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A Meta-Analysis of the Experimental Evidence on the Near- and Far-Transfer Effects Among Children's Executive Function Skills

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In the present meta-analysis we examined the near- and far-transfer effects of training components of children's executive functions skills: working memory, inhibitory control, and cognitive flexibility. We found a significant near-transfer effect ($g^+ = 0.44$, $k = 43$, $p < .001$) showing that the interventions in the primary studies were successful in training the targeted components. However, we found no convincing evidence of far-transfer ($g^+ = 0.11$, $k = 17$, $p = .11$). That is, training a component did not have a significant effect on the untrained components. By showing the absence of benefits that generalize beyond the trained components, we question the practical relevance of training specific executive function skills in isolation. Furthermore, the present results might explain the absence of far-transfer effects of working memory training on academic skills (Melby-Lervag & Hulme, 2013; Sala & Gobet, 2017).

Public Significance Statement
The present meta-analysis suggests that it is possible to foster executive functions in childhood by explicitly training them. However, these programs have limited practical relevance as they only promote the component(s), (working memory, inhibitory control, and cognitive flexibility) that are targeted in the training and do not have far-transfer effects to untrained component(s).

Keywords: executive functions, children, meta-analysis, intervention

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Executive functions in childhood are crucial skills as they have an important role in social-emotional and cognitive development (Zelazo & Carlson, 2012). These fundamental cognitive skills in the preschool age are strongly related to school readiness (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair, 2002) and they are more predictive of later academic achievement than IQ (Blair & Razza, 2007). In a previous meta-analysis on the concurrent and predictive relations of executive function skills and (later) academic achievement in childhood (Jacob & Parkinson, 2015) moderate associations were found both regarding math and reading skills. When children enter formal schooling, executive functions are also of high importance in the adjustment to the learning environment and developing social relationships (Liew, 2012). Children's ability to focus their attention on the relevant objects, inhibit distractors and impulsive responses, practice self-regulation and self-control by resisting the immediate gratification of their momentary needs, and solve problems in a flexible and creative manner are all necessary for academic success as well as for thriving in social relationships (McClelland & Cameron, 2012). Thus, the importance of executive functions in childhood is clear.

Executive functions are a set of cognitive skills that is responsible for planning and organizing our deliberate and goal-directed behavior (Lezak, 1982). These processes make us able to constantly monitor and flexibly adjust to the changes in the environment, to solve new and complex problems, and practice self-control (Jurado & Rosselli, 2007). Behavior regulation via these top-down processes is discussed in several theoretical frameworks. While some approaches consider executive functions as a unitary

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construct, others highlight the distinction between different components of executive functioning while hypothesizing varying degrees of unity among different numbers of components.

In Norman and Shallice's (1986) model the supervisory attentional system is responsible for the deliberate regulation of thoughts and behavior instead of giving schematic responses. Activation of this system makes us able to react in a more adaptive manner when it is required by the circumstances, for example, in new or unexpected situations when habitual responses would not be successful. In Baddeley and Hitch's (1994) model of working memory the central executive has a similar role; this component is responsible for the coordination and the regulation of the two subsystems: the phonological loop and the visuospatial sketchpad.

Other models argue that executive function skills can be considered to be a unitary construct with different numbers of separable components. In their seminal work, Miyake et al. (2000) examined the associations between the latent variables behind different types of executive function measures designed to tap working memory (updating), inhibition, and switching in adults. The factor analyses that provided the best fit resulted in three clearly separable but moderately correlated factors: (a) *updating* (also labeled as *working memory*) that is used to keep information in mind and to manipulate it; (b) *inhibition* that makes us able to control our attention, emotions, and behavior by restraining automatic or prepotent responses; and (c) *shifting* (also labeled as *cognitive flexibility*) which makes us able to look at a problem from different points of views and to switch between different rules and dimensions.

Lehto, Juujärvi, Kooistra, and Pulkkinen (2003) found evidence for three factors within children's executive function skills. However, as stated above, there is no general consensus on the number of components. Supporting this, in a sample of 11- to 12-year-old children, St. Clair-Thompson and Gathercole (2006) found evidence for two factors: one for updating (working memory) and one for inhibition. On the other hand, Wiebe, Espy, and Charak (2008) found that a unitary factor was just as good of a fit for 2- to 6-year-old children's results on working memory and inhibition tasks as models with separate factors for working memory and inhibitory control. Diamond (2013) considers executive function skills as a unitary construct with three separable components, however, she broadens this view with a developmental aspect: She posits that the executive function (EF) components of working memory and inhibitory control skills are mutually supportive of each other, and that cognitive flexibility is the latest to develop and builds on the other two components.

Although weak or at most moderate correlations among the components are consistently found in the literature (Bull & Scerif, 2001; Carlson, Moses, & Breton, 2002; Senn, Espy, & Kaufmann, 2004; St. Clair-Thompson & Gathercole, 2006), in most studies those disappear after controlling for age and other control variables like IQ (e.g., Hughes, 1998). It is important to note that studies using latent variables (Miyake et al., 2000) generally show stronger associations among different EF components. This discrepancy between results based on single tests as opposed to latent variables might imply that measurement imperfections such as task impurity might indeed play a major role in weakening the associations found among the components.

In sum, there is no consensus regarding whether the components of executive functions form a unitary construct in childhood. Accordingly, it is highly questionable whether training one of the components has an effect on the untrained executive function skills of children. In fact, in literature reviews on the efficacy of different interventions aiming to foster children's executive function skills, doubts have been expressed about the rationale of training specific components in isolation. Diamond and Lee (2011) suggested that Cogmed, a software that trains working memory skills, does not have significant effects on untrained executive function skills. Diamond and Ling (2016) concluded that while working memory trainings are successful in training working memory skills, gains do not generalize to either inhibitory control or flexibility. Finally, Blair (2017) postulated that results are mixed regarding the far-transfer effects of computerized working memory trainings and activities embedded in children's everyday lives should be more effective in training executive function skills in general.

The most important aim of the present meta-analysis was to gain a deeper understanding of whether and to what extent the different components of executive functions are trainable and whether training a specific executive function has an ameliorating effect on other main executive function components. This is of crucial importance because in the long run the main aim of training executive functions skills is to improve children's everyday functioning; for example, academic and social skills as well as emotion regulation. These complex skills are not supported by one sole executive function but generally rely on the interplay among most of them (Blair & Razza, 2007).

Meta-analytic studies so far have shown that training working memory is possible (Melby-Lervag & Hulme, 2013; Melby-Lervåg, Redick, & Hulme, 2016; Sala & Gobet, 2017); however, it has limited far-transfer effects on the above mentioned complex social, emotional, and academic skill sets. Melby-Lervåg and Hulme (2013) found no transfer effects of computerized working memory training on verbal and nonverbal ability, word decoding, or arithmetic. Further, Sala and Gobet (2017) found small far-transfer effects of working memory training on mathematics and literacy/word decoding, and no transfer to fluid or crystallized intelligence or science.

One possible explanation for the lack of far-transfer effect found on these complex skills is that there might not even be a far-transfer effect among the executive function components themselves (working memory, inhibition, cognitive flexibility) together which form the basis of the more complex social, academic, and emotional skills examined. In fact, previous meta-analyses (Melby-Lervag & Hulme, 2013; Sala & Gobet, 2017) have only confirmed the existence of near-transfer effects of working memory trainings (e.g., working memory training improving working memory), but could not show a far-transfer effect in children on inhibitory control (operationalized as Stroop-like tests in Melby-Lervag & Hulme, 2013, and as Stroop-tests, go/no-go tests, and the dichotic-listening task in Sala & Gobet, 2017), the only executive function component investigated in this respect to date. Although working memory training in childhood have received considerable attention, data about training other EF components which are just as important for complex everyday skills as working memory have not yet been synthetized to our knowledge.

Accordingly, our study aims to fill this gap in the literature by examining the evidence regarding the near- and far-transfer effects of training any and all of the main executive function components in childhood: working memory, inhibition, and cognitive flexibility. Near-transfer effect was defined as effects on the same executive function component(s) that were trained (excluding tasks that were practiced during the training), while far-transfer effect in the present study was considered as effects on executive function components that were untrained. By investigating these effects on all three main components of executive function skills in one meta-analytic study including data of both typically and atypically developing children, this study provides a unique extension of our existing knowledge on the clinically relevant question of training executive functions and therefore potentially improves the everyday functioning of children.

Based on the literature the following hypotheses were tested:

Hypothesis 1: We expected significant near-transfer effects but small or no far-transfer effects of training components of executive functions in childhood.

Hypothesis 2: Regarding the associations between the different pairs of components there is little evidence in the literature. Melby-Lervåg and Hulme's (2013) meta-analytic results suggest that working memory programs have a small but significant effect on inhibitory control measured by Stroop-like tasks. However, this effect was not significant in child samples (although this was based on a very limited number of studies). Accordingly, we expected that training working memory might have an effect on inhibitory control. Regarding the rest of the pairs of components, we had no prior expectations.

The results of the present meta-analysis are highly relevant to the clinical practice. A number of developmental psychopathologies are characterized by executive dysfunctions, some of which are directly linked to the behavioral symptoms. Many computer-based training programs aim to ameliorate the functioning of a single executive function component; for example, working memory trainings are frequently used with children living with attention-deficit/hyperactivity disorder (ADHD; e.g., Lomas, 2001). However, it is still questionable whether the benefits observed transfer to other skills such as inhibitory control or flexibility. In case training a single component does not affect the others, more complex trainings that target different executive function components are probably more suitable in the clinical practice.

Method

Operational Definition

The aim of the present meta-analysis was to examine the near- and far-transfer effects among the following executive function skills: working memory, inhibitory control, and cognitive flexibility or shifting. Accordingly, we categorized the interventions and the outcome measures of the primary studies based on the component(s) they targeted (see the online supplementary material). Most of the training programs utilized a game-like activity either in a computer (e.g., Alloway, Bibile, & Lau, 2013; Bennett, Holmes, & Buckley, 2013) or in a noncomputer setting (e.g., Caviola, Mammarella, Cornoldi, & Lucangeli, 2009; Dowsett & Livesey, 2000) but all of them trained executive function skills explicitly by practicing tasks that require one or more executive function skills. When the intervention contained elements fostering different components of executive functions, we considered them multicomponent trainings (e.g., Goldin et al., 2014; Traverso, Viterbori, & Usai, 2015), while if the targeted skill was clearly associated with one core executive component, we defined it as a single-component training (e.g., de Vries, Prins, Schmand, & Geurts, 2015; Volckaert & Noël, 2015).

