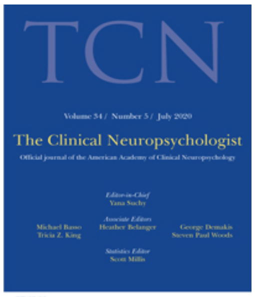

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A meta-analysis on verbal working memory in children and adolescents with ADHD

Ari Alex Ramos[a,b], Amer Cavalheiro Hamdan[a] and Liana Machado[b]

[a]Department of Psychology, Federal University of Paraná, Curitiba, Brazil; [b]Department of Psychology, University of Otago, Dunedin, New Zealand

ABSTRACT

Objective: Previous meta-analyses have demonstrated verbal working memory (WM) dysfunction in children and adolescents with attention deficit/hyperactivity disorder (ADHD); however, the findings are inconsistent. The main objective of this meta-analysis was to investigate the performance of children and adolescents with ADHD in the Digit Span Backwards (DSB) subtest from the Wechsler Intelligence Scale for Children or Wechsler Adult Intelligence Scale. We also sought to provide an updated meta-analysis on WM in children and adolescents with ADHD.
Method: PubMed, PsyINFO, Scopus, and Web of Science were searched to locate studies published between 1990 and 2016 that report DSB scores both of children and adolescents with ADHD and matched controls. Potential moderator variables were also analyzed.
Results: Forty-nine studies comparing children and adolescents with ADHD ($n = 4956$) against healthy controls ($n = 3249$) generated a medium-sized effect (Hedges' g) of 0.56 (95% CI [0.49, 0.64]), indicating poorer verbal WM performance in those with ADHD. A subgroup meta-analysis of studies with participants aged 8–16 years only demonstrated low heterogeneity ($I^2 = 17.06$, cf. 55.50 for the main analysis). Moreover, the meta-regression showed a negative association ($\beta = -.05$, $p = .02$) between DSB performance differences and increasing age, indicating that for every one year increase in age the effect size decreased by .05.
Conclusion: These results, which emanated from the largest meta-analysis concerning verbal WM in ADHD reported to date, reinforce WM as a key domain of cognitive dysfunction in ADHD, and point to age as the main variable influencing DSB performance difficulties.

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Attention-deficit/hyperactivity disorder; digit span backwards; WISC; WAIS; executive function

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders, with worldwide prevalence estimated at 7.2% in childhood and adolescence (Thomas, Sanders, Doust, Beller, & Glasziou, 2015). The core features of

CONTACT Ari Alex Ramos arialex.r@gmail.com Department of Psychology, Federal University of Paraná, Curitiba, Brazil

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ADHD are inattention and/or hyperactivity-impulsivity, along with other symptoms such as academic underachievement, impairment in social functioning and frequent disorganization (American Psychiatric Association, 2013). ADHD symptoms are clustered in three different subtypes of presentation: inattentive (ADHD-I), hyperactive/impulsive (ADHD-HI), and combined (ADHD-C). Inattentive behavior in ADHD includes avoidance or dislike of tasks that require sustained attention (e.g. schoolwork or listening to lectures), whereas hyperactivity/impulsivity encompasses excessive motor movements (e.g. squirming in seat, restlessness) and self-control difficulties (e.g. excessive talking) (American Psychiatric Association, 2013).

Several theoretical models have attempted to shed light on the neurocognitive mechanisms underlying ADHD symptoms. According to Barkley's prominent model, the key dysfunction in ADHD is response inhibition, which enables the ability to suppress a prepotent (dominant) response, to interrupt an ongoing response in favor of a more adaptive response, and to resist internal or external interferences to achieve goal-directed behaviors (Barkley, 1997). Barkley posited that inefficient response inhibition leads to deficiencies in executive functions such as self-regulation (e.g. the ability to control one's emotions) and working memory (WM) (see also Alderson et al., 2017; Sonuga-Barke, 2003, 2005). This chain of disruptions in executive functioning eventually results in the symptoms observed in ADHD (see also Sonuga-Barke, 2003, 2005). For example, inhibitory control difficulties can lead to the child struggling to maintain focus on goal-directed behaviors when distractions from the environment are present, resulting in hyperactivity/impulsivity/inattentiveness symptoms.

In contrast to inhibition models of ADHD, WM models propose that dysfunctional WM, which plays a fundamental role in the development of organized behaviors, is the central characteristic of ADHD (Kofler, Sarver, Harmon, et al., 2018; Rapport, Chung, Shore, & Isaacs, 2001). According to WM models of ADHD, impairments in response inhibition are a byproduct of WM deficits, as the activation of information in WM precedes the decision to suspend or delay a behavioral response (Kofler, Rapport, Bolden, & Altro, 2008). Moreover, it is deficiencies in WM that lead to behaviors characterized as inattentive, impulsive and/or hyperactive, for example in relation to shifts of attentional focus from monotonous or complex tasks to other environmental or internal stimuli (Kofler et al., 2011; Rapport et al., 2009, 2001).

The Rapport et al. (2001) WM model of ADHD was based on assumptions initially formulated by Baddeley and Hitch (1974) regarding how WM works. Baddeley and Hitch (1974) defined WM as a multicomponent system that requires information to be both stored and simultaneously manipulated in the mind to perform complex tasks. According to this approach, WM is composed of a central executive system and two subsidiary short-term systems—the phonological loop and the visuospatial sketchpad. While the former is responsible for storing speech-based information, the latter stores visuospatial information. The central executive, in addition to coordinating its two subsidiary systems, works as a mechanism for controlling attention and monitoring information, and is activated by complex activities that require focused attention (Baddeley, 1992, 1996; Baddeley & Hitch, 1974; Repovš & Baddeley, 2006). More recently, a fourth element was added to this WM model: the episodic buffer, defined as temporary storage responsible for binding information from different sources (such as phonological loop, visuospatial sketchpad, and long-term memory) and modalities (e.g. visual and verbal) into an organized structure that enables the planning of future actions (Baddeley, 2000; Repovš & Baddeley, 2006).

Setting aside the disagreement regarding whether WM difficulties transpire first, these models of ADHD all postulate that WM difficulties lead to symptoms of ADHD. Moreover, recent research has demonstrated links between WM and abilities fundamental to success in school and in everyday life, such as fluid intelligence (Brydges, Ozolnieks, & Roberts, 2017, in press), reading comprehension (Friedman, Rapport, Raiker, Orban, & Eckrich, 2017), written expression (Eckrich, Rapport, Calub, & Friedman, 2018), mathematical skills (Friedman, Rapport, Orban, Eckrich, & Calub, 2018), and organizational skills (Kofler, Sarver, Harmon, et al., 2018). These findings highlight the importance of having high functioning WM systems.

Evidence suggests that WM deficits may depend on the ADHD subtype. Although not always the case (e.g. Saydam et al., 2015), children with ADHD-I tend to show poorer performance on WM tasks relative to children with ADHD-HI or ADHD-C (Colbert & Bo, 2017; see also Martinussen & Tannock, 2006; Messina, Tiedemann, de Andrade, & Primi, 2006), whereas children with ADHD-C exhibit more difficulties during tasks assessing response inhibition (Desman, Petermann, & Hampel, 2008; Houghton et al., 1999; Lockwood, Marcotte, & Stern, 2001; Romero-Ayuso, Maestú, González-Marqués, Romo-Barrientos, & Andrade, 2006). These results support the model proposed by Diamond (2005) that response inhibition difficulties are the core deficit in ADHD with hyperactivity (ADHD-HI and ADHD-C), whereas WM dysfunction is the core deficit in ADHD-I. In the current quantitative synthesis, we performed a subgroup meta-analysis to determine influences of ADHD subtype on verbal WM function.

Several studies have demonstrated that impairment of verbal WM in ADHD is less evident across empirical findings compared to visuospatial WM (Brocki, Randall, Bohlin, & Kerns, 2008; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Rapport et al., 2008; Sowerby, Seal, & Tripp, 2011). For example, Sowerby et al. (2011) found that in children with ADHD, after controlling for comorbid learning and language difficulties, visuospatial WM remained significantly impaired, but impairment of verbal WM remained only marginally significant. However, others have reported that children with ADHD show impairments, albeit not necessarily to the same extent, in both verbal and visuospatial WM after controlling for comorbid learning and language difficulties (e.g. Martinussen & Tannock, 2006; see also Rapport et al., 2008). Moreover, evidence suggests that verbal WM should be impaired. First, poor verbal WM and poor vocabulary skills have been postulated to be intertwined and associated with ADHD symptoms in preschool children, with early verbal WM intervention being posited as an important step in treating ADHD during childhood (Gremillion & Martel, 2012; Gremillion, Smith, & Martel, 2018). Second, in contrast to several empirical findings, previous meta-analyses have identified impairment in verbal WM in children and adolescents with ADHD, but the magnitude of the effect sizes varies according to the number of studies included in each meta-analysis (see Table 1); thus, it was anticipated that a larger meta-analysis may produce a more reliable effect size for verbal WM in ADHD.

A prominent previous meta-analysis investigated several executive functions in ADHD (e.g. planning, inhibition, set-shifting) and estimated an effect size of 0.55

Table 1. Effect sizes from meta-analyses on verbal working memory in attention-deficit/hyperactivity disorder.

Authors (Year)	N (Studies)	N (ADHD)	N (Control)	Effect size	Lower limit	Upper limit
Previous meta-analyses						
Kasper et al. (2012)[a]	34	988	1086	0.69	0.53	0.84
Martinussen et al. (2005)[b,c]	13	475	557	0.56	0.29	0.83
Martinussen et al. (2005)[b,c]	12	464	538	0.43	0.24	0.62
Willcutt, Doyle, et al. (2005)[d]	11	661	718	0.55	0.44	0.66
Current meta-analysis[e]	49	4956	3249	0.56	0.49	0.64

Note. In this table, only Martinussen et al. (2005) used Cohen's *d*; the other authors chose Hedges' *g* as the effect size. The present meta-analysis estimated Hedges' *g* at 0.56, which is equivalent to Cohens' *d* at 0.56. As the sample size increases, the two effect sizes tend to approach each other in value, thus, avoiding erroneous conclusions when they are compared.

[a]Kasper et al. (2012) included several verbal WM tasks such as digit span backwards (DSB), number/letter sequencing, 1-back or 2-back, final word recall, and counting span.

[b]The authors reported two results: an outlier was excluded from the second (leaving 12 studies).

[c]Martinussen et al. (2005) included several verbal WM tasks such as DSB, number recall of Kaufman Assessment Battery for Children (K-ABC), word order, word span, and digit recall.

[d]Willcutt, Doyle, et al. (2005) reported effect sizes based on only two tests (working memory sentence span and DSB).

[e]Pitzianti et al. (2016) proved to be an outlier and thus was excluded.

