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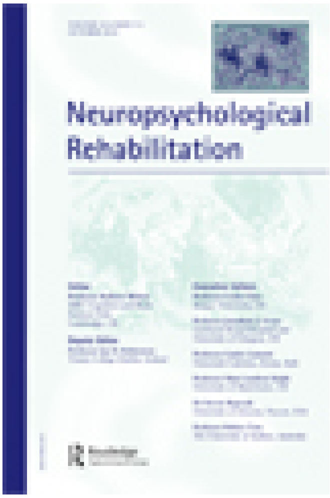
Janneke C A W Husson-Peijnenborgh
De Viersprong National Institute of Personality Disorders

Petra P M Hurks
Maastricht University

Albert P Aldenkamp
Maastricht University

Jos G M Hendriksen
Kempenhaeghe



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Janneke C. A. W. Peijnenborgh[abf], Petra M. Hurks[c], Albert P. Aldenkamp[bdef], Johan S. H. Vles[abd] & Jos G. M. Hendriksen[adf]

[a] Center of Neurological Learning Disabilities, Kempenhaeghe Epilepsy Center, Heeze, The Netherlands

[b] School of Mental Health and Neuroscience, Maastricht University, Maastricht, The Netherlands

[c] Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands

[d] Department of Neurology, University Hospital Maastricht, Maastricht, The Netherlands

[e] Department of Electrical Engineering, University of Technology, Eindhoven, The Netherlands

[f] Department of Behavioural Research, Kempenhaeghe Epilepsy Center, Heeze, The Netherlands

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Janneke C. A. W. Peijnenborgh[1,2,6], Petra M. Hurks[3], Albert P. Aldenkamp[2,4,5,6], Johan S. H. Vles[1,2,4], and Jos G. M. Hendriksen[1,4,6]

[1]Center of Neurological Learning Disabilities, Kempenhaeghe Epilepsy Center, Heeze, The Netherlands
[2]School of Mental Health and Neuroscience, Maastricht University, Maastricht, The Netherlands
[3]Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands
[4]Department of Neurology, University Hospital Maastricht, Maastricht, The Netherlands
[5]Department of Electrical Engineering, University of Technology, Eindhoven, The Netherlands
[6]Department of Behavioural Research, Kempenhaeghe Epilepsy Center, Heeze, The Netherlands

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The effectiveness of working memory (WM) training programmes is still a subject of debate. Previous reviews were heterogeneous with regard to participant characteristics of the studies included. To examine whether these programmes are of added value for children with learning disabilities (LDs), a systematic meta-analytic review was undertaken focusing specifically on LDs. Thirteen randomised controlled studies were included, with a total of 307 participants (age range = 5.5–17, Mean age across studies = 10.61, *SD* = 1.77).

Correspondence should be addressed to Janneke C.A.W. Peijnenborgh, P.O. Box 61, 5590 AB Heeze, The Netherlands. E-mail: peijnenborghj@kempenhaeghe.nl and Petra M. Hurks, P.O. Box 616, 6200 MD Maastricht, The Netherlands. E-mail: pm.hurks@maastrichtuniversity.nl

The research was conducted at Center for Neurological Learning Disabilities, Kempenhaeghe Epilepsy Center and Department of Psychology and Neuroscience, Maastricht University, The Netherlands

Potential moderator variables were examined, i.e., age, type of LD, training programme, training dose, design type, and type of control group. The meta-analysis indicated reliable short-term improvements in verbal WM, visuo-spatial WM, and word decoding in children with LDs after training (effect sizes ranged between 0.36 and 0.63), when compared to the untrained control group. These improvements sustained over time for up to eight months. Furthermore, children > 10 years seemed to benefit more in terms of verbal WM than younger children, both immediately after training as well as in the long-term. Other moderator variables did not have an effect on treatment efficacy.

Keywords: Attention deficit hyperactivity disorder (ADHD); Learning disorders; Working memory; Cognitive training; Treatment; Neurorehabilitation.

INTRODUCTION

Learning disabilities (LDs) are common among school-aged children. In short, the term “learning disabilities” refers to a set of problems interfering with learning of academic and/or social skills (Pennington, 2009) which can lead to major difficulties with adaptation to life and society (Wong & Butler, 2012). Examples of LDs are verbal learning disabilities, such as dyslexia or reading disabilities, attention deficit hyperactivity disorder (ADHD), and non-verbal learning disabilities, such as dyscalculia or maths disabilities (Hendriksen et al., 2007). Children with LDs represent the largest single category of children receiving special education (Bender, 2004). Prevalence estimates attained from surveys of nonclinical samples worldwide indicate that 5–17% of school-aged children meet the criteria for LDs (Kar, in press). Furthermore, recent data indicate a significant increase in prevalence estimates in the past decade. For instance, Boyle et al. (2011) report a 17% increase in prevalence rates of LDs for children aged 3–17 years. Therefore, the recent expansion in commercially available, computer-based cognitive training programmes, which promise to provide both significant and lasting improvements in performances of children with LDs, is an important treatment option.

The core symptoms and aetiology of LDs are believed to be neurobiological; they influence variations in brain development, and may be associated with multiple cognitive weaknesses—especially weaknesses in executive functioning (EF) (Pennington, 2009; Willcutt et al., 2011). EF is an umbrella term that refers to those top-down mental processes that enable goal-directed behaviour and novel problem solving (Miyake, Emerson, & Friedman, 2000) and are also associated with academic, occupational, and interpersonal performances (Diamond, 2013). Meta-analytic and factor analytic reviews consistently identified three core EFs—i.e., inhibition (or inhibitory control), working memory (WM), and cognitive flexibility (or set shifting) (Dickstein, Bannon, Castellanos, & Milham, 2006; Miyake et al., 2000; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Deficits in all three core EFs have been reported in children with a diversity of LDs, such as ADHD (Barkley, 1997), dyslexia (Wang & Gathercole, 2013), and non-verbal LDs (Semrud-Clikeman, Fine, & Bledsoe, 2013).

Of all the cognitive training studies to date, the fast majority focus on WM as the primary target for remediation (Rapport, Orban, Kofler, & Friedman, 2013). WM is the cognitive system responsible for storing, integrating and manipulating information during complex and demanding activities (Baddeley, 2000; Baddeley & Hitch, 1974). Consequently, WM is believed to be one of the more fundamental cognitive functions. From WM, higher order EFs are built, such as reasoning, problem solving abilities, and planning (Diamond, 2013; Klingberg et al., 2005). In literature, two approaches have been described to alleviate children's difficulties resulting from poor WM. The first approach is indirect, minimising failures in the classroom via effective classroom management of WM loads, i.e., a so-called bypass strategy in which teachers are instructed to give simple task instructions or the time to fulfil a task is modified (e.g., Alloway, Gathercole, & Elliott, 2010; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010). A negative consequence of this approach is that children do not learn to internalise the WM strategies. The second approach is aimed to stimulate WM more directly. Although WM has been viewed in the past as a constant trait, that cannot be influenced by training, recent studies suggest that this direct approach can indeed improve WM capacity as a consequence of adaptive and extended training, at least in healthy individuals (e.g., Klingberg, 2010). Ericcson, Chase, and Faloon (1980) found for one that an individual's digit span can significantly improve by repeating this WM task several times. Many current cognitive training programmes (e.g., Klingberg's CogMed or Prins' Braingame Brian) are based on the assumption that, by repeatedly performing WM tasks, participants themselves will elaborate on the different strategies that could improve their performance. These training programmes are adaptive: after successful performances, the difficulty of the tasks increases. In literature, these programmes are labelled as so-called "implicit WM programmes". Alternatively, some authors claim that participants need explicit help in elaborating on different strategies to improve their performance. In, for example, Diamond's Tools of the Mind and St Clair Thompson's Memory Booster, participants are not only asked to repeat the WM tasks, but are also instructed in different memory strategies. These cognitive training methods are known as so-called "explicit WM training".

