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Abstract

Working memory deficits are consistently found in ADHD children, which might underlie core ADHD symptoms, hindering ADHD children's academic achievement. Thus, one way to enhance ADHD children's academic achievement is to mitigate their working memory deficits through working memory training. A widely applied training is Cogmed Working Memory Training (WMT). Despite the prevalence of this training, its effect on ADHD children has been rarely reviewed. This study aims to fill this gap by systematically reviewing the effect of Cogmed WMT on ADHD school-age children's working memory, ADHD symptoms, and academic achievement. It systematically searched PsycINFO, Google Scholar (for accessing grey literature), and Cogmed websites. Eleven randomised controlled trials met the eligibility criteria. Findings of these studies were qualitatively synthesised. The internal and external validity of studies included in this review were critically assessed. Results showed that Cogmed WMT might have a positive effect on school-age ADHD children's performance on trained working memory tasks. However, the effect of this training was spurious for untrained working memory tasks, ADHD symptoms, and academic achievement. Findings of this study therefore did not yield strong support for Cogmed WMT having a positive effect on ADHD school-age children's academic achievement. Hence, educational practitioners need to maintain a critical attitude when considering whether to adopt Cogmed WMT for ADHD children. More research on the effect of Cogmed WMT on ADHD children is also needed.

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Keywords
Cogmed working memory training, Attention Deficit Hyperactivity Disorder, academic achievement

Resumen

Las deficiencias en la memoria de trabajo que se observan comúnmente en niños con TDAH pueden ser la causa de algunos de los principales síntomas del trastorno que afectan su desempeño académico. En consecuencia, el entrenamiento de la memoria de trabajo es una forma de mejorar el desempeño académico de los niños con TDAH con el fin de mitigar sus deficiencias. Un método de entrenamiento de memoria de trabajo ampliamente utilizado es el de Cogmed (WMT, por sus siglas en inglés). Sin embargo, a pesar de su prevalencia, su efecto en niños con TDAH pocas veces ha sido estudiado. Esta investigación pretende llenar ese vacío mediante la revisión sistemática del efecto del WMT de Cogmed en la memoria de trabajo, síntomas de TDAH y desempeño académico de niños en edad escolar. Once ensayos controlados aleatorizados que cumplían con los criterios de elegibilidad fueron encontraron por medio de la búsqueda sistemática en PsycINFO, Google Scholar (para cubrir literatura gris) y sitios web de Cogmed. Los hallazgos de estos estudios fueron sintetizados cualitativamente. En esta revisión se evaluaron críticamente la validez interna y externa de esos estudios. Los resultados muestran que es posible que el WMT de Cogmed tenga un efecto positivo en el desempeño de niños en edad escolar en las tareas de memoria de trabajo practicadas. Sin embargo, el efecto de este entrenamiento fue espurio para las tareas de memoria de trabajo no practicadas, síntomas de TDAH y desempeño académico. Por lo tanto, los hallazgos de este estudio no respaldan definitivamente el efecto positivo del WMT de Cogmed sobre el desempeño académico de niños en edad escolar. En consecuencia, los educadores necesitan mantener una actitud crítica al considerar el WMT para niños con TDAH. Adicionalmente, se necesita más investigación en el efecto del WMT de Cogmed en niños con TDAH.

Palabras Clave
Entrenamiento de memoria de trabajo de Cogmed, Transtorno por déficit de atención con hiperactividad, desempeño académico.

الملخص:

يلاحظ دوماً وجود عجز في الذاكرة العاملة لدى الأطفال المصابين باضطراب فرط الحركة وتشتت الانتباه، ما يجعل هذا العجز يكمن وراء الأعراض الرئيسية لهذا الاضطراب، معيقًا الإنجاز الأكاديمي للأطفال المصابين به. لذلك، فإن إحدى طرق تحسين الإنجاز الأكاديمي لهؤلاء الأطفال تكمن في تخفيف عجز الذاكرة العاملة لديهم، وذلك من خلال تدريبها. يعد تدريب الذاكرة العاملة "كوجمد WMT " أحد التدريبات المطبقة على نطاق واسع، وعلى الرغم من انتشاره فإنه قُلّما قُيّمت نتائج استعماله مع الأطفال المصابين باضطراب فرط الحركة وتشتت الانتباه. تهدف هذه الدراسة إلى سد هذه الفجوة وذلك من خلال إجراء مراجعة ممنهجة لأثر تدريب الذاكرة العاملة "كوجمد WMT " على الأطفال في سن الدراسة والمصابين باضطراب فرط الحركة وتشتت الانتباه، وكذلك على أعراض هذا الاضطراب، والإنجاز الأكاديمي لهؤلاء الأطفال. استُخدمت قاعدة البيانات سايكو انفو في عملية البحث، وموقع البحث غوغل سكولار (للوصول للأدبيات الرمادية)، إضافةً إلى المواقع الخاصة بتدريب "كوجمد". طابقت إحدى عشرة تجربة منضبطة معشاة معايير الأهلية، ثم جُمعت نتائج هذه الدراسات نوعياً، وقُيمت المصداقية الداخلية والخارجية للدراسات المتضمنة في هذه المراجعة تقييمًا نقديًا. أظهرت النتائج أن تدريب "كوجمد WMT " قد يكون له أثر إيجابي على أداء الأطفال في سن الدراسة والمصابين باضطراب فرط الحركة وتشتت الانتباه في حالة مهام الذاكرة العاملة المدربة، بينما كان أثر هذا التدريب زائفًا في حالة مهام الذاكرة غير المدربة وكذلك أعراض اضطراب فرط الحركة وتشتت الانتباه والإنجاز الأكاديمي. بالتالي فإن نتائج هذه الدراسة لم تخلص إلى الارتكاز على تدريب "كوجمد" للحصول على أثر إيجابي على الأطفال في سن الدراسة والمصابين باضطراب فرط الحركة وتشتت الانتباه. وعليه يحتاج الممارسون في المجال التعليمي لاعتماد موقف ناقد إذا رغبوا باستخدام تدريب الذاكرة العاملة "كوجمد" على الأطفال في سن الدراسة والمصابين باضطراب فرط الحركة وتشتت الانتباه. مازال تأثير تدريب الذاكرة العاملة "كوجمد" على الأطفال المصابين باضطراب فرط الحركة وتشتت الانتباه بحاجة إلى المزيد من الدراسات.