ADHD: Attention-Deficit/Hyperactivity Disorder.

regarding verbal WM (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). However, the authors did not interpret their results as evidence of verbal WM dysfunction due to small sample sizes and other inconsistencies observed in some of the studies included in the meta-analysis (e.g. sampling procedures and diagnostic criteria). Given that the authors found only a handful of studies that investigated executive functions in ADHD, including verbal WM ($n = 11$), we anticipated that the current meta-analysis with a larger number of studies would help clarify whether verbal WM dysfunction occurs in ADHD. Another important meta-analytical study focused exclusively on WM in children and adolescents with ADHD (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), and grouped several WM tasks according to modality (verbal or spatial) and type of processing (storage vs. storage/manipulation). The verbal WM effect size was initially estimated at 0.56, but was adjusted to 0.43 after the removal of an outlier (see Table 1).

Kasper, Alderson, and Hudec (2012) performed a larger meta-analysis on children and adolescents with ADHD, and the effect size was estimated at 0.69 for verbal WM, a larger effect than those estimated by previous quantitative syntheses (see Table 1). This meta-analysis focused on a wide range of potential moderating variables (e.g. age, sex, and number of experimental trials) to explore the effect size variance within and between studies. Interestingly, the authors decided to include only studies with participants between 8 and 16 years of age, a criterion that may have contributed to the lack of influence of age on the effect size variance. In the present study, we included children and adolescents aged 6 to 18 years in the main analysis. In a second step, to enable comparison with the largest meta-analysis to date, the current study first analyzed the age range of 8–16 years as a categorical moderating variable (subgroup meta-analysis), and then conducted a meta-regression with all the ages of ADHD participants to investigate and elucidate whether age influences the effect size variance.

The main goal of this meta-analysis was to investigate verbal WM in children and adolescents with ADHD in comparison with healthy controls, whose scores were obtained exclusively from the Digit Span Backwards (DSB) subtest of the Wechsler Intelligence Scale for Children (WISC) or the Wechsler Adult Intelligence Scale (WAIS) as these scales are some of the most widely used evaluation tools for neuropsychological assessment in places such as Canada and the United States (Rabin, Barr, & Burton, 2005), Brazil (Ramos & Hamdan, 2016), and Europe (Evers et al., 2012). DSB in particular was chosen because it is one of the most frequently used tests for assessing verbal WM (Conway et al., 2005). In contrast to Digit Span Forwards (DSF), which requires only the temporary storage and maintenance of information in mind, DSB requires storage, maintenance and manipulation of information and thus qualifies as a WM task (reviewed recently in Hurley & Machado, 2018). For instance, empirical findings have indicated that DSB requires executive functioning (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Carlesimo, Fadda, Lorusso, & Caltagirone, 2009; Conklin, Curtis, Katsanis, & Iacono, 2000; Grégoire & Van Der Linden, 1997; Hale, Hoeppner, & Fiorello, 2002; Wells, Kofler, Soto, Schaefer, & Sarver, 2018). Moreover, brain-based evidence shows that DSB enlists brain areas commonly involved in executive functions (e.g. dorsolateral prefrontal cortex and anterior cingulate cortex), which is less evident with DSF (Gerton et al., 2004; Hoshi et al., 2000; Sun et al., 2005; Tian et al., 2014; Yang et al., 2015). For example, activation of dorsal anterior cingulate cortex showed a positive DSB correlation and negative DSF correlation (Yang et al., 2015). Consistent with recommendations (Reynolds, 1997), composite digit span scores were not included in the current meta-analysis because they combine DSF and DSB scores, thus, preventing attribution of performance differences specifically to WM.

The present meta-analytical review adds to the existing literature by providing an updated meta-analysis on verbal WM in children and adolescents with ADHD, presenting 34 studies not previously included in meta-analyses on the topic. The a priori hypothesis was that a meta-analysis carried out using only DSB scores from WISC or WAIS would elucidate whether verbal WM dysfunction is a core neurocognitive feature of ADHD. Finally, the analysis of several potential moderator variables (covariates) was performed to investigate whether they account for some of the effect size variability within and between the studies included in the quantitative synthesis (Holmbeck, 1997).

Method

The systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). The PubMed, PsyINFO, Scopus, and Web of Science databases were searched on 02 January 2017, using the following keywords: ("ADHD" *OR* "ADD" *OR* "hyperkinetic syndrome" *OR* "attention deficit disorder" *OR* "attention deficit hyperactivity disorder") *AND* ("working memory" *OR* "digit span" *OR* "digit backward"; see Supporting Information A for more details). Note that the search term "digit span" returned articles that used terms that included these words (e.g. digit span backward and backward digit span). The period of interest covers the years from 1990 to 2016. In addition to the databases, the reference lists of the articles selected during the systematic review were thoroughly examined to find other possible studies of interest. All articles found were transferred to EndNote, after which multiple occurrences of the same reference were reduced to one. The abstract of each article was then examined to select articles deemed relevant to be included in the meta-analysis.

Included in the search were scientific articles published in English, Spanish, and Portuguese, with the goal of reducing the risk of publication and language biases (Egger, Zellweger-Zähner, et al., 1997). The samples were limited to populations consisting of children (6 years of age and older) and/or adolescents up to and including 18 years of age. Regarding ADHD diagnosis, studies had to report on children and adolescents who had been diagnosed according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-III-R, DSM-IV, DSM-IV-TR, or DSM-V) or the International Statistical Classification of Diseases and Related Health Problems (10th Edition; ICD-10) to be included in the meta-analysis; therefore, an indication of ADHD symptoms without a final diagnosis of ADHD was deemed an insufficient inclusion criterion. Only studies that reported the mean and the *SD* (or *SE* or confidence intervals) of the DSB scores from the WISC or WAIS were included. For studies that reported *SE* or confidence interval, we first converted these statistics into *SD* before conducting the meta-analysis. Following the same approach from previous meta-analyses (Kasper et al., 2012; Martinussen et al., 2005; Willcutt, Doyle, et al., 2005), we included DSB scores from any WISC/WAIS edition (e.g. WISC-III or WISC-R).

Excluded from the meta-analysis were unpublished works, Master's theses, and Doctoral dissertations. Also excluded were studies without a healthy control group, those with pharmacological intervention, and those that included children or adolescents with ADHD reported to exhibit comorbidities such as learning disabilities, schizophrenia, autism, bipolar disorder, or other neurological conditions. However, due to its high incidence in ADHD (Busch et al., 2002), samples with comorbidities of oppositional defiant disorder, conduct disorder, and anxiety disorder were not excluded.

A flow diagram illustrating the systematic review is given in Figure 1, showing that of the 126 articles initially selected, 76 were eliminated for the following reasons: lack of diagnostic criteria necessary for including participants in the ADHD group ($n = 1$); scores from DSB were not reported in the study ($n = 58$); the reported scores from DSB were different from the mean and the *SD* (or *SE* or confidence interval), such as correlation and linear regression ($n = 7$); scores from DSB refer to a previous study conducted by the authors ($n = 1$); studies that reported only the mean from DSB without *SD*, confidence interval, or *SE* ($n = 2$); inclusion of participants younger than 6 or older than 18 years ($n = 6$); lack of information concerning the Wechsler scale used ($n = 1$). Finally, 50 studies were retained and formally included in the meta-analysis; however, the study by Pitzianti et al. (2016) was subsequently eliminated, since it was deemed as an outlier according to Grubbs' test (Grubbs, 1950).

Data extraction

Regarding the data characteristics obtained from the studies, the following variables were compiled: primary author, publication date, title of the article, geographical location, and the version of the Wechsler scale (edition and language). Regarding the sample characteristics, the sample size, age range, IQ, sex, ADHD subtype, diagnostic criteria, and time elapsed since the last use of psychostimulant medication were

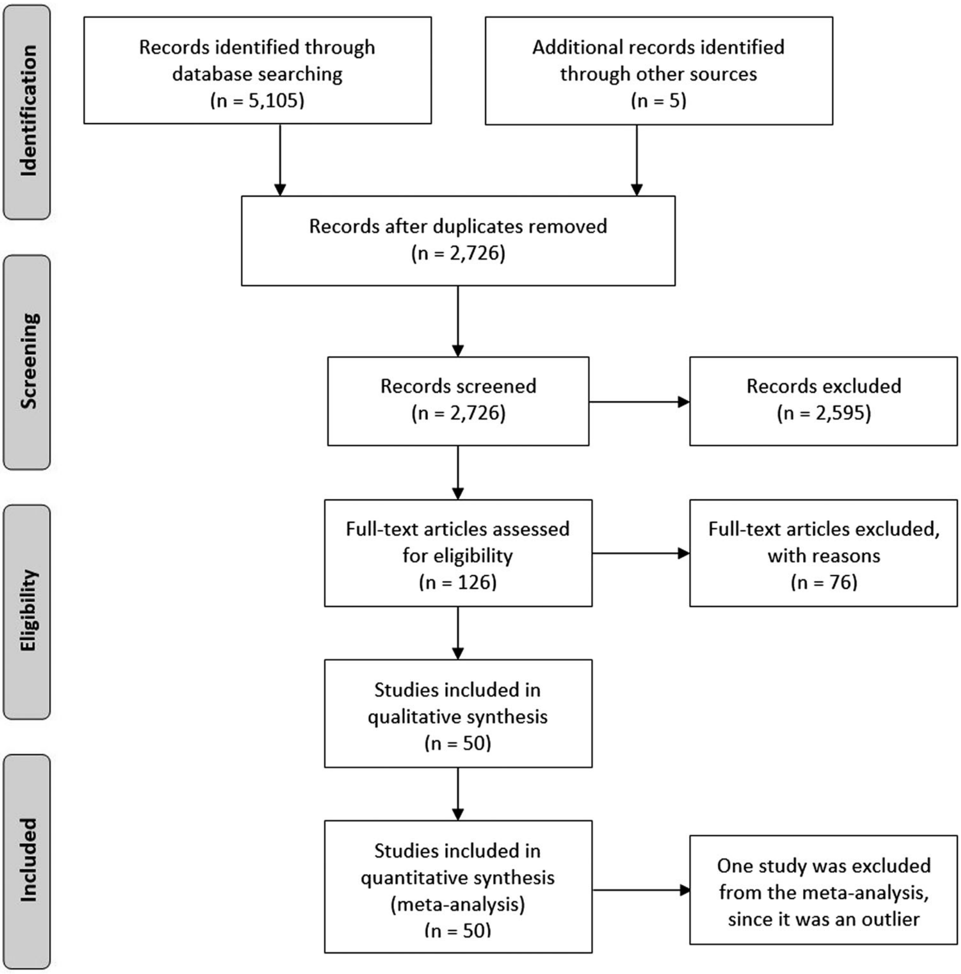

Figure 1. Systematic review flow diagram. Adapted from "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement" by D. Moher, A. Liberati, J. Tetzlaff, D. G. Altman, and The PRISMA Group, 2009. *PLoS Medicine, 6*(7), e1000097, p. 3.

recorded. For studies aimed at genetic investigation, only the scores of the control group and those of the probands were included in the meta-analysis. Table S1 in Supporting Information B shows the moderator variables selected during the systematic review to conduct the subgroup meta-analyses. Considering several studies did not report IQ scores (see Table 2), we did not analyze IQ as a covariate in the meta-regression to avoid confounding findings that may limit generalizability.