In order to be able to assess near- and far-transfer effects we also categorized the outcome measures according to which component it assessed. Instead of relying on the interpretation of the primary studies' authors of the tests, we categorized which component the task loaded on according to the previous considerations in the literature (Diamond, 2013; Friedman & Miyake, 2004; Garon, Bryson, & Smith, 2008; Miyake et al., 2000). For instance, backward digit, word, or spatial (e.g., Corsi block test) span tasks (e.g., Chacko et al., 2014) were coded as measures of working memory. It is important to note that forward span tests were considered to reflect short-term memory (STM) because they require no manipulation of the information kept in mind (Alloway, Gathercole, & Pickering, 2006) and were thus excluded in the present study. In case a measure including both forward and backward span task was reported in a study, it was still included as a measure of working memory (e.g., Dovis, Van der Oord, Wiers, & Prins, 2015). Additionally, we decided to combine results over verbal and visuospatial working memory because we found very similar results on the two kinds of working memory tasks (near-transfer effect on verbal working memory tasks: $g^+ = 0.48$, $k = 20$, $SE = 0.09$, 95% CI [0.30, 0.66], $p < .001$; near-transfer effect on nonverbal working memory tasks: $g^+ = 0.45$, $k = 22$, $SE = 0.07$, 95% CI [0.32, 0.61], $p < .001$; far-transfer effect on verbal working memory tasks: $g^+ = -0.04$, $k = 3$, $SE = 0.27$, 95% CI [−0.56, 0.49], $p = .89$; far-transfer effect on nonverbal working memory tasks: $g^+ = -0.30$, $k = 3$, $SE = 0.43$, 95% CI [−1.13, 0.54], $p = .49$). This is also in line with the evidence showing that working memory is a domain-general capacity (Alloway et al., 2006). It is important to note that the working memory interventions in the primary studies used both verbal and nonverbal tasks so we also could not differentiate trainings using verbal and nonverbal stimuli.

Tests that required children to inhibit either a prepotent/automatized reaction, a previously learnt response, or a distractor were included as measures of inhibitory control: go/no-go (Dowsett & Livesey, 2000), flanker (e.g., Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2011), Stroop-like tests (e.g., Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009), and AX-CPT (e.g., Dörrenbächer, Müller, Tröger, & Kray, 2014) were considered just like different tasks using the delay of gratification paradigm like the toy wait test (e.g., Rueda, Checa, & Cómbita, 2012) based on Diamond (2013). Similarly, the head-toes-shoulders-knees test was also considered a measure of inhibitory control (Ponitz, McClelland, Matthews, & Morrison, 2009) because children need to inhibit an automatized response—for instance, inhibit touching their head when the experimenter says so yet touching their toes instead. Although a second rule is introduced in the second phase of the test, it does not interfere with the first rule and does not require switching.

Tests that require children to switch between rules that refer to the same stimuli such as the dimensional card sorting test (e.g., Howard, Powell, Vasseleu, Johnstone, & Melhuish, 2016; Schmitt, 2013) and tasks requiring flexible adjustment of strategies such as the trail making test part B (e.g., Dovis et al., 2015), the Tower of London test (e.g., Goldin et al., 2014), or the Wisconsin card sorting test (Lomas, 2001) were categorized as measures of cognitive flexibility.

Search Strategy

As the present study was a part of a more extensive meta-analytic project (Takacs & Kassai, 2018) in which we synthetized all the available experimental results on the effectiveness of different kinds of behavioral interventions that aimed to promote executive functions (Diamond & Lee, 2011, e.g., physical exercise, art activity, executive function-specific curricula, martial arts, and mindfulness-based practice), we conducted a systematic search in the literature based on a detailed search string (see Appendix A). Four databases (PsycINFO, Web of Science, PsycARTICLES, and ERIC) were scanned to identify all the available journal articles and unpublished studies like dissertations and conference papers that reported on the effects of an explicit training of component(s) of executive functions with children. After excluding duplicates, 7,287 studies remained. Two independent research assistants scanned all of them based on their title and abstract. As a secondary search, the references of the selected studies in addition to relevant review articles and meta-analyses were checked to find all suitable results. Finally, as shown in Appendix B, we identified 38 studies with 47 contrasts that were suitable for the present study.

Inclusion Criteria

The included studies had to meet the following criteria:

- Randomized controlled design was utilized (The randomization was done either on an individual or on a group [e.g., classroom] basis).
- The results of the intervention group were compared with a passive or an active control group.
- The aim of the intervention was to explicitly train at least one of the three core executive function components: working memory, inhibitory control, or cognitive flexibility.
- The age of the sample was no more than 12 years at the beginning of the study.
- The paper reported the results of at least one outcome measure that used a neurocognitive test of executive functions.
- The paper was written in English.

Exclusion Criteria

To begin, we excluded all the studies that utilized an implicit approach for training. Accordingly, we did not include studies on physical exercise (e.g., Fisher et al., 2011), art activity (e.g., Schellenberg, 2004), executive function-specific curricula (e.g., Bierman et al., 2008), mindfulness-based meditation (e.g., Flook, Goldberg, Pinger, & Davidson, 2015), or neuro/biofeedback training (e.g., Beauregard & Lévesque, 2006), and those studies where teachers or parents were trained instead of the children (Lewis-Morrarty, Dozier, Bernard, Terracciano, & Moore, 2012). We could not include correlational studies (e.g., Wiebe, Espy, & Charak, 2008), as we wanted to draw conclusions about the causal relationships between the components.

As outcome measures, we only included neurocognitive tests of executive function conducted with the children. Accordingly, other kinds of instruments were excluded: We did not include teacher-, parent-, or self-reported assessment of executive functions like the Behavior Rating Inventory of Executive Function (e.g., de Vries et al., 2015). Additionally, instead of reaction time (RT), we preferred accuracy on these neurological tests (e.g., Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2011) because accuracy or error rates are considered a more reliable measure of executive functions in childhood (Diamond, Barnett, Thomas, & Munro, 2007). Finally, it is important to note that we did not include measures that were the same as the task the children practiced during the intervention as we considered these as direct measures of training efficacy and to reflect no near- or far-transfer effects. For instance, children practiced a go/no-go apparatus in the study of Dowsett and Livesey (2000) and were tested on the same machine afterward. As these tasks were explicitly practiced during the intervention, we excluded them from the analyses in order not to overestimate near-transfer effects. Finally, results had to be excluded in case we could not locate the full text in English (e.g., Aghababaei, Malekpour, & Abedi, 2012) or if we did not have sufficient statistics to calculate an effect size even after contacting the authors (e.g., St. Clair-Thompson & Holmes, 2008).

Coding

During the coding process, two research assistants coded every article according to a predefined coding schema regarding the following information: (a) bibliographic information (e.g., title, author(s), year of publication, and the country where the data was collected); (b) sample characteristics (e.g., the number and the mean age of the participants in the intervention and control groups, other characteristics of the sample such as IQ, SES, and clinical status); (c) study design (e.g., passive or active control); (d) characteristics of the intervention (e.g., the executive function component(s) it targeted, whether the training was conducted individually or in groups, whether it was applied on a computer or not); (e) the kind of outcome measure (e.g., working memory, inhibitory control, or flexibility) and whether it was a near-transfer measure (the component targeted in the intervention was the same as tested by the outcome measure) or far-transfer (the component targeted in the intervention was different from what the outcome measure tested) measure. Interrater reliability (ranging from 78% to 100% agreement between two coders) was acceptable in all cases.

As shown in Table 1 and 2, from the studies that reported on the results of more than one intervention or control conditions that met our inclusion criteria we included more contrasts. If there were two or more suitable intervention conditions, all of them were included as compared with the control group. The same strategy was used when a study contained more control conditions like an active and a passive control. For instance, Kyttälä, Kanerva, and Kroesbergen (2015) tested the effects of a combined working memory and a counting training alone by comparing them to a passive control condition. In this case only the combined working memory and counting training met our inclusion criteria, the counting training alone condition was considered an active control condition. Therefore, the results of the participants who received the working

Table 1
Overview of the Studies Included in the First Meta-Analysis Regarding Near-Transfer Effects

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Alloway Contrast 1	2013	Florida, North America	$M = 10.76$	Diagnosed: Learning impairments	Working memory training: "Jungle Memory" ($n = 24$)	Active control ($n = 32$)	Working memory (2 measures): 1. Mix of backward digit recall and processing letter recall 2. Shape recall
Alloway Contrast 2	2013	Florida, North America	$M = 10.76$	Diagnosed: Learning impairments	Working memory training: "Jungle Memory" ($n = 24$)	Passive control ($n = 32$)	Working memory (2 measures): 1. Mix of backward digit recall and processing letter recall 2. Shape recall
Bennett	2013	United Kingdom, Europe	7–12	Diagnosed: Down syndrome	Working memory training: "Junior Cogmed Working Memory Training: RoboMemo" ($n = 10$)	Passive control ($n = 11$)	Working memory (2 measures): 1. Counting recall 2. Odd one out
Bergman Nutley Contrast 1	2011	Sweden, Europe	4	Typically developing	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 25$)	Active control ($n = 25$)	Working memory (1 measure): 1. Odd one out
Bergman Nutley Contrast 2	2011	Sweden, Europe	4	Typically developing	Working memory training: "Cogmed Working Memory Training: RoboMemo + Nonverbal reasoning" ($n = 27$)	Active control ($n = 25$)	Working memory (1 measure): 1. Odd one out
Bigorra	2016	Spain, Europe	7–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 31$)	Active control ($n = 30$)	Working memory (2 measures): 1. Spatial recall 2. Letter number sequencing
Blakey	2015	England, Europe	$M = 4.33$; $SD = 3.58$	Typically developing	Working memory and inhibitory control and training: "Short executive function training program" ($n = 26$)	Active control ($n = 28$)	Working memory (1 measure): 1. Backward word task Inhibitory control (1 measure): 1. Peg tapping
Caviola	2009	Italy, Europe	9	Typically developing	Working memory training: "Metacognitive visuospatial working memory training" ($n = 22$)	Active control ($n = 24$)	Working memory (2 measures): 1. Backward digit recall 2. Corsi block test
Chacko	2014	New York, North America	7–11	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 44$)	Active control ($n = 41$)	Working memory (2 measures): 1. Listening recall 2. Spatial recall
de Vries Contrast 1	2015	Holland, Europe	8–12	Diagnosed: ASD	Working memory training: "Braingame Brian" ($n = 31$)	Active control ($n = 29$)	Working memory (1 measure): 1. N-back test
de Vries Contrast 2	2015	Holland, Europe	8–12	Diagnosed: ASD	Cognitive flexibility training: "Braingame Brian" ($n = 26$)	Active control ($n = 29$)	Cognitive flexibility (2 measure): 1. Number-gnome switch 2. Gender-emotion switch

