the effects of an intervention in typically developing children.

Four interventions (Mishra et al., 2016; Rabiner et al., 2010; Solan et al., 2003; Spaniol et al., 2018) were adaptive computerized training programs with which children practiced attentional control, often in a game-like context. *Adaptive* means that the task difficulty is adjusted to the child’s individual performance or ability level. One intervention was a metronome training during which children tapped a limb in a certain beat (Shaffer et al., 2001), and one consisted of audio-recording of sounds and attentional instructions (Murray et al., 2018).

For children with ADHD or attentional difficulties, children with reading impairments and typically developing children, implicit attentional control training has positive effects on some aspects of attention, such as visual attention and interference control, as well as response inhibition as measured with performance tasks. For children with ASD, this was not assessed on performance tasks. Effects of implicit attentional control training on non-trained cognitive domains (i.e. short-term memory and fluid intelligence) were not found (Mishra et al., 2016; Rabiner et al., 2010; Shaffer et al., 2001; Spaniol et al., 2018). Long-term effects (e.g. 6 months after the intervention) were not assessed in any of the studies conducted in this context.

Improvements in academic performance after implicit attentional control training were inconsistent between studies in children with ADHD or attention difficulties, with one study
finding improved reading and language processing but not writing (Shaffer et al., 2001), while another study found no improvements in either reading or mathematics (Rabiner et al., 2010). Children with reading impairments may show improved reading comprehension (Solan et al., 2003), but this was only studied in one study using within-group pretest-posttest analyses. Children with ASD may benefit in terms of mathematics and writing (Spaniol et al., 2018), but only one study including children from this population was included in the present review. For typically developing children, effects on academic performance or behavior were not measured (Murray et al., 2018). Long-term intervention effects were not assessed in any of the groups.

Improvements in attention and behavior of children with ADHD as reported by parents, teachers or clinicians are only inconsistently found and vary as a function of e.g. raters and time points: while one study finds improved teacher-rated attention shortly after the intervention but not at a 6-month follow-up (Rabiner et al., 2010) and one study finds improved parent-rated ADHD symptoms, aggressive symptoms and clinical functioning (Shaffer et al., 2001), another study reports no improvements in parent-rated ADHD symptoms soon after the intervention, but finds improvements 6 months later (Mishra et al., 2016). Children with ASD did not benefit in terms of teacher-reported symptoms of ASD (Spaniol et al., 2018). For typically developing children and children with reading impairments, effects on behavior were not assessed.

**Summary.** Implicit interventions for attentional control can improve performance on attentional control tasks and to some extent inhibitory control, in different groups of children (such as ADHD, typically developing children). So-called transfer effects, i.e. improvements in other cognitive domains or in other areas of functioning, are rare and inconsistent in this context.
3.2.1.2 Response inhibition. Response inhibition was targeted by three implicit interventions: two computerized interventions (Liu, Zhu, Ziegler, & Shi, 2015; Zhao, Chen, & Maes, 2018) and one non-computerized group intervention (Zhao, Chen, Fu, & Maes, 2015). All investigated intervention effects using RCT designs. These studies included only typically developing children, with sample sizes ranging from 30 to 40. Details are shown in the Appendix Table 2.

A non-adaptive computerized intervention did not have an effect on any performance outcome, including response inhibition (Liu et al., 2015). Using an adaptive computerized training, response inhibition was improved and transfer occurred to tasks assessing cognitive flexibility and working memory, but not interference control (i.e. the ability to suppress information irrelevant for a task) or fluid intelligence (i.e. the ability to plan, reason and solve new problems). The transfer effects to cognitive flexibility and working memory were not evident anymore 3 months or 6 months after the intervention (Zhao et al., 2018). The above-mentioned group training practicing response inhibition in physical movements yielded improved response inhibition but not enhanced interference control shortly after the training.

Effects on academic performance or behavior or other outcomes were not assessed.

Summary. Adaptive, but not non-adaptive, implicit interventions for response inhibition mainly yield short-term improvement in tasks of response inhibition, but not on related constructs such as interference control. This has only been studied in typically developing individuals. Effects on academic performance or other areas of functioning, such as behavior or social functioning, are unknown.

3.2.1.3 Working memory. Forty studies examined implicit working memory training. Sample sizes ranged from 9 to 480. Twenty-five had an RCT design, 11 were controlled clinical
trials and 4 used a pretest-posttest design. Study participants included typically developing children, children with attention and/or working memory problems, with ADHD, with varying levels of language ability, with low academic performance and with dyslexia. See Appendix Table 3 for more details. Given the extensive amount of studies in this domain, we will discuss findings in the context of specific programs offered.

**Cogmed/RoboMemo.** Thirteen studies examined the efficacy of Cogmed working memory training (Astle, Barnes, Baker, Colclough, & Woolrich, 2015; Barnes, Nobre, Woolrich, Baker, & Astle, 2016; Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Bergman-Nutley & Klingberg, 2014; Dunning, Holmes, & Gathercole, 2013; Foy & Mann, 2014; Green et al., 2012; Hitchcock & Westwell, 2017; Holmes & Gathercole, 2014; Holmes et al., 2010; Hovik, Saunes, Aarlien, & Egeland, 2013; Klingberg et al., 2005; Roberts et al., 2016). Results of one study were reported across two articles (Astle et al., 2015; Barnes et al., 2016) and one article reported two studies (Holmes & Gathercole, 2014). Four studies investigated the effects of the time-reduced version called RoboMemo (Bigorra, Garolera, Guijarro, & Hervás, 2016; Egeland, Aarlien, & Saunes, 2013; Mezzacappa & Buckner, 2010; Söderqvist & Bergman Nutley, 2015). Cogmed/RoboMemo is a computerized training including adaptive exercises for visual and/or verbal WM.

Consistently, improvements were found on performance measures of working memory directly after training up to 12 months later, except for one study in typically developing children which did not find increased working memory performance (Hitchcock & Westwell, 2017). Some studies reported improved attention, cognitive flexibility, response inhibition and (fluid) intelligence using performance measures, although results are not consistent between studies that reported these transfer effects (Beck et al., 2010; Bigorra et al., 2016; Egeland et
Nine studies examined the influence of the training on academic performance. Five studies found no effect of the intervention on reading, mathematics or writing (Bigorra et al., 2016; Dunning et al., 2013; Foy & Mann, 2014; Hitchcock & Westwell, 2017; Roberts et al., 2016). When assessed during the intervention period (i.e. when the training was still taking place), positive effects were found in one study on mathematics for children with subjective attention and working memory problems (Bergman-Nutley & Klingberg, 2014). One study found improved grades for mathematics during the school year of the intervention for children with low academic performance enrolled in grade 5 or 6 (Holmes & Gathercole, 2014). In the same study, also improvement in English grades were reported, although these were only found for children in grade 6, not grade 5. Two studies found improved reading but not mathematics performance shortly after the intervention and 8 months later (Egeland et al., 2013) and 2 years later (Söderqvist & Bergman Nutley, 2015).

Eight studies examined intervention effects on behavior and other (transfer) outcomes. Three found no positive effects of the interventions in these areas (Egeland et al., 2013; Hitchcock & Westwell, 2017; Roberts et al., 2016). Other studies did find improvements in EF behavior (including working memory, metacognition, initiating, monitoring, planning, organizing, shifting), inattention and hyperactivity and impulsivity which were maintained up to 6 months after the end of the intervention, although behavior reports are mostly not consistent between parents and teachers (Beck et al., 2010; Bigorra et al., 2016; Green et al., 2012; Klingberg et al., 2005; Mezzacappa & Buckner, 2010). Task-related attention or on-task behavior was improved in one study in children with ADHD immediately after the intervention (Green et al., 2012), but not in a study with typically developing children, both immediately
after the intervention and 3 months later (Hitchcock & Westwell, 2017). No effects on (psycho)social, emotional and behavioral symptoms and difficulties were found.

**WM updating.** Seven studies, described in 6 articles, examined WM updating training (Chen, Ye, Chang, Chen, & Zhou, 2017; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Kuhn & Holling, 2014; Peng & Fuchs, 2015; Studer-Luethi, Bauer, & Perrig, 2016; Yang, Peng, Zhang, Zheng, & Mo, 2017). WM updating training is based on the n-back task, in which a participant has to actively update information in the working memory store to give the required answer (e.g. is this picture the same as the one you saw three pictures before).

Improvements in cognitive function performance, such as working memory and fluid intelligence, is inconsistent. For example, two studies (one including typically developing children, one examining children with attention problems or learning disabilities) revealed improvements in fluid intelligence (Chen et al., 2017; Peng & Fuchs, 2015), while two other studies (including children from the same populations as the previous two studies) found that improvements only occurred for children who made significantly progress in the training program (Jaeggi et al., 2011) or only in crystallized intelligence (Studer-Luethi et al., 2016).

Five studies investigated the effects of updating training on reading, writing and/or mathematics. Improvements in mathematics were found in two studies: one showing increased mathematics performance shortly after the intervention (Kuhn & Holling, 2014) while effects in the other study appeared only 6 months after the intervention (Chen et al., 2017). Improvements in reading and writing (Chen et al., 2017; Studer-Luethi et al., 2016) were not found in two studies, while one study showed that intervention modality (i.e. verbal or visual) may have significant differential impact on reading skills. While verbal working memory updating training yielded positive effects on phonological reading skills (i.e. one’s ability to segment and manipulate sounds and letters), visual working memory updating positively...
impacted orthographic reading skills (i.e. the ability to identify patterns of specific letters as words) (Yang et al., 2017).

Effects on behavior or other outcomes were only assessed in two studies, which showed no changes in attitude and motivation after updating training (Yang et al., 2017).

*Cogmed vs. working memory updating.* One study (Ang, Lee, Cheam, Poon, & Koh, 2015) compared the effects of Cogmed training to those of (in this case, visual) working memory updating training for children with poor working memory and poor mathematics performance. Effects of both interventions were limited to improving performance on tasks similar to the training tasks, with no effects to other tasks or domains, such as mathematics.

*Other implicit working memory interventions.* Eleven studies examined various other working memory interventions. One study included children with ADHD or typically developing children with poor working memory (Wong, He, & Chan, 2013), while the others all included typically developing children (Gade, Zoelch, & Seitz-Stein, 2017; Henry, Messer, & Nash, 2014; Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; Mansur-Alves & Flores-Mendoza, 2015; Passolunghi & Costa, 2016; Rode, Robson, Purviance, Geary, & Mayr, 2014; Swanson & McMurran, 2018).

One article (Gade et al., 2017), reporting on four studies, investigated the effects of a block span training in four different samples. The training consisted in principle of showing children a 2D version of a Corsi board with nine boxes on a computer screen. Boxes lighted in various sequences, and the child had to repeat the sequences by touching the screen. Across these studies, no effects were found on working memory performance. This is in contrast with the other studies, where improved working memory performance was consistently found.
Effects on performance tasks measuring other cognitive functions (e.g. short-term memory, fluid intelligence and interference control) were not consistent between studies.

Five studies examined improvements in academic performance. Improvements in various aspects of reading were found, although results were not consistent across studies (Henry et al., 2014; Loosli et al., 2012; Rode et al., 2014). Improvements in mathematics were found in two studies directly after the intervention (Rode et al., 2014; Swanson & McMurran, 2018), with one study showing that these effects occur mostly for children with higher fluid intelligence (Swanson & McMurran, 2018). In young children age 5 to 6 years from the general population, early numerical development was found to be improved directly after the intervention (Passolunghi & Costa, 2016).

Only two studies examined intervention effects on behavior or other outcomes and found improved working memory shortly post-intervention as reported by parents (Wong et al., 2013) or teachers (Rode et al., 2014). No effects were found on parent-reported and teacher-reported inattention and hyperactivity/impulsivity, or on parent-reported inhibition, shortly after the intervention. Long-term effects (i.e. 3 months after the intervention) were investigated in one study, but no effects were found (Wong et al., 2013).

Summary. Effects of implicit working memory interventions are mainly evident in performance tasks closely related to the training tasks. Improvements in reading and mathematics are inconsistently found between studies, similar to improvements in behavior.

3.2.1.4 Cognitive flexibility. Only one study (Kray, Karbach, Haenig, & Freitag, 2012) that met the inclusion criteria of the present review examined implicit interventions specifically targeting cognitive flexibility. In an adaptive task switching training, 20 participants (i.e. children with ADHD) had to switch as fast and accurate as possible between two simple
computerized tasks. Improvements were found on task switching and verbal memory, but not on interference control, processing speed, semantic knowledge and matrix reasoning. Effects on other areas of functioning were not assessed. Details of the study can be found in Appendix Table 4.

3.2.1.5 Higher-order EF. Only three studies investigated implicit training for the same higher-order EF, i.e. reasoning (Amd & Roche, 2018; Cassidy, Roche, Colbert, Stewart, & Grey, 2016; Knoll et al., 2016). Details are shown in Appendix Table 5. All interventions were computerized, providing children with exercises of increasing difficulty to improve their non-verbal reasoning (i.e. a construct strongly related to measures fluid intelligence). Sample sizes ranged from 15 to 186, all children were selected from the general population. Training resulted in positive changes in fluid intelligence, which is a measure closely related to the training. No effects were found on transfer performance measures, such as memory, face perception and numerosity discrimination (Amd & Roche, 2018; Cassidy et al., 2016; Knoll et al., 2016). Effects on academic performance or behavior and other outcomes were not assessed.

3.1.2.6 Targeting multiple functions in one intervention. Sixteen studies, reported across 15 articles, investigated implicit interventions combining two or more SP/EF components (Amonn, Frölich, Breuer, Banaschewski, & Doepfner, 2013; Blakey & Carroll, 2015; Brock, Murrah, Cottone, Mashburn, & Grissmer, 2017; Farias et al., 2017; Goldin et al., 2014; Howard, Powell, Vasseleu, Johnstone, & Melhuish, 2017; Powell, Wass, Erichsen, & Leekam, 2016; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012; Schmitt, McClelland, Tominey, & Acock, 2015; Steiner, Frenette, Rene, Brennan, & Perrin, 2014a, 2014b; Tominey & McClelland, 2011; van der Oord, Ponsioen, Geurts, Brink, & Prins, 2012; Volckaert & Noël, 2015; Wiest, Wong, Minero, & Pumacahua, 2014). Additionally, three
studies, reported across two articles, did not examine effectiveness but focused explicitly on influential factors (Anguera et al., 2017; Katz & Shah, 2017). See Appendix Table 6 for more details. Most interventions were computerized tasks presented in a game-like context, one intervention (investigated across three studies) consisted of 1:1 book reading with a child and an adult (Howard et al., 2017), and three interventions were group interventions that targeted various SP and EF componets with interactive (non-computerized) tasks (Röthlisberger et al., 2012; Schmitt et al., 2015; Tominey & McClelland, 2011). Results of all of these studies are reported below.

Studies into the effectiveness of implicit interventions directed at multiple components included typically developing children, children from a low socio-economic background, and children with ADHD, with ASD or with learning-related delays. Sample sizes ranged from 19 to 276. Twelve studies used an RCT design, 4 had a (within or between subject) controlled clinical trial design, and 3 used a pretest-posttest design. Interventions varied from combining 2 to 4 cognitive components.

Thirteen studies examined effects of the interventions on cognitive functions assessed with performance tasks. Improvements were found on tasks assessing various EF components (e.g. attentional control, response inhibition, working memory and cognitive flexibility), but improvements were not consistent across studies. Two studies (Blakey & Carroll, 2015; Howard et al., 2017) examined long-term effects (i.e. 2 or 3 months post-intervention) on cognitive performance and found inconsistent improvements in some but not all assessed functions.

Academic performance was investigated in 6 studies. One study found improved mathematical reasoning but not performing numerical operations 3 months post-intervention (Blakey & Carroll, 2015). In contrast mathematics directly after the intervention were not affected in four other studies (Amonn et al., 2013; Farias et al., 2017; Schmitt et al., 2015;
Tominey & McClelland, 2011). One study found improved mathematics grades directly after the intervention but only for children with low school attendance (Goldin et al., 2014). Improvements in reading and writing improvements shortly after the end of the intervention were rare, although one study again found improved language grades for children with low school attendance (Goldin et al., 2014). Long-term effects on reading, writing and language were not assessed.

Behavior and other outcomes were examined in 8 studies, 4 of which did not find any effects of the interventions on these outcomes directly after the intervention (Brock et al., 2017; Schmitt et al., 2015; Steiner et al., 2014a, 2014b; Tominey & McClelland, 2011). One study revealed improvements in negative affect but not in positive affect, attention or ADHD symptoms (Volckaert & Noël, 2015). Other studies found improvements in ADHD symptoms, various aspects of everyday EF and behavior, although results were not consistent between raters (i.e. parents, teachers and clinicians) or time-points (i.e. directly after the intervention, 6 months later or 9 months later) (Amonn et al., 2013; Farias et al., 2017; Steiner et al., 2014a, 2014b; van der Oord et al., 2012).