The effectiveness of these (implicit and explicit) WM training methods is still under debate. Recently, in a review study, Melby-Lervag and Hulme (2013) found that over a course of four to five weeks of WM training, participants typically advanced in their performances on trained WM tasks, however, these positive effects were no longer found six months post-training. Also, these training effects seem to be specific for the to-be-trained WM tasks (so-called near transfer effects) and do not generalise to other skills (so-called far transfer effects), such as verbal ability, word decoding, and arithmetic (Melby-Lervag & Hulme, 2013). Melby-Lervag and Hulme (2013), as well as two other reviews, claim that it is too early to draw conclusions on the potential efficacy of WM training (Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Melby-Lervag & Hulme, 2013; Shipstead, Redick, & Engle, 2012). However, these reviews included a broad range of participants: both adults and children, healthy or with a broad range of disabilities. None of these authors specifically reviewed the effectiveness of WM training methods in children with LDs. It may be that children with LDs benefit more from these programmes, since LDs may arise from WM constraints operating at the point of learning new skills (Gathercole, Alloway, Willis, & Adams, 2006; St Clair-Thompson et al., 2010). Furthermore, age may be of influence: maybe younger children benefit more from WM training than older children (Jolles & Crone, 2012). WM appears to undergo considerable changes during childhood (Korkman, Lahti-Nuuttila, Laasonen, Kemp, & Holdnack, 2013). Spurts in this developmental trajectory seem to parallel a structural and functional maturation of frontoparietal areas and their connectivity with other brain regions (Cartwright, 2012). In their review paper, Melby-Lervåg and Hulme (2013) found larger gains after WM training programmes in studies that included only children younger than 10 years than in studies that included older children (i.e., 11–18 years) or adults. The authors opted to include age as a categorical variable in their meta-analyses, that is, young children aged < 10 years, older children aged 11–18 years, young adults aged 19–50, and older adults aged 51 and older, due to the non-normal distribution of age in the studies that were included in these meta-analyses. However, as mentioned above, these authors included both healthy participants and those with a broad range of disabilities in their analyses.

Therefore, the aim of this study is to provide a systematic review and meta-analysis of experimental studies examining the effectiveness of WM training programmes for children and adolescents with LDs. More specifically, the current review and meta-analysis investigates whether the claims are valid that WM training programmes improve WM, and as a consequence higher order EFs, in children with LDs, and thus lead to a decrease of the suffering of individuals with LDs. Also, the potential moderating factor "age" was studied in this context.

METHOD

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (www.prisma-statement.org) was used as a guideline in the design and report of the meta-analysis. This statement was developed as a consensus for the conduct and reporting of systematic reviews and meta-analyses.

Literature search

Figure 1 shows details of the method of literature search and the inclusion and exclusion criteria for the studies. Studies were identified by searching electronic databases (ERIC, PubMed, Summon, APA PsycNet) with keywords "Working Memory Training", and by scanning reference lists of articles and reviews. This resulted in 203 articles, which were screened for specific inclusion criteria. To be included, a study had to include children or adolescents with LDs. These participants had to receive an adaptive computerised training programme that aimed to improve WM skills. The study had to include a training group and a control group, which received no training or a different (non-WM) type of training. To examine treatment efficacy, all participants had to be tested before the start of the training and again afterwards. Thirteen studies met the inclusion criteria.

The different measures used in the studies to measure WM treatment efficacy were categorised as verbal WM, visuo-spatial WM, (non) verbal ability, inhibition, decoding and arithmetic, or none of the above. The first two are near transfer categories, the others are far transfer categories.

Meta-analytic procedure

All analyses were conducted with the use of the computer programme Comprehensive Meta-Analysis (Borenstein, Hedges, Higgins, & Rothstein, 2009). The effect size difference was calculated as the standardised mean difference of the pre-test and post-test scores for the control and treatment group, by using Hedges' g, corrected for small sample size bias, and the unbiased least squares estimate of the pooled standard deviation. In the case that a study provided multiple measurements (e.g., several similar measurements in one category), a weighted average of the means (based on population size) and the pooled standard deviation of those measurements were used to calculate Hedges' g. The variation in effect sizes between studies was examined by using the Q-test of homogeneity (Hedges & Olkin, 1985), and I^2 was calculated as an estimate of between-trial heterogeneity in standardised mean difference. However, the power to detect heterogeneity is relatively low because of the small number of included trials. Random effects models were used to test whether lower-quality trials had larger effect sizes. Forest plots were created to determine the distributions of effect sizes.

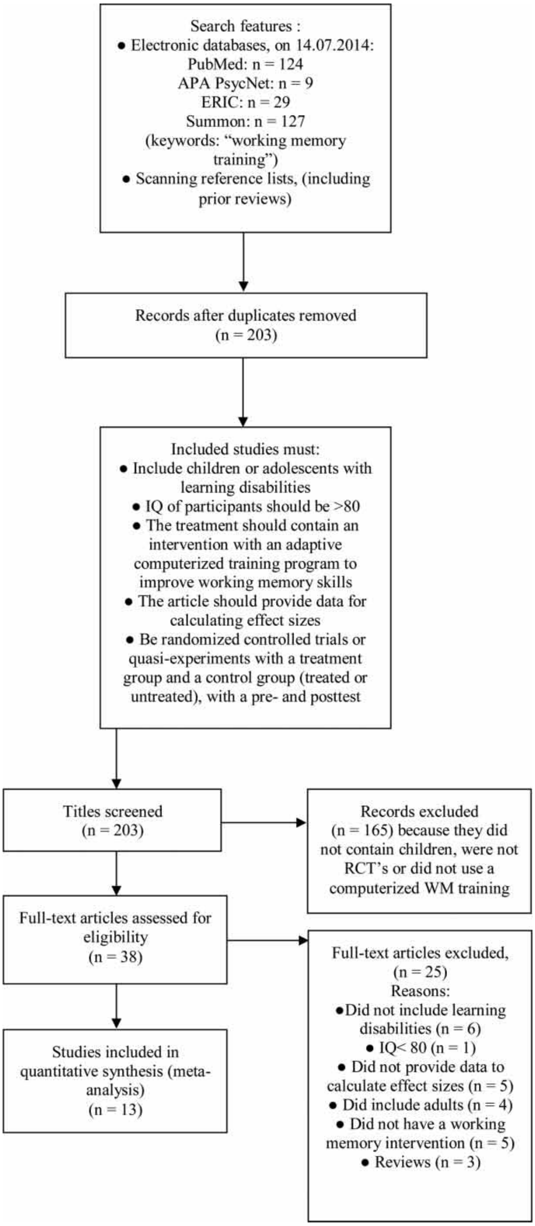

Figure 1. Flow diagram for the search and inclusion criteria for studies in this review. WM: Working Memory; ERIC: Education Resources Information Center; APA: American Psychological Association. Adapted from "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement," by D. Moher, A. Liberati, J. Tetzlaff, D. G. Altman, and The PRISMA Group, 2009, *PLoS Med 6*(6). Copyright 2009 by the Public Library of Science.