(*table continues*)

Table 1 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Dongen-Boomsma (Dissertation, Chapter VI)	2014	Holland, Europe	5–7	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 26$)	Active control ($n = 21$)	Working memory (2 measures): 1. Knox Cubes Leidse Diagnostische Test 2. Backward digit span
Dovis Contrast 1	2015	Holland, Europe	10	Diagnosed: ADHD	Working memory, inhibitory control and cognitive flexibility training: "Braingame Brian" (Full active; $n = 31$)	Active control ($n = 15$)	Working memory (1 measure): 1. Digit Span (WISC) Cognitive flexibility (1 measure): 1. Trail Making Test (switch-cost)
Dovis Contrast 2	2015	Holland, Europe	10	Diagnosed: ADHD	Inhibitory control and cognitive flexibility training: "Braingame Brian" (Partially active; $n = 31$)	Active control ($n = 30$)	Cognitive flexibility (1 measure): 1. Trail Making Test (switch-cost)
Dörrenbächer Contrast 1	2014	Germany, Europe	8–11	Typically developing	Cognitive flexibility training: "Task switching training" (high motivation; $n = 13$)	Active control ($n = 14$)	Cognitive flexibility (1 measure): 1. Task switching task
Dörrenbächer Contrast 2	2014	Germany, Europe	8–11	Typically developing	Cognitive flexibility: "Task switching training" (low motivation; $n = 14$)	Active control ($n = 14$)	Cognitive flexibility (1 measure): 1. Task switching task
Dunning Contrast 1	2013	United Kingdom, Europe	7–9	Low EF: "Low working memory"	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 34$)	Passive control ($n = 30$)	Working memory (2 measures): 1. Mix of backward digit span and listening recall 2. Mix of Mr. X, Odd one out
Dunning Contrast 2	2013	United Kingdom, Europe	7–9	Low EF: "Low working memory"	Working memory training: "Cogmed Working Memory Training: RoboMemo" ($n = 34$)	Active control ($n = 30$)	Working memory (2 measures): 1. Mix of backward digit span and listening recall 2. Mix of Mr. X, Odd one out
Espinet Experiment 1	2012	Canada, North America	2–4	Typically developing	Cognitive flexibility training: "Reflection training" ($n = 15$)	Active control ($n = 14$)	Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Espinet Experiment 2		Canada, North America	2–4	Typically developing	Cognitive flexibility training: "Reflection training" ($n = 14$)	Active control ($n = 14$)	Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Espinet Experiment 3 Contrast 1		Canada, North America	2–4	Typically developing	Cognitive flexibility training: "Reflection training" ($n = 20$)	Active control ($n = 16$)	Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Espinet Experiment 3 Contrast 2		Canada, North America	2–4	Typically developing	Cognitive flexibility training: "Reflection training" ($n = 20$)	Active control ($n = 20$)	Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort

Table 1 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Goldin	2014	Argentina, South America	6–7	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Mate Marote" (n = 73)	Active control (n = 38)	Inhibitory control (2 measures): 1. Child Attention Network Task—incongruent 2. Heart and Flowers—Fix incongruent Cognitive flexibility (3 measures): 1. Heart and Flowers—Mix congruent 2. Heart and Flowers—Mix incongruent 3. Tower of London
Holmes	2009	United Kingdom, Europe	8–11	Low EF: "Low working memory"	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 22)	Active control (n = 20)	Working memory (2 measure): 1. Mix of Mr. X, Odd one out 2. Counting recall
Hovik	2013	Norway, Europe	10–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 33)	Passive control (n = 34)	Working memory (2 measures): 1. Leiter R forward and backward 2. Mix of letter–number sequencing and sentence span
Howard Study 1, Contrast 1	2016	Australia	4	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Shared book reading one on one–Quincey Quokka's Quest" (n = 22)	Active control (n = 18)	Working memory (1 measure): 1. Mr. Ant Inhibitory control (1 measure): 1. Go/No-Go Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Howard Study 1, Contrast 2	2016	Australia	4	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Shared book reading in a group–Quincey Quokka's Quest" (n = 25)	Active control (n = 18)	Working memory (1 measure): 1. Mr. Ant Inhibitory control (1 measure): 1. Go/No-Go Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Howard Study 2	2016	Australia	4	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Shared book reading one-on-one–Quincey Quokka's Quest" (n = 19)	Active control (n = 21)	Working memory (1 measure): 1. Mr. Ant Inhibitory control (1 measure): 1. Go/No-Go Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Howard Study 3	2016	Australia	4	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Shared book reading one-on-one–Quincey Quokka's Quest" (n = 19)	Active control (n = 15)	Working memory (1 measure): 1. Mr. Ant Inhibitory control (1 measure): 1. Go/No-Go Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort

(*table continues*)

Table 1 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Klingberg	2005	Sweden, Europe	7–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 20)	Active control (n = 24)	Working memory (1 measure): 1. Span board task
*Kloo	2003	Austria, Europe	2–4	Typically developing	Cognitive flexibility training: "Card Sorting" (n = 14)	Active control (n = 15)	Cognitive flexibility (1 measure): 1. Dimensional Change Card Sort
Kroesbergen Contrast 1	2014	Holland, Europe	5	Typically developing	Working memory training: "Domain general working memory training" (n = 15)	Passive control (n = 21)	Working memory (2 measures): 1. Word recall backward 2. Odd one out
Kroesbergen Contrast 2	2014	Holland, Europe	5	Typically developing	Working memory training: "Domain specific working memory training" (n = 15)	Passive control (n = 21)	Working memory (2 measures): 1. Word recall backward 2. Odd one out
Kyttälä Contrast 1	2015	Finland, Europe	5.9	Typically developing	Working memory training: "Working memory and counting training" (n = 23)	Active control (n = 23)	Working memory (3 measures): 1. Backward word span 2. Backward digit span 3. Odd one out
Kyttälä Contrast 2	2015	Finland, Europe	5.9	Typically developing	Working memory training: "Working memory and counting training" (n = 23)	Passive control (n = 17)	Working memory (3 measures): 1. Backward word span 2. Backward digit span 3. Odd one out
Lomas (Dissertation)	2001	Virginia, North America	7–9	Diagnosed: ADHD	Working memory, inhibitory control and cognitive flexibility training: "LocuTour Multimedia Cognitive Rehabilitation" (n = 16)	Passive control (n = 15)	Inhibitory control (1 measure): 1. Continuous Performance Test—commission errors Cognitive flexibility (1 measure): 1. WCST—total correct
Luo	2013	China, Asia	8–11	Diagnosed: Dyslexia	Working memory and inhibitory control training: "Working memory and central executive tasks" (n = 15)	Active control (n = 15)	Working memory (2 measures): 1. Word span task backward 2. Digit span backward Inhibitory control (1 measures): 1. Stroop
Markomichali (Dissertation) Study 1, Contrast 1	2015	New Hampshire, North America	4–5	Typically developing	Inhibitory control training: "Waiting Game" (n = 12)	Active control (n = 13)	Inhibitory control (1 measure): 1. The Teddies Task
Markomichali (Dissertation) Study 1, Contrast 2	2015	New Hampshire, North America	4–5	Typically developing	Inhibitory control training: "Waiting Game" (n = 12)	Passive control (n = 13)	Inhibitory control (1 measure): 1. The Teddies Task
Markomichali (Dissertation) Study 2	2015	New Hampshire, North America	4–6	Low EF: "Low inhibition"	Inhibitory control training: "Waiting Game" (n = 19)	Passive control (n = 18)	Inhibitory control (2 measures): 1. The Teddies Task 2. Bee Delay Task

Table 1 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Re	2007	Italy, Europe	5	Diagnosed: ADHD	Working memory, inhibitory control and cognitive flexibility training: "Working Memory Control Training Program" (n = 5)	Passive control (n = 5)	Working memory (1 measure): 1. Dual Request Selective Task; Inhibitory control (1 measure): 1. Walk/Don't Walk
Re Sample 1	2015	Italy, Europe	5	Low EF: "ADHD symptoms"	Working memory, inhibitory control and cognitive flexibility training: "Working Memory Control Training Program" (n = 13)	Active control (n = 13)	Working memory (1 measure): 1. Dual Request Selective Task; Inhibitory control (1 measure): 1. Walk/Don't Walk
Re Sample 2	2015	Italy, Europe	5	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Working Memory Control Training Program" (n = 13)	Active control (n = 13)	Working memory (1 measure): 1. Dual Request Selective Task; Inhibitory control (1 measure): 1. Walk/Don't Walk
Röthlisberger Sample 1	2011	Swiss, Europe	5	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Small group intervention developed to promote EF" (n = 33)	Passive control (n = 38)	Working memory (1 measure): 1. Complex Span Task; Inhibitory control (1 measure): 1. Simple Flanker Task; Cognitive flexibility (1 measure): 1. Mixed Flanker Task
Röthlisberger Sample 2	2011	Swiss, Europe	6	Typically developing	Working memory, inhibitory control and cognitive flexibility training: "Small group intervention developed to promote EF" (n = 30)	Passive control (n = 34)	Working memory (1 measure): 1. Complex Span Task; Inhibitory control (1 measure): 1. Simple Flanker Task; Cognitive flexibility (1 measure): 1. Mixed Flanker Task
Rueda	2012	Spain, Europe	5	Typically developing	Inhibitory control training: "Computerized training of attention" (n = 19)	Active control (n = 18)	Inhibitory control (4 measures): 1. Delay of Gratification–Self 2. Delay of Gratification–Other 3. Child Gambling Task 4. Child ANT—omission error
Schmitt (Dissertation)	2013	Oregon, North America	3–5	Typically developing	Inhibitory control and cognitive flexibility training: "Self-regulation intervention" (n = 126)	Passive control (n = 150)	Inhibitory control (1 measure): 1. Head-Toes-Knees-Shoulders Task; Cognitive flexibility (1 measure): 1. DCCS
St. Clair-Thompson Study 1	2008	United Kingdom, Europe	6–7	Typical developing	Working memory training: "Memory Booster" (n = 22)	Passive control (n = 22)	Working memory (2 measures): 1. Listening recall task 2. Counting recall task
St. Clair-Thompson Study 2	2008	United Kingdom, Europe	6–7	Typically developing	Working memory training: "Memory Booster" (n = 18)	Passive control (n = 18)	Working memory (2 measures): 1. Listening recall task 2. Backward digit recall
St. Clair-Thompson	2010	United Kingdom, Europe	5–8	Typically developing	Working memory training: "Memory Booster" (n = 117)	Active control (n = 137)	Working memory (1 measure): 1. Listening recall

(*table continues*)