**Summary.** Across studies, improvements are evident in cognitive performance tasks. Similar to the training studies targeting only one cognitive functions, effects on cognitive task performance seemed to be related to the targeted cognitive functions, with those studies targeting a broad range of functions also finding improvements in a broad range of performance tasks. Children with an academic disadvantage (i.e. due to being English language learners or having low school attendance) are to benefit most from the interventions in terms of improved academic performance. Long-terms effects need to be investigated. Effects on behaviour or other outcomes were inconsistent between raters and time-points, regardless which cognitive components were targeted in the intervention.
3.2.1.7 Comparing interventions for different (combinations of) targets in one study.

Five studies reported across 6 articles examined whether the effects of an implicit training differed depending on the specific cognitive functions targeted with the training (Bergman Nutley et al., 2011; de Vries, Prins, Schmand, & Geurts, 2015; de Vries, Verdam, Prins, Schmand, & Geurts, 2017; Dovis, Van der Oord, Wiers, & Prins, 2015; Dowsett & Livesey, 2000; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). For example, one study compared the effects of a working memory training to the effects of a non-verbal reasoning training and a training directed at both working memory and non-verbal reasoning (Bergman Nutley et al., 2011). Four studies focused on individual (computerized) interventions that children could progress through with no or minimal guidance, while one study examined two interventions taking place in a 1:1 context with an adult (Dowsett & Livesey, 2000). Four studies were RCTs, one study had a controlled clinical trial design. Samples varied from 49 to 121, including typically developing children, children with ADHD, children with ASD and children with low socio-economic background who had difficulty with inhibition. Details can be found in Appendix Table 7.

First the study mentioned as an example in the paragraph above, comparing training for working memory, non-verbal reasoning and a combination of both showed that improvements in performance tasks post-intervention was strongly related to the trained function in typically developing children (Bergman Nutley et al., 2011). Children who participated in the working memory intervention improved in terms of working memory directly after the intervention but not non-verbal reasoning, while improvements in non-verbal reasoning but not working memory were found directly after non-verbal reasoning training. Children who participated in the combined training improved on both functions, but to a lesser extent than children who
received more training on either function. No transfer effects to visual or verbal short-term memory were seen. Long-term effects were not examined.

Similarly, positive effects on working memory were found after working memory training but not after training targeting inhibitory control (Dovis et al., 2015; Thorell et al., 2009). While one study found that training inhibitory control (i.e. attentional control and response inhibition) improved inhibitory control but not working memory (Dovis et al., 2015), another showed that neither inhibition nor working memory performance was not improved after inhibitory control training (Thorell et al., 2009). Another study did find improved response inhibition after a training targeting this function (Dowsett & Livesey, 2000). Compared to a mock-training, a working memory training or a cognitive flexibility training did not induce near-transfer (i.e. improved performance on cognitive tasks) nor far-transfer (i.e. improvements in behaviour) in children with ASD (de Vries et al., 2015; de Vries et al., 2017).

Academic performance was not assessed in any of these studies. Two studies examined behavior and other outcomes. One showed that training working memory or cognitive flexibility does not change behaviour of children with ASD, although quality of life may be affected depending on the amount of ASD traits before the study (see below) (de Vries et al., 2015; de Vries et al., 2017). Behavior of typically developing children was not affected after training (Dovis et al., 2015).

**Summary.** In line with findings reported across various implicit interventions, improvements seem to occur in those functions similar to the ones targeted in the intervention. Improvements even seem to occur proportionally to the amount of training received, although this was only explicitly examined in one study (Bergman Nutley et al., 2011). While working memory training is consistently found to improve working memory performance on tasks related to the training task, inhibitory control (i.e. attentional control and response inhibition)
seems to be more difficult to improve with implicit training, given inconsistent results between studies (Dowsett & Livesey, 2000; Thorell et al., 2009). Other SP and EF functions have not or only marginally been studied in this context.

3.2.2 Metacognition and/or strategy use. A total of 36 studies investigating metacognition and/or strategy use interventions were included. Interventions were found for attentional control, working memory, higher order EF and combinations of multiple targets.

3.2.2.1 Attentional control. Two related studies, one being the preliminary study (Tamm et al., 2010) for the RCT (Tamm, Epstein, Peugh, Nakonezny, & Hughes, 2013), investigated the effects of the Pay Attention! intervention in 23 respectively 105 children with ADHD. This intervention takes place in a 1:1 context with an adult and includes exercises for attentional control, as well as explicit instructions on how to apply the learned skills at home and in school. While the preliminary study showed improvements in fluid intelligence, working memory and cognitive flexibility performance directly after intervention, results of the RCT only showed improved performance on treatment-related strategy planning but not on other tasks. Academic performance was not assessed. Improvements in parent-rated ADHD symptoms were found across both studies (with the preliminary study reporting maintained improvement at a 9-month follow-up), while teacher-ratings were not found to be improved in the RCT. Details are displayed in Appendix Table 8.

3.2.2.2 Working memory. Five studies investigated metacognition and/or strategy use directed at working memory (Brown & Barclay, 1976) (Brown & Barclay, 1976; Capodieci, Gola, Cornoldi, & Re, 2018; Honoré & Noël, 2017; Rojas-Barahona, Förster, Moreno-Ríos, & McClelland, 2015; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010). Two studies had an
RCT design and 3 were designed as controlled clinical trials. Sample sizes ranged from 34 to 268, including typically developing children, children with ADHD symptoms, children with mental retardation, and children from a disadvantaged socio-economic background. See Appendix Table 9 for details.

Improvements in working memory performance were found directly after training across all studies. Performance on tasks of attentional control and response inhibition was assessed in one study, suggesting improvements after the intervention (Capodieci et al., 2018).

Academic performance was assessed in three studies. Results in terms of mathematics and arithmetic were inconsistent, with one study finding improvements on some but not all assessed outcomes (St Clair-Thompson et al., 2010), while the other study found no effects on arithmetic or numerical development (Honoré & Noël, 2017). Remembering classroom instruction was improved directly after intervention, suggesting that improvements are limited to academic tasks requiring strategies for working memory (St Clair-Thompson et al., 2010). Literacy skills and listening comprehension but not phonological awareness were improved in the third study (Rojas-Barahona et al., 2015). One study assessed behavioural outcomes and found improvements in 1 of 5 ADHD symptoms as rated by parents and teachers (Capodieci et al., 2018). Long-term effects were not assessed.

Summary. Metacognition and/or strategy use in working memory has only been limitedly studied. Positive effects in daily life were found in terms of classroom performance related to the trained working memory strategies, but not to areas that do not require the learned strategies (St Clair-Thompson et al., 2010).

3.2.2.3 Higher-order EF. Ten studies, reported across eleven articles, were included that investigated the influence of metacognition and/or strategy use on reasoning (Alexander
et al., 1989; Alexander et al., 1987; Barkl, Porter, & Ginns, 2012; Christoforides, Spanoudis, & Demetriou, 2016; Klauer, Willmes, & Phye, 2002; Molnár, 2011; Tomic & Klauer, 1996; Tzuriel & George, 2009) or planning (Ashman & Conway, 1993; Bul et al., 2018; Bul et al., 2016). Two studies focused explicitly on influential factors (Bul et al., 2018; Tomic & Klauer, 1996). However, since results of one of these studies (Bul et al., 2018) are based on the same data as used in another study (Bul et al., 2016), these two articles are reported together. Details are shown in Appendix Table 10.

Reasoning training took place in groups or in a 1:1 context with an adults. In all cases, reasoning performance was consistently improved directly after reasoning training. Two studies found improvements in reasoning tasks related to what was targeted in the intervention (i.e. analogical reasoning or inductive reasoning) directly after the intervention (Barkl et al., 2012; Tzuriel & George, 2009). Four studies investigated long-term effects and found maintained improvements up to 3 months (Barkl et al., 2012), 6 months (Alexander et al., 1989; Klauer et al., 2002) and 1 year (Molnár, 2011) after the end of the intervention. Only one study investigated changes in performance on other tasks and found directly after training improvements in reasoning tasks dissimilar to what was trained (but improvements were not maintained after 6 months), but no changes in crystallized intelligence (i.e. the ability to use skills or knowledge learned previously) or vocabulary (Klauer et al., 2002). Results regarding academic performance were inconsistent across the two studies investigating this, with one study into analogical reasoning training finding improvements in mathematic achievement but not in reading comprehension (Tzuriel & George, 2009), while the other, examining inductive reasoning training, found no improvements in mathematics achievement (Barkl et al., 2012). Behavioural changes were not investigated.

A group-based planning intervention for typically developing children led to inconsistent improvements in planning performance (i.e. improvement found on some but not
all tasks) (Ashman & Conway, 1993). Mathematics and reading were improved, while spelling remained unchanged. Long-term effects and behavioural outcomes were not assessed. In contrast, one study examined only behavioural outcomes after an individual computerized intervention directed at planning and organizing (Bul et al., 2018; Bul et al., 2016). Results suggest that the intervention was effective in consistently improving parent- and teacher-reported time-management and in parent-reported responsibility, which was maintained 10 weeks after the intervention. Reported improvements in working memory were inconsistent between parents and teachers, no effects on planning, organizing and social skills were found. Some improvements dependend on participant’s gender (see below).

Summary. Metacognition and/or strategy use interventions for reasoning are effective in improving reasoning, but effects on academic performance and behaviour are insufficiently studied. Improvements may be dependent on the amount of training received (Tomie & Klauer, 1996). While results of one planning intervention study were inconsistent (Ashman & Conway, 1993), another study investigating an intervention for planning, organizing and time-management showed positive effects on everyday functioning, particularly time-management, of children with ADHD (Bul et al., 2018; Bul et al., 2016).

3.2.2.4 Targeting multiple functions in one intervention. Eighteen studies examined metacognition and/or strategy use interventions directed at multiple targets (Banaschewski, Besmens, Zieger, & Rothenberger, 2001; Bolstad & Johnson, 1972; Calero, Gómez-Pérez, & Sierra, 2017; Campeño-Martínez, Santiago-Ramajo, Navarro-Asencio, Vergara-Moragues, & Santiuste Bermejo, 2017; Christiansen, Hirsch, König, Steinmayr, & Roehrle, 2015; Colmar, Davis, & Sheldon, 2016; Eastman & Rasbury, 1981; Kenworthy et al., 2014; Korzeniowski, Ison, & Difabio, 2017; Re, Capodieci, & Cornoldi, 2015; Rivera-Flores, 2015; Margaret
Semrud-Clikeman et al., 1999; Steiner et al., 2014a; Stoeger & Ziegler, 2008; Tamm & Nakonezny, 2015; Tamm, Nakonezny, & Hughes, 2012; Traverso, Viterbori, & Usai, 2015; van der Donk et al., 2017). Sample sizes ranged from 9 to 413 including typically developing children, children with ADHD, children showing disruptive or poor academic behaviour and children at social risk. Details are shown in Appendix Table 11.

The interventions targeting attentional control and response inhibition were all based on (or included elements of) self-instruction training according to Meichenbaum (Goodmon et al., 2014) (Goodman & Meichenbaum, 2017). Self-instruction training was used to teach children to verbalize plans and actions in order to control their attention and impulses. Effects on task performance was only investigated in two studies (Rivera-Flores, 2015; M. Semrud-Clikeman et al., 1999), showing improvements in impulsivity, and visual and auditory attention of children with ADHD directly after training. No effects on academic performance were found in this context, although this was only investigated in one study including children with poor academic habits and hyperactivity (Eastman & Rasbury, 1981). In terms of behaviour, improvements were found in different areas of social, emotional and behavioural functioning, although results are not always consistent between parents and teachers, and outcomes across studies were very different. No effects were found on on-task behaviour (Eastman & Rasbury, 1981). Long-term effects were not assessed.

One study investigated an intervention directed at attentional control, response inhibition and working memory for children with ADHD (Steiner, Sheldrick, Gotthelf, & Perrin, 2011). No improvements were found in cognitive performance (i.e. attention) assessed with performance tasks. Academic performance was not assessed. On the level of behaviour, improvements were found in inattention, ADHD symptoms and daily EF behaviour, although results were inconsistent between parent-, teacher- and self-report. Long-term effects were not examined.
A group-based training for children with ADHD and typically developing children, directed at attentional control, response inhibition, working memory and cognitive flexibility, resulted in improved attentional control and inhibition, but only for children with ADHD, not for typically developing children (Re et al., 2015). Effects on academic performance were not assessed, no effect were found on teacher-reported attention. Long-term effects were not examined.

Targeting attentional control, response inhibition, cognitive flexibility, planning, organization and metacognition in children with social risk led to improved planning, inhibition and cognitive flexibility performance (Korzeniowski et al., 2017) while attention was not improved. Behavioural outcomes were similar, with improvements in teacher-reported planning, inhibition and metacognition but not attention and organization. Academic performance was not assessed. Long-term effects were not investigated.

Two studies examined the same group-based intervention targeting attentional control, response inhibition, working memory and sensory awareness in children with ADHD (Tamm & Nakonezny, 2015; Tamm et al., 2012). Results of both studies show no effects on improved attention performance. One study find improvements in working memory and some aspects of inhibition (Tamm et al., 2012), while the other did not investigate this (Tamm & Nakonezny, 2015). Academic performance was not assessed. Positive effects were found on parent ratings of cognitive flexibility, inattention and emotion regulation but not on inhibition, planning and impulsivity. Long-term effects were not assessed.

An intervention directed at response inhibition, working memory and cognitive flexibility of typically developing children led to improved performance on tasks assessing the functions that were targeted with the intervention (Traverso et al., 2015). No improvements were found in fluid intelligence or parent-rated ADHD symptoms, suggesting no far transfer effects. Academic performance and long-term effects were not assessed.
Two studies used interventions for higher-order EF combined with working memory (Calero et al., 2017) or cognitive flexibility (Kenworthy et al., 2014). Improvements in performance were found in tasks related to the intervention targets. In the study targeting, amongst others, cognitive flexibility, behavioural outcomes were assessed, revealing improved classroom behavior, shifting and planning as reported by parents but not by teachers (Kenworthy et al., 2014). Academic performance and long-term effects were not investigated.

One study (Banaschewski et al., 2001) examining two intervention directed at attentional control, response inhibition and either sensorimotor abilities or planning showed improved performance on tasks related to trained functions and some improvements in behavior. There was no clear advantage of either intervention.

Finally, combining metacognition/strategies for attentional control with those for memory or monitoring and goal-setting did not affect academic performance (Colmar et al., 2016; Stoeger & Ziegler, 2008). Changes in cognitive task performance were not assessed. One study (Stoeger & Ziegler, 2008) examined behavioural and other outcomes and found improvements in time-management, self-reflection, self-efficacy and willingness to exert effort, after a training targeting attentional control, monitoring and goal-setting, but not on motivation or interests. In this same study, skills in time management, learning goal orientation and self-efficacy at baseline explained improvement in these domains. No other influential factors were examined.

**Summary.** Results on interventions including self-instruction (i.e. directed at attentional control and response inhibition) are mixed, with inconsistent reports of behavioural improvement and limited examination of task performance or academic performance post intervention. Improvements are mainly seen in cognitive tasks relying on the functions targeted by the intervention or in areas of daily living that depend on the same functions, although
reports are not always consistent between parents, teachers and children. Addressing attention and memory strategies does not seem to affect academic performance, although long-term effects are unknown (Colmar et al., 2016). Including strategies for goal-setting, next to attentional control and monitoring, has a significant positive effect on daily functioning in terms of time-management and self-reflection (Stoeger & Ziegler, 2008), suggesting again that the domains of functioning addressed by an intervention are the ones that show improved outcomes.

3.2.2.5 Comparing interventions for different (combinations of) targets in one study. One study (Jonkman, Hurks, & Schleepen, 2016) compared the effects of teaching children with ADHD on self-instruction strategies for (working) memory or for attention and perception and a sham-condition. Self-instruction strategies were used to improve children’s understanding of cognitive strategies necessary to perform specific tasks (Goodman & Meichenbaum, 2017). Improvements were found in attention and working memory performance after both the attention training as well as after the memory training. Academic performance was not assessed. Improvements in parent-reported ADHD symptoms were found directly after memory training but not after attention training. Long-term effects or influential factors were not assessed. Findings suggest that, with self-instruction training, improvements can be elicited on tasks that were not specifically targeted during the training. Details are shown in Appendix Table 12.