Moderator variables

To examine the variability in effect sizes between studies, the following moderator variables per study were coded by two authors (JP and PH) independently: age, design type, duration of training sessions, type of control group, type of LD and training programme. The mean age of the participants as reported in the study was separated into two groups: ≤ 10 and > 10, to examine whether age does have an influence on the effectiveness of the training. For design type, it was coded whether the participants were randomised or non-randomised into the treatment or control group. The total duration of training sessions was coded as intensive training (nine hours or more) or less intensive training (less than nine hours). The type of control group was coded, with a distinction between treated controls, e.g., a different (non-WM) training, or a non-adaptive WM training, and untreated controls, being made. The type of LD of the participants was coded as ADHD, verbal LD, non-verbal LD, combined or not specified. Finally, the training programme which was used was coded as CogMed, Jungle Memory, or Braingame Brian. Inter-rater reliability for the categorical moderators was measured using Cohen's (1960) kappa, $= .937$, 95% CI (0.85, 1.02), $p < .001$. In the case of a disagreement between raters, the original article was consulted and discussed until consensus was reached.

RESULTS

An overview of studies included ($n = 13$), the measurements used, and the associated moderators can be found in Table A1 in the Appendix. Two studies (Beck, Hanson, Puffenberger, Benniger, & Benniger, 2010; Van der Oord, Ponsioen, Geurts, Ten Brink, & Prins, 2012) fulfilled all inclusion criteria, but used questionnaires as measurements for WM; care should be taken in comparing the results of these studies including only so-called performance-based cognitive tests. Three different training programmes were used, namely, CogMed (n = 10), Braingame Brian ($n = 1$), and Jungle Memory ($n = 2$). Three age groups were defined, namely, ≤ 10 years ($n = 3$), > 10 years ($n = 7$), and age not specified or blank ($n = 1$). After assessing the different moderator variables for all studies, it became clear that only limited variability was found for the moderator variables type of LD, design type, and duration of training sessions across studies. For example, almost all studies included children with ADHD. Other LDs were hardly ever the subject of research (10 studies included only children with ADHD, one study included children with LDs not specified and those with ADHD, and two studies included children with LDs not specified). In all but three studies the children were divided randomly to the treatment or control group. Furthermore, in all studies (except for Prins, Dovis, Ponsioen, Ten

Brink, & Van der Oord, 2011; and Van Dongen-Boomsma, Vollebregt, Buitelaar, & Slaats-Willemse, 2014), the children used the WM training programme for more than nine hours. Due to this limited variability across studies, no analyses were performed on these moderator variables (type of LD, design type and duration of training sessions).

Furthermore, Table 1 shows large variations in the number of studies included for each category of measures used. The majority of the studies investigated the near transfer effects on WM (Verbal WM: $n = 9$ and Visuo-Spatial: $n = 9$). Only a few studies investigated far transfer effects (three to four studies investigated the different far effect categories, again see Table 1).

Of the seven categories of measures that we defined, we found that the treatment groups benefited significantly from WM training on near transfer measurements, measured immediately after training (immediate training effect): all the near transfer categories showed that the effect sizes were significant (Verbal WM: Hedges' $g = 0.64$, $p < .01$ and Visuo-Spatial WM: Hedges' $g = 0.63$, $p < .01$). In the far transfer category "Decoding", a significant effect was found immediately after training (Hedges' $g = 0.36$, $p < .05$). None of the other far transfer categories showed significant effects.

Of the 13 studies included, seven had a follow-up measurement (long-term training effect). An overview can be found in Table A2 (refer to Appendix). In Table 1, an overview of the results of the long-term training analysis can be found. We found that in the long term, children in the treatment group benefited significantly from WM training compared to the control group, for the same categories (Decoding, Verbal WM, and Visuo-Spatial WM) in which the treatment group benefited immediately after training. All the near transfer categories showed that the effect sizes were significant (Verbal WM: Hedges' $g = 0.54$, $p < .01$ and Visuo-Spatial WM: Hedges' $g = 0.39$, $p < .01$). In the far transfer category "Decoding" a significant effect was found (Hedges' $g = 0.48$, $p < .01$). Verbal Ability also revealed a significant effect (Hedges' $g = 1.47$, $p < .01$), but only one study was found that investigated long-term training effects in this category. For an overview of all the long-term training outcomes, refer to Table 1.

Influence of moderators on near transfer effects

Measurements in these categories can be seen as near transfer effects, because they measure skills that were trained (or were similar to the trained tasks).

Verbal working memory

Immediate training effects. Nine studies ($k = 9$) were included in the analysis of verbal WM, comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1

TABLE 1
Overview of meta-analysis on training effects per category

				95% CI			*Q test*			
Category	n	*Hedges'* g	SD	LL	UL	z-*value*	p-*value*	Q	p-*value*	I^2
Immediate training effects:										
Near transfer effects:										
Verbal WM	9	0.64	0.13	0.38	0.90	4.77	.00	11.05	.20	42.51
Visuo-Spatial WM	9	0.63	0.12	0.40	0.85	5.43	.00	11.05	.20	27.63
Far transfer effects:										
Arithmetic	3	0.25	0.16	−0.06	0.56	1.58	.11	0.39	.82	0.00
Inhibition	4	0.19	0.16	−0.13	0.51	1.14	.26	0.35	.95	0.00
Decoding	4	0.36	0.16	0.04	0.68	2.20	.03	1.52	.68	0.00
Non-verbal ability	4	0.34	0.28	−0.21	0.88	1.22	.22	7.71	.05	61.10
Verbal ability	3	0.36	0.28	−0.18	0.90	1.30	.19	4.06	.13	50.70
Long-term training effects										
Near transfer measurement:										
Verbal WM	5	0.54	0.20	0.16	0.91	2.81	.01	10.20	.04	60.79
Visuo-Spatial WM	5	0.39	0.20	0.00	0.78	1.98	.05	10.92	.03	63.35
Far transfer measurement:										
Arithmetic	2	0.29	0.18	−0.06	0.64	1.613	.11	0.17	.68	0.00
Inhibition	2	0.74	0.42	−0.09	1.57	1.746	.08	3.99	.05	74.92
Decoding	3	0.48	0.18	0.12	0.84	2.641	.01	2.47	.29	19.00
Non-verbal ability	2	0.02	0.20	−0.42	0.38	−0.097	.92	0.10	.76	0.00
Verbal ability	1	1.47	0.29	0.90	2.04	5.067	.00	0.00	1.00	0.00

Q test = Cochran's Q test; WM = Working Memory; CI = Confidence Interval; LL = lower limit, UL = upper limit.

(children in training groups: $n = 229$, $M_{\text{sample size}} = 25.44$, control group: $n = 204$, $M_{\text{sample size}} = 22.67$). The $M_{\text{effect size}}$ was medium, $g = 0.64$, 95% CI (0.38, 0.90), $p < .01$. The heterogeneity between the included studies was not significant, $Q(8) = 11.05$, $p = .20$, and $I^2 = 43\%$, indicating low to medium heterogeneity between the included studies. The forest plot with the overall average effect size, the confidence interval, and individual effect sizes can be found in Figure 2. Pairwise comparison of the moderators showed no significant effects for use of active or non-active controls and type of training programme. However, a significant effect was found on age: older children have higher effect sizes and therefore benefit more from WM training than children who are aged 10 years or younger, $Q(6) = 13.78$, $p = .03$, as can be seen in Table 2.