Analysis of the data and effect size

A meta-analysis was carried out in R version 3.5.0 (R Core Team, 2018) with RStudio (RStudio Team, 2015), using the meta package (Schwarzer, 2007). The random-effects model is the most appropriate model for the meta-analysis calculation as it is possible that the individual studies measure distinct effects (Engels, Schmid, Terrin, Olkin, & Lau, 2000). The restricted maximum likelihood method was chosen to estimate the

Table 2. Descriptive data and effect sizes from included studies in the meta-analysis.

Studies (Year of publication)	ADHD N	ADHD Age	ADHD IQ	Control N	Control Age	Control IQ	Hedges' g	95% CI LL	95% CI UL
Aly, Effat, Azb, and Abd Elsamei (2015)	30	10.2[a]	105.0	30	10.2[a]	107.9	1.333	0.770	1.896
Banaschewski et al. (2012)	302[b]	11.3	102.8	259[b]	12.2	107.6	0.527	0.358	0.696
Casas, Alba, Taverner, Rosello, and Mulas (2006)	33	10.0	106.1	15	10.9	117.8	1.855	1.132	2.578
Casas, Andrés, Castellar, Miranda, and Diago (2011)	21	13.9	108.1	21	13.9	105.8	0.934	0.294	1.575
Chiang and Gau (2008) – ADHD-C	52	8.5	105.0	52	8.7	114.3	0.350	–.038	0.737
Chiang and Gau (2008) – ADHD-I	17	8.5	108.6	52	8.7	114.3	0.346	–.205	0.897
Coutinho, Mattos, and Malloy-Diniz (2009)	186	11.5	96.8	80	12.4	98.5	0.417	0.153	0.682
Fan, Gau, and Chou (2014)	25	10.9	107.2	23	11.2	109.1	0.601	.021	1.181
Gau and Chiang (2013)	389[c]	12.0[a]	–	317[c]	12.0[a]	–	0.556	0.405	0.707
Gau and Shang (2010)	279	12.5	103.0	173	12.6	110.7	0.478	0.286	0.671
Gau, Chiu, Shang, Cheng, and Soong (2009)	53	12.7	107.3	53	12.7	108.6	0.245	–.137	0.627
Gremillion and Martel (2012)	201[b]	9.7	100.8	154[b]	9.8	104.7	0.395	0.183	0.607
Healey and Rucklidge (2006)	29	11.4	106.0	30	11.1	117.1	0.556	.035	1.077
Karalunas and Huang-Pollock (2013)	91	10.2	104.4	62	10.6	106.9	0.299	–.026	0.623
Kaufmann and Nuerk (2006)	16	10.2	–	16	10.4	–	–.158	–.852	0.536
Kim et al. (2014)	17	10.1	–	17	10.2	–	0.769	.069	1.469
Lee et al. (2008) – ADHD-C	200	8.6	102.3	47	10.2	119.0	0.841	0.515	1.168
Lee et al. (2008) – ADHD-HI	60	8.3	105.9	47	10.2	119.0	0.809	0.412	1.207
Lee et al. (2008) – ADHD-I	113	9.1	102.5	47	10.2	119.0	0.907	0.553	1.262
Lee et al. (2008) – HKD	46	8.0	103.9	47	10.2	119.0	1.073	0.637	1.509
Manassis, Tannock, Young, and John (2007) – ADHD	21	9.6	103.4	35	9.7	110.4	0.753	0.193	1.313
Manassis, Tannock, Young, and John (2007) – ADHD + ANX	35	9.8	103.5	35	9.7	110.4	0.457	–.018	0.932
Martinussen and Tannock (2006)	60[d]	8.7	101.7	25[d]	9.1	115.6	0.587	0.111	1.062
McAuley et al. (2014)	64	13.7	102.8	28	13.6	117.5	–.122	–.566	0.323
McInerney and Kerns (2003)	30	10.1	–	30	10.1	–	0.786	0.259	1.312
Mello et al. (2013)	12	10.7	–	11	9.1	–	1.132	0.238	2.026
Nguyen et al. (2014)	77[b]	11.5	91.6	141[b]	12.4	104.3	0.387	0.107	0.667
Nyman et al. (2010)	30	8.7	94.7	30	8.6	108.3	0.731	0.207	1.896
O'Brien, Dowell, Mostofsky, Denckla, and Mahone (2010) – ADHD Boys	30	10.5	107.6	48	10.1	115.3	0.290	–.169	0.927
O'Brien, Dowell, Mostofsky, Denckla, and Mahone (2010) – ADHD Girls	26	9.8	109.0	42	10.4	113.0	0.433	–.062	0.595
Øie, Sundet, and Rund (1999)	20	14.1	98.6	30	15.7	110.5	0.475	–.099	1.575
Pasini, Paloscia, Alessandrelli, Porfirio, and Curatolo (2007) – ADHD-C	25	10.1	–	44	10.6	100.0	0.711	0.205	0.737
Pasini, Paloscia, Alessandrelli, Porfirio, and Curatolo (2007) – ADHD-I	25	11.4	–	44	10.6	100.0	0.682	0.177	0.897
Passolunghi, Marzocchi, and Fiorillo (2005)	10	9.8	105.1	10	9.9	107.5	1.019	.074	0.682
Pitzianti et al. (2016)	13	10.2	97.5	13	11.9	106.3	3.059	1.873	4.244
Qian, Shuai, Cao, Chan, and Wang (2010) – ADHD	89	9.1	108.2	116	9.2	112.8	0.185	–.092	0.462
Qian, Shuai, Cao, Chan, and Wang (2010) – ADHD + ODD	53	9.3	107.0	116	9.2	112.8	0.249	–.077	0.575
Qian, Shuai, Chan, Qian, and Wang (2013) – 7-to 8-year old	153	7.8	104.6	55	8.1	111.9	0.276	–.033	0.585
Qian, Shuai, Chan, Qian, and Wang (2013) – 9-to 10-year old	182	9.3	105.9	100	9.5	116.3	0.293	.048	0.539
Qian, Shuai, Chan, Qian, and Wang (2013) – 11- to 12-year old	76	11.4	105.9	62	11.3	115.4	0.481	0.141	0.822
Qian, Shuai, Chan, Qian, and Wang (2013) – 13- to 15-year old	104	13.7	106.4	32	13.5	117.6	0.199	–.198	0.596
Rodríguez Pérez et al. (2009)	40	11.4	100.4	124	10.9	109.6	0.873	0.504	1.242
Rosenthal et al. (2006) – ADHD-C	28	11.4	102.0	27	11.5	109.5	0.693	0.147	1.238
Rosenthal et al. (2006) – ADHD-I	12	12.4	95.8	27	11.5	109.5	–.301	–.984	0.383
Rucklidge and Tannock (2002)	35	15.2	102.2	37	14.9	111.0	0.253	–.211	0.718
Saydam et al. – ADHD-C	37	8.9	103.6	36	9.3	108.3	0.516	.049	0.982

(continued)

Table 2. Continued.

Studies (Year of publication)	ADHD N	ADHD Age	ADHD IQ	Control N	Control Age	Control IQ	Hedges' *g*	95% CI LL	95% CI UL
Saydam et al. – ADHD-C + ODD/CD	37	9.1	102.3	36	9.3	108.3	0.596	0.126	1.065
Saydam et al. – ADHD-I	37	9.9	103.6	36	9.3	108.3	−.158	−.618	0.301
Schachar et al. (2007) – ADHD-C	353	8.8	100.6	67	9.8	118.4	0.826	0.559	1.094
Schachar et al. (2007) – ADHD-HI	142	8.6	104.8	67	9.8	118.4	0.773	0.473	1.073
Schachar et al. (2007) – ADHD-I	237	9.3	101.7	67	9.8	118.4	0.821	0.542	1.100
Schachar et al. (2007) – HKD	72	8.2	101.4	67	9.8	118.4	1.018	0.664	1.372
Siklos and Kerns (2004)	19	10.1	71.3	19	10.0	71.4	0.814	0.149	1.479
Simone, Bédard, Marks, and Halperin (2016)	63	8.6	103.6	51	8.5	110.4	0.573	0.196	0.950
Skowronek, Leichtman, and Pillemer (2008)	12	12.2	–	17	11.5	–	0.949	0.165	1.733
Soroa, Iraola, Balluerka, and Soroa (2009)	12	8.5	–	13	9.0	–	1.055	0.208	1.902
Sowerby et al. (2011)	40	8.4	94.7	40	8.4	101.4	0.371	−.071	0.814
Spronk et al. (2013)	15	14.8	99.1	19	14.8	96.5	.000	−.677	0.677
Tiffin-Richards, Hasselhorn, Woerner, Rothenberger, and Banaschewski (2008)	20	11.6	97.4	19	11.7	107.9	0.852	0.193	1.511
Tillman, Bohlin, Sørensen, and Lundervold (2009)	45	10.3	–	120	9.8	–	0.505	0.158	0.852
Toplak and Tannock (2005)	46	15.6	104.1	44	15.3	110.7	0.861	0.428	1.294
Toplak, Rucklidge, Hetherington, John, and Tannock (2003)	35	15.2	102.2	39	15.0	110.1	0.266	−.193	0.724
Udal et al. (2013)	26	12.6	97.8	69	12.3	99.9	0.723	0.260	1.186
Willcutt, Pennington, Olson, Chhabildas, and Hulslander (2005)	113	11.2	104.3	151	11.5	113.6	0.590	0.341	0.839
Wu, Anderson, and Castiello (2002)	58	10.5	103.3	29	10.6	113.7	0.426	−.024	0.877
B. R. Yang et al. (2007)	40	8.5	99.3	40	8.6	108.3	0.723	0.270	1.176
B. R. Yang et al. (2011)	100	8.4	98.5	100	8.5	106.8	1.044	0.749	1.340
Full effect size							*0.573*	*0.495*	*0.650*
Full effect size without Pitzianti et al. (2016)							*0.563*	*0.488*	*0.638*

Note. Dashes indicate information not provided. CI: Confidence Interval. LL: Lower Limit. UL: Upper Limit. ADHD: Attention-Deficit/Hyperactivity Disorder (C: combined subtype; I: inattentive subtype; HI: hyperactivity-impulsivity subtype). HKD: Hyperkinetic Syndrome. ODD: Oppositional-Defiant Disorder. CD: Conduct Disorder. ANX: Anxiety Disorder.