3.2.3 External aids and/or external modifications. Thirteen studies investigated the effectiveness of various external aids or external modifications (Baijot et al., 2016; Daghistan, 2016; Fedewa, Davis, & Ahn, 2015; Goodmon et al., 2014; Graziano, Garcia, & Landis, 2018; Helps, Bamford, Sonuga-Barke, & Söderlund, 2014; Söderlund, Sikström, & Smart, 2007;
Söderlund, Sikström, Loftesnes, & Sonuga-Barke, 2010; Söderlund, Björk, & Gustafsson, 2016; Su et al., 2017). Details are shown in Appendix Table 13. All examined interventions were directed at improving attentional control. Overall sample sizes ranged from 24 to 93. Four studies examined the influence of the external aid/ modification in the general population of school-aged children and four studies compared children from the general population to children with ADHD. The other studies included children with ADHD, children with very low IQ, children with dyslexia compared to children with dyslexia comorbid with ADHD, children with attentional difficulties but not necessarily diagnosed with ADHD and children with different levels of attentional abilities (sub-attentive, normal-attentive and super-attentive).

White noise. Five studies examined the effects of white noise (i.e. noise without melody, rhythm or meaning). White noise is thought to affect attentional abilities and inhibitory control (i.e. attentional control) by increasing the level of cerebral arousal. The five studies showed that white noise can be beneficial for children with attentional problems or ADHD with positive effects on vigilance (i.e. an attentional component underlying attentional control) (Baijot et al., 2016), inhibitory control (Helps et al., 2014) and (working) memory (Helps et al., 2014; Söderlund et al., 2007; Söderlund et al., 2010; Söderlund et al., 2016). The same studies show that typically developing children or children from the general population (i.e. not explicitly stated to have attentional difficulties) do not benefit from white noise and can sometimes even be negatively affected by it (i.e. performance worse under white noise conditions than when white noise is absent). Increasing the level of white noise from moderate to high had little additional beneficial effects for children with ADHD (Helps et al., 2014).

Music. One study examined the effects of listening to Mozart music versus silence while reading in a group of senior grade elementary students (Su et al., 2017). Although we
encountered multiple studies investigating the effects of Mozart music, this was the only study meeting our inclusion criterion stating that the intervention must be explicitly related to a component of SP/EF according to the authors of the paper (in this case, attentional control). In line with the studies above attentional performance of these ‘typically developing’ deteriorated with the addition of the music. Improvements in some, but not all, measures of reading were improvement and learning anxiety was decreased.

*Room adjustments.* The influence of room lightening was investigated in a group consisting of primary and middle school children (Barkmann, Wessolowski, & Schulte-Markwort, 2012). It was hypothesized that bright and cool lightening may improve inhibitory control/attention compared to regular lightening. Some positive effects on inhibitory control and attention were found but improvements were not consistent across different outcome measures. Reading speed was improved, while reading comprehension was not. Adjusting room lightening may have the potential to affect classroom functioning. Another study showed that decreasing visual and auditory distractors (i.e. by removing distracting objects and sounds) in the room did no influence task performance of a group of children with very low IQ (Brown, 1966).

*Classroom seating.* Three studies investigated alternative seating in the form of therapy balls or a Disc ‘O’ sit cushion. Both devices can be used to replace a regular chair and are thought to enhance children attentional control by reaching optimal sensory stimulation. For typically developing children, no effects were found of a therapy ball on on-task behavior or academic performance (Fedewa et al., 2015). Children with dyslexia and children with dyslexia and ADHD benefited from the therapy ball in terms of improvements in self-reported attention and motivation and in teacher-reported behavior (Goodmon et al., 2014). No effects on reading
comprehension were found. For children with attentional difficulties, the Disc ‘O’ Sit cushion was beneficial for teacher-reported attention and EF behavior (Pfeiffer, Henry, Miller, & Witherell, 2008). Although based on a limited amount of studies, children with ADHD and/or dyslexia seem to benefit from alternative seating.

*Other external aids.* Mind maps (i.e. visual aids connecting main concepts and related ideas or topics) were shown to have a positive effect on teacher-reported attention in a group of female students (male students were not included in this study) (Daghistan, 2016). Academic performance was not assessed. Finally, contrary to popular beliefs, fidget spinners (i.e. small toys that can be spun around in the hand) negatively influenced attention behavior of children with ADHD (Graziano et al., 2018).

*Summary.* There is a large variation in types of external aids and/or external modifications studied, that are directed at improving attentional control. White noise can be beneficial to enhance various aspects of cognition in a group of children with ADHD, but effects on academic performance or behavior remain to be determined. Typically developing children seem negatively affected by white noise, other groups of children have not been studies in this context. Alternative seating arrangements yield inconsistent results between studies and findings of other external aids need to be replicated in other studies. In sum, typically developing children seem to benefit less (or are even negatively affected) by the use of external aids, while especially children with ADHD can benefit from the use of aids or modifications.

3.2.4 Directly comparing various (combinations of) intervention approaches in one study. Six studies directly compared various (combinations of) intervention approaches,
meaning that they compared two or more interventions that were different from each other in their approach (i.e. implicit training, metacognition and/or strategy use or external aids/modification) within one study. Five studies, reported in six articles, compared implicit training to implicit training with metacognition and/or strategy use (King, 1991; Nelwan & Kroesbergen, 2016; Nelwan, Vissers, & Kroesbergen, 2018; Partanen, Jansson, Lisspers, & Sundin, 2015; Peng & Fuchs, 2015; van der Donk et al., 2015) and one compared an external aid to an external aid compared with metacognition and/or strategy use (Langberg et al., 2018). Studies included typically developing children, children with ADHD and children with learning difficulties, with sample sizes ranging from 46 to 274. Details are shown in Appendix Table 14.

Two studies (Peng & Fuchs, 2015; van der Donk et al., 2015) found no clear advantage of combined implicit training and metacognition and/or strategy use compared to implicit training alone, in that improvements after both intervention approaches were similar. In contrast, three other studies showed more improvements directly after training and maintenance 6 months later in cognitive performance after a combined training, rather than after implicit training only (King, 1991; Nelwan & Kroesbergen, 2016; Nelwan et al., 2018; Partanen et al., 2015). One study (Nelwan & Kroesbergen, 2016; Nelwan et al., 2018) also showed improved arithmetic ability after combined training compared to implicit training alone or a control group, while academic performance was not improved in another study (Partanen et al., 2015). One study compared two homework interventions, one relying on an external organizing aid and the other combining organizing aids with external supervision from an adult (Langberg et al., 2018). Both interventions were equally effective in improving homework performance and organization.
Summary: Additional metacognition and/or strategy use instruction may have added benefits to improvements found with implicit training alone. However, across studies, it is unclear whether this effect arises due to the incorporation of metacognition and/or strategy use or because of increases contact with an intervention coach. Combining an external aid with metacognition does not have concrete benefits in terms of improved performance or behavior.

3.2.5 Influences on intervention effectiveness. In total, forty studies investigated one or more factors that may influence the effectiveness of an intervention. Below, we described the findings per influential factor. It should be noted that studies differed extensively regarding the factors they examined and in which context (i.e. which intervention approach for which cognitive target). Given the limited comparability between studies, results should be interpreted with caution.

Baseline level of functioning. Baseline level of functioning is defined as the level of cognitive functioning before the start of the intervention. This includes the presence of neurodevelopmental disorders that are characterized by difficulties with cognitive functioning (e.g. ADHD, which can for example be characterized by difficulties with attentional control). Results are inconsistent, with 13 studies (Anguera et al., 2017; Christiansen et al., 2015; de Vries et al., 2015; de Vries et al., 2017; Helps et al., 2014; Holmes & Gathercole, 2014; Langberg et al., 2018; Re et al., 2015; Söderlund et al., 2007; Söderlund et al., 2010; Söderlund et al., 2016; Tominey & McClelland, 2011; Volckaert & Noël, 2015) examining a variety of intervention approaches and targets suggesting more benefits from an intervention for children with lower baseline functioning, while 5 other studies (Amd & Roche, 2018; Brock et al., 2017; Goodman & Meichenbaum, 2017; Peng & Fuchs, 2015; St Clair-Thompson et al., 2010) find
no differential improvement depending on baseline functioning. No definite conclusions regarding the impact of baseline functioning on intervention effectiveness can be drawn.

*Age.* While its exact influence remains to be determined, a number of studies suggest that age influences intervention effectiveness. Note that results of these studies are difficult to compare, given the large variation in age ranges and cognitive functions studied. Younger typically developing children (aged 3) benefit more from an implicit training for response inhibition than older children (aged 4) (Dowsett & Livesey, 2000). One study found that younger children in a sample of 5 to 6-year olds benefited more in terms of more improvements in inhibitory control (Volckaert & Noël, 2015) after an implicit intervention targeting multiple cognitive functions, while another study suggest that 6-year olds, not 5-year olds, were positively influenced by an intervention in terms of improved performance on a task related to inhibitory control (Röthlisberger et al., 2012). A broad group-based metacognition training targeting attentional control, response inhibition, cognitive flexibility, planning, organization and metacognition showed that age had a significant influence on the intervention effects (Korzeniowski et al., 2017). Cognitive flexibility improved for 7-year olds, planning increased for 8-year olds and metacognition was enhanced for 8 and 9-year olds, while no effects were found in children aged 10 to 11. Another study compared effects for younger (7-11 years) and older (9-13 years) children, with results suggesting that improvement was maintained 2 weeks post-intervention for young children but not for older children, while effects directly after the intervention were similar for both age groups. However, given the large overlap in age between the age groups, these results should be interpreted with caution (Brown & Barclay, 1976). Transfer of working memory training to academic performance was found for 6th grade students, but not for 5th grade students after an implicit working memory intervention (Holmes & Gathercole, 2014).
In contrast, three studies concluded that age did not differentially affect the outcome of an implicit group training targeting response inhibition (Zhao et al., 2015), an implicit intervention for higher-order EF (Amd & Roche, 2018), or a metacognitive working memory intervention were found depending on age (St Clair-Thompson et al., 2010).

In sum, these results seem to suggest that different cognitive functions are differentially affected by age, but more studies comparing wider age ranges and different cognitive functions are needed to draw firm conclusions.

*Gender.* Findings regarding the effects of gender are inconsistent. Gender was not found to influence outcomes of implicit interventions for response inhibition (Liu et al., 2015; Zhao et al., 2015). In a metacognition intervention for multiple cognitive functions, girls improved mainly in terms of inhibition, planning and cognitive flexibility, while boys improved in cognitive flexibility and metacognition (Korzeniowski et al., 2017). For a metacognition training targeting planning, organizing and time-management in children with ADHD (Bul et al., 2018; Bul et al., 2016), girls were most likely to show improvements in planning and organizing compared to boys. Boys with lower baseline levels of hyperactivity but more conduct problems improved more on planning and organizing than the other participants.

*Outcome measures.* Implicit verbal or visual working memory training (with the visual working memory training being based on Cogmed) affects only primary but not secondary memory (Gibson et al., 2011). Primary memory is used when the recalling of information is required shortly after the information was initially presented, while secondary memory is used when recalling of information is delayed. This effect was independent of the (mis)match between training and assessment modality (i.e. visual or verbal). This latter finding contrasts
with results from an updating training, suggesting that visual respectively verbal training does only affect outcomes of the same modality (Yang et al., 2017).

Gamification. The effects of gamification of an implicit working memory intervention training were investigated in one study (Prins, Dovis, Ponsioen, Brink, & Oord, 2011). Gamification refers to “the application of game features, mainly video game elements, into non-game context for the purpose of promoting motivation and engagement in learning” (Alsawaier, 2018). More training improvements in visual working memory for children with ADHD can (potentially) be reached when adding game elements, although effects on academic performance or behavior have not been assessed (Prins et al., 2011).

Intervention characteristics: duration, intensity and setting. Implicit working memory training positively affected fluid intelligence of children from the general population only when the training was sufficiently spaced (i.e. 20 days, but not 2, 5 or 10 days) (Wang, Zhou, & Shah, 2014). Intervention setting (i.e. in a small group or 1:1) did not affect the outcomes of a metacognitive inductive reasoning training (Barkl et al., 2012). Improvements in reasoning/fluid intelligence and mathematics performance was linearly dependent on the amount of metacognitive reasoning training typically children had received, with more training associated with more improvement (Tomic & Klauer, 1996). The amount of implicit training for working memory or nonverbal reasoning was found to be positively related to the amount of improvement in performance tasks (Bergman Nutley et al., 2011).

Training progress. Training progress (i.e. increase in scores during training) was shown to be associated with improvements in matrix reasoning and fluid intelligence in one study (Jaeggi et al., 2011), while another study finds that training performance is not related to fluid
intelligence improvement (Loosli et al., 2012). Improvements in fluid intelligence/reasoning after an implicit reasoning training were found to be dependent on how much the child progressed during the training, with only children who reached an advanced stage in the training showing improved fluid intelligence (Amd & Roche, 2018). One study explicitly investigated factors influencing effectiveness of an intervention combining implicit training and metacognition and/or strategy use for WM, planning, attentional control, response inhibition, metacognition and goal-setting of children with ADHD (van der Donk et al., 2017). Findings indicated that those with larger training gains also show larger benefits on untrained near transfer outcomes. Benefits of larger training gains were not found for far-transfer measures, suggesting that far transfer is related to other factors than training gains.

Other factors. Two large-scale, including respectively 200 and 1395 typically developing children examined the influence of socio-economic background on the effects of an implicit computerized intervention targeting response inhibition, working memory and cognitive flexibility (Katz & Shah, 2017). Results indicated that training effectiveness on cognitive tasks and academic performance was not influenced by socio-economic background.

Children who are still learning English and children with low school attendance benefit more from training than children who know the English language or attend school regularly, in that their mathematics and/or language grades improve (Schmitt et al., 2015). In contrast, the baseline level of language ability did not affect training gains from an implicit working intervention (Holmes et al., 2015).

4. Discussion

The aim of this review was to provide an up-to-date overview of primary school classroom interventions targeting sensory processing (SP) abilities and executive functions
(EF) for children and adolescents. As mentioned in the Introduction section of this paper, it is virtually impossible to attribute certain behaviors to either SP or EF, behaviorally and in the context of a classroom. Therefore, in the present review, interventions were not separated based on the discipline of origin (i.e. SP or EF), but rather based on the specific cognitive function (e.g. attentional control) that is targeted with the intervention. More specifically, we examined whether intervention approaches, directed at attentional control, response inhibition, WM, cognitive flexibility or higher-order EF, such as planning, organizing and reasoning, are effective in improving these cognitive functions and associated areas of functioning, such as academic performance and (classroom) behavior. More specifically, we compared the effectiveness of various intervention approaches - i.e., implicit training, metacognition and/or strategy use, external aids and or external modification, and/or a combination of two or more of these components - on cognition and other areas of functioning, such as academic performance and classroom functioning. Also, we reviewed studies into potential moderating factors, such as age, gender, intervention duration and gamification in this context, although we noticed that these factors have only been limitly examined.

Recently, results of several review studies were published that focused primarily on the effectiveness of implicit training programs targeting working memory abilities (Melby-Lervåg et al., 2016; Peijnenborgh et al., 2016). However, to the authors’ knowledge, no review exists on various approaches to classroom interventions (i.e. not only implicit training but also metacognition and/or strategy use and external aids) on a broader range of cognitive functions (i.e. not only working memory). The current review, therefore, adds important new knowledge to the evidence-base. In the review, we reported results of 132 unique studies with moderate to strong quality, which included a total of \( n = 11902 \) children in the primary school age range (i.e. approximately 4 to 12 years). The far majority of children participated in implicit interventions \( (n = 7100) \), while number of children included in studies into metacognition
and/or strategy use (n=1552), combinations of implicit training with metacognition and/or strategy use (n=1530), external dis/modifications (n=690) or studies directly comparing different intervention approaches (n=1030) are much lower. The majority of studies included typically developing children only (n=57) and children with ADHD or attentional difficulties (n=36), while only a small number of studies included children with ASD (n=4), children with a diagnosed learning disability (n=6) or children with cognitive problems or learning difficulties (n=12). The other studies (n=17) included combined samples, for example children with ADHD as well as typically developing children, children with sensory processing disorder and typically developing children, or children with ADHD or at risk for learning difficulties. Most studies included both boys and girls, whereas some studies (n=5) included only females (n=1) or males (n=4). In total, n=108 unique interventions or combinations of interventions were described, with the majority focusing on implicit training (n=56).

4.1 Summary of evidence

Before discussing our results, we want to emphasize that the studies included in our review are highly heterogeneous with respect to the cognitive functions targeted, the intervention approach taken, the duration and dose of the interventions, the children included (e.g. typically developing children or children with ADHD), age of the children, sample size, and outcome domains included, which makes a comparison among studies and study outcomes challenging. In the following paragraphs, we discuss our primary findings with respect to the effectiveness of different components of classroom cognitive interventions in children and adolescents.

4.1.1 Comparing different intervention approaches. Implicit interventions have been extensively researched: 58% of all studies included in the present review examined this
intervention approach. Studies examining this approach to target attentional control, response inhibition, working memory, cognitive flexibility or higher-order EF showed that children, on average, improved in their performance on trained cognitive tasks measured immediately after training. These are so-called ‘near transfer’ effects. Thus, repeatedly administering specific tasks improves, in general, one’s performance on the specific task(s) and/or on highly similar tasks. These results are in line with above-mentioned reviews on the effectiveness of working memory training programs (Melby-Lervåg et al., 2016; Peijnenborgh et al., 2016). However, our review showed that this principle holds true for training cognitive functions other than working memory as well. Similarly, results on far transfer effects (i.e. effects on tasks or functions that were not explicitly targeted by the intervention) of implicit training are fairly consistent, i.e., repeatedly performing a cognitive task does not, or only extremely limited, lead to a transfer to other domains of functioning.