الكلمات المفتاحية:
تدريب الذاكرة العاملة "كوجمد"، اضطراب فرط الحركة وتشتت الانتباه، الإنجاز الأكاديمي.

Introduction

Academic achievement predicts children’s concurrent and future life satisfaction (Crede et al., 2015), stable employment (Motte & Schwartz, 2005), and health (Hawkins, 1997). Thus, it is crucial to devise interventions for children at risk of academic underachievement, such as children with Attention Deficit Hyperactivity Disorder (ADHD). ADHD is a disorder with persistent inattentive or hyperactive/impulsive symptoms (American Psychiatric Association, 2013). ADHD children underachieve compared to non-ADHD peers in reading and maths even after controlling for child intelligence (Arnold et al., 2020; Massetti et al., 2008; Owens & Jackson, 2017; Scholtens et al., 2013).

For promoting ADHD children’s academic achievement, an influential approach is to enhance cognitive skills involved in academic performance (Strauss, 1972). Of these skills an important one is working memory, which temporarily stores information for higher-order cognitive processing (Gazzaniga et al., 2019). It consists of two short-term storages for storing verbal and visuospatial information respectively, and a central executive not specific to either the verbal or visuospatial domain (Baddeley & Hitch, 1974). The central executive regulates the dynamic allocation of attention to short-term storages (Baddeley et al., 2014). It therefore helps to retain task-relevant information such as self-directed rules, which are crucial for attention control and academic achievement (Barkley, 1997). Thus, working memory deficits might shape the central ADHD symptoms of attentive behaviour deficits (Kofler et al., 2010), contributing to ADHD children’s academic underachievement (Sarver et al., 2012). Alleviating working memory deficits consistently found in ADHD children (e.g., Martinussen & Tannock, 2006) might therefore enhance ADHD children’s academic achievement.

One training widely applied in over 30 countries (e.g., Melby-Lervåg & Hulme, 2016) is the computerised Cogmed working memory training (Cogmed WMT). It includes 25 40-min sessions across 5 weeks. During each session, children receive both verbal and visuospatial working memory tasks. An example of verbal working memory tasks is recalling sequences of digits. An example of visuospatial working memory tasks is recalling patterns of lamp lighting (Sala & Gobet, 2017). Being adaptive, it adjusts difficulty levels to children’s task performance. For enhancing task compliance, training aides reinforce on-task behaviours during training (Chacko et al., 2014). The rationale on the Cogmed website suggests that Cogmed WMT “improves on-task behaviours by increasing working memory capacity”, “helping us to perform efficiently and effectively in academic settings” (Pearson Education Ltd, 2019). Hence, Cogmed WMT is proposed to promote academic achievement by increasing children’s working memory capacity. This further reduces ADHD symptoms, enhancing on-task academic behaviours. For examining the effect of Cogmed MWT on ADHD children’s academic achievement, it is thus crucial to also examine training effects on working memory and ADHD symptoms.

However - despite the prevalence of Cogmed WMT - its effect on ADHD school-age children’s working memory, ADHD symptoms, and academic achievement is rarely reviewed. Systematic reviews are needed to inform educational practitioners of the effect of Cogmed WMT on ADHD children. This information may help them to decide whether to devote time and cost to this commercial training product for promoting the academic achievement of ADHD children. Spencer-Smith and Klingberg's (2015) systematic review (including adults) did not focus on school-age ADHD children. Chacko et al.'s (2013) systematic review included a limited number of studies, which were all published before 2013. Both studies also did not examine the effect of Cogmed WMT on ADHD children’s academic achievement. Shipstead et al.’s (2012) review included academic achievement. However, this study was not systematic and mixed various working memory trainings together. Thus, this study aims to provide an updated systematic review of the effect of Cogmed WMT on school-age ADHD children's working memory, ADHD symptoms, and academic achievement.

Methodology

For increasing the transparency of this systematic review, this study followed the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al., 2009). These are standardised guidelines for reporting information in systematic reviews (Selcuk, 2019). The PRISMA guidelines were adopted for enhancing the transparency, integrity, consistency, and accountability of this systematic review and avoiding bias in reporting (Moher et al., 2015).