Long-term training effects. Five studies ($k = 5$) were included in the analysis of effect sizes of measurements of verbal WM, comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1 (children in training groups: $n = 150$, $M_{\text{sample size}} = 30$, control group: $n = 156$, $M_{\text{sample size}} = 31.2$). The $M_{\text{effect size}}$ was medium, $g = 0.54$, 95% CI (0.16, 0.91), $p = .01$. The heterogeneity between the included studies was significant, $Q(4) = 10.20$, $p = .04$, and $I^2 = 60.8\%$, indicating moderate homogeneity between the included studies. The forest plot with the overall average effect size, the confidence interval, and individual effect sizes can be found in Figure 3. Pairwise comparison of the moderators showed no significant effects for use of active or non-active controls and type of training programme. However, a significant effect was found for age: children older than 10 years have a slightly higher mean effect size from WM training than children who are aged 10 years or younger, $Q(2) = 9.91$, $p = < .01$, as can be seen in Table 2.

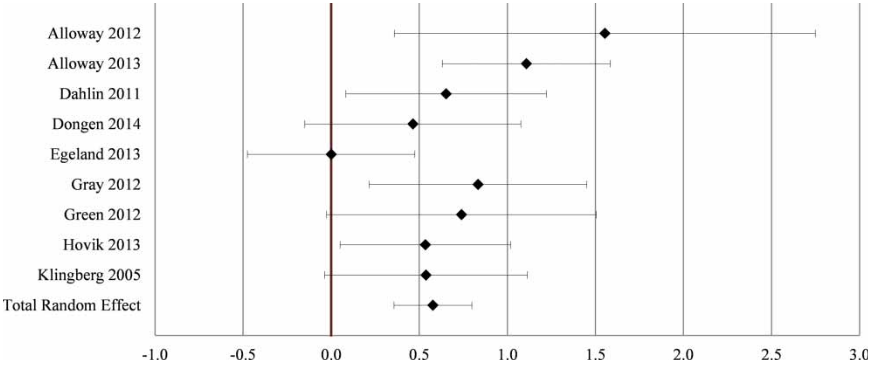

Figure 2. Forest plot of immediate training effects on verbal working memory.

TABLE 2
Analysis of moderators on training effects on verbal working memory

				Cochran's Q *test*		
Moderator variable	k	*Hedges'* g	SD	Q	p-*value*	I^2
Immediate training effects:						
Age						
≤ 10	3	0.56	0.16	0.31	.86	0.00
> 10	5	0.71	0.20	13.47	.01	70.30
Blank	1	0.65	0.29	0.00	1.00	0.00
treatment						
Treated	6	0.81	0.13	5.11	.40	2.22
Untreated	3	0.38	0.12	3.72	.16	46.17
intervention programme						
CogMed	7	0.49	0.10	6.10	.42	0.83
Jungle Memory	2	1.17	0.23	0.46	.50	0.00
Long-term training effects:						
Age						
≤ 10	1	0.55	0.30	0.00	1.00	0.00
> 10	3	0.60	0.33	9.91	.01	79.82
Blank	1	0.38	0.29	0.00	1.00	0.00
treatment						
Treated	2	0.92	0.37	3.17	.08	68.48
Untreated	3	0.30	0.15	0.74	.69	0.00
intervention programme						
CogMed	4	0.35	0.13	1.32	.73	0.00
Jungle Memory	1	1.29	0.28	0.00	1.00	0.00

In summary, WM training leads to significant improvements on verbal WM measurements in children with LDs compared to children who were not trained with an adaptive computerised WM training. This holds especially true for older children. This improvement (increased mean effect size) is sustained

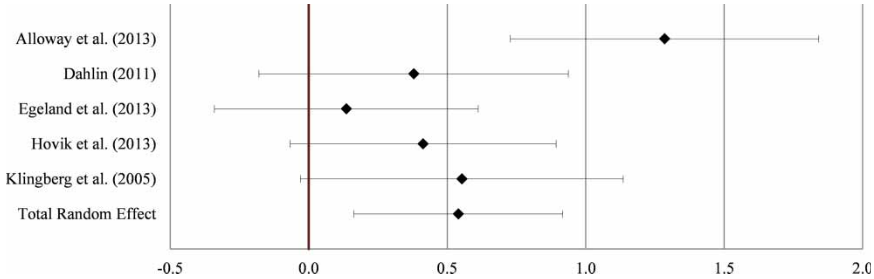

Figure 3. Forest plot of long-term training effects on verbal working memory.

over several months. Although almost all studies included measurements on verbal WM, there was little consensus on which measurement was used.

Visuo-spatial working memory

Immediate training effects. Nine studies ($k = 9$) were included in the analysis of visuo-spatial WM—measured by use of performance-based testing—comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1 (children in training groups: $n = 246$, $M_{\text{sample size}} = 27.33$, control group: $n = 230$, $M_{\text{sample size}} = 25.56$). The forest plot can be found in Figure 4. The mean effect size was medium, $g = 0.63$, 95% CI (0.40, 0.85), $p < .01$. The heterogeneity between the included studies was low and not significant, $Q(8) = 11.05$, $p = .20$ and $I^2 = 27$. Analysis of the moderators showed no significant moderator variable effects, as can be seen in Table 3.

Long-term training effects. Five studies ($k = 5$) were included in the analysis of effect sizes of measurements of visuo-spatial WM—measured by use of performance-based testing—comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1 (children in training groups: $n = 150$, $M_{\text{sample size}} = 30$, control group: $n = 156$, $M_{\text{sample size}} = 31.2$). The forest plot can be found in Figure 5. The mean effect size was small, $g = 0.39$, 95% CI (0.00, 0.78), $p < .05$. The heterogeneity between the included studies was moderate and significant, $Q(4) = 10.92$, $p = .03$, and $I^2 = 63\%$. Analysis of the moderators showed a medium to high significant difference between the different training programmes, $Q(3) = 10.90$, $p = .01$, indicating that Jungle Memory had more effect than CogMed. Other moderator variables had no significant effects on the heterogeneity. An overview of all moderator effects can be found in Table 3.

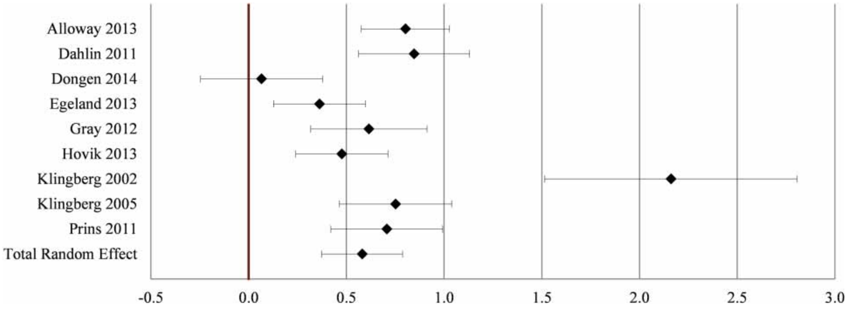

Figure 4. Forest plot of immediate training effects on visuo-spatial working memory.