In contrast to numerous studies on implicit training, only 11% of studies included in the present review examined the effects of metacognition and/or strategy use. Another 14% of studies combined implicit training with metacognition and/or strategy use. Comparisons across studies suggests that, similar to effects of implicit training, interventions based on metacognition and/or strategy instruction (in some cases in combination with implicit training) led to improvements in areas that were related to the ones targeted in the intervention. However, in contrast to the lack of transfer seen after implicit training, (adding) metacognition and/or strategy use can also lead to improvements in other domains of functioning, as long as they are related to what was targeted in the intervention. For example, an intervention implicitly training and teaching working memory strategies had positive influence on areas of classroom performance where working memory strategies could be used (e.g. remember classroom instructions) (St Clair-Thompson et al., 2010). These findings are in line with those of a small number of reviewed studies, explicitly comparing implicit training to interventions combining
implicit training and metacognition and/or strategy use (King, 1991; Nelwan & Kroesbergen, 2016; Nelwan et al., 2018; Partanen et al., 2015). Results suggested that adding metacognition/strategy use, mainly in the form of additional coaching from an adult, led to more (in some case far transfer) improvements compared to implicit training alone). However, outcomes on a behavioural level remain to be investigated.

External aids/external modification directed at enhancing attentional control (investigated in less than 1% of all included studies) seem to be mainly beneficial for children from clinical populations (e.g. ADHD) compared to typically developing children. Enthusiastically providing regular primary school children with various alternative seating devices or aids to increase attention is currently not evidence-based. However, given the relative ease with which these aids can be used and the positive effects on (mainly) children with ADHD suggest that effects on academic performance and behavioural functioning should be further explored.

4.1.2 Influential factors. Several factors seem to enhance the positive effect of the studied interventions. In terms of intervention characteristics, studies have indicated a dose-response training effect, i.e., a higher dose and practice spread over a larger time period leads in average to more improvement in terms of task performance (Tomic & Klauer, 1996; Wang et al., 2014). Also, children need to be challenged to perform tasks that are just outside their comfort zone, i.e. in terms of task difficulty, while obtaining sufficient support during the training by others, such as the teacher or the parents (Diamond & Ling, 2016; Peijnenborgh et al., 2016). For instance, non-adaptive training programs, in which task difficulty is not adjusted to the abilities of the child, were found to be far less effective in terms of performance, compared to adaptive training programs (e.g. (Liu et al., 2015).
Importantly, not only intervention characteristics, but also child characteristics may significantly affect intervention effectiveness. For example, it has been shown that children with learning disabilities aged 11 and older benefited more from a working memory training than younger children (Peijnenborgh et al., 2016). In line with this, Hurks (Hurks, 2012) asked $n = 81$ typically developing children enrolled in grades 3–6 of primary school to complete a verbal fluency task twice. During the task, children were instructed to name as many animals as possible within a 60 second time interval. In between task administrations, half of the children received a (strategy) instruction on how to efficiently search for animals in their semantic brain network and therefore to improve task performance ideally, while the other half served as a control group. The control group did not receive a (strategy) instruction. Hurks found that only the older children (i.e., those enrolled in grade 6) improved on VF after the (strategy) instruction on semantic clustering (Hurks, 2012). Younger children seemed to understand the strategy instructions provided, however, applying these instructions seemed to cost them so much cognitive energy that their overall performances on the 2nd task administration diminished compared to the control group. In the present review, the influence of various has been shown by several studies, suggesting that age, gender, baseline level of performance, fluid intelligence or diagnostic status impact improvement with training. Nevertheless, these findings are based on a very limited amount of studies, each investigating a different intervention for a different age group of different children. More studies are needed to clarify the impact of these factors.

Future studies might consider explicitly comparing different groups of children when studying an intervention. It might be the case that the ‘one size fits all’ approach frequently taken in interventions does not work. An illustrative example is the variety in different SP styles that are likely to each require an individual intervention approach. SP styles are thought to lie on a continuum from hyposensitive (also called ‘low registration’) to hypersensitive
(‘sensory sensitivity’) (Dunn, 1997). Additionally, response towards stimuli can be characterized as ranging from ‘active’ (for example by seeking out stimuli to reach a certain neurological threshold of SP or by avoiding stimuli to prevent crossing the neurological threshold of SP) to ‘passive’ (Dunn, 1997). Targeting all of these SP styles with the same intervention (e.g. white noise) is likely to differentially affect children with different SP styles.

4.2 Limitations of the included studies and recommendations

We identified several limitations of the studies included in the present review, which we will discuss next. Also, we will offer recommendations for future research. First, we noticed that a large percentage of the studies included in the review (i.e. 126 of the 258 unique studies) scored ‘weak’ when we assessed the (potential) risk bias of the studies. The Quality Assessment Tool for Quantitative Studies (Effective Public Health Practice Project) (Thomas et al., 2004), recommended by the Consolidated Standards of Reporting Trials (CONSORT) (Moher et al., 2010), was used to assess this risk bias within the studies included in our review. More specifically, we evaluated the (potential) risk bias of each study on eight criteria: i.e. selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs, intervention integrity, and analyses. We noticed that the authors of the studies included often did not provide sufficient detailed information on the study design and the participants included, which consequently led to an evaluation ‘weak’ on the bias tool. For instance, the authors often lacked provide information on the number of withdrawals and drop-outs in their study, or they did not provide evidence that the psychometric properties (e.g. validity or reliability) of the outcome parameters are moderate to good. Therefore, an overall score ‘weak’ on risk bias can indicate that the study results are likely biased, but it can also mean that we do not have sufficient evidence to be (more) certain that it is not biased. Guidelines on reporting
trials (Moher et al., 2010) may help improve the reporting of empirical studies and thereby increase their quality/reduce the risk of bias.

Second, as per our inclusion criteria, pretest-posttest designs \((n = 16)\) were included in the present review. The lack of a control group limits the reliability of the results from such studies, since changes in outcomes may not necessarily reflect an effect of the intervention but may be caused by practice effects or natural fluctuations, e.g. in the participant’s motivation. Although these designs are valuable for preliminary results and pilot studies,

Third, many studies did not include long-term measurements. Knowing which interventions or intervention approaches lead to long-lasting effects is important, since long-lasting effects (especially in terms of academic performance or behavior) can be considered a main aim of interventions directed at children. Also, the studies that did include such an assessment varied significantly in the definition of ‘long-term’, i.e. intervals ranged from 2 weeks to 2 years post-intervention. This variability limits drawing solid conclusions about the sustainability of intervention effects.

Fourth, conclusions drawn in the individual papers were often based on non-significant or marginal significant ‘trend’ findings. Conclusions in our review are based on the results of the statistical analyses presented in the paper, in combination with their previously determined significance cut-off value. Therefore, our results might differ from the conclusions presented in the individual papers. In line with this, a majority of studies did not adjust for multiple testing in their analyses, potentially leading to false-positive findings. This should be taken into account when interpreting their results.

Fifth, only relatively few studies included children with common learning disabilities, e.g. dyslexia and dyscalculia. Cognitive deficits are not a core symptom of these learning disorders, but children with dyslexia and/or dyscalculia, as a group, have been related to multiple cognitive complaints or weaknesses—especially in executive functioning.
4.3 Limitations of the present review

As mentioned above, the present review adds to current knowledge on effects of interventions of various approaches and directed at various cognitive functions. Compared to previous reviews (Melby-Lervåg et al., 2016; Peijnenborgh et al., 2016; Resch et al., 2018), we included a broad range of intervention approaches, cognitive functions targeted, and children across various populations that are likely to be encountered in regular primary school. However, this variety in approaches, targets and participants was also paralleled by an increase in heterogeneity in outcome measures, age of participants, and duration and frequency of interventions. A meta-analysis, which requires a certain consistency in study design and outcomes measures, was therefore not carried out. In the context of the relatively small amount of studies included investigating interventions directed at metacognition and/or strategy use or external aids compared to the number of studies into implicit training, it was deemed valuable to narratively synthesize the results of the studies. It is possible that inconsistent findings between studies are due to the various influential factors (see above). To make future studies more comparable in this regard, we strongly advise to use a set of common outcome measures to evaluate the effectiveness of cognitive interventions. Moreover, it is recommended that future studies explicitly take into account the various possible influential factors or even explicitly compare their influence on intervention factors within a study.

The focus of the present review on intervention that specifically target one or more cognitive function may be considered another limitation. Activities other than cognitive interventions may improve children’s cognitive functions, and more specifically EF and SP, as well (Diamond & Lee, 2011). Examples are: aerobics, martial arts, yoga, social skills interventions and mindfulness. A recent meta-analysis concludes that these type of intervention are effective in enhancing self-regulation (i.e. a combination of various EF) in typically
developing children aged 0 to 19, although effectiveness of interventions such as yoga and mindfulness have mostly been investigated for children beyond primary school age (Pandey et al., 2018). Also, school curricula have been shown to enhance cognitive development, and specifically EF. For example, the Tools of the Mind, a curriculum for preschool and kindergarten, trains teachers to teach, support and train children explicitly on EF at school during their regular classes (Bodrova & Leong, 2007). The EF (strategy) instructions and practices in the Tools of the Mind curriculum are explicitly interwoven in all academic activities, such as reading and mathematics (Diamond & Lee, 2011). Although the initial results are promising of these methods, further research (e.g., by including a pre-intervention measures) is still needed. Potentially, cognitive interventions are more effective if they are immediately applied to the task/function of interest, such as reading, writing, arithmetic.

**4.5 Concluding remarks**

Targeting components of SP/EF mainly leads to improvements in domains of functioning where the trained functions or the learned strategies are applicable and relevant. This suggests that interventions should be targeted at those areas that need to be improved, and not rely on the idea that wide-ranging improvements in everyday life and academic performance can be elicited solely by training SP/EF. Academic performance or behavior are likely to improve most when cognitive components underlying these areas of functioning are targeted in the relevant context, with the use of sufficient practice and clear strategies. Importantly, we stress that factors likely of influence on intervention effectiveness other than intervention approach, such as intervention dose and duration, but also child characteristics, require further investigation. It is essential to clarify when interventions work and for whom they are (most)
effective to provide useful, evidence-based recommendations for future studies as well as to educational practitioners.

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References


Appendix. Classroom interventions for SP and EF

Resch, C., Meijs, C., de Groot, R., van der Wurff, I., Xu, K., & Hurks, P.

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Search strategy

Main search terms per category and full electronic search strategy for the PubMed electronic database.

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<tr>
<td>Executive function (EF) /</td>
<td>attention OR cognitive flexibility OR executive function</td>
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<tr>
<td>Sensory processing (SP)</td>
<td>OR goal management OR goal setting OR information processing OR inhibition OR inhibitory control OR initiation of actions OR initiative OR metacognition OR organization OR planning OR problem solving OR reasoning OR self-monitoring OR self-regulation OR sensorimotor OR sensory integration OR sensory modulation OR sensory processing OR shifting OR speed of processing OR switching OR updating OR working memory</td>
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Full Search PubMed


AND

(intervention[Title/Abstract] OR modification[Title/Abstract] OR program[Title/Abstract] OR remediation[Title/Abstract] OR stimulation[Title/Abstract] OR therapeutic[Title/Abstract] OR therapy[Title/Abstract] OR training[Title/Abstract] OR treatment[Title/Abstract])

NOT

("addresses"[Publication Type] OR "autobiography"[Publication Type] OR "bibliography"[Publication Type] OR "biography"[Publication Type] OR "book illustrations"[Publication Type] OR "clinical conference"[Publication Type] OR "congresses"[Publication Type] OR "dataset"[Publication Type] OR "dictionary"[Publication Type] OR "directory"[Publication Type] OR "duplicate publication"[Publication Type] OR "ephemera"[Publication Type] OR "festschrift"[Publication Type] OR "interactive tutorial"[Publication Type] OR "interview"[Publication Type] OR "lectures"[Publication Type] OR "legal cases"[Publication Type] OR "legislation"[Publication Type] OR "news"[Publication Type] OR "newspaper article"[Publication Type] OR "personal narratives"[Publication Type] OR "pictorial works"[Publication Type] OR "portraits"[Publication Type] OR "..."
"review"[Publication Type] OR "video audio media"[Publication Type] OR "webcasts"[Publication Type])

Sort by: Author Filters: English; Dutch; Preschool Child: 2-5 years; Child: 6-12 years; Humans
Codebook

Data were extracted using the following coding for study characteristics, participant characteristics, intervention characteristics and outcomes.

**Study characteristics.** ‘Author’ refers to the first author of the article or articles reporting on the study. Year of publication is included. The study design is noted under ‘design’.

**Participant characteristics.** The ‘sample size’ represents the total study sample, which, dependent on the study design, may have been divided over several groups. Only if the groups differed strongly regarding their sample size, sample sizes per group were given. Whenever available, age range was presented since this is thought to reflect the suitable target group of the investigated intervention. If this information was not available, mean age or school grade were provided. Unless explicitly mentioned, all studies included boys and girls. Clinical diagnoses (e.g. ADHD or dyslexia) or other specific inclusion criteria (e.g. low working memory ability or reading impairments) were recorded. Whenever authors did not explicitly mention that children were selected based on clinical diagnoses and/or specific impairments, ‘typically developing’ (i.e. ‘TD’) was coded.

**Intervention characteristics.** A short description of the intervention was provided, including the setting. The setting was coded ‘individual’ when the intervention could be performed by children themselves with no or minimal adult guidance. Setting was ‘group’ when the intervention took place in a group and children could interact with each other (in contrast to, for example ‘individual’ interventions that were used by multiple children at the same time in the
classroom, but without any interaction between them). In a 1:1 setting, the intervention was provided by an adult (e.g. a teacher or a research assistant) to one child at a time. Additionally, an intervention was referred to as being adaptive or not, i.e. whether the intervention could be systematically adapted in difficulty. Intervention approach (i.e. implicit training, metacognition and/or strategy use, external aid/modification or combination) and target (e.g. attentional control or working memory) were mentioned. Whenever applicable, the control intervention was described.