[a]Mean age reported by the authors refers to the full sample (ADHD and controls).

[b]The number of children and adolescents whose DSB scores were reported in the study. However, the mean and *SD* of age and IQ refer to the full sample in each group (clinical and control).

[c]Descriptive statistics reported only for the full sample and not separated according to group (clinical and control).

[d]DSB data were not available for some ADHD and control participants; the full sample was composed of 62 participants with ADHD and 34 control participants.

between-study variance (Patterson & Thompson, 1971). Hedges' *g*, also known as the corrected effect size, was used. It is an unbiased estimate of the effect size of the population (Hedges, 1981) and is appropriate for situations involving studies with small sample sizes ($n < 20$) (Hedges & Olkin, 1985; Lakens, 2013). The interpretation of Hedges'*g* is based on benchmarks suggested by Cohen (1988): 0.2 = a small effect; 0.5 = a medium effect; 0.8 = a large effect. The common language effect size (McGraw & Wong, 1992), for which interpretation is based on percentage (0% to 100%), was also used. The calculation of the effect sizes was based on the mean and the *SD* of DSB scores from the samples with ADHD and the control group.

As a mere matter of convention, this meta-analysis uses positive *g* values to indicate effects unfavorable to the group with ADHD. Possible outliers, defined as "data points that lie at a distance from other data points because they are the result of inaccuracies" (Aguinis, Gottfredson, & Joo, 2013, p. 281), were identified using Grubbs' test (Grubbs, 1950). Raw scores and scaled or age-adjusted scores were included in the meta-analysis, which is deemed acceptable since in all cases ADHD scores were compared against age-matched controls; this rationale is also in accordance with previous meta-analyses (Kasper et al., 2012; Martinussen et al., 2005; Willcutt, Doyle, et al., 2005).

Heterogeneity and publication bias

Heterogeneity occurs when a difference found in the results from the individual studies either is not explained by sample error or exceeds the sample error (Cumming, 2012) and may not be satisfactorily attributed to chance (Engels et al., 2000). In addition to the Q statistic, which measures the effect size variance regarding the degrees of freedom, the interpretation of heterogeneity in this meta-analysis was based on the I^2 statistic (Higgins & Thompson, 2002), which measures the percentage of the effect size variability not caused by sample error and generates an amplitude that varies between 0% and 100% (Higgins & Thompson, 2002; Huedo-Medina, Sánchez-Meca, Marín-Martínez, & Botella, 2006). To interpret I^2 results, the benchmarks proposed by Higgins, Thompson, Deeks, and Altman (2003)—low (25%), moderate (50%), and high (75%)—were adopted in the present meta-analysis.

Publication bias occurs when published studies are not representative of the entire body of research that has been conducted in a specific area of interest, which can result in incorrect conclusions and harmful treatments (Rothstein, Sutton, & Borenstein, 2005). The preference for studies with statistically significant results (the file drawer problem) remains the main cause of publication bias (Button, Bal, Clark, & Shipley, 2016). In this meta-analysis, publication bias was studied principally using funnel plots. When no bias exists, the funnel plot assumes the shape of an inverted funnel, and the plotted data exhibit a symmetrical distribution on both sides (Egger, Smith, Schneider, & Minder, 1997; Sterne & Egger, 2001). In consideration of the fact that a bias analysis-based exclusively on funnel plots is primarily visual (Egger, Smith, et al., 1997), precarious (Ioannidis, 2008) and subjective (Duval, 2005; Sterne, Becker, & Egger, 2005), its use was complemented with Duval and Tweedie's trim-and-fill method (Duval & Tweedie, 2000). This method assumes that a meta-analysis has been affected by publication bias when the funnel plot is asymmetrical. Thus, besides the included samples (n_0), the trim-and-fill method estimates the number of relevant samples (k_0) not included in the meta-analysis due to publication bias. Since k_0 and its respective effect sizes are unknown, the trim-and-fill method estimates these values and plots the absent samples on the funnel plot, thus, making it symmetrical and recalculating the "real" center of the funnel (Duval, 2005; Duval & Tweedie, 2000).

Results

The descriptive data from the samples and estimated effect sizes (Hedges' g) are shown in Table 2. The full effect size was initially moderate (0.57, 95% CI [0.50, 0.65]). However, the study by Pitzianti et al. (2016) with an effect size of 3.06 (95% CI [1.87, 4.24]) was subsequently removed from the meta-analysis since it proved to be an outlier according to the Grubbs test ($G = 5.13$, $p < .05$). The exclusion of this study lowered the heterogeneity percentage (I^2) from 59.58 ($Q = 163.29$, $df = 66$) to 55.50

($Q = 146.07$, $df = 65$). Therefore, the final estimated g value of 0.56 (95% CI [0.49, 0.64]) was adopted for this meta-analysis. After excluding the study by Pitzianti et al. (2016), this meta-analysis included a sample of 4956 participants with ADHD and a sample of 3249 healthy controls. A total of 49 studies were included, and DSB scores were obtained from 66 ADHD samples and 53 control samples.

Four studies were published in Spanish, and the remaining studies in English. All the studies included in the meta-analysis were carried out using the WISC and/or WAIS versions developed for use with the population of the country in which it was conducted. Only one study found no difference between the ADHD group and the control group, that is, $g = 0$ (Spronk, Vogel, & Jonkman, 2013), and four studies reported better performance in the ADHD group (Kaufmann & Nuerk, 2006; McAuley, Crosbie, Charach, & Schachar, 2014; Rosenthal, Riccio, Gsanger, & Jarratt, 2006; Saydam, Ayvasik, & Alyanak, 2015). A Hedges'*g* value estimated at 0.56 indicates that the average DSB performance of the children and adolescents with ADHD was found to be slightly more than one half of a *SD* below the average of the healthy controls. According to Dunlap (1999), an effect size of 0.56 corresponds to 0.65 in the common language effect size (the statistic that allows one to determine the real effect size in terms of probability). This means that a child chosen randomly from the control group has a 65% probability of achieving a higher score than a child with ADHD.

The moderate degree of heterogeneity ($I^2 = 55.50$; $Q = 146.07$, $df = 65$) suggests that 55% of the variability between the effect sizes is a consequence of actual heterogeneity and is not explained by sample error (Huedo-Medina et al., 2006). Table 3 summarizes the results from the subgroup meta-analyses, and Table S1 in Supporting Information B shows the details about the moderator variables included in the meta-analysis. Age seemed to be the main explanation for the moderate level of heterogeneity, since the subgroup meta-analysis of 29 studies that included only children and adolescents aged 8 to 16 years estimated a medium-sized effect at 0.45 (95% CI [0.37, 0.53]), with a low level of heterogeneity ($I^2 = 17.06$). To address the question of whether the effect size varied by age, we performed a meta-regression with the average age of the ADHD group as a covariate. Findings suggest an association between age and verbal WM performance differences. Age accounted for 12.76% (R^2) of the variance in true effects, with a medium level of residual heterogeneity ($I^2 = 54.49$; $Q = 136.21$, $df = 64$), which means that approximately 55% of the unaccounted variability in the meta-regression may be explained by other covariates. The coefficient for age ($\beta = -.05$, $p = .02$, 95% CI [–.08, –.01]) suggested that for every increase of one year of age the effect size decreased by .05. Figure 2 shows the dispersion of the studies with ADHD age as a covariate. The size of the symbols in Figure 2 reflects the weight given to each study included in the meta-analysis; larger symbols represent studies with a more precise effect (greater statistical power that is reflected in smaller confidence intervals).

Regarding other moderators (see Table 3), it was initially thought that ADHD subtypes could explain the variability of the data; however, these subgroup meta-analyses showed that only ADHD hyperactive/impulsive (ADHD-HI, $n = 2$) and hyperkinetic syndrome (HKD, $n = 2$) subtypes were homogeneous, with $I^2 = .00$. The edition of the Wechsler scale used also provided minimal insight regarding the variability of the

Table 3. Subgroup meta-analyses.

Moderators	Subgroups	*N*	Effect size	Lower limit	Upper limit	I^2	*Q*
Age range							
	8- to 16-year old	29	0.450	0.370	0.531	17.06	33.76
	Other age ranges	37	0.636	0.526	0.745	65.21	103.49
Sex							
	Boys	8	0.692	0.278	1.106	68.93	22.53
	Girls	1	0.433	–.062	0.927	–	–
	Mixed	51	0.567	0.481	0.653	57.60	117.92
	Not Informed	6	0.501	0.407	0.596	.00	3.84
ADHD subtype							
	Mixed	32	0.438	0.368	0.508	32.75	46.10
	ADHD-C	15	0.652	0.520	0.785	45.62	25.74
	Not Informed	8	0.742	0.516	0.967	43.44	12.38
	ADHD-I	7	0.493	0.113	0.874	24.70	75.71
	ADHD-HI	2	0.786	0.547	1.026	.00	.02
	HKD	2	1.040	0.765	1.315	.00	.04
Wechsler edition							
	WISC-III	36	0.594	0.494	0.694	52.38	73.49
	WISC-R	12	0.691	0.457	0.926	58.76	26.67
	WISC-IV	8	0.405	0.283	0.527	.00	2.72
	C-WISC	8	0.425	0.210	0.641	72.89	25.82
	WISC-III/WAIS-III	2	0.797	0.481	1.113	.00	0.18
Diagnostic criteria							
	DSM-IV	50	0.535	0.457	0.612	52.57	103.31
	DSM-IV-TR	11	0.624	0.330	0.919	65.07	28.63
	ICD-10	2	1.040	0.765	1.315	.00	.04
	DSM-III-R	1	0.475	–.099	1.049	–	–
	DSM-V	1	0.594	0.217	0.972	–	–
Medication status							
	24 h	19	0.461	0.371	0.550	18.30	22.03
	48 h	11	0.807	0.684	0.930	23.57	13.08
	Not informed	10	0.707	0.373	1.042	74.29	35.01
	Nonmedicated	8	0.350	0.206	0.494	32.66	10.40
	On the Day	6	0.378	0.128	0.627	41.67	8.57
	Naïve	5	0.718	0.444	0.992	58.54	9.65
	7 half-lives	2	0.581	0.219	0.943	.00	0.63
Sample size							
	more than 30	41	0.554	0.469	0.639	60.40	101.00
	less than 30	25	0.592	0.431	0.754	46.55	44.90
Wechsler language							
	Canadian English	17	0.709	0.569	0.850	49.43	31.64
	American English	10	0.438	0.329	0.547	13.86	10.45
	Chinese	10	0.413	0.232	0.593	65.33	25.96
	Chinese (Taiwan)	4	0.505	0.394	0.617	.00	2.40
	Spanish (Spain)	4	1.126	0.696	1.555	48.04	5.77
	Italian	3	0.737	0.403	1.071	.00	0.40
	Turkish	3	0.316	–.155	0.786	67.53	6.16
	Norwegian	3	0.563	0.313	0.813	.00	0.66
	Brazilian Portuguese	2	0.642	–.009	1.292	55.76	2.26
	New Zealander English	2	0.449	0.112	0.786	.00	0.28
	German	2	0.353	–.636	1.343	76.62	4.28
	Dutch	1	.000	–.677	0.677	–	–
	Finnish	1	0.731	0.207	1.255	–	–
	Korean	1	0.769	.069	1.469	–	–

Note. ADHD: Attention-Deficit/Hyperactivity Disorder (C: combined subtype; I: inattentive subtype; HI: hyperactive-impulsive subtype). WISC: Wechsler Intelligence Scale for Children (III: third edition; R: revised; IV: fourth edition). C-WISC: Chinese Revised Wechsler Intelligence Scale for Children. WAIS: Wechsler Adult Intelligence Scale (III: third edition). DSM: Diagnostic and Statistical Manual of Mental Disorders (III-R: third edition, revised; IV: fourth edition; IV-TR: fourth edition, text revised; V: fifth edition). ICD-10: International Statistical Classification of Diseases and Related Health Problems – 10th Edition.