Table 1 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Thorell Contrast 1	2009	Sweden, Europe	4–5	Typical developing	Working memory training: “Cogmed Working Memory Training: RoboMemo” (n = 17)	Active control (n = 14)	Working memory (2 measures): 1. Span Board Task (WAIS-R-NI) 2. Word Span Task
Thorell Contrast 2	2009	Sweden, Europe	4–5	Typically developing	Working memory training: “Cogmed Working Memory Training: RoboMemo” (n = 17)	Passive control (n = 16)	Working memory (2 measures): 1. Span Board Task (WAIS-R-NI) 2. Word Span Task
Thorell Contrast 3	2009	Sweden, Europe	4–5	Typically developing	Inhibitory control training: “Cogmed Inhibition Training: RoboMemo” (n = 18)	Active control (n = 14)	Inhibitory control (2 measures): 1. Day-Night Stroop Task—error 2. Go/No-Go Task—commission error
Thorell Contrast 4	2009	Sweden, Europe	4–5	Typically developing	Inhibitory control training: “Cogmed Inhibition Training: RoboMemo” (n = 18)	Passive control (n = 16)	Inhibitory control (2 measures): 1. Day-Night Stroop Task—error 2. Go/No-Go Task—commission error
Tominey	2011	Oregon, North America	3–5	Typically developing	Inhibitory control and cognitive flexibility training: “Circle Time Games” (n = 28)	Passive control (n = 37)	Inhibitory control (1 measure): 1. Head-Toes-Knees-Shoulders Task
Traverso	2015	Italy, Europe	5	Typically developing	Working memory and inhibitory control training: “EF promoting small group program–Chicco and Nana” (n = 32)	Passive control (n = 43)	Working memory (2 measures): 1. Backward Word Span 2. Keep Track Inhibitory control (4 measures): 1. Circle drawing task 2. Arrow flanker task 3. Gift wrap 4. Delay task
Volckaert	2015	Belgium, Europe	4–5	Typically developing	Inhibitory control training: “Inhibition training” (n = 24)	Active control (n = 23)	Inhibitory control (1 measure): 1. Mix of Traffic lights, Cat-Dog-Fish, Monster Stroop, Head-Toes-Knees-Shoulders (Inhibition factor)
Wong	2014	China, Asia	6–12	Low EF: “Low working memory”	Working memory training: “Computerized working memory training” (n = 26)	Passive control (n = 25)	Working memory (1 measure): 1. Span Board task

Note. ADHD = attention-deficit/hyperactivity disorder; ASD = autism spectrum disorder; EF = executive function. The study marked by * was excluded from the analyses because it had an outlying effect size.

Table 2
Overview of the Studies Included in the Second Meta-Analysis Regarding Far-Transfer Effects

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Bigorra	2016	Spain, Europe	7–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training" (n = 31)	Active control (n = 30)	Inhibitory control (1 measure): 1. CPT II (commission errors) Cognitive flexibility (3 measures): 1. Tower of London 2. WCST (perseverative errors) 3. Trail making test B
Blakey	2015	England, Europe	M = 4.33; SD = 3.58	Typically developing	Working memory and inhibitory control and training: "Short executive function training program" (n = 26)	Active control (n = 28)	Cognitive flexibility (2 measures): 1. FIST 2. SWIFT mixed switch
Chacko	2014	New York, North America	7–11	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training" (n = 44)	Active control (n = 41)	Inhibitory control (1 measure): 1. CPT (commission errors)
de Vries Contrast 1	2015	Holland, Europe	8–12	Diagnosed: ASD	Working memory training: "Braingame Brian" (n = 31)	Active control (n = 29)	Inhibitory control (1 measure): 1. Stop task (commission error) Cognitive flexibility (2 measure): 1. Number-gnome switch 2. Gender-emotion switch
de Vries Contrast 2	2015	Holland, Europe	8–12	Diagnosed: ASD	Cognitive flexibility training: "Braingame Brian" (n = 31)	Active control (n = 29)	Working memory (1 measure): 1. N-back test Inhibitory control (1 measure): 1. Stop task (commission error)
Dongen-Boomsma (Dissertation, Chapter VI.)	2014	Holland, Europe	5–7	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 24)	Active control (n = 21)	Inhibitory control (3 measures): 1. Day/Night Stroop 2. Shape school control red 3. Shape school control yellow Cognitive flexibility (2 measures): 1. Shape school switch red 2. Shape switch yellow
Dovis Contrast 2	2015	Holland, Europe	10	Diagnosed: ADHD	Inhibitory control and cognitive flexibility training: "Braingame Brian" (Partially active; n = 28)	Active control (n = 30)	Working memory (1 measure): 1. Digit Span (WISC)
Dowsett Contrast 1	2000	Australia	3	Low EF: "Low inhibition"	Cognitive flexibility training: Practicing EF promoting tasks (n = 7)	Passive control (n = 5)	Inhibitory control (1 measure): 1. Go/No-go discrimination apparatus
Dowsett Contrast 2	2000	Australia	4–5	Low EF: "Low inhibition"	Cognitive flexibility training: Practicing EF promoting tasks (n = 8)	Passive control (n = 4)	Inhibitory control (1 measure): 1. Go/No-go discrimination apparatus

(*table continues*)

Table 2 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Dörrenbächer Contrast 1	2014	Germany, Europe	8–11	Typically developing	Cognitive flexibility training: "Task switching training (high motivation" (n = 13)	Active control (n = 14)	Working memory (2 measures): 1. Backward digit span 2. Counting span Inhibitory control (3 measures): 1. CPT AY 2. CPT BX 3. Stroop test
Dörrenbächer Contrast 2	2014	Germany, Europe	8–11	Typically developing	Cognitive flexibility training: "Task switching training (low motivation" (n = 13)	Active control (n = 14)	Working memory (2 measures): 1. Backward digit span 2. Counting span Inhibitory control (3 measures): 1. CPT AY 2. CPT BX 3. Stroop test
Dunning Contrast 1	2013	United Kingdom, Europe	7–9	Low EF: "Low working memory"	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 17)	Passive control (n = 30)	Inhibitory control (1 measure): 1. CPT (commission error)
Dunning Contrast 2	2013	United Kingdom, Europe	7–9	Low EF: "Low working memory"	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 31)	Active control (n = 29)	Inhibitory control (1 measure): 1. CPT (commission error)
Egeland	2013	Norway, Europe	10–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 33)	Passive control (n = 34)	Inhibitory control: 1. Color word test 2. Continuous Performance Test—Hyperactivity-Impulsivity Cognitive Flexibility 1. Trail making test (Task 4—divided attention)
Karbach Contrast 1	2009	Germany, Europe	8–10	Typically developing	Cognitive flexibility training: "Task-switching training" (n = 14)	Active control (n = 14)	Working memory (2 measures): 1. Mix of reading span and counting span 2. Mix of symmetry span and navigation span Inhibitory control (1 measure): 1. Mix of color and number Stroop task
Karbach Contrast 2	2009	Germany, Europe	8–10	Typically developing	Cognitive flexibility training: "Task-switching training + verbal self-instructions" (n = 14)	Active control (n = 14)	Working memory (2 measures): 1. Mix of reading span and counting span 2. Mix of symmetry span and navigation span Inhibitory control (1 measure): 1. Mix of color and number Stroop task

Table 2 (*continued*)

First author	Publication year	Place	Age (in years)	Clinical status of the sample	Intervention condition	Control condition	Outcome measure
Karbach Contrast 3	2009	Germany, Europe	8–10	Typically developing	Cognitive flexibility training: "Switch training + verbal instructions + variable training" (n = 14)	Active control (n = 14)	Working memory (2 measures): 1. Mix of reading span and counting span 2. Mix of symmetry span and navigation span Inhibitory control (1 measure): 1. Mix of color and number Stroop task
Klingberg	2005	Sweden, Europe	7–12	Diagnosed: ADHD	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 20)	Active control (n = 24)	Inhibitory control (1 measure): 1. Stroop test
Thorell Contrast 1	2009	Sweden, Europe	4–5	Typical developing	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 17)	Active control (n = 14)	Inhibitory control (2 measures): 1. Day-Night Stroop Task—error 2. Go/No-Go Task—commission error
Thorell Contrast 2	2009	Sweden, Europe	4–5	Typically developing	Working memory training: "Cogmed Working Memory Training: RoboMemo" (n = 17)	Passive control (n = 16)	Inhibitory control (2 measures): 1. Day-Night Stroop Task—error 2. Go/No-Go Task—commission error
Thorell Contrast 3	2009	Sweden, Europe	4–5	Typically developing	Inhibitory control training: "Cogmed Inhibition Training: RoboMemo" (n = 18)	Active control (n = 14)	Working memory (2 measures): 1. Span Board Task (WAIS-R-NI) 2. Word Span Task
Thorell Contrast 4	2009	Sweden, Europe	4–5	Typically developing	Inhibitory control training: "Cogmed Inhibition Training: RoboMemo" (n = 18)	Passive control (n = 15)	Working memory (2 measures): 1. Span Board Task (WAIS-R-NI) 2. Word Span Task
Traverso	2015	Italy, Europe	5	Typically developing	Working memory and inhibitory control training: "EF promoting small group program–Chicco and Nana" (n = 32)	Passive control (n = 43)	Cognitive flexibility (1 measure): 1. Go/No-Go (shifting phase) 2. Dots task
Volckaert	2015	Belgium, Europe	4–5	Typically developing	Inhibitory control training: "Inhibition training" (n = 24)	Active control (n = 23)	Working memory (1 measure): 1. Mix of Categospan, Words Span, Block tapping test (Working memory factor) Cognitive flexibility (1 measure): 1. Mix of Traffic lights Head-Toes-Knees-Shoulders Monster Stroop (Flexibility factor)
Wong	2014	China, Asia	6–12	Low EF: "Low working memory"	Working memory training: "Computerized working memory training" (n = 26)	Passive control (n = 25)	Inhibitory control (1 measure): 1. Stroop task

Note. ADHD = attention-deficit/hyperactivity disorder; ASD = autism spectrum disorder; EF = executive function.

memory and counting training were contrasted to the results of the participants of the counting training (active control) and to those who did not participated in any intervention (passive control; for a similar procedure see: Bakermans-Kranenburg, van IJzendoorn, & Juffer, 2003; Mol, Bus, de Jong, & Smeets, 2008; Takacs, Swart, & Bus, 2015).