**Outcomes.** For each study, the time points of assessment were recorded. Outcomes were divided in three categories: I: cognitive functions assessed with a performance task, II: academic performance, and III: behavior and other outcomes. Academic performance were either task assessing academic skills such as reading or mathematics, or school grades. Behavior and other outcomes were mostly assessed with parent- and teacher-reported questionnaires, but could also be clinician-rated, self-report or observation-based. Reported results pertain to the analysis related to the study design, e.g. for an RCT, results of between-group comparisons, possible over time, are reported, while for a pretest-posttest design, change between pretest and posttest is described. ‘+’ indicates an improvement, ‘=’ indicates no improvement, and ‘-’ indicates a deterioration. Initially, presented results pertain to the first post-intervention assessment. If outcomes were maintained to a follow-up assessment, this is explicitly stated. Additionally, it is noted when no outcomes within a certain outcome category were assessed (i.e. ‘NA’). Analyses of potential influential factors are reported. Studies with the main aim of comparing intervention effectiveness based on different influential factors are reported under a separate heading.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
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<td>ASD</td>
<td>Autism Spectrum Disorder</td>
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<td>C</td>
<td>Control</td>
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<td>CR</td>
<td>Clinician rated</td>
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<td>Fi</td>
<td>Full instruction</td>
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<td>GPA</td>
<td>Grade Point Average</td>
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<td>I</td>
<td>Intervention</td>
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<td>LI</td>
<td>Limited instruction</td>
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<td>LLA</td>
<td>Low language ability</td>
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<td>TD</td>
<td>Typically developing</td>
</tr>
<tr>
<td>TR</td>
<td>Teacher report</td>
</tr>
<tr>
<td>w</td>
<td>weeks</td>
</tr>
<tr>
<td>WM</td>
<td>Working memory</td>
</tr>
<tr>
<td>y</td>
<td>year</td>
</tr>
<tr>
<td>Study characteristics</td>
<td>Participant characteristics</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Mishra, 2016 [1]</td>
<td>RCT n=18</td>
</tr>
<tr>
<td>Rabiner, 2010 [3]</td>
<td>RCT n=77</td>
</tr>
<tr>
<td>Shaffer, 2001 [4]</td>
<td>RCT n=56</td>
</tr>
</tbody>
</table>
## CLASSROOM INTERVENTIONS FOR SP AND EF: A REVIEW

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Sample Size</th>
<th>Age</th>
<th>Intervention Details</th>
<th>Setting</th>
<th>Control</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solan, 2003 [5]</td>
<td>RCT</td>
<td>n=30</td>
<td>M=11y</td>
<td>Mild to moderate reading impairments&lt;br&gt;Computerized attention enhancing tasks&lt;br&gt;Setting: individual, computerized Adaptive</td>
<td></td>
<td>Implicit training; Attentional control</td>
<td>Pre – Post&lt;br&gt;Only within-group pre-post changes reported&lt;br&gt;I: + visual attention (both I and C)&lt;br&gt;II: reading comprehension I+ C = II: NA</td>
</tr>
<tr>
<td>Spaniol, 2018 [6]</td>
<td>RCT</td>
<td>n=15</td>
<td>6-10y</td>
<td>Computerized progressive attentional training (CPAT) targeting sustained attention, selective attention, orienting of attention and executive attention&lt;br&gt;Setting: individual, computerized Adaptive</td>
<td></td>
<td>Implicit training; Attentional control</td>
<td>Computer games&lt;br&gt;Pre - Post&lt;br&gt;I: = fluid intelligence&lt;br&gt;II: + mathematics, passage copying; = reading comprehension&lt;br&gt;III: = behavioral symptoms of ASD (TR)</td>
</tr>
</tbody>
</table>
### Table 2. Implicit training for response inhibition

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
</tr>
<tr>
<td>Zhao, 2015[8]</td>
<td>RCT</td>
<td>n=30 Age: M=10y TD</td>
<td>Execute an action (i.e. bodily movements) only when command preceded by verbal command 'Wesley says'. Setting: group Not adaptive</td>
</tr>
<tr>
<td>Zhao, 2018[9]</td>
<td>RCT</td>
<td>n=39 Age: 10-12y TD</td>
<td>Computerized go/no-go task. Setting: individual, computerized Adaptive</td>
</tr>
</tbody>
</table>

### Table 2. Implicit training for response inhibition

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
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<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
</tr>
<tr>
<td>Zhao, 2015[8]</td>
<td>RCT</td>
<td>n=30 Age: M=10y TD</td>
<td>Execute an action (i.e. bodily movements) only when command preceded by verbal command 'Wesley says'. Setting: group Not adaptive</td>
</tr>
<tr>
<td>Zhao, 2018[9]</td>
<td>RCT</td>
<td>n=39 Age: 10-12y TD</td>
<td>Computerized go/no-go task. Setting: individual, computerized Adaptive</td>
</tr>
</tbody>
</table>
Table 3. Implicit training for working memory

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
<th>Time points of assessment</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
<td>Design</td>
<td>Sample size, age, other characteristics</td>
<td>Intervention</td>
<td>Approach &amp; target</td>
<td>Control</td>
<td>Time points of assessment</td>
<td>I: Cognitive functions assessed with performance task</td>
</tr>
<tr>
<td>Astle, 2015 / Barnes, 2016</td>
<td>RCT</td>
<td>n=27 Age: 8-11y Mostly female TD</td>
<td>Cogmed</td>
<td>Implicit training; WM</td>
<td>Non-adaptive training</td>
<td>Pre - Post</td>
<td>I: verbal STM, verbal WM, visual STM, visual WM</td>
</tr>
<tr>
<td>Beck, 2010[12]</td>
<td>Controlled clinical trial</td>
<td>n=49 Age: 7-17y (M=11) ADHD and/or learning difficulties, and clinically relevant score on BRIEF WM scale or at least 6 symptoms of inattentiveness according to DSM-IV</td>
<td>Cogmed</td>
<td>Implicit training; WM</td>
<td>Waitlist</td>
<td>Pre - Post - 4m</td>
<td>I: + verbal WM, verbal WM, visual WM</td>
</tr>
<tr>
<td>Dunning, 2013[14]</td>
<td>RCT</td>
<td>n=94 Age: 7-9y Low WM</td>
<td>Cogmed</td>
<td>Implicit training; WM</td>
<td>C1: non-adaptive training C2: no training</td>
<td>Pre - Post - 1y</td>
<td>I: + verbal WM (maintained at 1y), visual STM (not maintained), visual WM (not maintained); = verbal STM, classroom-based WM: following instructions, detecting rhymes, sentence counting (+ at 1y), sentence recall; IQ, attention</td>
</tr>
</tbody>
</table>
| **Foy, 2014**<sup>[15]</sup> | Controlled clinical trial | n=55  
Age: 4-6y  
TD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Waitlist | Pre - Post | I: + visual WM, verbal WM, behavioral self-regulation  
II: = letter knowledge, phoneme awareness, reading  
III: NA |
| **Green, 2012**<sup>[16]</sup> | RCT  
n=26  
Age: 7-14y  
(M=9)  
ADHD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Non-adaptive WM training | Pre - Post | I: + verbal WM  
II: NA  
III: + on-task behavior; = ADHD behavior (PR) |
| **Hitchcock, 2017**<sup>[17]</sup> | RCT  
n=148  
Age: 10-13y  
(M=12)  
TD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | C1: non-adaptive training  
C2: no training | Pre - Post- 3m | I: = verbal WM, sustained attention, selective attention  
II: = reading comprehension, mathematics  
III: = task-related attention, social/emotional/behavioral difficulties (PR) |
| **Holmes, 2010**<sup>[18]</sup> | Pretest-posttest design  
n=25  
Age: 8-11y  
ADHD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | NA | Pre - Post - 6m | I: + verbal STM (- at 6m), visual STM (not maintained), verbal WM (not maintained), visual WM (maintained at 6m)  
II: NA  
III: NA |
| **Holmes exp. 1, 2014**<sup>[19]</sup> | Pretest-posttest design  
n=22  
Age: 8-9y  
TD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | NA | Pre - Post | I: + verbal STM, visual STM, verbal WM, visual WM  
II: NA  
III: NA |
| (Influential factor: Gains in STM and WM more pronounced for children with low baseline WM.) |
| **Holmes exp. 2, 2014**<sup>[19]</sup> | Controlled clinical trial  
n=100  
Age: 9-11y  
Low academic performance | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Non-trained | Pre - Post | I: NA  
II: + English grade (only for children in 6th grade), mathematics grade  
III: NA |
| (Influential factors: No influence of baseline WM on intervention effect on academic grade.) |
| **Hovik, 2013**<sup>[20]</sup> | RCT  
n=67  
Age: 10-12y  
ADHD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Care as usual | Pre - Post - 8m | I: + visual WM, verbal WM, manipulation WM (all maintained at 8m)  
II: NA  
III: NA |
| **Klingberg, 2005**<sup>[21]</sup> | RCT  
n=53  
Age: 7-12y  
ADHD | Cogmed  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Non-adaptive training | Pre - Post - 3m | I: + visual WM, verbal STM, response inhibition, fluid intelligence (all maintained at 3m)  
II: NA |
### Classroom Interventions for SP and EF: A Review

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Age</th>
<th>Setting</th>
<th>WM</th>
<th>Prepost-</th>
<th>I:</th>
<th>II:</th>
<th>III:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roberts, 2016</td>
<td>RCT</td>
<td>452</td>
<td>6-7y Low WM</td>
<td>Cogmed</td>
<td>Implicit training; WM</td>
<td>usual classroom teaching (n=226)</td>
<td>+ inattention (PR), hyperactivity/impulsivity (PR; maintained at 3m), oppositional behavior (PR; only at 3m); = all TR outcomes</td>
<td>6m - 12m - 24m</td>
<td>+ visual STM (maintained at 12m but not 24m); = visual WM, verbal WM, verbal STM, IQ</td>
</tr>
<tr>
<td>Bigorra, 2015</td>
<td>RCT</td>
<td>66</td>
<td>7-12y ADHD</td>
<td>RoboMemo (time-reduced Cogmed)</td>
<td>Implicit training; WM</td>
<td>Non-adaptive training</td>
<td>Pre - Post - 6m</td>
<td>+ WM composite (maintained at 6m), response inhibition (not maintained at 6m); = sustained attention, planning, cognitive flexibility, task switching</td>
<td>= reading comprehension</td>
</tr>
<tr>
<td>Egeland, 2013</td>
<td>RCT</td>
<td>67</td>
<td>10-12y ADHD</td>
<td>RoboMemo (time-reduced Cogmed)</td>
<td>Implicit training; WM</td>
<td>Untreated</td>
<td>Pre - Post - 8m</td>
<td>+ processing speed (not maintained at 8m); = response inhibition, switching, flexibility, controlled attention, attention</td>
<td>= reading (maintained at 8m); = mathematics</td>
</tr>
<tr>
<td>Mezzacappa, 2010</td>
<td>Pretest-posttest design</td>
<td>9</td>
<td>8-10y ADHD symptoms, low SES</td>
<td>RoboMemo (time-reduced Cogmed)</td>
<td>Implicit training; WM</td>
<td>NA</td>
<td>Pre - Post</td>
<td>+ verbal WM, visual WM</td>
<td>NA</td>
</tr>
<tr>
<td>Söderqvist, 2015</td>
<td>Controlled clinical trial</td>
<td>42</td>
<td>9-10y TD</td>
<td>RoboMemo (time-reduced Cogmed)</td>
<td>Implicit training; WM</td>
<td>Usual education</td>
<td>Pre - 2y</td>
<td>NA</td>
<td>= reading; = mathematics</td>
</tr>
<tr>
<td>Chen, 2018</td>
<td>RCT</td>
<td>54</td>
<td>M=10y</td>
<td>Visual and verbal WM updating training, based on n-back task.</td>
<td>Implicit training; WM</td>
<td>No training</td>
<td>Pre - Post - 6m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Influential factors: reading improvement was explained by magnitude of improved verbal WM during intervention.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Age</th>
<th>TD</th>
<th>Program</th>
<th>Setting</th>
<th>Methodology</th>
<th>Outcome Measures</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaeggi, 2011 [28]</td>
<td>Controlled clinical trial</td>
<td>76</td>
<td>M=8-9y</td>
<td>ADHD or developmental disorder or LD</td>
<td>Video game-like verbal and visual WM updating tasks</td>
<td>Implicit training: WM</td>
<td>Knowledge and vocabulary training in videogame context</td>
<td>Pre - Post - 3m</td>
<td>= matrix reasoning/fluid intelligence; II: NA; III: NA</td>
</tr>
<tr>
<td>Kuhn, 2014 [29]</td>
<td>Controlled clinical trial</td>
<td>59</td>
<td>M=9y</td>
<td>TD</td>
<td>Video game-like verbal and visual WM updating tasks</td>
<td>Implicit training: WM</td>
<td>C1: Computerized adaptive training of number sense C2: Regular school lessons</td>
<td>Pre - Post</td>
<td>I: = visual WM; II: mathematics I1/C1&gt;C2; III: NA</td>
</tr>
<tr>
<td>Peng, 2017 [30]</td>
<td>RCT</td>
<td>74</td>
<td>M=4-5y</td>
<td>TD</td>
<td>Video game-like verbal and visual WM updating tasks (same program as Jaeggi et al., 2011 [28])</td>
<td>Implicit training: WM</td>
<td>C1: Fruit ninja computer game (potentially inhibitory control training) C2: No intervention</td>
<td>Pre - Post - 6m - 12m</td>
<td>I: + fluid intelligence; II: NA; III: NA</td>
</tr>
<tr>
<td>Studer-Luethi, 2016 [31]</td>
<td>RCT</td>
<td>99</td>
<td>M=8y</td>
<td>TD</td>
<td>Visual WM updating training, based on n-back task.</td>
<td>Implicit training: WM</td>
<td>C1: Reading training C2: General classroom activities</td>
<td>Pre - Post - 3m</td>
<td>I: = crystallized intelligence, WM (not maintained at 3m); = fluid intelligence, inhibitory control; II: = reading, mathematics; III: NA</td>
</tr>
<tr>
<td>Yang exp. 1, 2017 (exp 1 is supplemented by exp 2) [32]</td>
<td>RCT</td>
<td>23</td>
<td>M=9y</td>
<td>Dyslexia</td>
<td>Verbal WM updating training, based on n-back task.</td>
<td>Implicit training: WM</td>
<td>Idiom King video game focusing on verbal skills</td>
<td>Pre - Post</td>
<td>I: NA; II: + phonological awareness accuracy, fast word naming; = phonological awareness RT, orthographic awareness; III: = attitude and motivation</td>
</tr>
</tbody>
</table>

**Influential factors:** Only children who made significant progress during training showed improvements on other tasks, which were maintained 3m after training.
## Classroom Interventions for SP and EF: A Review

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Sample Size</th>
<th>Age</th>
<th>Condition</th>
<th>Intervention</th>
<th>Outcome</th>
<th>Influential Factors</th>
</tr>
</thead>
</table>
| Yang exp. 2, 2017<sup>[32]</sup> | RCT | n=22 | M=9y | Dyslexia | Visual WM updating training, based on n-back task. | Implicit training; WM | Pull the carrot video game | Pre - Post  
I: NA  
II: = fast word naming, orthographic awareness accuracy  
III: = attitude and motivation |
| Ang, 2015<sup>[33]</sup> | Controlled clinical trial | n=111 | 6-7y | Poor WM and mathematics performance | I1: Visual WM updating training  
Setting: individual, computerized  
I2: Cogmed  
Setting: individual, computerized | Implicit training; WM | C1: active control, similar to updating WM training but without memory component  
C2: waitlist control | Pre - Post - 6m  
I: + visual WM (I2>I1/C, = at 6m); = visual updating (I1>I2/C at 6m), letter rotation, verbal WM  
II: = mathematics  
III: NA  
*Influential factors:* No effects of language skills or IQ. |
| Gade exp. 1, 2017<sup>[34]</sup> | RCT | n=20 | M=5y | TD | Training a visual WM task (Corsi Block) Span task  
Setting: 1:1 Adaptive | Implicit training; WM | Children were read a story and asked to make drawings. | Pre - Post  
I: = visual WM, verbal WM, executive WM/attention  
II: NA  
III: NA  
*Influential factors:* Improvements on training tasks (not transfer tasks) originated from children with low pretest scores. |
| Gade exp. 2, 2017<sup>[34]</sup> | RCT | n=31 | M=5y | TD | Training a visual WM task (Corsi Block) Span task  
Setting: 1:1 Adaptive | Implicit training; WM | Children were read a story and asked to make drawings. | Pre - Post  
I: = visual WM, verbal WM, executive WM/attention  
II: NA  
III: NA  
*Influential factors:* Improvements on training tasks (not transfer tasks) originated from children with low pretest scores. |
| Gade exp. 3, 2017<sup>[34]</sup> | RCT | n=20 | M=5y | TD | Training a visual WM task (Corsi Block) Span task  
Setting: 1:1 Adaptive | Implicit training; WM | Children were read a story and asked to make drawings. | Pre - Post  
I: = visual WM, verbal WM, executive WM/attention  
II: NA  
III: NA  
*Influential factors:* Improvements on training tasks (not transfer tasks) originated from children with low pretest scores. |
| Gade exp. 4, 2017<sup>[34]</sup> | RCT | n=20 | M=5y | TD | Training a visual WM task (Corsi Block) Span task  
Setting: 1:1 Adaptive | Implicit training; WM | Children were read a story and asked to make drawings. | Pre - Post  
I: = visual WM, verbal WM, executive WM/attention  
II: NA  
III: NA  
*Influential factors:* Improvements on training tasks (not transfer tasks) originated from children with low pretest scores. |
### Classroom Interventions for SP and EF: A Review