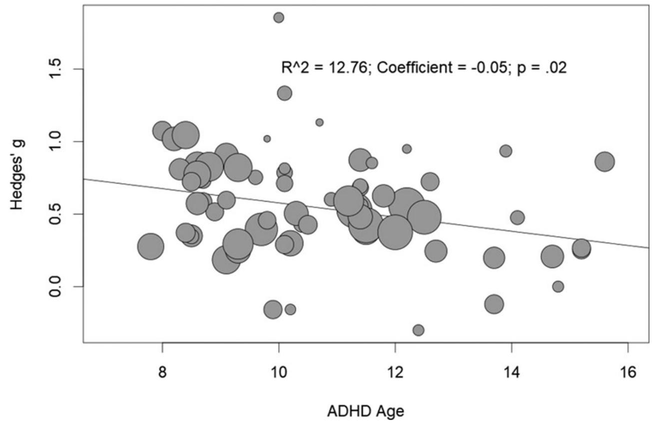

Figure 2. Meta-regression of 66 Attention-Deficit/Hyperactivity Disorder (ADHD) samples showing that age influences the effect size.

data. Only eight studies that applied the WISC-IV exhibited homogeneity (I^2 = .00); the remaining editions of the scale all exhibited a moderate to high degree of heterogeneity. To investigate the possible influence of the language of the Wechsler scale on effect size variability, we also performed a subgroup meta-analysis with the language version as a covariate. Interestingly, studies with the American English version ($n = 10$) estimated more homogeneous results (I^2 = 13.86) than studies with the Canadian English version ($n = 17$; I^2 = 49.43). Ten ADHD samples from China provided medium heterogeneity (I^2 = 65.33), but the samples from Taiwan ($n = 4$) were homogeneous (I^2 = .00). Homogeneous results (I^2 = .00) were also observed for the Italian ($n = 3$), Norwegian ($n = 3$), and New Zealander English ($n = 2$) samples. Note, however, that for most of the language versions, low statistical power due to small sample sizes (two to four studies) limits interpretation of the results.

Regarding the time elapsed since the most recent psychostimulant medication, there was some indication that withdrawing medication decreased heterogeneity. Namely, both subgroups who had their medication withdrawn for at least 1 day exhibited a low percentage of heterogeneity ($I^2 < 24$). In contrast, the nonmedicated subgroup (I^2 = 32.66) and the subgroup in which medication was suspended on the day of the test (I^2 = 41.67) exhibited moderate degrees of heterogeneity. The hypothesis that the studies including less than 30 participants (in one or both of the groups) are more heterogeneous (I^2 = 46.55) than studies containing more than 30 participants (I^2 = 60.40) was discarded since the calculated heterogeneity percentages were not in the predicted direction (Higgins et al., 2003). The diagnostic criteria, medication status, and sex of participants also failed to provide plausible explanations.

The analysis of the funnel plot shown in Figure 3, in which the *x-axis* gives the *g* values and the *y-axis* shows the respective *SE*, indicates a possible publication bias in the main meta-analysis, indicated by the asymmetrical form, which is more heavily weighted toward the left (without the white symbols). If there was homogeneity, at least 95% of the samples would fall within the funnel (Sterne & Egger, 2001). Duval and Tweedie's trim-and-fill method indicates that at least nine statistically nonsignificant samples are necessary to correct the publication bias (represented in Figure 3 by

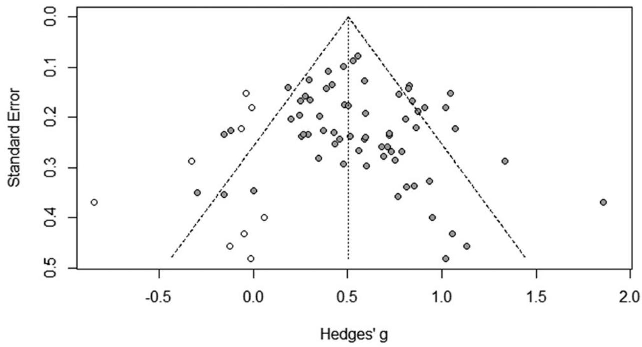

Figure 3. Funnel plot for the analysis of publication bias. Grey symbols indicate the samples ($n = 66$) actually included in the meta-analysis, and white symbols indicate the number of samples with nonsignificant results ($n = 9$) necessary to reduce the publication bias, thus making the funnel symmetrical.

white symbols). After applying Duval and Tweedie's trim-and-fill method, the *g* value changed to 0.50 (95% CI [0.42, 0.58]). However, it must be noted that the confidence interval greatly overlapped with the full effect size of 0.56 (95% CI [0.49, 0.64]), which means that the bias observed in this meta-analysis is small, and both of the effect sizes fall in a medium-sized range (Cohen, 1988).

Discussion

As far as we know, this is the largest meta-analysis concerning verbal WM in ADHD conducted to date. This meta-analysis makes an important contribution to the existing literature by indicating that children and adolescents with ADHD exhibit poorer DSB performance, with a medium-sized effect of 0.56 (95% CI [0.49, 0.64]). Table 1 shows that this result coincides with those found by Willcutt, Doyle, et al. (2005) and by Martinussen et al. (2005), regarding verbal WM in children and adolescents with ADHD. In contrast, the meta-analysis by Kasper et al. (2012) estimated a slightly larger effect of 0.69. The main explanation for this discrepancy likely relates to the rationale underlying the selection of tasks to estimate a verbal WM index.

Both Willcutt, Doyle, et al. (2005) and Martinussen et al. (2005) selected verbal WM tasks based on the assumption that WM requires storage, maintenance and manipulation of information in mind—a rationale that was also applied in the current meta-analysis. Conversely, Kasper et al. (2012) followed a different approach, in which verbal WM tasks were classified as requiring low (e.g. DSF or number recall) or high (e.g. DSB or 2-back) central executive demand. However, the inclusion of DSF to estimate a single verbal WM index may be a confounding variable since DSF and DSB do not tap the same cognitive processes (Gignac, Kovacs, & Reynolds, 2018; Reynolds, 1997). For instance, DSF does not require mental manipulation of information and thus qualifies as a measure of short-term memory not WM (Diamond, 2013). It seems that the selection of verbal WM tasks may account for the discrepancy in effect sizes between the present meta-analysis and the meta-analysis by Kasper et al. (2012).

A second main finding from the current study relates to age as the strongest covariate that may explain the moderate level of heterogeneity. The meta-analysis of subgroups with children and adolescents aged 8 to 16 years decreased the level of heterogeneity (I^2) from 55.50 (moderate) to 17.06 (low), and the meta-regression suggested that age accounts for 12.76% (R^2) of the variance of the effect size. These findings suggest that poorer verbal WM performance in ADHD is age-related, with younger children with ADHD presenting with greater difficulties, as has been indicated in previous studies (Siegel & Ryan, 1989; Sowerby et al., 2011). This effect of age may be accounted for by two main reasons. First, whereas the ability to hold and manipulate information in mind (as required by the DSB task) normally develops and improves progressively during childhood and adolescence (Cowan, Scott Saults, & Elliott, 2002; Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Diamond, 2013; Luciana, Conklin, Hooper, & Yarger, 2005), younger children with ADHD have shown particular problems, which suggests that verbal WM in ADHD develops at a slower pace compared to typical controls (Sowerby et al., 2011). Second, inhibitory control, which enables an individual to maintain focus on a specific task despite internal or external interferences and contributes to the efficacy of verbal WM, has been postulated as a core deficit in ADHD (Barkley, 1997) that may be age sensitive (Macdonald, Beauchamp, Crigan, & Anderson, 2014). In relation to this, in addition to the normal developmental struggle with inhibitory control during childhood, younger children with ADHD also face poorer inhibitory control related to their ADHD (Oosterlaan, Logan, & Sergeant, 1998; Pievsky & McGrath, 2018), thus, compounding difficulties at younger ages.

A third important finding from this quantitative synthesis was the low degree of heterogeneity ($I^2 = 13.86$) for the American English samples in the subgroup meta-analysis of Wechsler scale language version (see Table 3), which indicates that language version may moderate the effect size variance. The idea that language version may be a moderating factor fits with previous research that found differences in digit span performance across four different language versions of WAIS-III (Mexico, Spain, Puerto Rico, and the United States), such that Mexican samples presented with lower digit span scores than Spanish or American normative samples (Funes, Rodriguez, & Lopez, 2016). However, because seven out of the ten American English samples analyzed in the current study were aged 8–16 years, it may be that age played a more prominent role in the low level of heterogeneity than the language version of the scale. The Taiwanese, Italian, New Zealander English, and Norwegian samples showed homogeneous results ($I^2 = .00$), whereas moderate to high heterogeneity (I^2 between 48.04 and 76.62) was estimated for studies from Spain, Turkey, Brazil, and Germany; however, these findings should be interpreted with caution since the analyses included only two to four studies. Jackson and Turner (2017) recently noted that at least five studies are necessary to provide a satisfactory minimum level of statistical power in random-effects models. Thus, while these results provide some indication that language version may moderate the effect size variance; future research will be needed to confirm the results.

The remaining selected moderating variables largely failed to provide evidence explaining the moderate degree of variability in the main analysis ($I^2 = 55.50$). For example, the subgroup meta-analysis of Wechsler scale edition for the most part also presented moderate degrees of heterogeneity (ranging from 52% to 73%), except for the eight studies with WISC-IV, which provided homogeneous results (I^2 = .00). Since previous research indicates that the subtype ADHD-I exhibits a closer relationship with WM functioning compared to the subtypes ADHD-C and ADHD-HI (e.g. Colbert & Bo, 2017), we predicted that the ADHD subtypes might explain some of the effect size variance, but this was not verified by the subgroup meta-analysis. Only seven samples with ADHD were diagnosed exclusively with ADHD-I, compared to 15 samples with ADHD-C and 32 samples with a mixture of two or three subtypes. It may be that the inclusion of a greater number of studies with participants diagnosed specifically with ADHD-I could have explained part of the unexplained variance.