A systematic search was performed via PsycINFO, Google Scholar, and Cogmed WMT websites. Google Scholar was utilised for accessing grey literature to reduce publication bias. Publication bias might lower the chance for studies of small scale or with negative findings to be published (Chow & Eckolm, 2018). Keywords used include *Cogmed Working Memory Training* or *Cogmed* or *working memory training* or *working memory intervention* or *working memory* and *ADHD* or *attention deficit hyperactivity disorder* or *inattention* and *academic achievement* or *achievement* or *academic performance* or *academic success* or *school success*. The systematic search was conducted in November 2019. Therefore, studies reviewed in this article were all published before this time.

The eligibility criteria of this review followed the Participant, Intervention, Comparison, and Outcome (PICO) framework (Sharma et al., 2015). This framework helped the author to systematically examine study features to decide whether to include particular studies in this review (Eldawlatly et al., 2018). Studies meeting the following four eligibility criteria were included in this review. First, study samples were school-age children with formal ADHD diagnoses or rated by parents or teachers as showing ADHD-associated inattentive behaviours. Second, studies evaluated the effect of Cogmed WMT by randomised controlled trials with control groups. Third, studies included at least one of the three outcomes: working memory, ADHD symptoms, and academic achievement. Fourth, studies were written in English.

For data extraction, this study adopted Spencer-Smith and Klingberg's (2015) data extraction form. It was adapted from the widely applied Cochrane Consumers and Communication Group data extraction template (Ryan et al., 2016). Compared to this comprehensive tool, Spencer-Smith and Klingberg's (2015) form was more concise. It also has been efficiently used to systematically evaluate the effect of Cogmed WMT. It followed the PICO framework described above. The PICO framework is useful for summarising components of study evidence on the effect of particular interventions (Methley et al., 2014). Hence, this study extracted data on participant characteristics (Participant), training features (Intervention), types of control groups (Comparison), and outcome assessments (Outcome).

Compared to Spencer-Smith and Klingberg (2015), this study included more specific information on gender, ADHD subtypes, comorbidities, and medication. These variables might shape heterogeneities in training effects. This study also included all outcome measures reported in the studies. This was in contrast to Spencer-Smith and Klingberg (2015), who only coded the most commonly reported measures. For working memory, short-term storage tasks (e.g., forward recall) were only coded when they were mixed with working memory measures. Data extraction was double-checked by the author and was cross-checked with other systematic reviews (e.g., Chacko et al., 2014) when the same study was included in multiple systematic reviews. Discrepancies across studies were resolved with reference to the original studies.

Risk of bias within studies was assessed by the Revised Cochrane Risk-of-Bias Tool for Randomised Trials (RoB 2 Tool) (Sterne et al., 2019). This is one of the most widely used tools to assess the risk of bias in randomised controlled trials (Minozzi et al., 2020). Adopting this tool was for examining study internal validity, which might affect the confidence that could be placed on the overall evidence of systematic reviews (Moher et al., 2015). RoB 2 Tool assessed potential bias in sample randomisation, deviations from intended interventions, missing outcome data, outcome measurement, and selected report of results. A risk-of-bias algorithm was used to rate studies as having low risk of bias, some concerns, or high risk of bias. Results of studies with high risk of bias were not incorporated into result synthesis. This was for reducing the potential of bias in examining training effects. In addition to internal validity, risk of bias across studies (external validity) was assessed by Glasgow et al.'s (2007) checklist enriched with Rothwell's (2006) items. The adoption of this checklist was because it was one of the few available tools for examining external validity. It investigated potential bias in participant selection, intervention implementation, outcome measurement, and long-term follow-ups.

Study results were qualitatively synthesised by summarising findings for working memory, ADHD symptoms, and academic achievement respectively. Methodological issues that might negatively affect study internal and external validity were discussed to point out directions for future improvement.