<table>
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<tr>
<th>Study</th>
<th>Type</th>
<th>N</th>
<th>Age</th>
<th>TD</th>
<th>Setting</th>
<th>Adapted</th>
<th>Implicit Training</th>
<th>WM</th>
<th>Pre-Post</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henry, 2014</td>
<td>RCT</td>
<td>n=36</td>
<td>Age: 5-8y</td>
<td>TD</td>
<td>Training of one verbal (Listening Recall) and one visual (Odd-One-Out) WM task</td>
<td>Implicit training: WM</td>
<td>WM</td>
<td>Pre - Post- 6m- 12m (academic tasks only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loosli, 2012</td>
<td>Controlled clinical trial</td>
<td>n=66 (I: n=24, C: n=42)</td>
<td>Age: 9-11y</td>
<td>TD</td>
<td>Visual WM span training</td>
<td>Implicit training: WM</td>
<td>WM</td>
<td>Pre - Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mansur-Alvez, 2015</td>
<td>RCT</td>
<td>n=53</td>
<td>Age: M=11y</td>
<td>TD</td>
<td>Verbal WM training</td>
<td>Implicit training: WM</td>
<td>WM</td>
<td>Pre - Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passolunghi, 2016</td>
<td>RCT</td>
<td>n=48</td>
<td>Age: M=5y</td>
<td>TD</td>
<td>WM training consisting of paper-and-pencil tasks to enhance visual, verbal and executive WM according to Baddeley’s WM model.</td>
<td>Implicit training: WM</td>
<td>C1: numeracy training C2: usual school activities</td>
<td>Pre - Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rode, 2014</td>
<td>Controlled clinical trial</td>
<td>n=282*</td>
<td>Grade 3</td>
<td>TD</td>
<td>Memorizing a series of visually presented numbers interspersed with math tasks</td>
<td>Implicit training: WM</td>
<td>WM</td>
<td>Pre - Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swanson, 2018</td>
<td>RCT</td>
<td>n=54</td>
<td>Age: 7-10y</td>
<td>TD</td>
<td>I1: Training verbal and visual WM I2: Training verbal and visual WM</td>
<td>Implicit training: WM</td>
<td>WM</td>
<td>Pre - Post</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Only 66 children were assessed on the post-test WM tests*
<table>
<thead>
<tr>
<th>Study</th>
<th>Design Type</th>
<th>Sample Characteristics</th>
<th>Interventions</th>
<th>Setting</th>
<th>Training Modality</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wong, 2014 [41]</td>
<td>Controlled clinical trial</td>
<td>n=53&lt;br&gt;Age: 6-12y&lt;br&gt;TD or ADHD and poor WM as indicated on BRIEF WM scale</td>
<td>Training of visual and verbal WM</td>
<td>Individual, computerized</td>
<td>Adaptive</td>
<td>WM training does not compensate for low fluid intelligence on far transfer measures. However, effects on verbal WM were more robust for those with low rather than high fluid intelligence.</td>
</tr>
<tr>
<td>Gibson, 2011 [42]</td>
<td>RCT</td>
<td>n=47&lt;br&gt;Age: 11=16y (M=12) ADHD</td>
<td>I1: Verbal WM training&lt;br&gt;Setting: individual, computerized&lt;br&gt;I2: Visual WM training (Exercises in both interventions partly extracted from Cogmed)&lt;br&gt;Setting: individual, computerized</td>
<td>Adaptive</td>
<td>Implicit training; WM</td>
<td>Only primary, not secondary, memory is affected by training. No effect of intervention modality matched with outcome.</td>
</tr>
<tr>
<td>Holmes, 2015 [43]</td>
<td>Pretest-posttest design</td>
<td>n=32&lt;br&gt;Age: 8-11y&lt;br&gt;Low language abilities (LLA) vs normal language abilities (NLA)</td>
<td>Cogmed</td>
<td>Individual, computerized</td>
<td>Adaptive</td>
<td>Language ability does not seem to impact training effects on verbal and visual STM, verbal and visual WM, language and IQ.</td>
</tr>
<tr>
<td>Prins, 2011 [44]</td>
<td>RCT</td>
<td>n=51&lt;br&gt;Age: 7-12y ADHD</td>
<td>I1: Visual WM training in game format&lt;br&gt;Setting: individual, computerized</td>
<td>Adaptive</td>
<td>Implicit training; WM</td>
<td>Game elements have positive influence on training effectiveness.</td>
</tr>
</tbody>
</table>
I1: 2 training days, 10 sessions/d  
I2: 5 training days, 4 sessions/d  
I3: 10 training days, 2 sessions/d  
I4: 20 training days, 1 session/d  
Setting: individual, computerized  
Adaptive | Implicit training; WM | Extra math instruction with teachers, 1 session/d for 20d | Pre - Post  
I: fluid intelligence I4>I1/I2/I3  
Influential factors: Only participants in the most spaced group (I4) showed improvements in fluid intelligence. The more spaced the training, the greater the transfer |
Table 4. Implicit training for cognitive flexibility

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
</tr>
<tr>
<td>Kray, 2012[46]</td>
<td>Cross-over design</td>
<td>n=20 Age: 7-12y Male ADHD</td>
<td>Task-switching training: Switch as fast and accurately as possible between two simple tasks. Setting: individual, computerized (computerized) Adaptiveness not described</td>
</tr>
</tbody>
</table>

I: verbal WM, switching; = interference control, processing speed, semantic knowledge, matrix reasoning II: NA III: NA
# Table 5. Implicit training for higher-order EF

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Time points of assessment</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
<td>Design</td>
<td>Sample size, age, other characteristics</td>
<td>Intervention</td>
<td>Approach &amp; target</td>
<td>Control</td>
<td>Time points of assessment</td>
</tr>
</tbody>
</table>
| Amd, 2018 [47]        | Pretest-posttest design     | n=35 Age: 6-14y (M=9) TD | Strengthening Mental Abilities with Reasoning Training (commercially available as Raise your IQ) | Implicit training; Reasoning | NA | Pre - Post | I: + relational reasoning/fluid intelligence  
II: NA  
III: NA  
*Influential factors:* improvement only for children who progressed to stage 13 of the training and beyond on the training, but not for those who progressed only to stage 7. No effect of age, baseline relational/reasoning ability or baseline visual analogy performance. |
| Cassidy, 2016 [48]    | Pretest-posttest design     | n=15 Age: 10-12y TD | Computerized reasoning training consisting of logical statements that can either be correct or incorrect. (relational framing skills intervention) | Implicit training; Reasoning | NA | Pre - Post | I: + IQ, relational ability  
II: NA  
III: NA |
| Knoll, 2016 [49]      | Controlled clinical trial   | n=186 Age: 11-13y TD | Relational reasoning training, based on Raven’s Progressive Matrices | Implicit training; Reasoning | C1: Numerosity discrimination training  
C2: Face perception training | Pre - Post - 6m | I: + relational reasoning/fluid intelligence >C1/C2 (maintained at 6m)  
= numerosity discrimination, visual memory, verbal WM, face perception (C2/I/C1)  
II: NA  
III: NA |
Table 6. Implicit training targeting multiple functions in one intervention

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Outcomes</th>
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</thead>
<tbody>
<tr>
<td>Author</td>
<td>Design</td>
<td>Intervention approach &amp; target</td>
<td>Control</td>
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<tr>
<td>Volckaert, 2015 [50]</td>
<td>RCT</td>
<td>n=47</td>
<td>Handicrafts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age: 5-6y Mainly female TD</td>
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<tr>
<td></td>
<td></td>
<td>Mainly female TD</td>
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<td>Adaptive</td>
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<td>A series of games/exercises aimed at increasing the different components of inhibition functions (interrupt an ongoing response, impulsivity management, inhibition of a predominant response, inhibition of external distractors) and involving the use of fictional characters aimed at improving the child’s metacognition relative to those functions. Setting: group Adaptive</td>
<td>Implicit training; Attentional control, response inhibition</td>
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<tr>
<td>Blakey, 2015 [51]</td>
<td>RCT</td>
<td>n=54</td>
<td>Handicrafts</td>
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<td></td>
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<td>Age: 4y TD</td>
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<td>Computerized tasks</td>
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<td>Setting: individual, computerized Adaptive</td>
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<td>Adaptive</td>
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<tr>
<td>Steiner, 2014 [52,53]</td>
<td>RCT</td>
<td>n=70</td>
<td>Handicrafts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age: 7-11y ADHD</td>
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<td></td>
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<td>ADHD</td>
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<td></td>
<td></td>
<td>Captain’s Log exercises directed at attention and WM</td>
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<tr>
<td>Study</td>
<td>Design</td>
<td>N</td>
<td>Age</td>
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<tr>
<td>Wiest, 2014 [54]</td>
<td>Pretest-posttest design</td>
<td>n=30</td>
<td>9-13y (M=10)</td>
</tr>
<tr>
<td>Powell, 2016 [56]</td>
<td>RCT</td>
<td>n=19</td>
<td>3-9y</td>
</tr>
<tr>
<td>Brock, 2017 [56]</td>
<td>RCT</td>
<td>n=87</td>
<td>M=6y Low SES</td>
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<tr>
<td>Howard exp. 1, 2016</td>
<td>RCT</td>
<td>n=65</td>
<td>3-5y</td>
</tr>
<tr>
<td>Howard exp. 2, 2016</td>
<td>RCT</td>
<td>n=40</td>
<td>3-5y</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>n</td>
<td>Age</td>
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<tr>
<td>Howard exp. 3, 2016 [57]</td>
<td>RCT</td>
<td>43</td>
<td>3-5y TD</td>
</tr>
<tr>
<td>Röthlisberger, 2012 [58]</td>
<td>Controlled clinical trial</td>
<td>135</td>
<td>5y vs 6y TD</td>
</tr>
<tr>
<td>Schmitt, 2015 [59] (Same intervention as Tominey, 2001)</td>
<td>RCT</td>
<td>276</td>
<td>3-5y (M=4) TD</td>
</tr>
<tr>
<td>Tominey, 2011 [60] (same intervention as Schmitt, 2015)</td>
<td>RCT</td>
<td>65</td>
<td>3-5y (M=3) TD</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Intervention</td>
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<tr>
<td>Amonn, 2013 [61]</td>
<td>Within-subject control design</td>
<td>n=30 Age: 7-13y (M=10) ADHD</td>
<td>RehaCom targeting divided attention, vigilance, concentration and verbal memory, topological memory, reaction behavior, memory of words, planning. Setting: individual, computerized Adaptive</td>
</tr>
<tr>
<td>Farias, 2017 [62]</td>
<td>Pretest-posttest design</td>
<td>n=27 Age: 8-12y ADHD with comorbid LD</td>
<td>Captain’s Log MindPower builder Computerized Cognitive Training (CCT) Setting: individual, computerized Adaptive</td>
</tr>
<tr>
<td>van der Oord, 2014 [63]</td>
<td>RCT</td>
<td>n=43 Age: 8-12y ADHD</td>
<td>Braingame Brian Setting: individual, computerized Adaptive</td>
</tr>
</tbody>
</table>
| Goldin, 2014 [64] | Controlled clinical trial | n=111 Age: 6y Low SES | Matemarote: computerized games for EF Setting: individual, computerized Adaptive | Implicit training; Response inhibition, WM, planning | Less cognitively demanding games but with similar motor responses. Pre - Post I: orienting attention central cue, inhibition/cognitive flexibility RT; orienting attention exogenous cue, alerting, executive control, inhibition/cognitive flexibility accuracy, planning II: Language grades/mathematics grades but only for children with low school attendance III: NA
<table>
<thead>
<tr>
<th>Influential factors</th>
<th>Anguera, 2017 [65]</th>
<th>Pretest-posttest design</th>
<th>n=57 Age: 8-12y SPD comorbid with ADHD (n=20) vs SPD only (n=13) vs TD (n=24)</th>
<th>The Project: EVO intervention: a self-guided intervention combining visuomotor and perceptual discrimination tasks. Setting: individual, computerized Adaptive</th>
<th>Implicit training; Attentional control, response inhibition, cognitive flexibility, visuomotor tracking</th>
<th>NA</th>
<th>Pre - Post - 9m (only PR)</th>
<th>I: perceptual discrimination, sustained attention, impulsivity, multitask ability, reaction time II: NA III: SPD&amp;ADHD + inattention (PR; maintained at 9m); SPD only/TD = inattention (PR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katz exp. 1, 2017 [64]</td>
<td>RCT</td>
<td>n=1395 (I: n=1024, C: n=371) Age: 6-18y (M=11) TD</td>
<td>Lumosity: computerized cognitive intervention training various cognitive functions Setting: individual, computerized Adaptive</td>
<td>Implicit training; Response inhibition, WM, cognitive flexibility</td>
<td>No intervention</td>
<td>Pre - Post</td>
<td>I: EF composite including: inhibition, verbal STM, verbal WM, planning, cognitive flexibility II: grammatical reasoning, arithmetic test III: NA</td>
<td></td>
</tr>
<tr>
<td>Katz exp. 2, 2017 [64]</td>
<td>Controlled clinical trial</td>
<td>n=200 Age: 11-14y (M=12) TD</td>
<td>Lumosity: computerized cognitive intervention training various cognitive functions Setting: individual, computerized Adaptive</td>
<td>Implicit training; Response inhibition, WM, cognitive flexibility</td>
<td>Completing games of National Geographic Kids</td>
<td>Pre - Post</td>
<td>I: EF composite including: inhibition, verbal STM, verbal WM, planning, cognitive flexibility, grammatical reasoning, arithmetic test; Processing speed II: grammatical reasoning, arithmetic test III: NA</td>
<td></td>
</tr>
</tbody>
</table>

*Influential factors: The intervention equalizes academic outcome for those who do not regularly attend school (e.g. due to family issues) to those who do attend regularly.*

*Influential factors: The intervention led to some improvements only for children who had combined SPD&ADHD, not for children with SPD only or TD children.*

*Influential factors: Little influence of SES on training impact.*
Table 7. Implicit training comparing interventions for different (combinations of) targets in one study

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Time points of assessment</th>
<th>Main findings</th>
<th>Influential factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
<td>Design</td>
<td>Sample size, age, other characteristics</td>
<td>Intervention</td>
<td>Approach &amp; target</td>
<td>Control</td>
<td>Time points of assessment</td>
<td>Main findings</td>
</tr>
<tr>
<td>Bergman Nutley, 2011 [67]</td>
<td>RCT</td>
<td>n=112 Age: 4y TD</td>
<td>I1: Cognmed I2: Nonverbal reasoning training (NVR), consisting of geometrical figures; the training was based on the same tasks that were also used for the assessment in this study of near transfer I3: CB = combined WM and NVR training (balanced to have the same training load as single training) Setting: individual, computerized Adaptive</td>
<td>Implicit training; I1: WM I2: Reasoning (non-verbal)</td>
<td>PL (n=25) = same paradigm as CB but non-adaptive/remained at the easiest level</td>
<td>Pre - Post</td>
<td>I: + problem-solving (I2/I3&gt;C/I1), visual WM (I1/I3&gt;C/I2), fluid intelligence/non-verbal reasoning (I2/I3&gt;C/I1); = visual STM, verbal STM II: NA III: NA</td>
</tr>
<tr>
<td>de Vries, 2015 [64,65]</td>
<td>RCT</td>
<td>n=121 Age: 8-12y ASD</td>
<td>I1: Braingame Brian as WM training I2: Braingame Brian as cognitive flexibility training Setting: individual, computerized Adaptive</td>
<td>Implicit training; I1: WM I2: Cognitive flexibility</td>
<td>Non-adaptive mock training</td>
<td>Pre - Post - 6w</td>
<td>I: visual WM: I1&gt;12/C (N= at 6w), = emotion flexibility, updating WM, flexibility, inhibition, sustained attention II: NA III: = EF behavior, social behavior, ADHD behavior, quality of life</td>
</tr>
<tr>
<td>Dovis, 2015 [70]</td>
<td>RCT</td>
<td>n=89 Age: 8-12y ADHD</td>
<td>I1: Braingame Brian targeting WM, cognitive flexibility, inhibition I2: Braingame Brian targeting only inhibition and cognitive flexibility, WM tasks in non-adaptive mode Setting: individual, computerized</td>
<td>Implicit training; I1: Response inhibition, WM, cognitive flexibility I2: Response</td>
<td>Non-adaptive</td>
<td>Pre - Post - 3m</td>
<td>I: + response inhibition (I2&gt;C), interference control (I1/I2&gt;C), visual STM (I1&gt;C), visual WM (I1&gt;C); = verbal WM, verbal STM, cognitive flexibility, fluid intelligence Note. After correction for multiple testing, only effect on visual STM remained. Results maintained at 3m for I1 but not for I2 II: NA III: = ADHD symptoms (PR/TR), EF behavior (PR)</td>
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<tr>
<td>Thorell, 2009 [72]</td>
<td>Controlled clinical trial</td>
<td>n=65</td>
<td>Age: 4-5y TD</td>
<td>I1: Cogmed I2: Inhibitory control training Setting: individual, computerized Adaptive</td>
<td>Implicit training; I1: WM I2: Attentional control, response inhibition</td>
<td>C1: Active: playing computer games C2: Passive</td>
<td>Pre - Post I: + visual WM (I1&gt;C), verbal WM (I1&gt;C), visual attention (I1&gt;C); = interference control, response inhibition, auditory attention, problem-solving, response speed II: NA III: NA</td>
</tr>
</tbody>
</table>
## Table 8. Metacognition and/or strategy use for attentional control

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
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</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
<td><strong>Approach &amp; target</strong></td>
<td><strong>Control</strong></td>
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<tr>
<td>Tamm, 2010 [73]</td>
<td>Pretest-posttest design</td>
<td>n=23</td>
<td>Pay Attention! To train sustained, selective, alternating and divided attention. Includes discussion on how learned skills can be implemented at home or in school. Setting: 1:1</td>
<td>Metacognition/strategic use; Attentional control</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>(Preliminary study for Tamm, 2013)</td>
<td>Age: 8-14y (M=9) ADHD</td>
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<tr>
<td>Tamm, 2013 [74]</td>
<td>RCT</td>
<td>n=105</td>
<td>Pay Attention! To train sustained, selective, alternating and divided attention. Includes discussion on how learned skills can be implemented at home or in school. Few minute meeting after sessions with parent and interventionist to discuss training and how to implement skills at home and in school. Setting: 1:1</td>
<td>Metacognition/strategic use; Attentional control</td>
<td>Waitlist</td>
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<tr>
<td></td>
<td>(Based on preliminary study Tamm, 2010)</td>
<td>Age: 7-15y (M=9y) ADHD</td>
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</table>
**Table 9. Metacognition and/or strategy use for working memory**