Meta-Analytic Procedures

We used the software Comprehensive Meta-Analysis (CMA), Version 3.0 (Borenstein, Hedges, Higgins, & Rothstein, 2005) to calculate the effect size for each contrast for the standardized mean difference between the intervention and the control conditions, which was the dependent variable in the present meta-analysis. We chose the effect size of Hedges' *g* over Cohen's *d* because it corrects for small sample sizes (Borenstein, Hedges, Higgins, & Rothstein, 2009). A positive effect size reflected the advantage of the intervention condition, while a negative effect suggested that the control condition outperformed the intervention group. For calculating the effect sizes, the raw means and standard deviations on the posttests in the intervention and the control groups were used or other statistics regarding the difference between the two groups on the posttest (e.g., *t*- or *F*-statistics). When more than one appropriate outcome measure was reported in a study, we calculated effect sizes for all of those. The software takes the average of the effect sizes found on all outcome measures per study before taking the average over all contrasts; thus, these measures are not considered independent. The results were scanned for outliers with a standardized residual exceeding ± 3.29 (Tabachnik & Fidell, 2007).

We conducted two meta-analyses: one for the near-transfer and one for the far-transfer effect. Thus, we tested the effects of training an executive function component on that specific component in the first model, and the effects of training an executive function component on the untrained components. Because there was a wide range of different samples, interventions, and outcome measures, we used the random-effects model to calculate the average effect sizes. The random-effects model allows for such between-study variance (Borenstein et al., 2009). Under this model the average effect size is calculated after weighting the contrasts by the inverse of the sampling error. Thus, studies with larger samples weigh more into the average. We conducted retrospective statistical power calculations to assess whether we had sufficient power for testing the average near- and far-transfer effects. We found that statistical power was above 80% in both cases, using the variance estimates found in the analyses, to show a small effect of 0.20 (Borenstein et al., 2009).

It is plausible that there is an effect whether, for instance, children practice on a computer during the intervention and have noncomputerized tests as outcome measures. Thus, we calculated the near- and far-transfer effects when the medium of the intervention and the outcome measure was congruent (both applied on the computer or both were noncomputer based) and when not. Results were very similar, therefore the effect of medium was not considered further.

Additionally, we inspected the average near- and far-transfer effects on each component separately. Further, the *Q*-statistics was utilized to calculate the heterogeneity of the average effect sizes. A significant *Q*-value indicates a heterogeneous effect. Finally, we selected the contrasts in which they only trained a single component and assessed the effect on the untrained components separately in order to conduct fine-grained analyses regarding the specific relations among the components.

In order to assess the effects of differences between the primary studies that might have an influence on the results such as the clinical status and the age of the sample, the length of the intervention, whether the study utilized an active or a passive control condition, the year of publication, or the continent the study was conducted in, subgroup analyses were planned to be conducted in order to compare the contrasts based on categorical moderator variables (e.g., clinical status of the sample), while metaregression was planned in case of continuous variables (e.g., publication year) in both meta-analyses. Moderator variables had to have at least four contrasts in each category to suffice for testing statistical significance (Bakermans-Kranenburg et al., 2003). Moreover, power analyses for the moderator and metaregression analyses were conducted (Hedges & Pigott, 2004). That is, because a nonsignificant effect could reflect the lack of statistical power instead of truly no effect (Hedges & Pigott, 2004). In fact, power estimates showed low power for all moderator variables except for the mean age of the sample, the number of intervention sessions, and the year of publication in case of the far-transfer effect. Thus, we decided to report preliminary descriptive results instead of statistical testing when the analysis was underpowered: the average effects in the different categories without statistically contrasting them for subgroup analyses and regression coefficients without the corresponding *p* value for metaregression analyses.

Publication bias was inspected in both sets of studies because studies with significant results are more likely to be published. Thus, significant findings are more likely to be included in a meta-analysis and this tendency may lead to an overestimation of the average effect size (Rothstein, Sutton, & Borenstein, 2006). Moreover, Rosenthal's fail-safe *n* was calculated, which is an estimate regarding how many missing studies with a null finding would be needed for the average effect size to turn nonsignificant. In case of a robust effect, this fail-safe number should exceed $5k + 10$ where k is the number of contrasts included (Rosenthal, 1979).

Finally, we conducted an additional meta-analysis to be able to directly compare the near- and far-transfer effects. We selected the studies that reported on both near- and far-transfer measures and calculated the standardized mean difference between the near- and far-transfer effect sizes found in each study, which was the dependent variable in this final analysis. In case there were more than one near- or far-transfer measures, we took the average effect. A positive effect size in this analysis showed that the near-transfer effect was larger, while a negative effect suggested a larger far-transfer effect.

Results

Preliminary Analyses

Near-transfer effect. There was one outlying contrast in the model that was excluded (Kloo & Perner, 2003). The extremely large effect size in that study might be due to the fact that the outcome measure was very similar to the intervention task. In fact, the same paradigm was used but with different stimuli. Thus, the average effect of near-transfer was calculated based on the results of 35 studies including 43 contrasts with 2,402 children in total between the ages of 2 and 11 years shown in Table 1. The studies were published between 2001 and 2016. Thirty-nine contrasts were peer-reviewed journal articles and four of the contrasts were found in nonrefereed reports such as doctorate dissertations. The studies were geographically dispersed: 27 contrasts were from Europe, 10 from North America, three from Australia, two from Asia, and one from South America. From the 43 contrasts, 25 used a typically developing sample of children, while 18 sampled children with either a clinical diagnosis or behavioral problems reported by parents or teachers. In 23 of the contrasts, the intervention was compared with an active control condition. In 15 contrasts, a passive control group was used, while in five studies the results of the intervention group were compared with both kinds of control groups.

Twenty-seven of these contrasts used a single-component training program: In 19 contrasts working memory skills, in five contrasts inhibitory control, and in five contrasts cognitive flexibility were trained. Additionally, there were 16 contrasts utilizing a training in which more than one of the components were trained: Three contrasts included an intervention for working memory and inhibition and in three contrasts they trained inhibition and flexibility and in 11 contrasts all three components were targeted.

For assessing potential bias, we planned to conduct subgroup and metaregression analyses. We could not test the moderator of the continent the study was conducted in because not all categories had at least four contrasts (Europe: $g^+ = 0.50$, $k = 27$, $SE = 0.08$, 95% CI [0.35, 0.66], $p < .001$; North America: $g^+ = 0.30$, $k = 10$, $SE = 0.11$, 95% CI [0.09, 0.51], $p = .01$; Asia: $g^+ = 0.50$, $k = 2$, $SE = 0.22$, 95% CI [0.07, 0.94], $p = .02$; South America: Hedges' $g = 0.15$, $k = 1$, $SE = 0.20$, 95% CI [−0.24, 0.54], $p = .45$; Australia: $g^+ = 0.40$, $k = 3$, $SE = 0.19$, 95% CI [0.04, 0.77], $p = .03$).

Studies with children who were diagnosed with a neurodevelopmental disorder or showed behavioral problems had an effect size of $g^+ = 0.39$, $k = 18$, $SE = 0.08$, 95% CI [0.22, 0.55], $p < .001$, while studies with typically developing samples showed a similar result, $g^+ = 0.47$, $k = 25$, $SE = 0.08$, 95% CI [0.31, 0.63], $p < .001$. Studies using an active control group had an average effect size of $g^+ = 0.38$, $k = 28$, $SE = 0.06$, 95% CI [0.27, 0.49], $p < .001$, while contrasts utilizing a passive control group showed a standardized mean difference of $g^+ = 0.45$, $k = 20$, $SE = 0.11$, 95% CI [0.24, 0.65], $p < .001$. The mean age of the sample (coefficient: −0.02, $SE = 0.03$, 95% CI [−0.08, 0.03]), the number of intervention sessions (coefficient: −0.003, $SE = 0.01$, 95% CI [−0.02, 0.01]), and the year of publication (coefficient: −0.03, $SE = 0.02$, 95% CI [−0.07, 0.01]) had very small relationships with the effect size.

According to the visual examination of the funnel plot, there was no asymmetry around the average effect size and therefore the present results did not seem to be affected by a possible publication bias. Moreover, the fail-safe number was found to be 1,126, which suggests a robust effect in case of 43 contrasts.

Far-transfer. Far-transfer effect was assessed based on 16 studies including 17 contrasts with the data of 810 children in total between the ages of 3 to 12 years shown in Table 2. All the studies were peer-reviewed journal articles, published between 2000 and 2015. Again, the set of the studies was geographically diverse: Data for 13 contrasts was collected in Europe, two in Australia, one in North America, and one in Asia. From these contrasts, five focused on typically developing children, while 12 used either a diagnosed (ADHD, autism spectrum disorder [ASD]) sample or children whose parents or teachers reported behavioral problems. Twelve contrasts compared the training with an active control condition, seven with a passive control condition, while in two studies the results of the intervention group were compared with both kinds of control groups. In nine contrasts, the training focused on working memory skills, in two contrasts on inhibitory skills, in five contrasts on cognitive flexibility, while only in three contrasts they trained more than one component (that is, working memory and inhibition in two contrast, and inhibition and flexibility in one contrast).

We could not test the effect of continent as a moderator because there were not enough contrasts in each category (Europe: $g^+ = 0.18$, $k = 13$, $SE = 0.08$, 95% CI [0.02, 0.33], $p = .02$; Australia: $g^+ = -0.28$, $k = 2$, $SE = 0.41$, 95% CI [−1.08, 0.52], $p = .49$; North America: Hedges' $g = -0.02$, $k = 1$, $SE = 0.22$, 95% CI [−0.44, 0.40], $p = .93$; Asia: Hedges' $g = -0.30$, $k = 1$, $SE = 0.28$, 95% CI [−0.85, 0.24], $p = .28$).

Studies that included clinical samples or children who showed behavioral problems had an effect size of $g^+ = 0.08$, $k = 12$, $SE = 0.08$, 95% CI [−0.08, 0.24], $p = .31$, while studies with typically developing samples showed an average effect size of $g^+ = 0.20$, $k = 5$, $SE = 0.14$, 95% CI [−0.07, 0.47], $p = .15$. Studies using an active control group had an average effect size of $g^+ = 0.13$, $k = 12$, $SE = 0.08$, 95% CI [−0.03, 0.29], $p = .11$, while contrasts utilizing a passive control group also showed an effect of $g^+ = 0.06$, $k = 7$, $SE = 0.13$, 95% CI [−0.19, 0.30], $p = .66$.

However, due to sufficient estimated statistical power, we tested the effects of the mean age, the number of intervention sessions, and the year of publication in metaregression analyses; neither of these variables had a significant effect on the effect size (mean age of the sample: coefficient: 0.006, $SE = 0.03$, 95% CI [−0.06, 0.07], $p = .86$; number of intervention sessions: coefficient: −0.001, $SE = 0.01$, 95% CI [−0.02, 0.02], $p = .88$; year of publication: coefficient: −0.01, $SE = 0.02$, 95% CI [−0.05, 0.03], $p = .75$).