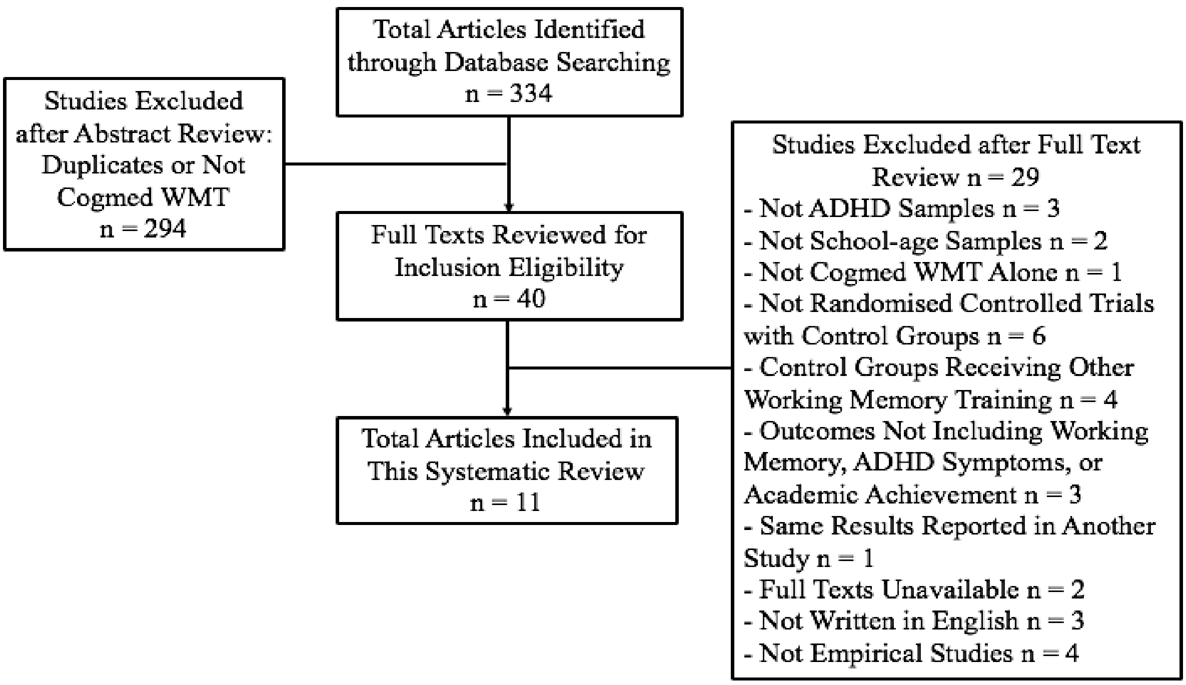
Results

Study Inclusion

A flow chart for the systematic literature search and eligibility check of studies is presented in Figure 1. A total of 334 studies were found after the systematic search. After reviewing abstracts, 294 were excluded as they were either duplicates or did not examine the effect of Cogmed WMT.

Figure 1

Flow Diagram for Systematic Literature Search and Eligibility Check



After reviewing full texts, a further 29 studies were excluded, which did not meet the eligibility criteria. Information of these 29 studies is presented in Table 1

Table 1
Studies Not Meeting the Eligibility Criteria

Reasons for Exclusion	Studies
Not ADHD Samples	Anderson et al. (2018); Roording-Ragetile et al. (2017); Phillips et al. (2016)
Not School-Age Samples	Liu et al. (2017); van Dongen-Boomsma et al. (2014)
Not Cogmed WMT Alone	Chacko et al. (2018)
Not Randomised Controlled Trials with Control Groups	Gibson et al. (2011); Holmes et al. (2010); Mezzacappa & Buckner (2010); Muris et al. (2018); Stevens et al. (2016); Weckstein et al. (2017)
Control Groups Receiving Other Working Memory Training	van der Donk et al. (2013); van der Donk et al. (2015); van der Donk et al. (2016); van der Donk (2017)
Outcomes not Including Working Memory, ADHD Symptoms, or Academic Achievement	Graham & Benninger (2016); Janbahan (2018); Mawjee et al. (2017)
Same Results Reported in Another Study	Bigorra et al. (2016)
Full Texts Unavailable	Bir (2019); Elliot (2019)
Not Written in English	Dentz et al. (2015); van Dongen-Boomsma et al. (2015); Villemonteix (2018)
Not Empirical Studies	Chacko et al. (2013); Shipstead et al. (2012); Spencer-Smith & Klingberg (2015); Robinson et al. (2014)

The rest of the studies (11) met the eligibility criteria. They were hence included in this systematic review. Study characteristics of these studies are presented in Table 2.

Study	Participants							Control	Training	Outcome Assessment					
	Number		Age	Country	Type	Comorb-dity	Medic-ation	Type	Site	Timing	Working Memory		ADHD Symptoms		Academic Achievement
	Male	Female									Verbal	Visuospatial	Rating Scale	Psychological Test	
Beck et al., 2010	36	16	7-17	US	C PI	CD ODD ANX MD	32	Waitlist	Home	1 month after training 4 months after training	Behaviour Rating Inventory of Executive Function (parent, teacher)		Conners' Rating Scale (parent, teacher) DSM-IV Inattentive Symptoms (parent)	none	none
Bigorra et al., 2016	29	36	7-12	Spain	C	CD ODD No ASD or ANX	ND	Placebo	Home	1-2 weeks after training 6 months after training	Behaviour Rating Inventory of Executive Function (parent, teacher) Digit Span Backward Letter-number Sequencing	Spatial Span Backward	Conners' Rating Scale Strengths and Difficulties Questionnaire (parent, teacher) Child Behaviour Checklist (parent) Teachers' Report Form	Conners' Continuous Performance Test	A Spanish Reading Comprehension Test
Chacko et al., 2014	66	19	7-11	US	C PI	CD ODD No PDD	25	Placebo	Home	3 weeks after training	Listening Recall	Spatial Recall	Disruptive Behaviour Disorders Rating Scale (parent, teacher)	Continuous Performance Test	Wide Range Achievement Test
*Dahlin, 2011	46	11	9-12	Sweden	ND	No ODD No ASD	ND	Waitlist	School	5-6 weeks after training 6-7 months after training	none		none		Text Comprehension Phonological Non-Word Reading Orthographic Verification
*Dahlin, 2013	46	11	9-12	Sweden	ND	No ODD No ASD	ND	Waitlist	School	6 weeks after training 6-7 months after training	none		none		Basic Number Screening Test Addition and Subtraction Verification
Egeland et al., 2013	49	18	10-12	Norway	C	No PDD No TS No BD No CD	46	Waitlist	School	Post-training[#] 8 months after training	none		ADHD Rating Scale-IV (parent, teacher) Strengths and Difficulties Questionaire	Colour Word Test Trail Making Test	Key Math LOGOS Reading Test Battery