<table>
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<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
<th>Time points of assessment</th>
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<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
<td><strong>Control</strong></td>
<td><strong>Outcomes</strong></td>
<td><strong>Main findings</strong></td>
</tr>
<tr>
<td>Brown, 1976 [76]</td>
<td>Controlled clinical trial</td>
<td>n=66 (Young: n=27, Old: n=39) Age: young = 7-11y (M=9) vs old = 9-13y (M=12) Mental retardation</td>
<td>I1: Anticipation as memorization strategy I2: Cumulative rehearsal as memorization strategy Setting: 1:1 Adaptiveness not described</td>
<td>Metacognition/strategy use; WM Labeling as memorization strategy</td>
<td>Pre - Post- 2w</td>
<td>I: + listening recall (maintained at 2w for old children but not young children) II: NA III: NA</td>
</tr>
<tr>
<td>Capodici, 2018 [76]</td>
<td>RCT</td>
<td>n=34 Age: 5y ADHD symptoms</td>
<td>Small group sessions during which training focused on WM exercises and strategies to perform well. Setting: group and individual Adaptiveness not described</td>
<td>Metacognition/strategy use; WM Typical school activities</td>
<td>Pre - Post</td>
<td>I: + verbal STM, verbal WM, visual WM, selective verbal WM, inhibition/attentional control, impulsivity control II: NA III: + 1/5 ADHD symptoms (TR/PR); = 4/5 ADHD symptoms (PR/TR)</td>
</tr>
<tr>
<td>Honoré, 2017[77]</td>
<td>RCT</td>
<td>n=34 Age: 5-6y TD</td>
<td>Games tapping the executive WM according to Baddeley's WM model using visual-encoding strategies. Setting: group</td>
<td>Metacognition/strategy use; WM Vocabulary learning program</td>
<td>Pre - Post - 6m</td>
<td>I: + verbal WM (1 of 5 parameters at post, 1 of 5 parameters at 6m); = visual WM, other verbal WM parameters II: = numerical development, arithmetic III: NA</td>
</tr>
<tr>
<td>Rojas-Barahona, 2015 [78]</td>
<td>Controlled clinical trial</td>
<td>n=268 (I: n=144, C: n=124) Age: M=4y Socio-economically disadvantaged TD</td>
<td>Computerized program training phonological and visuospatial WM Setting: individual, computerized Adaptive</td>
<td>Metacognition/strategy use; WM Listening to songs about recognizing different body parts, focused on motor action</td>
<td>Pre - 3m</td>
<td>I: + overall WM, visual WM, phonological WM II: + overall early literacy skills, book and print awareness, alphabet knowledge, listening comprehension; = phonological awareness III: NA</td>
</tr>
</tbody>
</table>
| St Clair-Thompson, 2010 [20] | Controlled clinical trial | n=254* (I: n=117, C: n=137)  
**Age:** 5-8y TD  
* Note. The n=254 participants only completed two of the post-test measures, while the other 6 measures were completed by subgroups of 34 to 141 participants. | Memory Booster: computer game teaching memory strategies, i.e. repetition, visual images, storytelling, and grouping  
**Setting:** individual, computerized  
**Adaptive** | Metacognition/strategy use; WM  
I: + verbal STM, verbal WM (NA at 5m); = visual STM  
II: + remembering classroom instructions, mental arithmetic (NA at 5m); = sentence completion, arithmetic, mathematics  
III: NA | no intervention | Pre - Post - 5m  
I: + verbal STM, verbal WM (NA at 5m); = visual STM  
II: + remembering classroom instructions, mental arithmetic (NA at 5m); = sentence completion, arithmetic, mathematics  
III: NA  
**Influential factors:** No differential effects depending on age (5-6y vs 7-8y) or WM score (low vs normal). |
## Table 10. Metacognition and/or strategy use for higher-order EF

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning</strong></td>
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<tr>
<td>Ashman, 1993 [80]</td>
<td>Controlled clinical trial</td>
<td>n=147 (I: n=58, C: n=89)</td>
<td>Process-based instruction focusing on planning and the planning process in a stepwise manner.</td>
<td>Metacognition/strategy use; Planning</td>
<td>Regular classroom</td>
</tr>
<tr>
<td></td>
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<td>Age: 9-12y TD</td>
<td>Setting: group Adaptiveness not described</td>
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<tr>
<td>Bull, 2016/2018 [81,82]</td>
<td>RCT</td>
<td>n=170</td>
<td>Plan-It Commander: serious game including mini games directed at planning as well as a social community to ask questions. Setting: individual, computerized</td>
<td>Metacognition/strategy use; Planning, organizing and time-management in daily life</td>
<td>Care as usual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age: 8-12y Mostly male ADHD</td>
<td>Setting: individual, computerized</td>
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</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Alexandre, 1989 [83]</td>
<td>Controlled clinical trial</td>
<td>n=50</td>
<td>Training based on encoding, inferring, mapping, and applying delivered via direct/explicit instruction model Setting: group, individual, 1:1</td>
<td>Metacognition/strategy use; Reasoning (analogical)</td>
<td>Normal preschool activities (n=30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age: 4-5y Non-proficient reasoners</td>
<td>Setting: group, individual, 1:1 Adaptive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alexandre exp. 2, 1987 [84]</td>
<td>Controlled clinical trial</td>
<td>n=23</td>
<td>Teacher-modeling to solve analogical reasoning problems while using verbalization of the task</td>
<td>Metacognition/strategy use;</td>
<td>Normal preschool activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age: 3-8y (M=5) Gifted</td>
<td>Setting: group, individual, 1:1 Adaptive</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Main findings**

<table>
<thead>
<tr>
<th>Time points of assessment</th>
<th>I: Cognitive functions assessed with performance task</th>
<th>II: Academic performance</th>
<th>III: Behavior and other outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre - Post</td>
<td>I: + planning Porteus Maze; = Planning trail-making, planning PLAN task</td>
<td>II: + mathematics, reading comprehension; = spelling</td>
<td>III: NA</td>
</tr>
<tr>
<td>Pre - Post - 10w</td>
<td>I: NA</td>
<td>II: NA</td>
<td>III: + WM (PR, maintained at 10w), time-management (PR, TR; maintained at 10w), responsibility (PR, maintained at 10w); = EF behavior Planning/organizing (PR/TR), WM (TR), time perception (PR), social skills (PR/TR): cooperation, assertiveness, self-control; self-efficacy (SR)</td>
</tr>
</tbody>
</table>

**Influential factors:** Girls most likely to show more improvements in planning/organizing compared to estimated intervention effect of total group of participants. Boys with lower baseline levels of hyperactivity and higher levels of conduct disorder symptoms showed more improvements in planning/organizing after the intervention compared to the estimated intervention effect of the total group of participants.
<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Setting</th>
<th>Reasoning Strategy</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barkl, 2012 [85]</td>
<td>Controlled clinical trial</td>
<td>n=47 Age: M=8y TD</td>
<td>Setting: 1:1 Adaptivity unknown</td>
<td></td>
<td>Changes in reasoning and awareness were related to attentional control and fluid intelligence, and this relation was stronger for younger children. Awareness of schemes mediates the influence of the intervention on reasoning.</td>
</tr>
<tr>
<td>Christoforides, 2016 [86]</td>
<td>Controlled clinical trial</td>
<td>n=180 Age: 8-10y (M=9) and 10-13y (M=11) TD</td>
<td>Setting: 1:1 Adaptivity unknown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molnar, 2011 [87]</td>
<td>Controlled clinical trial</td>
<td>n=252 (I: n=90, C: n=162) Age: 6-8y TD</td>
<td>Setting: group or 1:1 Adaptivity not described</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>n</td>
<td>Age</td>
<td>TD</td>
<td>Intervention</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-----------------</td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Klauer, 2002</td>
<td>Controlled trial</td>
<td>279</td>
<td>M=7</td>
<td>TD</td>
<td>Metacognitive program to teach children to recognize a problem, differentiate between types of problems, and apply an adequate solution.</td>
</tr>
<tr>
<td>Tzuriel, 2009</td>
<td>RCT</td>
<td>53</td>
<td>7</td>
<td>TD</td>
<td>ARP (Analogical Reasoning Program) including education on basic analogy concepts, practicing adaptive analogy problems and generalization to daily life. (Similar to Klauer’s reasoning program)</td>
</tr>
<tr>
<td>Tomic exp. 2, 1996</td>
<td>Controlled trial</td>
<td>23</td>
<td>7</td>
<td>TD</td>
<td>Klauer’s program of inductive reasoning</td>
</tr>
</tbody>
</table>

**Influential factors:** transfer on intelligence tests and on math performance was linear dependent on amount of prior training.
Table 1. Metacognition and/or strategy use targeting multiple functions in one intervention

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
<th>Time points of assessment</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
<td><strong>Control</strong></td>
<td><strong>Outcomes</strong></td>
<td><strong>Main findings</strong></td>
<td><strong>Influential factors</strong></td>
</tr>
<tr>
<td>Bolstad, 1972 [91]</td>
<td>Controlled clinical trial</td>
<td>n=38</td>
<td>Self-regulation of disruptive behavior including reinforcement</td>
<td>Metacognition/strategy use; Attentional control, response inhibition</td>
<td>C1: No regulation C2: External regulation of disruptive behavior including reinforcement</td>
<td>During I and C</td>
<td>I: Cognitive functions assessed with performance task II: Academic performance III: Behavior and other outcomes</td>
</tr>
<tr>
<td>Campeno-Martinez, 2017 [92]</td>
<td>Pretest-posttest design</td>
<td>n=26 Age: 7-10y ADHD</td>
<td>EIP-AR: Educational Intervention Program to Increase Attention and Reflexivity (EIP-AR); including implicit training and self-instruction according to Meichenbaum</td>
<td>Metacognition/strategy use; Attentional control, response inhibition</td>
<td>NA</td>
<td>Pre - Post</td>
<td>I: NA II: NA III: aggression (TR), social isolation (PR); = aggression (PR), ADHD symptoms no hyperactivity (PR/TR), ADHD symptoms hyperactivity (PR/TR), social isolation (TR), anxiety (PR/TR)</td>
</tr>
<tr>
<td>Christianesen, 2015 [93]</td>
<td>Controlled clinical trial</td>
<td>n=413 Age: 3-6y (M=4) TD</td>
<td>I1: Behavior modification (BM) related to attentional skills I2: BM + Attention training (AT)</td>
<td>Metacognition/strategy use; Attentional control, response inhibition</td>
<td>Passive (n=220)</td>
<td>Pre - Post - 6m</td>
<td>I: NA II: NA III: + (I1&gt;I2&gt;C) social, emotional and behavioral functioning (TR), ADHD symptoms (unknown rater)</td>
</tr>
<tr>
<td>Eastman, 1981 [94]</td>
<td>Controlled clinical trial</td>
<td>n=11 Grade 1</td>
<td>Self-instruction training: think out loud. No further description</td>
<td>Metacognition/strategy use; Attentional</td>
<td>Regular classroom teaching</td>
<td>Pre - Post</td>
<td>I: NA II: = academic performance</td>
</tr>
</tbody>
</table>

Attentional control and response inhibition
## Classroom Interventions for SP and EF: A Review

<table>
<thead>
<tr>
<th>Study Details</th>
<th>Setting</th>
<th>Design</th>
<th>Sample Size</th>
<th>Description</th>
<th>Outcomes</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rivera-Flores, 2015 [95]</td>
<td>1:1 Adaptiveness not described</td>
<td>Pretest-posttest design</td>
<td>n=10 Age: 6-8y ADHD</td>
<td>Self-instructional cognitive training, adapted from Meichenbaum</td>
<td>Metacognition/strategic use; Attentional control, response inhibition</td>
<td>III: = on-task behavior</td>
</tr>
<tr>
<td>Semrud-Clikeman, 1999 [96]</td>
<td>Group Adaptiveness not described</td>
<td>Controlled clinical trial</td>
<td>n=33 (I: n=21, C: n=12) Age: 8-12y Mostly male ADHD</td>
<td>Training focusing on sustained attention and problem-solving skills consisting of tasks from the attention process training (APT) by Sohlberg.</td>
<td>Metacognition/strategic use; Attentional control, response inhibition</td>
<td>Waitlist</td>
</tr>
<tr>
<td>Steiner, 2011 [97]</td>
<td>Group Adaptiveness not described</td>
<td>Pretest-posttest design</td>
<td>n=28 Age: M=12y ADHD</td>
<td>Braintrain: Visual and auditory exercises to reduce impulsivity and increase attention and WM. Including goal-setting for sessions. Implicit training (&amp; small component metacognition/strategies)</td>
<td>Metacognition/strategic use; Attentional control, response inhibition, WM</td>
<td>Waitlist</td>
</tr>
<tr>
<td>Re, 2015 [98]</td>
<td>Group Adaptiveness not described</td>
<td>RCT</td>
<td>n=52 Age: 5y ADHD symptoms vs TD</td>
<td>Group activities directed at EF consisting of practice of various EF and metacognition (i.e. similar to self-instruction)</td>
<td>Metacognition/strategic use; Attentional control, response inhibition, WM, cognitive flexibility</td>
<td>Typical school activities</td>
</tr>
</tbody>
</table>

**Attentional control, response inhibition and working memory**

**Attentional control, response inhibition, working memory and cognitive flexibility**

**Influential factors:** Children with ADHD symptoms benefit from the training while TD children do not clearly benefit.
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Age</th>
<th>Intervention Details</th>
<th>Setting</th>
<th>EFs Assessed</th>
<th>Pre-Post</th>
<th>Influential Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korzeniowski, 2017</td>
<td>Controlled clinical trial</td>
<td>178</td>
<td>6-10y</td>
<td>Cognitive intervention program to simultaneously stimulate multiple EF</td>
<td>Adaptive</td>
<td>Cognition, planning, inhibition, cognitive flexibility, attention</td>
<td>Pre - Post</td>
<td>Cognitive training was effective in 7-9 year olds but not in 10-11 year olds. Benefits differed according to age: cognitive flexibility for the 7-year olds, planning for the 8-year olds, and metacognition for the 8 and 9-year olds. Girls who received the training outperformed their controls in terms of inhibitory control, planning and cognitive flexibility, boys showed the same result in cognitive flexibility and metacognition. SES may have an influence on intervention effect but more research is needed.</td>
</tr>
<tr>
<td>Tamm, 2012</td>
<td>Pretest-posttest design</td>
<td>24</td>
<td>3-7y (M=5)</td>
<td>Small-group activities focusing on different EF. Simultaneous parent training regarding generalization and use of metacognitive techniques.</td>
<td>Adaptive</td>
<td>Attentional control, response inhibition, working memory and sensory awareness</td>
<td>Pre - Post</td>
<td>Cognitive training was effective in 7-9 year olds but not in 10-11 year olds. Benefits differed according to age: cognitive flexibility for the 7-year olds, planning for the 8-year olds, and metacognition for the 8 and 9-year olds. Girls who received the training outperformed their controls in terms of inhibitory control, planning and cognitive flexibility, boys showed the same result in cognitive flexibility and metacognition. SES may have an influence on intervention effect but more research is needed.</td>
</tr>
<tr>
<td>Tamm, 2015</td>
<td>RCT</td>
<td>24</td>
<td>3-7y (M=5)</td>
<td>Small-group activities focusing on different EF. Simultaneous parent training regarding generalization and use of metacognitive techniques.</td>
<td>Adaptive</td>
<td>Attentional control, response inhibition, working memory and sensory awareness</td>
<td>Waitlist</td>
<td>Cognitive training was effective in 7-9 year olds but not in 10-11 year olds. Benefits differed according to age: cognitive flexibility for the 7-year olds, planning for the 8-year olds, and metacognition for the 8 and 9-year olds. Girls who received the training outperformed their controls in terms of inhibitory control, planning and cognitive flexibility, boys showed the same result in cognitive flexibility and metacognition. SES may have an influence on intervention effect but more research is needed.</td>
</tr>
<tr>
<td>Traverso, 2015</td>
<td>RCT</td>
<td>90 (I: n=35, C: n=55)</td>
<td>5y</td>
<td>Various game-like activities focusing on different EF have to be performed in small groups. At the end of the game, strategies are discussed on how to approach problems and new situations.</td>
<td>Not adaptive</td>
<td>Attentional control, response inhibition, working memory and sensory awareness</td>
<td>Pre - Post</td>
<td>Cognitive training was effective in 7-9 year olds but not in 10-11 year olds. Benefits differed according to age: cognitive flexibility for the 7-year olds, planning for the 8-year olds, and metacognition for the 8 and 9-year olds. Girls who received the training outperformed their controls in terms of inhibitory control, planning and cognitive flexibility, boys showed the same result in cognitive flexibility and metacognition. SES may have an influence on intervention effect but more research is needed.</td>
</tr>
</tbody>
</table>