From a clinical standpoint, the results reinforce verbal WM as a key cognitive function affected by ADHD, in accordance with our primary hypothesis. Verbal WM is a pivotal cognitive function in the classroom, given that students rely on it to accomplish daily school activities (e.g. Alloway & Alloway, 2010; Orban, Rapport, Friedman, Eckrich, & Kofler, 2018). Furthermore, children with poorer verbal WM may present with problems such as academic underachievement, high levels of distractibility, poor creativity in complex tasks, difficulties in following instructions, and failures to complete assignments (Alloway et al., 2009; Gathercole et al., 2008). Thus, the assessment of verbal WM may help towards preventing educational underachievement in children with ADHD. In relation to this, although, most past efforts to train WM in children with ADHD have had limited success, a recent approach has demonstrated promise (Kofler, Sarver, Austin, et al., 2018).

An important limitation of this meta-analysis is the reliance on only DSB to provide a verbal WM index in ADHD, which prevents generalizability to other verbal WM tasks such as *n*-back and reading/listening span. Other tasks might provide different effect sizes. Inclusion of a variety of WM tasks, considered separately via subgroup meta-analyses, would enable an investigation of the influence of task complexity on verbal WM performance (e.g. 2-back vs. 3-back). However, care would need to be taken to ensure the tasks are matched regarding aspects other than WM, to avoid misinterpretation. A second limitation of the present meta-analytical study is that the funnel plot analysis and Duval and Tweedie's trim-and-fill method revealed a publication bias in the main meta-analysis. Although there is no consensus among researchers regarding the inclusion of unpublished studies in a meta-analysis (Hopewell, Clarke, & Mallett, 2005), it is probable that the inclusion of unpublished studies with statistically nonsignificant results would correct the asymmetry of the funnel plot (Egger, Smith, et al., 1997). Conversely, an important characteristic of the current meta-analysis that tends to reduce publication bias is the inclusion of studies published in Spanish, a strength not commonly found in meta-analytic studies. Sterne, Egger, and Smith (2001) pointed out that studies with statistically significant results have more probability of being published in English than those with nonsignificant outcomes; as a consequence, meta-analyses including only studies published in English may suffer from publication and language biases.

In conclusion, this was the first meta-analysis focused exclusively on DSB for estimating effect sizes for verbal WM differences in children and adolescents with

ADHD. The results clearly demonstrate that children and adolescents with ADHD have significantly poorer verbal WM compared to typically developing controls. Additionally, our quantitative synthesis provided an update on previous meta-analyses concerning verbal WM in ADHD by including 34 studies not included in past meta-analyses on the topic (Kasper et al., 2012; Martinussen et al., 2005; Willcutt, Doyle, et al., 2005). The meta-regression reported here suggests an association between age and DSB performance differences, such that verbal WM performance difficulties appear to lessen with increasing age. Future meta-analyses should include scores from DSF and DSB to explore potential performance differences in ADHD between verbal short-term memory (DSF) and verbal WM (DSB). In addition, future meta-analyses should determine the true influence of Wechsler scale language version on verbal WM performance.

Disclosure statement

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ORCID

Ari Alex Ramos http://orcid.org/0000-0002-7117-9728
Liana Machado http://orcid.org/0000-0002-0856-3831

References

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013). Best-practice recommendations for defining, identifying, and handling outliers. *Organizational Research Methods*, *16*, 270–301. doi:10.1177/1094428112470848

Alderson, R. M., Patros, C. H., Tarle, S. J., Hudec, K. L., Kasper, L. J., & Lea, S. E. (2017). Working memory and behavioral inhibition in boys with ADHD: An experimental examination of competing models. *Child Neuropsychology*, *23*, 255–272. doi:10.1080/09297049.2015.1105207

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*(1), 20–29. doi:10.1016/j.jecp.2009.11.003

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development*, *80*, 606–621. doi:10.1111/j.1467-8624.2009.01282.x

*Aly, H. Y., Effat, S. M. A., Azb, H. M., & Abd Elsamei, A. M. (2015). Executive functions among Egyptian children with attention deficit hyperactivity disorder and reading disabilities. *Middle East Current Psychiatry*, *22*, 97–106. doi:10.1097/01.XME.0000461749.64397.af

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Publishing.

*indicates study included in the meta-analysis.

American Psychological Association. (2015). *APA dictionary of psychology*. Washington, DC: Author.

Baddeley, A. D. (1992). Working memory. *Science*, *255*, 556–559. doi:10.1126/science.1736359

Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology: Section A*, *49*(1), 5–28. doi:10.1080/713755608

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*, 417–423. doi:10.1016/S1364-6613(00)01538-2

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

*Banaschewski, T., Jennen-Steinmetz, C., Brandeis, D., Buitelaar, J. K., Kuntsi, J., Poustka, L., … Asherson, P. (2012). Neuropsychological correlates of emotional lability in children with ADHD. *Journal of Child Psychology and Psychiatry*, *53*, 1139–1148. doi:10.1111/j.1469-7610.2012.02596.x

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65–94. doi:10.1037/0033-2909.121.1.65

Brocki, K. C., Randall, K. D., Bohlin, G., & Kerns, K. A. (2008). Working memory in school-aged children with attention-deficit/hyperactivity disorder combined type: Are deficits modality specific and are they independent of impaired inhibitory control? *Journal of Clinical and Experimental Neuropsychology*, *30*, 749–759. doi:10.1080/13803390701754720

Brydges, C. R., Ozolnieks, K. L., & Roberts, G. (2017). Working memory—Not processing speed—Mediates fluid intelligence deficits associated with attention deficit/hyperactivity disorder symptoms. *Journal of Neuropsychology*, *11*, 362–377. doi:10.1111/jnp.12096

Brydges, C.R., Ozolnieks, K.L. & Roberts, G. (2017). Working memory – not processing speed – mediates fluid intelligence deficits associated with attention deficit/hyperactivity disorder symptoms. *Journal of Neuropsychology*, *11*, 362–377. doi:10.1111/jnp.12096

Busch, B., Biederman, J., Cohen, L. G., Sayer, J. M., Monuteaux, M. C., Mick, E., … Faraone, S. V. (2002). Correlates of ADHD among children in pediatric and psychiatric clinics. *Psychiatric Services*, *53*, 1103–1111. doi:10.1176/appi.ps.53.9.1103

Button, K. S., Bal, L., Clark, A., & Shipley, T. (2016). Preventing the ends from justifying the means: Withholding results to address publication bias in peer-review. *BMC Psychology*, *4*(1), 59. doi:10.1186/s40359-016-0167-7

Carlesimo, G. A., Fadda, L., Lorusso, S., & Caltagirone, C. (2009). Verbal and spatial memory spans in Alzheimer's and multi-infarct dementia. *Acta Neurologica Scandinavica*, *89*, 132–138. doi:10.1111/j.1600-0404.1994.tb01648.x

*Casas, A. M., Alba, A. M., Taverner, R. T., Rosello, B., & Mulas, F. (2006). Dificultades en el aprendizaje de matemáticas en niños con trastorno por déficit de atención e hiperactividad [Learning difficulties in mathematics in children with attention deficit hyperactivity disorder]. Revista Neurología, 42(Suppl. 2), S163–S170. Retrieved from https://www.neurologia.com/articulo/2005788

*Casas, A. M., Andrés, M. I. F., Castellar, R. G., Miranda, B. R., & Diago, C. C. (2011). Habilidades lingüísticas y ejecutivas en el Trastorno por Déficit de Atención (TDAH) y en las Dificultades de Comprensión Lectora (DCL.). *Psicothema*, *23*, 688–694. Retrieved from http://www.redalyc.org/articulo.oa?id=72722232025

*Chiang, M., & Gau, S. S. F. (2008). Validation of attention-deficit–hyperactivity disorder subtypes among Taiwanese children using neuropsychological functioning. *Australian & New Zealand Journal of Psychiatry*, *42*, 526–535. doi:10.1080/00048670802050603

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Colbert, A. M., & Bo, J. (2017). Evaluating relationships among clinical working memory assessment and inattentive and hyperactive/impulsive behaviors in a community sample of children. *Research in Developmental Disabilities*, *66*, 34–43. doi:10.1016/j.ridd.2017.04.010

Conklin, H. M., Curtis, C. E., Katsanis, J., & Iacono, W. G. (2000). Verbal working memory impairment in schizophrenia patients and their first-degree relatives: Evidence from the digit span task. *American Journal of Psychiatry*, *157*, 275–277. doi:10.1176/appi.ajp.157.2.275

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*, 769–786. doi:10.3758/BF03196772

*Coutinho, G., Mattos, P., & Malloy-Diniz, L. F. (2009). Neuropsychological differences between attention deficit hyperactivity disorder and control children and adolescents referred for academic impairment. *Revista Brasileira de Psiquiatria*, *31*, 141–144. doi:10.1590/S1516-44462009000200011

Cowan, N., Scott Saults, J., & Elliott, E. M. (2002). The search for what is fundamental in the development of working memory. In R. V. Kail & H. W. Reese (Eds.), *Advances in child development and behavior* (Vol. 29, pp. 1–49). Amsterdam: Elsevier Ltd.

Crone, E. A., Wendelken, C., Donohue, S., van Leijenhorst, L., & Bunge, S. A. (2006). Neurocognitive development of the ability to manipulate information in working memory. *Proceedings of the National Academy of Sciences of the United States of America*, *103*, 9315. doi:10.1073/pnas.0510088103

Cumming, G. (2012). *Understanding the new statistics: Effect sizes, confidence intervals, and meta-analysis*. New York: Routledge.

Desman, C., Petermann, F., & Hampel, P. (2008). Deficit in response inhibition in children with attention deficit/hyperactivity disorder (ADHD): Impact of motivation? *Child Neuropsychology*, *14*, 483–503. doi:10.1080/09297040701625831

Diamond, A. (2005). Attention-deficit disorder (attention-deficit/ hyperactivity disorder without hyperactivity): A neurobiologically and behaviorally distinct disorder from attention-deficit/ hyperactivity disorder (with hyperactivity)). *Development and Psychopathology*, *17*, 807–825. doi:10.1017/S0954579405050388

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. doi: 10.1146/annurev-psych-113011-143750

Dunlap, W. P. (1999). A program to compute McGraw and Wong's common language effect size indicator. *Behavior Research Methods, Instruments, & Computers*, *31*, 706–709. doi:10.3758/BF03200750

Duval, S. (2005). The Trim and Fill method. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment, and adjustments* (pp. 127–144). Chichester, UK: Wiley.