													(parent, teacher)	Conners' Continuous Performance Test	
Gray et al., 2012	52	8	12-17	Canada	ND	LD No CD No ANX No MDD	59	Academy of Math	School	3 weeks after training	Digit Span Backward	CANTAB Spatial Working Memory	Strengths and Weakness of ADHD-symptoms and Normal-behaviour Scale (parent, teacher) IOWA Conners Scale (parent, teacher)	D2 Test of Attention	Wide Range Achievement Test
Green et al., 2012	17	9	7-14	US	C PI PH-I	No MDD No ASD No BD	10	Placebo	Home	Post-training	Digit Span Forward and Backward Letter-number Sequencing	none	Restricted Academic Situations Task Conners' Parent Rating Scale	none	none
Hovik et al., 2013	49	18	10-12	Norway	C	No PDD No TS No CD No BD	46	Waitlist	School	Post-training 8 months after training	Letter-number Sequencing Sentence Span	Visual Span Forward and Backward	none		none
Klingberg et al., 2005	44	9	7-12	Sweden	C PI	No ODD No ASD No MDD No CD No BD	none	Placebo	Home	5-6 weeks after baseline assessment 3 months after training	Digit Span Forward and Backward	Spatial Span Forward and Backward	Conners' Rating Scale ADHD Symptom Rating (parent, teacher)	Stroop Interference Task	none
Steeger et al., 2016	29	16	11-15	US	C PI PH-I	ODD, CD ANX, MDD TS, TD	35	Placebo	Home	Post-training	Behaviour Rating Inventory of Executive Functioning (parent and teacher) Digit Span Backward	Spatial Span Backward	ADHD Rating Scale-IV (parent, teacher)	none	none

Table 2

Participants, methodologies, and outcomes of randomized controlled trials

Note. ND = no data provided, C = combined-type ADHD, PI = predominantly inattentive ADHD, PH-I = predominantly hyperactive/impulsive ADHD, ODD = oppositional defiant disorder, ANX = anxiety disorder, MD = mood disorder, MDD = major depressive disorder, PDD = pervasive developmental disorder, CD = conduct disorder, ASD = autism spectrum disorder, TS = Tourette's syndrome, BD = bipolar disorder, LD = learning difficulties, TD = Tie Disorder; DSM-IV = Diagnostic and Statistical Manual of Mental Disorders, fourth edition.
* group assignment processes not specified
[#] post-training means that the specific time of post-training assessments were not mentioned in the studies

Synthesis of Study Results

Working Memory. According to the RoB 2 Tool, three studies (Green et al., 2012; Kingberg et al., 2005; Hovik et al., 2013) were rated as having high risk of bias. The major source of bias was measurement inappropriateness. Green et al. (2012) and Klingberg et al. (2005) conflated short-term storage and working memory. They combined forward and backward recall tasks. Forward recall tasks tapped into short-term storage, which did not require information manipulation as a key component of working memory (Shipstead et al., 2012). Hovik et al. (2013) included sentence span (remembering heard sentences) in their working memory composite. This task was shown by Klem et al. (2015) to tap language processing skills rather than working memory. Hence, measures in these studies might not be appropriate. According to the RoB 2 Tool, they were judged as having high risk of bias and were hence excluded.

The rest of the studies including working memory measures except Beck et al. (2011) all applied a placebo Cogmed training in the control group. The placebo training was identical to Cogmed WMT except that it was non-adaptive with low difficulty (Klingberg et al., 2005). It helped the researchers to control for nonspecific training features such as computer usage.

A positive finding came from Bigorra et al. (2016). They assessed working memory by parent and teacher-rated children's working memory problems and a working memory composite. This composite was composed of backward recall of digits (backward digit span), backward recall of block tapping (backward spatial span), and letter number sequencing. Letter-number sequencing asked children to recall heard letters and numbers in alphabetic and numerical orders respectively (Mielicki et al., 2018). The sample of this study consisted of 65 Spanish ADHD children aged 7 to 12. Results showed that children receiving Cogmed WMT improved significantly more than controls 1-2 weeks (d = .81) and 4 months (d = .12) after training. In addition, children receiving Cogmed WMT were rated by their teachers and parents to have fewer working memory problems 4 months after training (d = -.84 and -.61). This positive training effect was also significant 1-2 weeks after training for teacher ratings (d = -.36).