Assessing the funnel plot, the studies were evenly distributed around the average effect size suggesting no evidence of publication bias. As the average effect was not significant, the fail-safe *n* estimate was meaningless. No outlying contrasts were found.

Near-Transfer Effect

To test our first hypotheses, we calculated the average effect size in the first meta-analysis for the difference between the intervention and the control conditions on the executive function component(s) that were trained in the intervention. As shown in Table 3, a significant moderate overall effect ($g^+ = 0.44$) was found, which was heterogeneous, Q (42) = 75.62, $p = .001$ (see Figure 1 for the forest plot). When inspecting the results separately for the three components, near-transfer effects were significant on each of them. There was a medium-

Table 3
Near- and Far-Transfer Effects on the Different Executive Function Components

Outcome measure	Transfer effect	Number of contrasts (k)	Average effect size ($g+$)	Standard error (SE)	95% confidence interval	p
Overall	Near-transfer	43	.44	.06	[.32, .55]	<.001
	Far-transfer	17	.11	.07	[−.03, .25]	.11
Working memory	Near-transfer	31	.50	.07	[.35, .64]	<.001
	Far-transfer	6	−.01	.15	[−.31, .29]	.94
Inhibitory control	Near-transfer	20	.24	.06	[.12, .36]	<.001
	Far-transfer	13	.11	.09	[−.06, .28]	.21
Cognitive flexibility	Near-transfer	14	.37	.09	[.19, .54]	<.001
	Far-transfer	7	.15	.10	[−.05, .34]	.14

sized near-transfer effect on working memory ($g^+ = 0.50$), while the effects were small on the other two components (inhibitory control: $g^+ = 0.24$, cognitive flexibility: $g^+ = 0.37$).

As a second step, we tested whether single-component trainings had a different near-transfer effect as compared with multicomponent interventions. This was done because it is plausible that an intervention that is more focused on training one skill is more effective than aiming an intervention to foster more skills at a time. Single-component working memory trainings and multicomponent interventions including working memory training had similar near-transfer effects on working memory (single-component: $g^+ = 0.54$, $k = 19$, $SE = 0.10$, 95% CI [0.35, 0.72], $p < .001$; multicomponent: $g^+ = 0.42$, $k = 12$, $SE = 0.11$, 95% CI [0.20, 0.63], $p < .001$). Similarly, single-component inhibition trainings had similar near-transfer effects on inhibition as compared with multicomponent interventions including inhibitory control training (single-component: $g^+ = 0.18$, $k = 5$, $SE = 0.15$, 95% CI [−0.11, 0.47], $p = .21$; multicomponent: $g^+ = 0.25$, $k = 15$, $SE = 0.07$, 95% CI [0.12, 0.39], $p < .001$). Finally, single-component flexibility trainings had a similar near-transfer effect on flexibility measures as multicomponent interventions including flexibility training (single-component: $g^+ = 0.51$, $k = 5$, $SE = 0.25$, 95% CI

Near-transfer effect

Study name	Statistics for each study							Sample size	
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Intervention	Control
Lomas (2001)	-0,190	0,352	0,124	-0,879	0,500	-0,539	0,590	16	15
Dörrenbacher (2014)	-0,127	0,383	0,146	-0,878	0,623	-0,333	0,739	14	13
Markomichali (2015) - Chapter 6	-0,056	0,324	0,105	-0,690	0,578	-0,172	0,863	19	18
Markomichali (2015) - Chapter 5	-0,005	0,388	0,151	-0,766	0,756	-0,013	0,990	12	13
de Vries (2015)	0,017	0,261	0,068	-0,494	0,529	0,067	0,947	29	29
Alloway (2012)	0,141	0,269	0,072	-0,386	0,668	0,525	0,600	24	32
Thorell (2009)	0,148	0,345	0,119	-0,528	0,823	0,428	0,669	18	15
Goldin (2014)	0,151	0,199	0,040	-0,239	0,541	0,759	0,448	73	38
Re (2015) A	0,166	0,469	0,220	-0,754	1,086	0,353	0,724	10	10
Kyttala (2015)	0,175	0,305	0,093	-0,422	0,772	0,574	0,566	23	20
Chacko (2014)	0,178	0,216	0,047	-0,245	0,602	0,826	0,409	44	41
Bennett (2013)	0,218	0,421	0,177	-0,606	1,043	0,519	0,604	10	11
Rõthlisberger (2001) B	0,233	0,249	0,062	-0,255	0,720	0,936	0,349	30	34
Hovik (2013)	0,242	0,243	0,059	-0,234	0,717	0,996	0,319	33	34
Schmitt (2013)	0,265	0,121	0,015	0,027	0,502	2,186	0,029	126	150
Dovis (2015)	0,275	0,259	0,067	-0,234	0,783	1,059	0,289	30	30
Tominey (2011)	0,279	0,249	0,062	-0,209	0,766	1,120	0,263	28	37
Traverso (2015)	0,292	0,235	0,055	-0,168	0,753	1,244	0,214	32	43
Rõthlisberger (2001) A	0,334	0,238	0,057	-0,132	0,800	1,405	0,160	33	38
Howard (2016) A	0,339	0,311	0,097	-0,271	0,949	1,090	0,276	24	18
Caviola (2009)	0,374	0,294	0,086	-0,201	0,949	1,274	0,203	22	24
Rueda (2012)	0,397	0,326	0,106	-0,242	1,035	1,218	0,223	19	18
Luo (2013)	0,406	0,361	0,130	-0,302	1,113	1,123	0,261	15	15
Howard (2016) B	0,408	0,316	0,100	-0,211	1,028	1,292	0,196	19	21
Volckaert (2015)	0,430	0,290	0,084	-0,139	0,999	1,481	0,139	24	23
Dongen-Boomsma (2014)	0,434	0,302	0,091	-0,158	1,025	1,437	0,151	24	20
Howard (2016) C	0,477	0,344	0,119	-0,198	1,152	1,385	0,166	19	15
Re (2015) B	0,489	0,470	0,220	-0,431	1,409	1,042	0,298	10	10
Wong (2014)	0,560	0,281	0,079	0,008	1,111	1,989	0,047	26	25
Holmes (2009)	0,579	0,310	0,096	-0,029	1,187	1,868	0,062	22	20
Bergman Nutly (2011)	0,607	0,282	0,080	0,053	1,160	2,148	0,032	26	25
Blakey (2015)	0,609	0,275	0,076	0,071	1,148	2,217	0,027	26	28
Bigorra (2015)	0,641	0,259	0,067	0,132	1,149	2,469	0,014	31	30
St Clair-Thompson (2008) B	0,678	0,303	0,092	0,083	1,272	2,233	0,026	22	22
Kroesbergen (2014)	0,682	0,341	0,117	0,012	1,351	1,996	0,046	15	21
Dunning (2013)	0,757	0,257	0,066	0,252	1,261	2,941	0,003	34	30
Espinet (2012) A	0,840	0,378	0,143	0,100	1,580	2,224	0,026	15	14
Espinet (2012) B	0,858	0,384	0,148	0,104	1,611	2,231	0,026	14	14
Klingberg (2005)	1,019	0,317	0,100	0,399	1,639	3,219	0,001	20	24
Espinet (2012) C	1,079	0,342	0,117	0,408	1,750	3,152	0,002	20	18
St Clair-Thompson (2010)	1,146	0,135	0,018	0,881	1,411	8,463	0,000	117	137
St Clair-Thompson (2008) A	1,305	0,359	0,129	0,601	2,009	3,633	0,000	18	18
Re (2007)	2,229	0,760	0,578	0,740	3,719	2,933	0,003	5	5
	0,438	0,059	0,003	0,323	0,553	7,451	0,000		

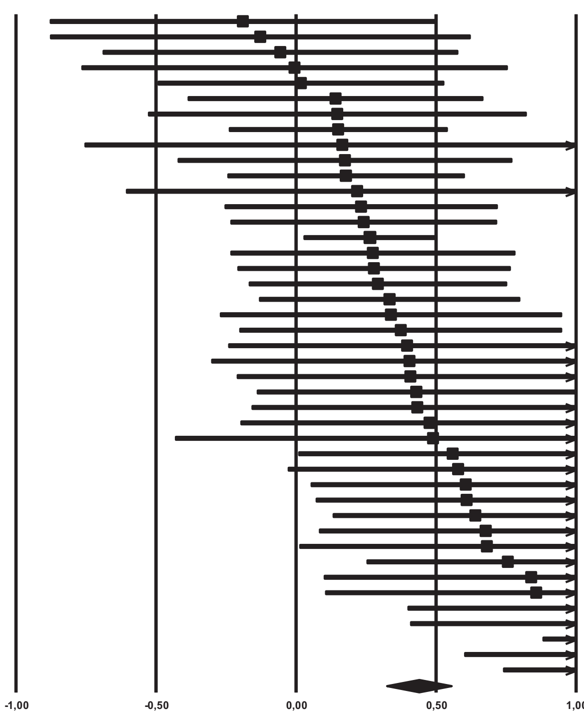

Figure 1. Forest plot of the studies that assessed near-transfer effects.

[0.02, 1.01], $p = .04$; multicomponent: $g^{+} = 0.31$, $k = 9$, $SE = 0.08$, 95% CI [0.16, 0.47], $p < .001$).

Far-Transfer Effect

Far-transfer effect was tested in the second meta-analysis by computing the average standardized difference between the intervention and the control groups on the executive function components that were not trained in the interventions. As shown in Table 3 and Figure 2, the overall between-component far-transfer effect was small and not significant. This effect was not heterogeneous, Q (16) = 15.39, $p = .50$. In the same vein, inspecting the far-transfer effects on the components separately, there was no significant effect on any of the three components. In sum, components of executive function skills do not seem to be facilitated unless directly trained.

The Effects of Single-Component Trainings

In order to further examine the specific relations between the three components, we tested the far-transfer effects of single-component trainings on the other two untrained components. After excluding the contrasts in the set of studies assessing far-transfer effects that targeted more than one component, there remained 22 contrasts. As shown on Figure 3, there were no significant far-transfer effects among the components. However, it is important to note that in most cases we had a very limited number of contrasts to test the connections between the components and the issue of statistical power has to be considered. It might be interesting to note that only one study (Volckaert & Noël, 2015) assessed the effects of inhibitory control training on cognitive flexibility skills and it showed a moderate effect, Hedges' $g = 0.55$, $SE = 0.29$, 95% CI [−0.02, 1.12], $p = .06$.

Comparing Near- and Far-Transfer Effects

Finally, in order to be able to statistically compare the near- and far-transfer effects, we conducted an additional meta-analysis including only the 13 studies that reported on both near- and far-transfer measures (see Figure 4). We took the average near- and far-transfer effects found in each study and calculated the effect size for the standardized mean difference between the two effects. There were 13 studies that could be included. The average effect was $g^{+} = 0.28$ ($SE = 0.09$, 95% CI [0.11, 0.45], $p = .001$), which confirmed that on average the near-transfer effect was significantly larger than the far-transfer effect.