Duval, S., & Tweedie, R. (2000). A nonparametric "trim and fill" method of accounting for publication bias in meta-analysis. *Journal of the American Statistical Association*, *95*, 89–98. doi: 10.1080/01621459.2000.10473905

Eckrich, S. J., Rapport, M. D., Calub, C. A., & Friedman, L. M. (2018). Written expression in boys with ADHD: The mediating roles of working memory and oral expression. *Child Neuropsychology*, 17, 1–23. doi:10.1080/09297049.2018.1531982

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ: British Medical Journal*, *315*, 629–634. doi:10.1136/bmj.315.7109.629

Egger, M., Zellweger-Zähner, T., Schneider, M., Junker, C., Lengeler, C., & Antes, G. (1997). Language bias in randomised controlled trials published in English and German. *The Lancet*, *350*, 326–329. doi:10.1016/S0140-6736(97)02419-7

Engels, E. A., Schmid, C. H., Terrin, N., Olkin, I., & Lau, J. (2000). Heterogeneity and statistical significance in meta-analysis: An empirical study of 125 meta-analyses. *Statistics in Medicine*, *19*, 1707–1728. doi:10.1002/1097-0258(20000715)19:13 < 1707::AID-SIM491 > 3.0.CO;2-P

Evers, A., Muñiz, J., Bartram, D., Boben, D., Egeland, J., Fernández-Hermida, J. R., … Urbánek, T. (2012). Testing practices in the 21st century: Developments and European psychologists' opinions. *European Psychologist*, *17*, 300–319. doi:10.1027/1016-9040/a000102

*Fan, L. Y., Gau, S. S. F., & Chou, T. L. (2014). Neural correlates of inhibitory control and visual processing in youths with attention deficit hyperactivity disorder: A counting Stroop functional MRI study. *Psychological Medicine*, *44*, 2661–2671. doi:10.1017/S0033291714000038

Friedman, L. M., Rapport, M. D., Orban, S. A., Eckrich, S. J., & Calub, C. A. (2018). Applied problem solving in children with ADHD: The mediating roles of working memory and mathematical calculation. *Journal of Abnormal Child Psychology*, *46*, 491–504. doi:10.1007/s10802-017-0312-7

Friedman, L. M., Rapport, M. D., Raiker, J. S., Orban, S. A., & Eckrich, S. J. (2017). Reading comprehension in boys with ADHD: The mediating roles of working memory and orthographic conversion. *Journal of Abnormal Child Psychology*, *45*, 273–287. doi:10.1007/s10802-016-0171-7

Funes, C. M., Rodriguez, J. H., & Lopez, S. R. (2016). Norm comparisons of the Spanish-language and English-language WAIS-III: Implications for clinical assessment and test adaptation. *Psychological Assessment*, *28*, 1709–1715. doi:10.1037/pas0000302

Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviours in children with poor working memory. *Learning and Individual Differences*, *18*, 214–223. doi:10.1016/j.lindif.2007.10.003

*Gau, S. S. F., & Chiang, H. L. (2013). Association between early attention-deficit/hyperactivity symptoms and current verbal and visuo-spatial short-term memory. *Research in Developmental Disabilities*, *34*(1), 710–720. doi:10.1016/j.ridd.2012.10.005

*Gau, S. S. F., Chiu, C. D., Shang, C. Y., Cheng, A. T. A., & Soong, W. T. (2009). Executive function in adolescence among children with attention-deficit/hyperactivity disorder in Taiwan. *Journal of Developmental & Behavioral Pediatrics*, *30*, 525–534. doi:10.1097/DBP.0b013e3181c21c97

*Gau, S. S. F., & Shang, C. Y. (2010). Executive functions as endophenotypes in ADHD: Evidence from the Cambridge Neuropsychological Test Battery (CANTAB). *Journal of Child Psychology and Psychiatry*, *51*, 838–849. doi:10.1111/j.1469-7610.2010.02215.x

Gerton, B. K., Brown, T. T., Meyer-Lindenberg, A., Kohn, P., Holt, J. L., Olsen, R. K., & Berman, K. F. (2004). Shared and distinct neurophysiological components of the digits forward and backward tasks as revealed by functional neuroimaging. *Neuropsychologia*, *42*, 1781–1787. doi:10.1016/j.neuropsychologia.2004.04.023

Gignac, G. E., Kovacs, K., & Reynolds, M. R. (2018). Backward and forward serial recall across modalities: An individual differences perspective. *Personality and Individual Differences*, *121*, 147–151. doi:10.1016/j.paid.2017.09.033

Grégoire, J., & Van Der Linden, M. (1997). Effect of age on forward and backward digit spans. *Aging, Neuropsychology, and Cognition*, *4*, 140–149. doi:10.1080/13825589708256642

*Gremillion, M. L., & Martel, M. M. (2012). Semantic language as a mechanism explaining the association between ADHD symptoms and reading and mathematics underachievement. *Journal of Abnormal Child Psychology*, *40*, 1339–1349. doi:10.1007/s10802-012-9650-7

Gremillion, M. L., Smith, T. E., & Martel, M. M. (2018). Verbal working memory as a longitudinal mechanism of vocabulary problems in preschoolers with ADHD. *Journal of Psychopathology and Behavioral Assessment*, *40*(1), 130–138. doi:10.1007/s10862-017-9625-7

Grubbs, F. E. (1950). Sample criteria for testing outlying observations. *The Annals of Mathematical Statistics*, *21*(1), 27–58. doi:10.1214/aoms/1177729885

Hale, J. B., Hoeppner, J. A. B., & Fiorello, C. A. (2002). Analyzing digit span components for assessment of attention processes. *Journal of Psychoeducational Assessment*, *20*, 128–143. doi:10.1177/073428290202000202

*Healey, D., & Rucklidge, J. J. (2006). An investigation into the relationship among ADHD symptomatology, creativity, and neuropsychological functioning in children. *Child Neuropsychology*, *12*, 421–438. doi:10.1080/09297040600806086

Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational Statistics*, *6*, 107–128. doi:10.2307/1164588

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Higgins, J., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*, 1539–1558. doi:10.1002/sim.1186

Higgins, J., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analysis. *British Medical Journal*, *327*, 557–560. 327.7414.557 doi:10.1136/bmj,

Holmbeck, G. N. (1997). Toward terminological, conceptual, and statistical clarity in the study of mediators and moderators: Examples from the child-clinical and pediatric psychology literatures. *Journal of Consulting and Clinical Psychology*, *65*, 599–610. doi:10.1037/0022-006X.65.4.599

Hopewell, S., Clarke, M., & Mallett, S. (2005). Grey literature and systematic reviews. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 49–72). Chichester, UK: Wiley.

Hoshi, Y., Oda, I., Wada, Y., Ito, Y., Yutaka, Y., Oda, M., … Mamoru, T. (2000). Visuospatial imagery is a fruitful strategy for the digit span backward task: A study with near-infrared optical tomography. *Cognitive Brain Research*, *9*, 339–342. doi:10.1016/S0926-6410(00)00006-9

Houghton, S., Douglas, G., West, J., Whiting, K., Wall, M., Langsford, S., … Carroll, A. (1999). Differential patterns of executive function in children with attention-deficit hyperactivity disorder according to gender and subtype. *Journal of Child Neurology*, *14*, 801–805. doi:10.1177/088307389901401206

Huedo-Medina, T. B., Sánchez-Meca, J., Marín-Martínez, F., & Botella, J. (2006). Assessing heterogeneity in meta-analysis: Q statistic or I^2 index? *Psychological Methods*, *11*, 193. doi:10.1037/1082-989X.11.2.193

Hurley, R., & Machado, L. (2018). Using transcranial direct current stimulation to improve verbal working memory: A detailed review of the methodology. *Journal of Clinical and Experimental Neuropsychology*, *40*, 790–804. doi:10.1080/13803395.2018.1434133

Ioannidis, J. P. (2008). Interpretation of tests of heterogeneity and bias in meta-analysis. *Journal of Evaluation in Clinical Practice*, *14*, 951–957. doi:10.1111/j.1365-2753.2008.00986.x

Jackson, D., & Turner, R. (2017). Power analysis for random-effects meta-analysis. *Research Synthesis Methods*, *8*, 290–302. doi:10.1002/jrsm.1240

*Karalunas, S. L., & Huang-Pollock, C. L. (2013). Integrating impairments in reaction time and executive function using a diffusion model framework. *Journal of Abnormal Child Psychology*, *41*, 837–850. doi:10.1007/s10802-013-9715-2

Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review*, *32*, 605–617. doi:10.1016/j.cpr.2012.07.001

*Kaufmann, L., & Nuerk, H. C. (2006). Interference effects in a numerical Stroop paradigm in 9- to 12-year-old children with ADHD-C. *Child Neuropsychology*, *12*, 223–243. doi:10.1080/09297040500477483

*Kim, S. H., Han, D. H., Lee, Y. S., Kim, B. N., Cheong, J. H., & Han, S. H. (2014). Baduk (the game of go) improved cognitive function and brain activity in children with attention deficit hyperactivity disorder. *Psychiatry Investigation*, *11*, 143–151. doi:10.4306/pi.2014.11.2.143

Kofler, M. J., Rapport, M. D., Bolden, J., & Altro, T. A. (2008). Working memory as a core deficit in ADHD: Preliminary findings and implications. *The ADHD Report*, *16*, 8–14. doi:10.1521/adhd.2008.16.6.8

Kofler, M. J., Rapport, M. D., Bolden, J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2011). Working memory deficits and social problems in children with ADHD. *Journal of Abnormal Child Psychology*, *39*, 805–817. doi:10.1007/s10802-011-9492-8

Kofler, M. J., Sarver, D. E., Austin, K. E., Schaefer, H. S., Holland, E., Aduen, P. A., … Lonigan, C. J. (2018). Can working memory training work for ADHD? Development of central executive training and comparison with behavioral parent training. *Journal of Consulting and Clinical Psychology*, *86*, 964–979. doi:10.1037/ccp0000308

Kofler, M. J., Sarver, D. E., Harmon, S. L., Moltisanti, A., Aduen, P. A., Soto, E. F., & Ferretti, N. (2018). Working memory and organizational skills problems in ADHD. *Journal of Child Psychology and Psychiatry*, *59*(1), 57–67. doi:10.1111/jcpp.12773

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863.doi:10.3389/fpsyg.2013.00863

*Lee, S. I., Schachar, R. J., Chen, S. X., Ornstein, T. J., Charach, A., Barr, C., & Ickowicz, A. (2008). Predictive validity of DSM-IV and ICD-10 criteria for ADHD and hyperkinetic disorder. *Journal of Child Psychology and Psychiatry*, *49*(1), 70–78. doi:10.1111/j.1469-7610.2007.01784.x