The use of a working memory composite helped the authors to reduce Type I error associated with multiple comparisons. However, using a composite also made it unfeasible to separately examine training effects on verbal or visuospatial working memory. Separate analyses for verbal and visuospatial working memory were performed by Steeger et al. (2016). Their sample included 45

US ADHD children aged 11 to 15. In contrast to Bigorra et al. (2016), the authors did not reveal any positive training effect on parent or teacher ratings. In addition, children receiving Cogmed WMT improved significantly more than controls in verbal working memory assessed by backward digit span only (η^2 = .05). Training effect on visuospatial working memory assessed by backward spatial span was insignificant with a small to medium effect size (η^2 = .04). Similar findings were reported by Gray et al. (2012) in 60 12-17-year-old Canadian ADHD children. For the whole sample, significant and positive training effects were found on both verbal and visuospatial working memory (partial η^2 = .13 and .08). However, when excluding children without a confirmed ADHD diagnoses, the training effect on visuospatial working memory was insignificant with a small to medium effect size (partial η^2 = .04). Thus, it was spurious whether Cogmed WMT could improve ADHD children's visuospatial working memory.

It should be pointed out that Gray et al.'s (2012) finding might also be due to study characteristics. First, it applied a computerised math training in the control group. Similar to Cogmed WMT, this training was adaptive. This adaptive nature thus helped to control for cognitive efforts and the amount and quality of child-aide interactions, which might differ between Cogmed WMT and the placebo training with different difficulties (Dovis et al., 2012). However, training children's math skills could also improve their working memory. This was so especially for visuospatial working memory, which might be involved in solving mathematical tasks (Swanson, 2006). This cognitive overlap might lead to an underestimation of the effect of Cogmed WMT, necessitating the development of adaptive training not tapping working memory.

Second, while using a trained task (backward digit span) for verbal working memory, Gray et al. (2012) assessed visuospatial working memory by an untrained task. This untrained task was the Cambridge Neuropsychological Test Automated Battery (CANTAB) spatial working memory task. It required children to avoid opening the same box twice in search for tokens (Cacciamani et al., 2018). Thus, it might be the case that the positive effect of Cogmed WMT was limited to trained tasks. This suggestion was also supported by Chacko et al. (2014). Their sample included 85 ADHD children aged 7 to 11 in the US. No significant training effect was revealed on two untrained working memory tasks. The untrained verbal working memory task was listening recall or recalling final words of sentences while judging their veracity (d = .07). The untrained visuospatial working memory task was spatial recall or recalling dot locations while judging whether the shape with a red dot was the same or opposite to the other shape (d = .29).

Chacko et al. (2014) were additionally aware of possible training time differences between Cogmed WMT and the placebo training with different difficulties. They enhanced the equivalence of time by modifying the number of trials each session to control for session completion time. Hence, the positive training effect found by Bigorra et al. (2016) might also be due to training time differences.

In summary, this section showed that Cogmed WMT might have a positive effect on school-age ADHD children’s trained verbal working memory tasks. However, the effect of this training was spurious on visuospatial working memory especially for untrained tasks. Adaptive trainings not tapping working memory with similar training time need to be developed.

ADHD Symptoms. According to the RoB 2 Tool, parent ratings of ADHD symptoms in Beck et al. (2010) and both parent and teacher ratings in Egeland et al. (2013) were rated as having high risk of bias. They applied a waitlist control group, where participants did not receive any form of treatment. In this condition, it was impossible to blind parents and/or teachers as participants of training studies to treatment conditions. Hence, they were susceptible to the expectancy effect. This would happen when parents and teachers in the Cogmed WMT group expected the training to have a positive effect on ADHD symptoms. This expectation could lead them to underrate ADHD symptoms. Therefore, unblinded parent ratings in Beck et al. (2010) and unblinded parent and teacher ratings in Egeland et al. (2013) were rated as having high risk of bias in outcome measurement. They were hence excluded. It has to be pointed out that due to differences between Cogmed WMT and the math training applied in the control group by Gray et al. (2012), it might also be difficult to blind raters in Gray et al. (2012). However, raters in this study were not provided with any indication in favour of either training. Hence, unblinding was unlikely to have a direct influence on outcome assessments. The rest of the studies were all double-blinded trials. They thus did not suffer from issues associated with blinding.

Among the seven studies with measures on ADHD symptoms (including teacher report in Beck et al., 2010), five studies did not reveal any training effect on parent- or teacher-rated ADHD symptoms (Beck et al., 2010; Chacko et al., 2014; Gray et al., 2012; Green et al., 2012; Steeger et al., 2016). Only two studies revealed positive training effects. Klingberg et al. (2005) studied 53 ADHD children aged 7-12 in Sweden. They found that parent- but not teacher-rated ADHD symptoms (inattention and hyperactivity) reduced significantly more for the training than control group 5-6 weeks after baseline assessment (d = -1.21 and -.43) and 3 months after training (d = -

.67 and -.42). This parent-teacher discrepancy might be due to the lower sensitivity of teacher rating, as teacher ratings were based on relatively restricted and structured academic settings (Yerys et al., 2017). Under classroom management demands, teachers might selectively pay attention to negative behavioural problems. They thus might be less sensitive to ADHD symptom improvement. This suggestion also echoed Bigorra et al.'s (2016) finding. They found that positive training effect on teacher-rated ADHD symptoms was significant 6 months (d = -.69) but not 1-2 weeks after training (d = -.55). It was hence possible that teacher ratings required larger effects in the long term to be detected.