Discussion

The present meta-analysis is a quantitative synthesis of the literature on the near- and far-transfer effects among the three core components of executive functioning: working memory, inhibitory control, and cognitive flexibility in childhood. As a first step, we assessed whether training has a significant effect on tasks tapping on the same component but other than the ones explicitly trained during the intervention. Moreover, we tested if training a specific component of executive functions has a significant transfer effect on any of the untrained components and whether this far-transfer effect is similar in size to the near-transfer effect observed in the case of the trained component. Finally, we directly compared the near- and far-transfer effects.

Overall, we found a significant, medium-sized near-transfer effect. However, no far-transfer effect appeared. More specifically, there were significant near-transfer effects on all three components: a moderate-sized effect on working memory and small-sized effects on inhibition and cognitive flexibility. In contrast, no far-transfer effects were found on working memory, inhibitory control, or flexibility. The finding that there was a significant near-transfer effect excludes the possibility that the interventions in the primary studies were not effective in training the components that they targeted. Instead, performance on the components that were trained did significantly improve, however, these gains did not transfer to the untrained components. No effects were found when we tested the specific

Far-transfer effect

Studyname	Statistics for each study							Sample size	
	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Intervention	Control
Dowsett (2000) A	-0,487	0,567	0,321	-1,598	0,625	-0,858	0,391	7	5
Thorell (2009)	-0,384	0,356	0,127	-1,082	0,314	-1,079	0,281	18	15
Wong (2014)	-0,301	0,277	0,077	-0,845	0,243	-1,085	0,278	26	25
Bigorra (2015)	-0,085	0,255	0,065	-0,585	0,415	-0,333	0,739	31	30
Dowsett (2000) B	-0,057	0,592	0,350	-1,217	1,102	-0,097	0,923	8	4
Chacko (2014)	-0,020	0,215	0,046	-0,441	0,401	-0,092	0,926	44	41
Dovis (2015)	0,000	0,259	0,067	-0,508	0,508	0,000	1,000	28	30
de Vries (2015)	0,002	0,254	0,064	-0,495	0,499	0,009	0,993	33	29
Karbach (2009)	0,056	0,370	0,137	-0,670	0,781	0,150	0,881	14	14
Blakey (2015)	0,114	0,269	0,072	-0,412	0,641	0,426	0,670	26	28
Dongen-Boomsma (2014)	0,161	0,310	0,096	-0,447	0,769	0,519	0,604	23	18
Egeland (2013)	0,175	0,243	0,059	-0,301	0,651	0,722	0,471	33	34
Dörrenbacher (2014)	0,204	0,384	0,148	-0,549	0,957	0,532	0,595	13	13
Dunning (2013)	0,350	0,267	0,071	-0,174	0,873	1,309	0,191	31	26
Traverso (2015)	0,376	0,234	0,055	-0,082	0,835	1,610	0,107	32	43
Volckaert (2015)	0,395	0,290	0,084	-0,174	0,964	1,360	0,174	24	23
Klingberg (2005)	0,840	0,311	0,096	0,232	1,449	2,706	0,007	20	24
	0,112	0,070	0,005	-0,025	0,249	1,602	0,109		

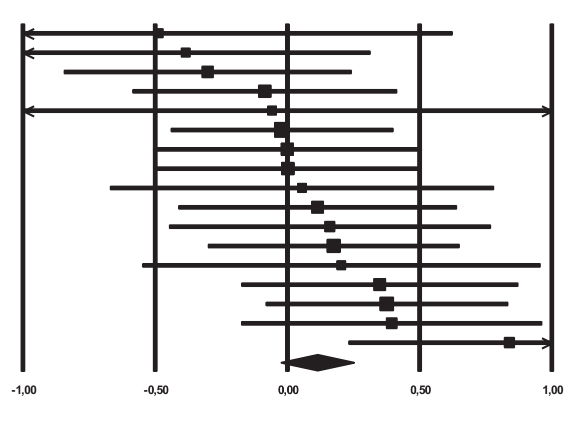

Figure 2. Forest plot of the studies that assessed far-transfer effects.

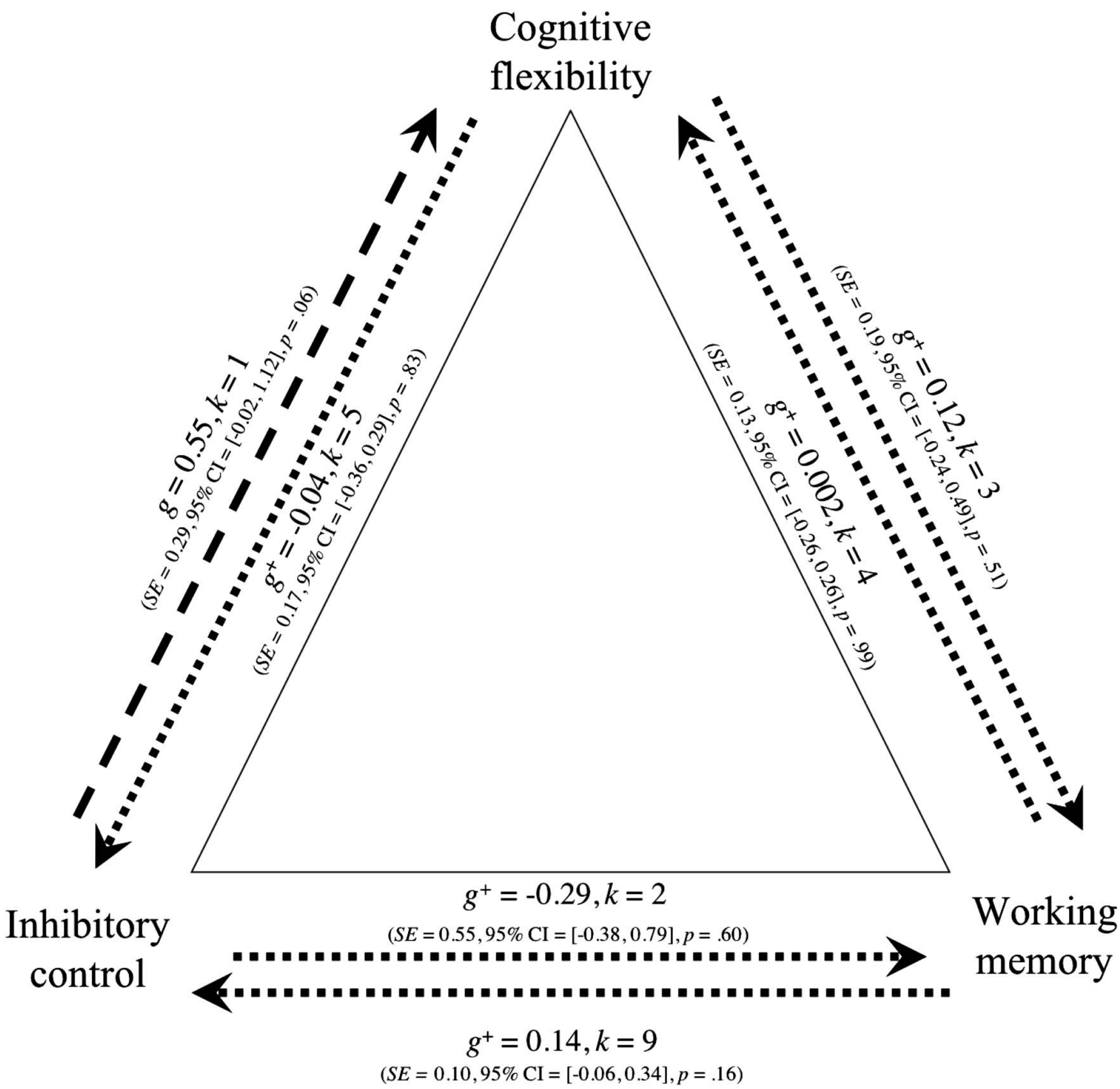

Figure 3. The specific training effects among the three executive function components in childhood. Continuous lines show significant effects, dotted lines signal nonsignificant effects, while the broken line suggests a significant result that is based on only one study.

far-transfer effects of single-component trainings either. In line with the results of Melby-Lervåg and Hulme (2013) and Sala and Gobet (2017), who found no significant transfer effect of working memory trainings on inhibitory control in child samples, we also revealed no transfer effect of working memory trainings on inhibitory control. The only study where a single-component training had marginally significant far-transfer effect was a preliminary result based on only one contrast (Volckaert & Noël, 2015) revealing that training inhibition might have an ameliorating effect on cognitive flexibility. However, it is important to note that in this study the flexibility outcome measures used were based on typical inhibitory control tests (e.g., the traffic lights task, the head-toes-knees-shoulders task, a semantic Stroop-test [Monster Stroop]), at the end of which they added an extra block that required switching between the previously practiced rules. Thus, these measures might be somewhat similar to the inhibitory control games that were practiced during the intervention. In sum, the present results neither confirm nor disprove the conclusions of Diamond and Ling (2016) who showed in a narrative literature review that the effects of computerized working memory training do not transfer to self-control or flexibility.