TABLE 3
Analysis of moderators on visuo-spatial working memory

Moderator variable	k	*Hedges'* g	*SD*	*Cochran's* Q *test* Q	 p-*value*	I^2
Immediate training effects:						
Age						
$\leq$ 10	3	0.53	0.22	2.94	.23	32.02
$>$ 10	5	0.66	0.18	7.28	.12	45.07
Blank	1	0.85	0.30	0.00	1.00	0.00
treatment						
Treated	6	0.70	0.17	8.79	.12	43.13
Untreated	3	0.53	0.15	1.66	.44	0.00
intervention programme						
CogMed	8	0.60	0.13	10.11	.17	32.16
Jungle Memory	1	0.80	0.24	0.00	1.00	0.00
Long-term training effects:						
Age						
$\leq$ 10	1	−0.30	0.29	0.00	1.00	0.00
$>$ 10	3	0.50	0.20	3.56	.17	43.78
Blank	1	0.72	0.29	0.00	1.00	0.00
treatment						
Treated	2	0.08	0.36	3.46	.06	71.10
Untreated	3	0.59	0.21	3.80	.15	47.32
intervention programme						
CogMed	4	0.38	0.26	10.90	.01	72.47
Jungle Memory	1	0.43	0.26	0.00	1.00	0.00

It can be concluded, with respect to visuo-spatial WM, that children with LDs who followed an adaptive WM training have a higher mean effect size in the long term compared to children who did not follow an adaptive WM training. These effects can be seen as near transfer effects, because the measurements resemble the trained tasks. As with Verbal WM, there is moderate to

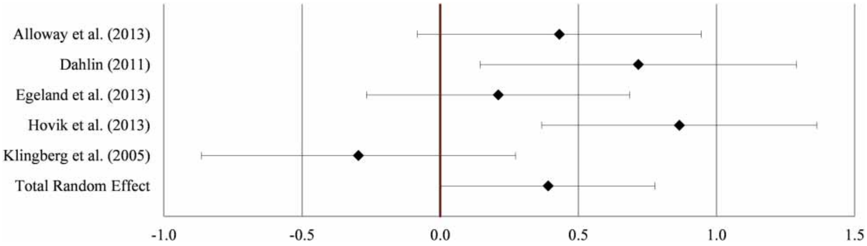

Figure 5. Forest plot of long-term training effects on visuo-spatial working memory.

large heterogeneity between the results and increased heterogeneity compared to the immediate training effects.

Influence of moderators on far transfer effects

This category comprises measurements that measure skills which were not trained in the different computerised WM programmes.

Decoding

Immediate training effects. Four studies ($k = 4$) were included in the analysis of effect sizes of measurements of decoding—measured by use of performance-based testing—comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1 (children in training groups: $n = 105$, M_{sample} size = 26.25, control group: $n = 95$, M_{sample} size = 23.75). The forest plot can be found in Figure 6. The mean effect size was small, $g = 0.36$, 95% CI (0.04, 0.68), $p = .00$. The heterogeneity between the included studies was low, but not significant, $Q(3) = 1.52$, $p = .68$, and $I^2 = 0$. The outcome of the moderator analysis indicated that moderator variables have no significant effects on the heterogeneity as can be seen in Table 4. This indicates that age and type of training programme does not make a difference on the overall effects of WM training.

Long-term training effects. Three studies ($k = 3$) were included in the analysis of effect sizes of measurements of decoding—measured by use of performance-based testing—comparing pre-test and post-test gains between children who used a WM training programme and the control group, as shown in Table 1 (children in training groups: $n = 97$, M_{sample} size = 32.3, control group: $n = 98$, M_{sample} size = 32.7). The forest plot can be found in Figure 7. The mean effect size was small to medium, $g = 0.48$, 95% CI (0.12, 0.84), $p = .01$. The heterogeneity between the included studies was low, but not significant, $Q(2) = 2.47$, $p = .29$, and $I^2 = 19\%$. The outcome

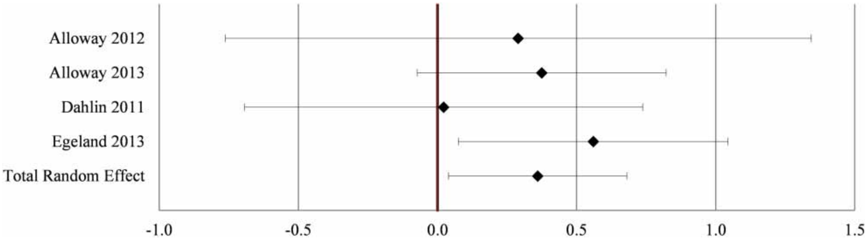

Figure 6. Forest plot of immediate training effects on decoding.

TABLE 4
Analysis of moderators on decoding

Moderator variable	k	*Hedges'* g	SD	*Cochran's* Q *test* Q	p-*value*	I^2
Immediate training effects:						
Age						
≤ 10	3	0.45	0.16	0.40	.82	0.00
Blank	1	0.02	0.37	0.00	1.00	0.00
treatment						
Treated	2	0.36	0.21	0.02	.89	0.00
Untreated	2	0.36	0.26	1.49	.22	32.80
intervention programme						
CogMed	2	0.36	0.26	1.49	.22	32.80
Jungle Memory	2	0.36	0.21	0.02	.89	0.00
Long-term training effects:						
Age						
≤ 10	2	0.61	0.18	0.59	.44	0.00
Blank	1	0.05	0.37	0.00	1.00	0.00
treatment						
Treated	1	0.46	0.26	0.00	1.00	0.00
Untreated	2	0.44	0.34	2.44	.12	59.01
intervention programme						
CogMed	2	0.44	0.34	2.44	.12	59.01
Jungle Memory	1	0.46	0.26	0.00	1.00	0.00

of the moderator analysis indicated that moderator variables have no significant effects on the heterogeneity as can be seen in Table 4.

Most studies did not include decoding measures. However, the studies that included decoding measurements showed a small but promising effect on decoding in children with LDs that followed a WM training when compared to children who did not follow a WM training. This can be promising because decoding skills are not part of WM training and can be seen as far transfer effects.

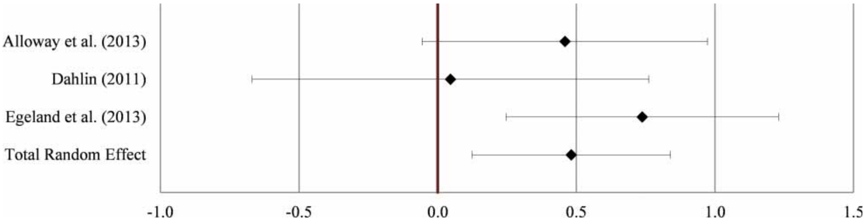

Figure 7. Forest plot of long-term training effects on decoding.

DISCUSSION

Working memory (WM) training programmes promise to provide both significant and lasting improvements in performances of children and adolescents with learning disabilities (LDs). This paper reviewed whether these claims regarding the efficacy of these programmes are empirically sound. In an extensive literature search we found only 13 studies which focused on training WM in children and adolescents with LDs, encompassing three different WM training programmes. These 13 randomised controlled trials included a total of 307 children who completed a WM training (age range: 5.5–17, $M_{\text{age across studies}} = 10.61$, $SD = 1.77$). The majority of studies (10 of the 13) included children with ADHD ($n = 244$), whereas one study included both children with ADHD and LDs not specified ($n = 32$). Two studies included children with LDs not specified ($n = 31$). No study until now focused on the effectiveness of WM training of children with non-verbal LDs, such as dyscalculia or maths disabilities, or verbal LDs, such as dyslexia, or reading disabilities.