Training effects on parent-rated ADHD symptoms in Klingberg et al. (2005) could also be due to the therapeutic effect. Compared to the placebo training, the more challenging Cogmed WMT might provide more opportunities for child-parent cooperative problem-solving. This could further increase the amount and quality of child-parent interactions, which might reduce parent ratings of child ADHD symptoms (Chacko et al., 2013). However, the more demanding Cogmed WMT could also stimulate more frustration in ADHD children (Bigorra et al., 2016). More frustration and less motivation would increase the difficulty for parents and teachers to maintain children's training compliance as shown in Steeger et al. (2016). This was in contrast to the ease of completion in the placebo training. Thus, difficulties in managing children and more challenging working memory tasks might lead parents and teachers to overrate the ADHD symptoms of children receiving Cogmed WMT. This nocebo effect might underlie the negative findings of the five studies mentioned earlier. Although the nocebo effect and the therapeutic effect were in opposite directions, they could both bias parent and teacher ratings.

Bias in rating scales necessitates the adoption of other forms of assessment. Popular choices were more objective performance-based psychological tests. One example was the Continuous Performance Test asking children to respond to non-X letters. Commission errors of responding to X assessed impulsivity. Omission errors of omitting X assessed inattention (Stevens et al., 2016). Another example was the Stroop interference task. It assessed response inhibition by the time and accuracy of reading colour words printed in different colours (Muris et al., 2018). Using these two tasks, two studies (Bigorra et al., 2016; Klingberg et al., 2005) revealed a short-term positive effect of Cogmed WMT on sustained attention, impulse control, and response inhibition (*d* from .34 to .60). This positive training effect persisted 6 months after training in Bigorra et al. (2016). However, it did not persist 3 months after training in Klingberg et al. (2005) with a small

to medium effect size (*d* = .25). In addition, Chacko et al. (2014), Egeland et al. (2013), and Gray et al. (2012) did not reveal any training effect even in the short term (about 3 weeks after training) on attention, inhibition, or impulse control.

A problem with performance-based psychological tests is task impurity. Apart from putative cognitive abilities, they are influenced by lower-level cognitive processing (Snyder et al., 2015). In addition, it was spurious whether results of laboratory tests could transfer to real-life academic functioning. For dealing with this issue, Green et al. (2012) used the ecologically valid Restricted Academic Situations Task. This task involved a simulated classroom academic task, children's off-task behaviours on which were observed by researchers. Green et al.'s (2012) sample consisted of 26 ADHD children aged 7 to 14 in the US. They showed that off-task behaviours decreased significantly more for children receiving Cogmed WMT than the placebo training. This result was revealed despite no statistically significant group difference in parent ratings. As this study is the only study using this approach, replications in different samples are needed.

In short, it was spurious whether Cogmed WMT could have a positive effect on school-age ADHD children's ADHD symptoms assessed by either parent and teacher ratings or performance-based psychological tests. This was especially so as ratings were susceptible to bias and psychological tests suffered from task impurity. One study demonstrated a positive effect of Cogmed WMT on observed on-task behaviours during academic tasks, which needs replications.

Academic Achievement

According to the RoB 2 Tool, two studies were rated as having some concerns (Dahlin, 2010; Dahlin, 2013). They did not report sample allocation procedures. Thus, it was uncertain whether these procedures were randomised and concealed or not. These issues were rated as having some concerns according to the RoB 2 Tool. As they were not rated as having high risk of bias, they were included in the following discussion.

There were two studies applying a waitlist control group. Egeland et al. (2013) studied 67 Norwegian ADHD children aged 10 to 12. Dahlin (2011) studied 57 9-12-year-old Swedish children diagnosed as ADHD or rated by teachers or school psychologists as having attention problems. Both found a significant and positive training effect on reading comprehension both

post training and 6-8 months after training (d = .88 and .91 for Dahlin, 2010). Egeland et al. (2013) additionally revealed a positive training effect on word decoding (η^2 = .34 and .36). However, this was not revealed by Dahlin (2011). With regard to maths, Dahlin (2013) found a positive training effect of Cogmed WMT on the Basic Number Screening Test (BNST) 6 weeks after training (d = .69). This test assessed number concepts and calculations. However, no training effect was revealed for the timed addition and subtraction verification task in Dahlin (2011) and Key Math in Egeland et al. (2013). Key Math included a timed verbally presented calculation task and an untimed real-life math problem solving task.

This inconsistency might be related to specific task features. An important feature of the BNST was that it did not have a time constraint. Thus, it might be less dependent on automatic retrieval of arithmetic facts from long-term memory (Geary, 1993). It also had adult-read explicit instructions. This might make it less attentionally demanding or stressful. In addition, it did not embed mathematical problems in social contexts. Hence, ADHD children's impaired social interactions (Rich et al., 2009) might affect their performance less. Therefore, it might be the case that tests that were less attentionally demanding and relying less on social understanding or long-term memory might be more sensitive to ADHD children's academic achievement. It was unclear whether negative results were due to test insensitivity or a genuine lack of training effects.

In contrast to studies with a waitlist control group, all studies applying the placebo training in the control group revealed no training effects on literary or mathematical academic achievement (Bigorra et al., 2016; Chacko et al., 2014; Gray et al., 2012). All studies revealed no significant difference between children receiving Cogmed WMT and the placebo training in their improvement on standardised achievement tests. These tests included the Wide Range Achievement Test. This was a consistent and reliable measure of cross-age academic progress. It incorporated word reading, sentence comprehension, spelling, and mathematical computation (Woodward et al, 1975).