**Attentional control, response inhibition, working memory and sensory awareness**

**Response inhibition, working memory and cognitive flexibility**

**Working memory and higher-order EF**
## Classroom Interventions for SP and EF: A Review

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Sample Size</th>
<th>Age</th>
<th>Setting</th>
<th>Cognitive Flexibility and Higher-order EF</th>
<th>Other Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calero, 2017</td>
<td>Pretest-posttest design</td>
<td>n=26, Age: 7-12y</td>
<td>In a situation of social exclusion</td>
<td>Executive Function Mediation Program for Children, training: trains WM (verbal and visual), comparison, categorization, classification, planning, organization and attribution of mental states. Additionally, training focuses on generalization to daily life, looking where skills can be applied in daily life. Setting: group Adaptiveness not described</td>
<td>Metacognition</td>
<td>NA</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>III: NA</td>
</tr>
<tr>
<td>Kenwot hy, 2014</td>
<td>RCT</td>
<td>n=67 (n=20; I: n=47, C: n=20), Age: 7-11y ASD</td>
<td>Unstuck and On Target: to teach what physical/mental flexibility, goal setting and planning are, and why they are useful skills; how to use them, coping skills. Additional parental support at home. Implicit training, psycho-education, metacognition/strategies</td>
<td>Metacognition and physical flexibility, planning, goal-setting</td>
<td>Social skills training with additional parental support at home</td>
<td>Pre - Post</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>I: + non-verbal problem solving, flexibility, planning</td>
</tr>
<tr>
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<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III: + classroom observation, shifting (PR), planning (PR); = social responsiveness (PR/TR), other TR reported outcomes</td>
</tr>
<tr>
<td>Banaschewski, 2011</td>
<td>Cross-over design</td>
<td>n=9, Age: 7-10y Male ADHD</td>
<td>I1: Sensorimotor training including motor and sensory exercises and impulse control motor tasks (e.g. verbalizing complex motor tasks) I2: Cognitive-behavioral training based on self-instruction by Meichenbaum</td>
<td>Metacognition</td>
<td>NA</td>
<td>Pre - Post I1 - Post I2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>I: Postural practice: I1 +, I1 vs I2 NS; Kinesthesia: NS; Motor coordination: NS; Cognitive impulse control: I2 +, I1 vs I2 NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>III: Hyperkinesis (PR): I1 +, I1 vs I2; Aggressive behaviors (PR): I1 +, I1 vs I2 NS; Depressive/anxious symptoms (PR): NS</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Sample Size</td>
<td>Age</td>
<td>Setting</td>
<td>Intervention Details</td>
<td>Outcomes</td>
</tr>
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</tr>
<tr>
<td>Colmar, 2016</td>
<td>RCT</td>
<td>n=50</td>
<td>M=8y</td>
<td>Group</td>
<td>Memory Mates: memory and attention strategies embedded in regular classroom teaching (including self-talk)</td>
<td>Pre - Post I: NA II: = reading, spelling, mathematics III: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TD</td>
<td></td>
<td>Setting: group</td>
<td>Usual classroom teaching without use of Memory Mates strategies</td>
</tr>
<tr>
<td>Stoeger, 2008</td>
<td>RCT</td>
<td>n=219</td>
<td>M=10y</td>
<td>Group</td>
<td>Self-regulated learning including self-evaluation, monitoring, goal-setting and learning strategies directed at homework behavior</td>
<td>Pre - Post I: NA II: = Scholastic achievement III: + time-management, self-reflection on learning, self-efficacy, helplessness, willingness to exert effort; = motivational orientations, interest</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TD</td>
<td></td>
<td>Setting: group</td>
<td>No training</td>
</tr>
<tr>
<td>van der Donk, 2017</td>
<td>Pretest-posttest design</td>
<td>n=164</td>
<td>8-12y</td>
<td>Adaptive and individual, computerized</td>
<td>Pay Attention in Class (PAC) consisting of psychoeducation about EF, adaptive WM tasks and strategies for generalization.</td>
<td>Pre - Post I: verbal WM and visual WM: those with larger training gains improved more on these measures II: = word reading fluency, math, spelling: no moderating effects III: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ADHD</td>
<td></td>
<td>Setting: 1:1 and individual, computerized</td>
<td>Metacognition/strategic use; WM, planning, attentional control, response inhibition, metacognition, goal-setting</td>
</tr>
</tbody>
</table>
Table 12. Metacognition and/or strategy use comparing interventions for different (combinations of) targets in one study

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
<td>Design</td>
<td>Sample size, age, other characteristics</td>
<td>Intervention</td>
</tr>
<tr>
<td>Jonkman, 2016</td>
<td>RCT</td>
<td>n=34 Age: 8-12y Mostly female ADHD</td>
<td>I1: Memory strategy training: children are taught to use verbalisation, Meichenbaum strategies, specific memory strategies (e.g. rehearsal), and applied them in training exercises I2: Attention-perceptual-motor training, also based on Meichenbaum + training exercises Setting: group Adaptive</td>
</tr>
</tbody>
</table>
Table 13. External aid/modification for attentional control

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Time points of assessment</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
<td><strong>Approach &amp; target</strong></td>
<td><strong>Control</strong></td>
<td><strong>Main findings</strong></td>
</tr>
<tr>
<td>Baijot, 2016 [111]</td>
<td>Cross-over design</td>
<td>n=30 Age: 7-12y ADHD vs TD</td>
<td>White noise</td>
<td>External aid/modification; Attentional control</td>
<td>No noise</td>
<td>During I and C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Setting: individual</td>
<td></td>
<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III: NA</td>
</tr>
<tr>
<td>Helps, 2014 [112]</td>
<td>Cross-over design</td>
<td>n=90 Age: 8-10y Sub-attentive vs normal attentive vs super-attentive</td>
<td>I1: Moderate level of white noise</td>
<td>External aid/modification; Attentional control</td>
<td>No noise</td>
<td>During I and C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Setting: individual</td>
<td></td>
<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III: NA</td>
</tr>
<tr>
<td>Söderlund, 2007 [113]</td>
<td>Cross-over design</td>
<td>n=42 Age: 9-13y (M=11y) Male ADHD vs TD</td>
<td>White noise</td>
<td>External aid/modification; Attentional control</td>
<td>No noise</td>
<td>During I and C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Setting: individual</td>
<td></td>
<td></td>
<td>II: NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>III: NA</td>
</tr>
<tr>
<td>Söderlund, 2010 [114]</td>
<td>Cross-over design</td>
<td>n=51 Age: 11-12y Attentive (n=41) or inattentive (n=10)</td>
<td>White noise</td>
<td>External aid/modification; Attentional control</td>
<td>No noise</td>
<td>During I and C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Setting: individual</td>
<td></td>
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<td>II: NA</td>
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<td>III: NA</td>
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<tr>
<td>Söderlund, 2016 [115]</td>
<td>Cross-over design</td>
<td>n= 40 Age: ADHD: M=12y</td>
<td>White noise</td>
<td>External aid/modification;</td>
<td>No noise</td>
<td>During I and C</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Group demographics</td>
<td>Variables</td>
<td>Setting</td>
<td>Intervention</td>
<td>During I &amp; C</td>
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<tr>
<td><strong>Music</strong></td>
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<tr>
<td>Su, 2017 [116]</td>
<td>Pretetst-posttest design (cross-over)</td>
<td>n=62</td>
<td>Senior grade elementary school TD</td>
<td>Mozart music while reading</td>
<td>External aid/modification; Attentional control</td>
<td>Silence (while reading)</td>
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<td>Setting: individual</td>
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<td></td>
<td>II: + reading comprehension: direct process, reading rate; - reading comprehension: indirect process</td>
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<td>III: + learning anxiety; - cognitive load/attention</td>
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<tr>
<td><strong>Room adjustments</strong></td>
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<tr>
<td>Barkman, 2012 [117]</td>
<td>Controlled clinical trial</td>
<td>n=93</td>
<td>Primary (M=8y) and middle school (M=15y) TD</td>
<td>Lighting &quot;concentrate&quot;: bright and cold light</td>
<td>External aid/modification; Attentional control</td>
<td>Standard lighting</td>
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<td>Setting: individual</td>
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<td>II: + reading speed; = reading comprehension</td>
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<td></td>
<td>III: = attitude to school</td>
</tr>
<tr>
<td>Brown, 1966 [118]</td>
<td>Controlled clinical trial</td>
<td>n=28</td>
<td>Age: 4-11y Very low IQ</td>
<td>Experimental room, quiet and few distractions</td>
<td>External aid/modification; Attentional control</td>
<td>Normal classroom conditions with normal auditory and visual distractors</td>
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<td>Setting: individual</td>
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<td>II: NA</td>
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<td>III: NA</td>
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<tr>
<td><strong>Classroom seating</strong></td>
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<tr>
<td>Fedewa, 2015 [119]</td>
<td>RCT</td>
<td>n=67</td>
<td>Grade 2 elementary TD</td>
<td>Therapy ball</td>
<td>External aid/modification; Attentional control</td>
<td>Regular chair</td>
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<td>Setting: individual</td>
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<td>II: = literacy, mathematics</td>
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<td>III: = on-task behavior; - behavior</td>
</tr>
<tr>
<td>Goodmon, 2014 [120]</td>
<td>Cross-over design</td>
<td>n=24</td>
<td>Age: 9-11y Dyslexia vs dyslexia comorbid with ADHD</td>
<td>Therapy ball</td>
<td>External aid/modification; Attentional control</td>
<td>Regular chair</td>
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<td>Setting: individual</td>
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<td>II: = reading comprehension</td>
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<td></td>
<td>III: + attention/motivation (SR); +/- desirable/undesirable behavior (SR)</td>
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<td>Influential factors: No difference between children with ADHD and dyslexia vs children with dyslexia only.</td>
</tr>
<tr>
<td>Pfeiffer, 2008 [121]</td>
<td>RCT</td>
<td>n=63</td>
<td>Grade 2 elementary Attention difficulties</td>
<td>Disc 'O' Sit cushions</td>
<td>External aid/modification; Attentional control</td>
<td>Regular chair</td>
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<td>Setting: individual</td>
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<td>II: NA</td>
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<td>III: + attention and EF behavior (TR)</td>
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<tr>
<td><strong>Other external aids</strong></td>
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<tr>
<td>Daghista, 2016 [122]</td>
<td>Controlled clinical trial</td>
<td>n=40</td>
<td>Age: M=10y Female</td>
<td>Mind maps to support attention in language class</td>
<td>External aid/modification;</td>
<td>Traditional teaching</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Setting: individual</td>
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</tbody>
</table>
## CLASSROOM INTERVENTIONS FOR SP AND EF: A REVIEW

<table>
<thead>
<tr>
<th>TD</th>
<th>Setting: group</th>
<th>Attentional control</th>
<th>II: NA</th>
<th>III: + observed attention</th>
</tr>
</thead>
</table>
Table 14. Directly comparing various intervention approaches in one study

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Participant characteristics</th>
<th>Intervention characteristics</th>
<th>Approach &amp; target</th>
<th>Control</th>
<th>Outcomes</th>
<th>Time points of assessment</th>
<th>Main findings</th>
<th>Influential factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td><strong>Design</strong></td>
<td><strong>Sample size, age, other characteristics</strong></td>
<td><strong>Intervention</strong></td>
<td><strong>Control</strong></td>
<td><strong>Outcomes</strong></td>
<td><strong>Time points of assessment</strong></td>
<td><strong>Main findings</strong></td>
<td><strong>Influential factors</strong></td>
</tr>
<tr>
<td>King, 1991 [124]</td>
<td>Controlled clinical trial</td>
<td>n=46 Grade 5 (elementary) TD</td>
<td>I1: Guided peer-questioning (asking strategic questions and giving answers) following self-instruction steps I2: Unguided peer-questioning I3: Usual problem-solving procedure Setting: with a peer Adaptiveness not described</td>
<td>I1: Implicit training &amp; metacognition and/or strategy use</td>
<td>NA</td>
<td>Pre - Post</td>
<td>I: Problem-solving ability: I1&gt;I2/I3, Peer interaction: question asked: =, explanations given: I1&gt;I2/I3 II: NA III: NA</td>
<td>Injluential factors: Added coaching has positive effects on outcomes.</td>
</tr>
<tr>
<td>Nelwan, 2016/2018 [125,126]</td>
<td>Controlled clinical trial</td>
<td>n=66 Age: 9-12y Attentional and mathematical difficulties</td>
<td>I1: Jungle Memory WM training and high amount of coaching I2: Jungle Memory WM training and low amount of coaching Setting: individual, computerized &amp; 1:1 Adaptive</td>
<td>I1: Implicit training &amp; metacognition and strategy use I2: Implicit training I3: Implicit training Problem-solving</td>
<td>No training</td>
<td>Pre - Post</td>
<td>I: + visual WM (I1&gt;I2/C); = verbal WM II: + arithmetic (I1&gt;I2/C) III: NA</td>
<td></td>
</tr>
<tr>
<td>Partanen, 2015 [127]</td>
<td>Controlled clinical trial</td>
<td>n=64 Age: M=8y Male Special educational need</td>
<td>I1: Cogmed Setting: individual computerized Adaptive I2: Cogmed &amp; metacognitive strategies on how to approach a task Setting: Individual, computerized &amp; group</td>
<td>I1: Implicit training I2: Implicit training &amp; metacognition and/or strategy use WM</td>
<td>Wait-list</td>
<td>Pre - Post - 6m</td>
<td>I: = non-verbal reasoning, verbal WM + visual WM forward and backward: I2&gt;C (not maintained at 6m), visual WM forward: I2&gt;C (maintained at 6m) II: = arithmetic, reading, writing III: NA</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Sample</td>
<td>Intervention</td>
<td>Setting</td>
<td>Passive</td>
<td>Baseline</td>
<td>Post-intervention</td>
<td>Influential Factors</td>
</tr>
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</table>
| **Peng, 2015** [30]          | RCT    | n=58   | I1: WM training with strategy instruction: explicitly taught a strategy and encouraged to use it during each trial of every task  
I2: WM training without strategy instruction  
Setting: 1:1 Adaptive | Adaptive | I1: Implicit training & metacognition/strategies  
I2: Implicit training WM | Passive | Pre - Post  
I: + verbal WM (I1>C); = visual STM, speed of speech, listening comprehension, recall of story  
II: NA  
III: NA | Influential factors: no moderating effects of non-verbal IQ, pre-training academic and WM skills. |
| **van der Donk, 2015** [109] | RCT    | n=100  | I1: Cogmed  
Setting: individual, computerized Adaptive  
I2: Pay Attention in Class (PAC) consisting of psychoeducation about EF, adaptive WM tasks and strategies for generalization.  
Setting: individual, computerized Adaptive | Adaptive | I1: Implicit training  
I2: Implicit training & metacognition/strategies  
I1: WM  
I2: WM, planning, attentional control, response inhibition, metacognition, goal-setting | NA | Pre - Post - 6m  
I: For both I1 and I2: + attentional control (not maintained at 6m), verbal WM (maintained at 6m), visual WM (at 6m I1>I2), planning (maintained at 6m), inhibition (maintained at 6m); - sustained attention  
II: For both I1 and I2: = learning efficiency quotient (incl. reading, math, spelling)  
III: For both I1 and I2: + EF behavior (PR; not maintained at 6m), EF behavior (TR; maintained at 6m), attention problems (PR, TR; maintained at 6m), externalizing problems (PR; maintained at 6m); = behavior in class (TR), externalizing behavior (TR), quality of life (PR, SR) | |
| **Langberg, 2018** [128]     | RCT    | n=274 (I1: n=111, I2: n=111, C: n=52)  
Age: M=12y TD | I1: HOPS (Homework Organization and Planning Skills) refined  
Setting: 1:1  
Adaptiveness not described  
| Adaptive | I1: Metacognition/strategies & external aid  
I2: External aid  
I1: Organizing  
I2: Attentional control, response inhibition | Waitlist | Pre - Post - 6m  
I: NA  
II: = GPA  
III: + homework problems (PR; I1/I2>C), homework performance (PR; I1>C), children’s organization (I1/I2>C) | Influential factors: HOPS seemed more beneficial for students with more severe psychopathology and EF impairment. |
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[47] Amd M, Roche B. Assessing the Effects of a Relational Training Intervention on Fluid Intelligence Among a Sample of Socially Disadvantaged Children in Bangladesh. The Psychological Record 2018;68(2):141-149.


Graziano PA, Garcia AM, Landis TD. To Fidget or Not to Fidget, That Is the Question: A Systematic Classroom Evaluation of Fidget Spinners Among Young Children With ADHD. Journal of Attention Disorders 2018:1087054718770009.
[126] Nelwan M, Vissers C, Kroesbergen EH. Coaching positively influences the effects of working memory training on visual working memory as well as mathematical ability. Neuropsychologia 2018;113:140-149.