Over a course of 4–5 weeks of WM training, children with LDs included in the studies typically showed improved performances in trained (verbal and visuospatial) WM tasks measured immediately after training: so-called near transfer effects. These results on near transfer effects are in line with Melby-Lervag and Hulme (2013) who included both healthy individuals and individuals with LDs. However, our results are contrary to those of Shipstead et al. (2012), who found only near transfer effects for short-term memory (STM) tasks and not for WM tasks. However, Shipstead et al. (2012) included only healthy children and adults, whereas our review showed that WM tasks have significant near transfer effects in children with LDs. Our data seemed to confirm the hypothesis that the effectiveness of WM training should be evaluated in different populations. Also, age is an important moderator variable showing that children above 10 years benefit more on Verbal WM than children who are 10 years or younger.

In our study, far transfer effects revealed a small but still significant positive effect on tasks involving decoding immediately after training. This is an important finding, indicating that children with LDs benefit from WM training on tasks other than the trained tasks, at least immediately after training. This is in line with the larger effects on Verbal WM. Speed and accuracy of decoding may be a more fluid skill than, for example, verbal ability and thus benefit more from training.

Long-term effects on near and far transfer variables were only assessed in seven studies (six for CogMed and one for Jungle Memory) and revealed significant effect sizes on Verbal WM (medium effect), Visuo-Spatial WM (small effect), and Decoding (small to medium effect) in children with LDs. Analysis of the moderator variables showed again that children above the age of 10 years benefit more than younger children on Verbal WM. König and Kievit (2011) state that cognitive treatment is more effective when children are old enough to have insight into their neurocognitive deficits and the need to use training, which might explain why the older children in our study benefit more from WM training than the children who are 10 years or younger. In terms of Visuo-Spatial WM, we found larger improvements when the child was trained with Jungle Memory compared to CogMed, but there was only one study which used Jungle Memory and measured Visuo-Spatial WM, so results need to be replicated before firm conclusions can be drawn.

To summarise, the results revealed positive and sustaining effects in the three training programmes under review using both near and far transfer variables in children with LDs immediately after the training and sustained over several months. This indicates that it is possible to train WM, which may lead to a decrease of problems from LDs. Research focused especially on children with LDs such as ADHD, which is a shortcoming of the current studies because children with other LDs (both verbal and non-verbal) are also known to suffer from deficits in WM.

Limitations and recommendations

Our review revealed a number of limitations in the reviewed studies and therefore provides several recommendations for future research. An important methodological drawback in the studies under review was the diverse methodologies being used, e.g., limited numbers of participants and varying times of evaluation. Also, different outcome measures were used. The methods used to measure WM varied significantly among studies: five different verbal WM tests were used in 11 studies and eight different visuo-spatial WM tests in nine studies. Also, most studies included performance-based tests administered to the subjects. For instance, far transfer measures often included were Raven's Progressive Matrices (Raven, 1990, 1995), a measure of non-verbal reasoning, and the Stroop Color Word task, a measure of attention and inhibition. Interestingly, except for Van der Oord et al. (2012) and Beck et al. (2010), no other studies involved parents. These authors used questionnaires for parents claiming to measure, for example, WM or other executive functions (EFs), such as inhibition, attention, or non-verbal reasoning. Both found small effects on the WM scale of the BRIEF. We believe these measures should be considered in future research, because these behaviours are related to deficits in EFs (Huizinga & Smidts, 2011) and parents could provide important information about far transfer effects in the daily life of children. However, very low correlations were found between questionnaires (i.e., the BRIEF) and experimental EF tasks (Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007). We can only speculate on why these correlations are so low (e.g., different concepts are being measured). Therefore, we strongly advise analysis of the efficacy studies focusing on only questionnaires measuring cognition or those on performance-based cognitive tests separately.

Secondly, six studies did not include long-term measurements, therefore a solid conclusion on the sustainability of training effects is not possible. Of those studies investigating the long-term effects of WM training programmes, the interval of follow-up varied significantly, ranging from nine weeks to eight months post-intervention. The actual goal of intervention is achievement of long-term effects, i.e., positive effect on educational career for which we believe that at least a 12-month follow up is required. This could give information on effects after the completion of an entire grade. All these factors made it difficult unequivocally to compare results. Furthermore, it is not possible to draw conclusions on the effects from WM training on the difficulties of the LD itself, because research only focused on underlying mechanisms of WM.

Thirdly, when reviewing the different studies, we noticed an interesting evolution of training programmes beings used. Historically, paper-and-pencil training programmes (e.g., self-instructional training) were used, evolving into a computer-based training at the beginning of the 21st century (CogMed) giving rise more recently to a gaming environment (Braingame Brian) in order to improve motivation in children. The use of a virtual gaming environment has not yet been researched, but looks promising. A virtual gaming environment offers the possibility of objectively measuring behaviour in a challenging but safe and ecologically valid environment while maintaining control over stimulus delivery and measurement (Schultheis, Himelstein, & Rizzo, 2002).

Fourthly, all studies in our review used implicit training programmes, therefore, conclusions on the effectiveness of explicit versus implicit training programmes cannot be made here. Overall, we concluded that there is only little systematic randomised controlled research in WM training programmes for children with LDs. Reported results mainly concern CogMed in children with ADHD, but results are promising and show both short-term and long-term benefits. Future studies are needed on different populations of LDs, using different training programmes, e.g., gaming environment and virtual reality training, due to the increased prevalence rates in LDs (Boyle et al., 2011).

Towards a triple pathway model in cognitive intervention

So far, most of the studies on WM training efficacy include children with ADHD. These studies do not control for or examine the moderating effects of "subtypes of ADHD". We believe that the "one size fits all" approach often used in studies on WM training and ADHD fails to recognise the diversity of symptom expressions in children with ADHD. Therefore, WM should not be the only focus of training programmes. To illustrate this point, we refer to the triple pathway model of ADHD, as described by Sonuga-Barke, Bitsakou, and Thompson (2010). These authors stated that WM deficits, as well as other cognitive deficits such as disinhibition, are only one cluster of core problems seen in some children with ADHD. According to the model, motivational problems (e.g., an aversion towards delay), and timing deficits are two other important and unique characteristics of ADHD. These three clusters of deficits have their own unique neural substrate: respectively, dorsal fronto-stratial circuits for cognitive functions, ventral fronto-stratial circuits for motivation, and the cerebellum and the basal ganglia for timing (Sonuga-Barke et al., 2010). As such, each neural substrate can be disturbed, leading to diverse expressions of ADHD, but also emphasising the need for different approaches to "deal" with these diverse expressions. Sonuga-Barke et al. indicated that only 20.7% of all children with ADHD have a cognitive deficit, that is, with or without another problem in timing and/or motivation. This indicates that only one-fifth of all children with ADHD would benefit from a cognitive training method, such as the WM training. Based on this, one can conclude that at least four out of five of all children with ADHD would benefit (more) from another training, e.g., focusing on motivation or timing or a combination of motivation, timing, and/or WM elements. None of the existing training programmes in our review takes all three into consideration and matches results on WM training efficacy to "ADHD subtypes".