The lack of far-transfer effect found in the present meta-analysis even within the set of executive function skills makes it—though logically not impossible—still highly unlikely that training unique executive functions could have measurable ameliorating transfer effect on more distantly related and complex constructs, such as academic and social skills (Blair & Razza, 2007) that rely just as much on the trained executive function component as on the other untrained and largely unaffected components. The results of the present meta-analysis therefore provide a possible explanation for the previously found absence of far-transfer effects of working

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Total
	Statistics for each study							
Dörrenbacher (2014)	-0,322	0,372	0,139	-1,052	0,408	-0,865	0,387	27
Traverso (2015)	-0,083	0,232	0,054	-0,538	0,372	-0,358	0,720	75
de Vries (2015)	0,015	0,254	0,064	-0,482	0,513	0,060	0,953	58
Volckaert (2015)	0,035	0,286	0,082	-0,525	0,594	0,121	0,904	47
Klingberg (2005)	0,176	0,308	0,095	-0,428	0,779	0,570	0,568	44
Chacko (2014)	0,196	0,213	0,046	-0,222	0,615	0,920	0,358	85
Dongen-Boomsma (2014)	0,268	0,301	0,090	-0,322	0,857	0,890	0,373	44
Dovis (2015)	0,271	0,256	0,066	-0,230	0,773	1,060	0,289	60
Dunning (2013)	0,402	0,259	0,067	-0,105	0,910	1,553	0,120	64
Blakey (2015)	0,488	0,268	0,072	-0,037	1,013	1,821	0,069	54
Thorell (2009)	0,519	0,342	0,117	-0,151	1,190	1,517	0,129	33
Bigorra (2015)	0,717	0,254	0,065	0,218	1,215	2,820	0,005	61
Wong (2014)	0,848	0,275	0,076	0,308	1,387	3,081	0,002	51
	0,279	0,086	0,007	0,110	0,448	3,234	0,001	

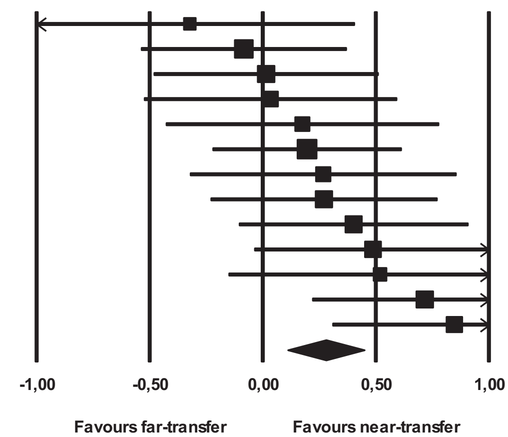

Figure 4. Forest plot of the studies in which we could directly compare the near- and far-transfer effects.

memory trainings on academic skills (Melby-Lervag & Hulme, 2013; Melby-Lervåg et al., 2016; Sala & Gobet, 2017).

The present meta-analysis shows that there are limited practical benefits—other than on the trained component—of training single executive function components in childhood. Thus, it might be more advisable, both in the educational and in the clinical practice, to use approaches that target multiple executive function components.

Most moderator analyses were underpowered in the present meta-analyses. Thus, those results should be interpreted with caution. For instance, considering the wide age range of the samples in the primary studies of the present meta-analysis (2–12 years), we intended to test the effect of children's age. The pattern suggested a very weak relationship between age and the effect sizes. However, considering the lack of statistical power in case of the near-transfer effect, we cannot draw firm conclusions. Further studies are needed to clarify the connection between age and the strength of near- and far-transfer effects among executive function components.

Beyond the practical implications of the present meta-analysis, it might also raise issues on the construct of executive functioning in childhood on a theoretical level. The lack of causal evidence for significant relationships among the three core components might contradict accounts of executive functions as a single construct (Wiebe et al., 2008) or a unitary construct with dissociable components (Miyake et al., 2000). Instead the present results seem to support the notion that working memory, inhibitory control, and cognitive flexibility are mutually independent constructs and suggest that the correlations among them (Bull & Scerif, 2001; Carlson et al., 2002; Hughes, 1998; Senn et al., 2004; St. Clair-Thompson & Gathercole, 2006; Wiebe et al., 2008) might simply reflect co-occurrences. For example, the three components might simply be maturing in a parallel timeframe as a consequence of their common neural correlates. Alternatively, there might be a possible third variable such as verbal or nonverbal IQ or socioeconomic status that results in observable correlations among the components. Another possibility is that there might be a common component that the three executive skills share, which might not be sufficiently affected by training single components. This latter account could result in a lack of transfer effect observed even in case a unitary executive function construct existed.

Limitations

Several problems emerge with measuring executive functions. First, the issue of task impurity means that most executive tasks do not exclusively tap on the executive functions of interest, but also on other executive and nonexecutive processes (Miyake et al., 2000). An example for the first is the Wisconsin card sorting task, which is a widely used measure of cognitive flexibility as it requires switching between rules. However, in order to switch between the rules, inhibition skills are also required to restrain acting according to the previously used, now inappropriate rule. Examples for the second are that scores on a verbal fluency test can be biased by the participant's vocabulary skills, or performance on a Stroop test can be affected by reading skills.

Second, we face the problem of (what could be called) "component impurity" meaning, that the correlation between different tasks that are believed or intended to measure the same executive functions components tend to be low to moderate (see, e.g., Miyake et al., 2000). Therefore, in case of our meta-analytic study on interventions that aimed to analyze the transfer effects of training executive functions, the effect sizes might be weakened by the relatively low correlations between the within-component tasks. This problem could have been alleviated by using "latent variables" (proposed by Miyake et al., 2000), variables that have been created by statistically "extracting" the "overlap" among tasks intended to measure the same EF component. However, in our case this could not be done as primary studies reported on performance on single tests. Further, because all measurable tasks have only a partial overlap with the hypothetical background construct that they aim to measure, the effects of training task "A" only partially transfers to the background construct, which only has a partial overlap with task "B," which further weakens the measurable effect of training task "A" on the performance on task "B." Finally, it is also problematic that different tests are used with different age groups and it is questionable how comparable those are.

Further, when analyzing the effects of training certain executive function components, it would have been very useful to have an intervention check, for example, to have data available on the difference between the scores on a specific task at the beginning and at the end of the training. The sizes of the measured near- and far-transfer effects would have been more meaningful if compared with this original measurement on the "effectiveness of training."

As mentioned above, it was difficult to gather data on single-component trainings. Training multiple executive functions components at once might actually decrease the duration of the training of one specific executive function component, therefore potentially lowering the effectiveness of the training on that specific component, which eventually can lead to an underestimation of the transfer effects. Available data on the duration and intensity of the training of specific executive function components would have been useful.

In the same vein, although we could locate enough contrasts to test the near- and far-transfer effects of the trainings on a component, fine-grained analyses regarding the specific relationships among the specific components lacked more studies for a robust synthesis thus only allowing for preliminary results.

Conclusions

The results of the present meta-analysis provide an important contribution to our knowledge about training executive functions in childhood. Our meta-analytic findings show that it is possible to improve children's executive functions. However, the findings also suggest that there is limited rationale for training a single component of executive functions in the clinical or educational practice, as these gains do not seem to transfer to untrained components. Thus, the practical relevance of training a single executive function component, as it is the case for widespread working memory training programs like Cogmed, has very limited practical relevance when applied in the treatment of neuropsychological disorders such as ADHD.

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Appendix A

Search String

(Training OR intervention OR curricul* OR Mindful* OR meditat* OR sport* OR exercise OR physical activity OR aerobic* OR martial OR yoga OR mindful* OR "tools of the mind" OR montessori OR "Promoting Alternative Thinking Strategies" OR CogMeg OR "Head Start REDI" OR "Chicago School Readiness Project") AND ("cognitive control" OR "behavioral control" OR "self-control" OR "effortful control" OR "self-regulat*" OR regulat* OR "executive functi*" OR attention OR "working memory" OR inhibit* OR planning OR "cognitive flexibility" OR "delayed gratification" OR monitoring) AND (child* OR student* OR toddler* OR preschooler* OR kindergartner*) AND (experiment* or quasi-experiment*)

(*Appendices continue*)

Appendix B

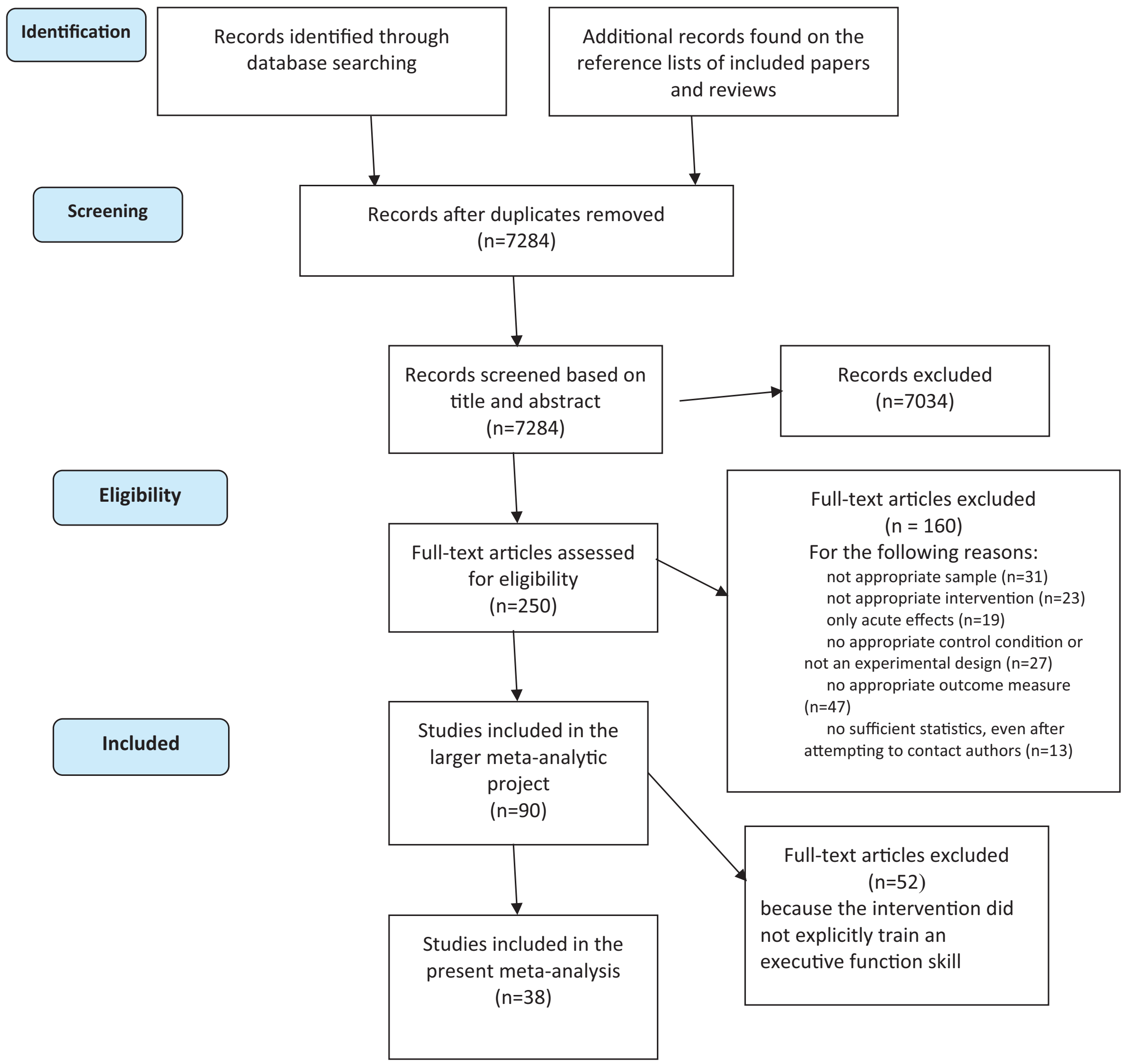

Figure B. PRISMA Flow Diagram. See the online article for the color version of this figure.

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