One factor possibly underlying these negative findings is developmental inertia. Standardised achievement tests often assessed cumulative academic achievement, which were heavily influenced by previous learning (Gathercole, 2014). Hence, they might be less sensitive to latest increases in learning capacities. For dealing with this issue, long-term follow-ups are needed. Among the three studies, only Bigorra et al. (2016) examined long-term training effect 6 months

after training. However, the 6-month follow-up might not be sufficiently long for training effect to transfer to academic achievement. For example, using a longer 8-month follow-up, Egeland et al. (2013) revealed a positive effect of Cogmed WMT on academic achievement. Dahlin (2011) found a positive training effect on reading comprehension at a similar 6-month follow-up. This might be because the authors broke narratives into smaller parts followed by questions. This practice might decrease the attentional demand of this task, thus increasing its sensitivity to subtle changes in ADHD children's reading comprehension.

To put it briefly, studies applying a waitlist control group showed a positive effect of Cogmed WMT on school-age ADHD children's reading comprehension. Studies employing active control groups consistently revealed no training effects on academic achievement. It remains uncertain whether these negative results were due to a genuine lack of training effects or achievement test insensitivity and limited study lengths.

External Validity

With reference to Table 2, several sources of bias might negatively affect study external validity. With regard to participant selection, all studies were conducted in a few countries (the US, Spain, Sweden, Norway, and Canada). This was possibly due to the eligibility criterion of studies written in English. Results based on subjects from Western industrialised countries should not be assumed to represent diverse populations in the world (Schulz et al., 2018). Studies on more diverse populations are needed. Second, the majority of studies employed much more males than females. This was partly due to the higher rate of ADHD diagnosis in boys than girls (Arnett et al., 2015). For increasing sample representativeness for girls, studies with more balanced gender compositions are needed.

With regard to outcome reporting, examining possible moderators of training effects is meaningful. Identifying moderators is helpful to specify the differential effects of Cogmed WMT on various groups of children. This information is further useful for informing training implementation. It waits to be explored whether the effect of Cogmed WMT is affected by gender differences in ADHD. For example, girls are less hyperactive and impulsive than boys (Dahlin, 2013). In addition, the ADHD population is inherently heterogeneous with various ADHD subtypes, comorbidities, and medications. These conditions might moderate the effect of Cogmed

WMT. However, their effects are poorly understood. For example, medication could alleviate ADHD children's working memory deficits. This might leave less improvement space for Cogmed WMT. At the same time, medication might make children have more cognitive resources at baseline to acquire further cognitive improvement through Cogmed WMT. Hence, studies examining possible moderators are needed (e.g., van der Donk et al., 2016). A possible difficulty in this area is to gain sufficient sample sizes for various groups of children. Caution should also be taken to properly treat the collinearity problem in multiple comparisons.

With regard to intervention implementation, Cogmed WMT was implemented in either the home or school setting. There might be differences in contextual factors (e.g., who played the role of training aides and the training environment). Differences in contextual factors might pose challenges to finding generalisability across settings. Thus, the influence of possible context-related differences needs further explorations.

With regard to long-term follow-ups, the length of follow-ups are highly inconsistent form 3 months (Klingberg et al., 2005) to 8 months (Egeland et al., 2013). A possibly valuable question to ask is how long the follow-up should be for examining the long-term effects of Cogmed WMT. The nature of academic achievement is largely different from training tasks (Adey & Shayer, 1993). Hence, it might take time for the effect of Cogmed WMT to transfer to children's academic achievement. If this process costs longer than one year, current studies with follow-ups shorter than one year might not be sufficient.

Conclusion

This study is a systematic review of the effect of Cogmed WMT on school-age ADHD children's working memory, ADHD symptoms, and academic achievement. It showed a positive effect of Cogmed WMT on trained verbal working memory tasks. However, the training effect was spurious on untrained working memory tasks, ADHD symptoms, and academic achievement. These findings did not accord with Klingberg's (2010) claim. This claim suggested that Cogmed WMT could induce plasticity in the neural network for working memory. In this case, training effects could transfer to untrained cognitive tasks and daily academic performance.

It has to be pointed out that current studies suffer from several limitations. There is a lack of adaptive training not tapping working memory. There is only one study applying ecologically valid tasks for off-task behaviours. Questions remain regarding achievement test insensitivity. Therefore, studies in these areas might be helpful for further elucidating the effect of Cogmed WMT. In addition, future studies need to include more diverse samples. Future systematic reviews might test for publication bias by using funnel plots. This was not performed in this study.

Nevertheless, findings of this study remind the readers to maintain a critical attitude towards Cogmed WMT. This is particularly important considering its popularity. On the website it writes that training benefits are "research-based" "substantial and long-lasting" with "significant improvements for people with ADHD" (Cogmed, 2019). This review does not provide strong support for these claims. Thus, these recommendations need to be supported by rigorous research in the future. Educational practitioners should not unreflectively receive these advertisements. They need to be critical in deciding whether to adopt Cogmed WMT for promoting the academic achievement of ADHD school-age children. This is especially so as Cogmed WMT requires investment of time and cost.

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