Currently, some limited research on training the "motivational pathway" is available, including research into the inclusion of context in training programmes. For instance, Prins et al. (2011) developed a game in which elements from CogMed were intertwined in a storyline that may be motivating to the child. Prins et al. (2011) compared both games to evaluate the effect of a storyline and context on motivation. Children with ADHD are known to be highly motivated to play computer games and are less hampered by their ADHD problems during the playing of such games (Shaw, Grayson, & Lewis, 2005). Prins, Dovis, Ponsioen, and Ten Brink (2007) suggested that a training tool (for example, to train EFs) would be more effective if this training is disguised as a computer game with a storyline. Future studies should investigate whether children with specific "subtypes" of ADHD benefit more from the addition of a gaming element and/or giving specific instructions on motivational strategies. If our hypotheses are correct, children with ADHD- motivation deficits (with or without deficits in timing or WM) would benefit most from a training including motivation elements.

Accurate time perception, as representing Sonuga Barke's timing mechanism, helps to predict, anticipate, and respond competently to everyday situations and/or future events and is therefore an elementary aspect of our human adaptive system (e.g., Booth & Siegler, 2006; Gonzalez-Garrido et al., 2008). Increasing empirical evidence suggests that timing, along with other broad constructs, such as motor planning and sequencing, is relevant to attentional problems (Hurks & Hendriksen, 2011). Only a few studies have addressed the efficacy of techniques focusing on timing (Cosper, Lee, Peters, & Bishop, 2009; Shaffer et al., 2001) using an Interactive Metronome®, that provides accurate real-time guide sounds to indicate users' temporal accuracy as they perform a series of prescribed movements. These studies found improvements on aspects of attention, motor, and perceptual-motor functioning and academic performance in children with severe attentional problems. Again, future studies should investigate whether children with specific "subtypes" of ADHD benefit more from the addition of a timing element and/or giving them specific instructions on temporal processing strategies. If our hypotheses are correct, children with ADHD-timing deficits (with or without deficits in motivation or WM) would benefit most from training that included timing elements.

At present, no study has investigated correlations between WM training efficacy and subtypes of ADHD, therefore no conclusions can be made (a) whether only specific children with ADHD benefit from WM training programmes and (b) whether a training combining timing, WM and/or rewards that suits the symptoms of the individual child with ADHD would result in larger near and far transfer effects. This warrants further research.

CONCLUSIONS

This review and meta-analysis is the first to analyse effect sizes on both near and far transfer effects, as a result of WM training programmes for children with LDs. Results are limited (mainly ADHD and CogMed) but promising (both significant near and far transfer effects). Based on theoretical considerations we argue that WM training needs to be supplemented by modules focusing on motivation and timing.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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APPENDIX

TABLE A1
Characteristics and effect size for immediate training studies included in the meta-analysis

Study	*Category*	*Measurement*	*Learning Disorder*	*Average age*	*Type of control*	*Intervention programme*	*Hedges' g*	SE
Alloway (2012)	Arithmetic	Achievement: Arithmetic	ADHD	>10	Treated	Jungle Memory	0.550	0.545
Alloway et al. (2013)	Arithmetic	Maths	ADHD	>10	Treated	Jungle Memory	0.184	0.227
Egeland, Aarlien, and Saunes (2013)	Arithmetic	Mathematics	ADHD	>10	Untreated	CogMed	0.268	0.244
Dahlin (2011)	Inhibition	Stroop: Time (s)	ADHD	N.A.	Untreated	Cogmed	0.087	0.283
Van Dongen-Boomsma et al. (2014)	Inhibition	Day Night Stroop Task Control Time	ADHD	≤10	Treated	CogMed	0.323	0.318
	Inhibition	Day Night Stroop Task Switch Time	ADHD	≤10	Treated	CogMed		
Klingberg, Forssberg, and Westerberg (2002)	Inhibition	Stroop Task Accuracy	ADHD	>10	Treated	CogMed	0.081	0.535
	Inhibition	Stroop Task Time	ADHD	>10	Treated	CogMed		
Klingberg et al. (2005)	Inhibition	Stroop Task Time	ADHD	>10	Treated	CogMed	0.206	0.293
	Inhibition	Stroop Task Accuracy	ADHD	>10	Treated	CogMed		
Alloway (2012)	Decoding	Achievement: Spelling	ADHD	>10	Treated	Jungle Memory	0.290	0.537
Alloway et al. (2013)	Decoding	Spelling	ADHD	>10	Treated	Jungle Memory	0.375	0.228
Dahlin (2011)	Decoding	Word decoding	ADHD	N.A.	Untreated	CogMed	0.022	0.365
	Decoding	Orthographical verification	ADHD	N.A.	Untreated	CogMed		
	Decoding	Reading comprehension	ADHD	N.A.	Untreated	CogMed		
Egeland et al. (2013)	Decoding	LOGOS Reading fluency correct	ADHD	>10	Untreated	CogMed	0.560	0.247
	Decoding	Word decoding quality	ADHD	>10	Untreated	CogMed		
Dahlin (2011)	Non-verbal ability	Raven; RCPM	ADHD	N.A.	Untreated	CogMed	0.176	0.283

Van Dongen-Boomsma et al. (2014)	Non-verbal ability	Raven's progressive matrices	ADHD	≤10	Treated	CogMed	-0.091	0.309
Klingberg et al. (2002)	Non-verbal ability	Raven's progressive matrices	ADHD	>10	Treated	CogMed	1.877	0.642
Klingberg et al. (2005)	Non-verbal ability	Raven's progressive matrices	ADHD	≤10	Treated	CogMed	0.228	0.290
Alloway (2012)	Verbal ability	Intelligence (Vocabulary)	ADHD	>10	Treated	Jungle Memory	0.954	0.564
Alloway et al. (2013)	Verbal ability	IQ: Vocab (Verbal)	ADHD	>10	Treated	Jungle Memory	0.519	0.230
Van Dongen-Boomsma et al. (2014)	Verbal ability	WPPSI-R Sentences	ADHD	≤10	Treated	CogMed	−0.126	0.309
Alloway (2012)	Verbal WM	Verbal WM	ADHD	>10	Treated	Jungle Memory	1.554	0.610
Alloway et al. (2013)	Verbal WM	Verbal WM	ADHD	>10	Treated	Jungle Memory	1.108	0.243
Dahlin (2011)	Verbal WM	Digit Span forward	ADHD	N.A.	Untreated	CogMed	0.652	0.290
	Verbal WM	Digit Span back	ADHD	N.A.	Untreated	CogMed		
Van Dongen-Boomsma et al. (2014)	Verbal WM	Digit Span forward	ADHD	≤10	Treated	CogMed	0.464	0.313
	Verbal WM	Digit Span backward	ADHD	≤10	Treated	CogMed		
Egeland et al. (2013)	Verbal WM	CAVLT-2 Level of learning	ADHD	>10	Untreated	CogMed	0.000	0.243
Gray et al. (2012)	Verbal WM	Digit Span backward	ADHD	>10	Treated	CogMed	0.833	0.316
Green et al. (2012)	Verbal WM	WISC WM Index	ADHD	≤10	Treated	CogMed	0.739	0.391
Hovik, Saunes, Aarlien, and Egeland (2013)	Verbal WM	Auditory WM	ADHD	>10	Untreated	CogMed	0.535	0.247
Klingberg et al. (2005)	Verbal WM	Digit Span	ADHD	≤10	Treated	CogMed	0.538	0.294
*Beck et al. (2010)**	*Verbal WM*	*BRIEF-P WM*	*ADHD*	*>10*	*Untreated*	*CogMed*	*0.392*	*0.291*
	Verbal WM	*BRIEF-T WM*	*ADHD*	*>10*	*Untreated*	*CogMed*		
*Van der Oord et al. (2012)**	*Verbal WM*	*BRIEF WM*	*ADHD*	*≤10*	*Untreated*	*Braingame Brian*	*0.279*	*0.303*
Alloway et al. (2013)	Visuo-spatial WM	Visuo-spatial WM	ADHD	>10	Treated	Jungle Memory	0.802	0.235
Dahlin (2011)	Visuo-spatial WM	Span Board forward	ADHD	N.A.	Untreated	CogMed	0.846	0.295

(*Continued*)

TABLE A1
Continued

Study	*Category*	*Measurement*	*Learning Disorder*	*Average age*	*Type of control*	*Intervention programme*	*Hedges'* g	SE
	Visuo-spatial WM	Span Board back	ADHD	N.A.	Untreated	CogMed		
Van Dongen-Boomsma et al. (2014)	Visuo-spatial WM	Knox Cubes LDT forward	ADHD	≤10	Treated	CogMed	0.066	0.325
	Visuo-spatial WM	Knox Cubes LDT backward	ADHD	≤10	Treated	CogMed		
Egeland et al. (2013)	Visuo-spatial WM	BVRT	ADHD	>10	Untreated	CogMed	0.363	0.245
Gray et al. (2012)	Visuo-spatial WM	CANTAB Spatial Span	ADHD	>10	Treated	CogMed	0.615	0.310
Hovik et al. (2013)	Visuo-spatial WM	Visual WM	ADHD	>10	Untreated	CogMed	0.477	0.246
	Visuo-spatial WM	Manipulation WM	ADHD	>10	Untreated	CogMed		
Klingberg et al. (2002)	Visuo-spatial WM	Trained visio spation WM	ADHD	>10	Treated	CogMed	2.161	0.673
	Visuo-spatial WM	Span Board	ADHD	>10	Treated	CogMed		
Klingberg et al. (2005)	Visuo-spatial WM	Span Board	ADHD	≤10	Treated	CogMed	0.752	0.299
Prins et al. (2011)	Visuo-spatial WM	Corsi Block Tapping Test Visuospatial WM	ADHD	≤10	Treated	CogMed	0.707	0.298

WM: Working memory. * Beck et al. (2010) and Van der Oord et al. (2012) were not included in the analysis because questionnaires were used as measurements for WM. ADHD = Attention deficit hyperactivity disorder; RCPM = Raven's Coloured Progressive Matrices; WPPSI-R = Wechsler Preschool and Primary Scale of Intelligence Revised; CAVLT = Children's Auditory Verbal Learning Test; BRIEF-P = Behavior Rating Inventory of Executive Function Parent; BRIEF-T = Behavior Rating Inventory of Executive Function Teacher; LDT = Leidse Diagnostische Test; BVRT = Benton Visual Retention Test; CANTAB = Cambridge Neuropsychological Testing Automated Battery.

TABLE A2
Characteristics and effect size for long-term training studies included in the meta-analysis

Study	*Category*	*Measurement*	*Learning Disorder*	*Average age*	*Type of control*	*Intervention Program*	*Hedge's g*	SE
Alloway et al. (2013)	Arithmetic	Maths	ADHD	> 10	Treated	Jungle Memory	0.366	0.261
Egeland et al. (2013)	Arithmetic	Mathematics	ADHD	> 10	Untreated	CogMed	0.219	0.243
Dahlin (2011)	Inhibition	Stroop: Time (s)	ADHD	n.a.	Untreated	CogMed	1.167	0.306
Klingberg et al. (2005)	Inhibition	Stroop Task: Time	ADHD	> 10	Treated	CogMed	0.320	0.294
	Inhibtion	Stroop Task Accuracy	ADHD	> 10	Treated	CogMed		
Alloway et al. (2013)	Decoding	Spelling	ADHD	> 10	Treated	Jungle Memory	0.459	0.263
Dahlin (2011)	Decoding	Word decoding	ADHD	n.a.	Untreated	CogMed	0.046	0.365
	Decoding	Orthographical verification	ADHD	n.a.	Untreated	CogMed		
	Decoding	Reading comprehension	ADHD	n.a.	Untreated	CogMed		
Egeland et al. (2013)	Decoding	LOGOS Reading fluency correct	ADHD	> 10	Untreated	CogMed	0.738	0.251
	Decoding	Word decoding quality	ADHD	> 10	Untreated	CogMed		
Dahlin (2011)	Non-verbal ability	Raven; RCPM	ADHD	n.a.	Untreated	CogMed	−0.081	0.283
Klingberg et al. (2005)	Non-verbal ability	Raven's progressive matrices	ADHD	≤ 10	Treated	CogMed	0.044	0.289
Alloway et al. (2013)	Verbal ability	IQ: vocab (Verbal)	ADHD	> 10	Treated	Jungle Memory	1.473	0.291
Alloway et al. (2013)	Verbal WM	Verbal WM	ADHD	> 10	Treated	Jungle Memory	1.285	0.284
Dahlin (2011)	Verbal WM	Digit Span forward	ADHD	n.a.	Untreated	CogMed	0.379	0.285
	Verbal WM	Digit Span back	ADHD	n.a.	Untreated	CogMed		
Egeland et al. (2013)	Verbal WM	CAVLT-2 Level of learning	ADHD	> 10	Untreated	CogMed	0.136	0.243
Hovik et al. (2013)	Verbal WM	Auditory WM	ADHD	> 10	Untreated	CogMed	0.413	0.245

(Continued)

TABLE A2
Continued

Study	*Category*	*Measurement*	*Learning Disorder*	*Average age*	*Type of control*	*Intervention Program*	*Hedge's* g	SE
Klingberg et al. (2005)	Verbal WM	Digit Span	ADHD	≤ 10	Treated	CogMed	0.553	0.297
Alloway et al. (2013)	Visuo-spatial WM	Visuo-spatial WM	ADHD	> 10	Treated	Jungle Memory	0.431	0.262
Dahlin (2011)	Visuo-spatial WM	Span Board forward	ADHD	n.a.	Untreated	CogMed	0.717	0.292
	Visuo-spatial WM	Span Board back	ADHD	N.A.	Untreated	CogMed		
Egeland et al. (2013)	Visuo-spatial WM	BVRT	ADHD	> 10	Untreated	CogMed	0.210	0.243
Hovik et al. (2013)	Visuo-spatial WM	Visual WM	ADHD	> 10	Untreated	CogMed	0.865	0.254
	Visuo-spatial WM	Manipulation WM	ADHD	> 10	Untreated	CogMed		
Klingberg et al. (2005)	Visuo-spatial WM	Span Board	ADHD	≤ 10	Treated	CogMed	−0.296	0.290

WM: Working memory. ADHD = Attention deficit hyperactivity disorder; RCPM = Raven's Coloured Progressive Matrices; CAVLT = Children's Auditory Verbal Learning Test; BVRT = Benton Visual Retention Test.