Lockwood, K. A., Marcotte, A. C., & Stern, C. (2001). Differentiation of attention-deficit/hyperactivity disorder subtypes: Application of a neuropsychological model of attention. *Journal of Clinical and Experimental Neuropsychology*, *23*, 317–330. doi:10.1076/jcen.23.3.317.1179

Luciana, M., Conklin, H. M., Hooper, C. J., & Yarger, R. S. (2005). The development of nonverbal working memory and executive control processes in adolescents. *Child Development*, *76*, 697–712. doi:10.1111/j.1467-8624.2005.00872.x

Macdonald, J. A., Beauchamp, M. H., Crigan, J. A., & Anderson, P. J. (2014). Age-related differences in inhibitory control in the early school years. *Child Neuropsychology*, *20*, 509–526. doi:10.1080/09297049.2013.822060

*Manassis, K., Tannock, R., Young, A., & John, S. F. (2007). Cognition in anxious children with attention deficit hyperactivity disorder: A comparison with clinical and normal children. *Behavioral and Brain Functions*, *3*(1), 4. [Mismatch] doi:10.1186/1744-9081-3-4

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *44*, 377–384. doi:10.1097/01.chi.0000153228.72591.73

*Martinussen, R., & Tannock, R. (2006). Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. *Journal of Clinical and Experimental Neuropsychology*, *28*, 1073–1094. doi:10.1080/13803390500205700

*McAuley, T., Crosbie, J., Charach, A., & Schachar, R. (2014). The persistence of cognitive deficits in remitted and unremitted ADHD: A case for the state-independence of response inhibition. *Journal of Child Psychology and Psychiatry*, *55*, 292–300. doi:10.1111/jcpp.12160

McGraw, K. O., & Wong, S. (1992). A common language effect size statistic. *Psychological Bulletin*, *111*, 361. doi:10.1037/0033-2909.111.2.361

*McInerney, R. J., & Kerns, K. A. (2003). Time reproduction in children with ADHD: Motivation matters. *Child Neuropsycholy*, *9*, 91–108. doi:10.1076/chin.9.2.91.14506

McInnes, A., Humphries, T., Hogg-Johnson, S., & Tannock, R. (2003). Listening comprehension and working memory are impaired in attention-deficit hyperactivity disorder irrespective of language impairment. *Journal of Abnormal Child Psychology*, *31*, 427–443. [Mismatch] doi:10.1023/a:1023895602957

*Mello, C. B., Rossi, A. S. U., Cardoso, T. S. G., Rivero, T. S., Moura, L. M., Nogueira, R. G., … Muszkat, M. (2013). Neuroimaging and neuropsychological analyses in a sample of children with ADHD—Inattentive subtype. *Clinical Neuropsychiatry*, *10*, 45–55. Retrieved from http://www.clinicalneuropsychiatry.org/pdf/01Berlim.pdf

Messina, L. D F., Tiedemann, K. B., de Andrade, E. R., & Primi, R. (2006). Assessment of working memory in children with attention-deficit/hyperactivity disorder. *Journal of Attention Disorders*, *10*(1), 28–35. doi:10.1177/108705284299

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Group, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Journal of Clinical Epidemiology*, *62*, 1006–1012. doi:10.1016/j.jclinepi.2009.06.005

*Nguyen, T. T., Glass, L., Coles, C. D., Kable, J. A., May, P. A., Kalberg, W. O., … Mattson, S. N. (2014). The clinical utility and specificity of parent report of executive function among children with prenatal alcohol exposure. *Journal of the International Neuropsychological Society*, *20*, 704–716. doi:10.1017/S1355617714000599

*Nyman, A., Taskinen, T., Grönroos, M., Haataja, L., Lähdetie, J., & Korhonen, T. (2010). Elements of working memory as predictors of goal-setting skills in children with attention-deficit/hyperactivity disorder. *Journal of Learning Disabilities*, *43*, 553–562. doi:10.1177/0022219410375001

*O'Brien, J. W., Dowell, L. R., Mostofsky, S. H., Denckla, M. B., & Mahone, E. M. (2010). Neuropsychological profile of executive function in girls with attention-deficit/hyperactivity disorder. *Archives of Clinical Neuropsychology*, *25*, 656–670. doi:10.1093/arclin/acq050

*Øie, M., Sundet, K., & Rund, B. R. (1999). Contrasts in memory functions between adolescents with schizophrenia or ADHD. *Neuropsychologia*, *37*, 1351–1358. doi:10.1016/S0028-3932(99)00043-3

Oosterlaan, J., Logan, G. D., & Sergeant, J. A. (1998). Response inhibition in AD/HD, CD, comorbid AD/HD + CD, anxious, and control children: A meta-analysis of studies with the stop task. *Journal of Child Psychology and Psychiatry*, *39*, 411–425. doi:10.1111/1469-7610.00336

Orban, S. A., Rapport, M. D., Friedman, L. M., Eckrich, S. J., & Kofler, M. J. (2018). Inattentive behavior in boys with ADHD during classroom instruction: The mediating role of working memory processes. *Journal of Abnormal Child Psychology*, *46*, 713–727. doi:10.1007/s10802-017-0338-x

*Pasini, A., Paloscia, C., Alessandrelli, R., Porfirio, M. C., & Curatolo, P. (2007). Attention and executive functions profile in drug naive ADHD subtypes. *Brain and Development*, *29*, 400–408. doi:10.1016/j.braindev.2006.11.010

*Passolunghi, M. C., Marzocchi, G. M., & Fiorillo, F. (2005). Selective effect of inhibition of literal or numerical irrelevant information in children with attention deficit hyperactivity disorder (ADHD) or arithmetic learning disorder (ALD). *Developmental Neuropsychology*, *28*, 731–753. doi:10.1207/s15326942dn2803_1

Patterson, H. D., & Thompson, R. (1971). Recovery of inter-block information when block sizes are unequal. *Biometrika*, *58*, 545–554. doi:10.2307/2334389

Pievsky, M. A., & McGrath, R. E. (2018). The neurocognitive profile of attention-deficit/hyperactivity disorder: A review of meta-analyses. *Archives of Clinical Neuropsychology*, *33*, 143–157. doi:10.1093/arclin/acx055

*Pitzianti, M., D'Agati, E., Pontis, M., Baratta, A., Casarelli, L., Spiridigliozzi, S., … Pasini, A. (2016). Comorbidity of ADHD and high-functioning autism: A pilot study on the utility of the overflow movements measure. *Journal of Psychiatric Practice*, *22*(1), 22–30. doi:10.1097/PRA.0000000000000120

*Qian, Y., Shuai, L., Cao, Q., Chan, R. C. K., & Wang, Y. (2010). Do executive function deficits differentiate between children with attention deficit hyperactivity disorder (ADHD) and ADHD comorbid with oppositional defiant disorder? A cross-cultural study using performance-based tests and the behavior rating inventory of executive function. *The Clinical Neuropsychologist*, *24*, 793–810. doi:10.1080/13854041003749342

*Qian, Y., Shuai, L., Chan, R. C. K., Qian, Q. J., & Wang, Y. (2013). The developmental trajectories of executive function of children and adolescents with attention deficit hyperactivity disorder. *Research in Developmental Disabilities*, *34*, 1434–1445. doi:10.1016/j.ridd.2013.01.033

R Core Team. (2018). *R: A language and environment for statistical computing (Version 3.5.0)*. Vienna: R Foundation for Statistical Computing.

Rabin, L. A., Barr, W. B., & Burton, L. A. (2005). Assessment practices of clinical neuropsychologists in the United States and Canada: A survey of INS, NAN, and APA division 40 members. *Archives of Clinical Neuropsychology*, *20*(1), 33–65. doi:10.1016/j.acn.2004.02.005

Ramos, A. A., & Hamdan, A. C. (2016). O crescimento da avaliação neuropsicológica no Brasil: Uma revisão sistemática [The growth in neuropsychological assessment in Brazil. *Psicologia: Ciência e Profissão*, *36*, 471–485. doi:10.1590/1982-3703001792013

Rapport, M. D., Alderson, R. M., Kofler, M. J., Sarver, D. E., Bolden, J., & Sims, V. (2008). Working memory deficits in boys with attention-deficit/hyperactivity disorder (ADHD): The contribution of central executive and subsystem processes. *Journal of Abnormal Child Psychology*, *36*, 825–837. doi:10.1007/s10802-008-9215-y

Rapport, M. D., Bolden, J., Kofler, M. J., Sarver, D. E., Raiker, J. S., & Alderson, R. M. (2009). Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): A ubiquitous core symptom or manifestation of working memory deficits? *Journal of Abnormal Child Psychology*, *37*, 521–534. doi:10.1007/s10802-008-9287-8

Rapport, M. D., Chung, K. M., Shore, G., & Isaacs, P. (2001). A conceptual model of child psychopathology: Implications for understanding attention deficit hyperactivity disorder and treatment efficacy. *Journal of Clinical Child Psychology*, *30*(1), 48–58. doi:10.1207/S15374424JCCP3001_6

Repovš, G., & Baddeley, A. D. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience*, *139*(1), 5–21. doi:10.1016/j.neuroscience.2005.12.061
Reynolds, C. R. (1997). Forward and backward memory span should not be combined for clinical analysis. *Archives of Clinical Neuropsychology*, *12*(1), 29–40. doi:10.1016/S0887-6177(96)00015-7
*Rodríguez Pérez, C., Álvarez García, D., González Castro, M. P., García Sánchez, J. N., Álvarez Pérez, L., Núñez Pérez, J. C., … Bernardo Gutiérrez, A. B. (2009). TDAH y Dificultades de Aprendizaje en escritura: Comorbilidad en base a la Atención y Memoria Operativa [ADHD and Writing learning disabilities: Comorbidity in basis of attention and working memory]. *European Journal of Education and Psychology, 2,* 181-198. Retrieved from https://dialnet.unirioja.es/servlet/articulo?codigo=3060503
Romero-Ayuso, D., Maestú, F., González-Marqués, J., Romo-Barrientos, C., & Andrade, J. (2006). Disfunción ejecutiva en el trastorno por déficit de atención con hiperactividad en la infancia [Executive dysfunction in attention deficit hyperactivity disorder in childhood]. *Revista de Neurología*, *42*, 265–271.
*Rosenthal, E. N., Riccio, C. A., Gsanger, K. M., & Jarratt, K. P. (2006). Digit Span components as predictors of attention problems and executive functioning in children. *Archives of Clinical Neuropsychology*, *21*, 131–139. doi:10.1016/j.acn.2005.08.004
Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2005). Publication bias in meta-analysis. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 1–7). Chichester, UK: Wiley.
RStudio Team. (2015). *RStudio: Integrated development for R*. Boston, MA: RStudio, Inc.
*Rucklidge, J. J., & Tannock, R. (2002). Neuropsychological profiles of adolescents with ADHD: Effects of reading difficulties and gender. *Journal of Child Psychology and Psychiatry*, *43*, 988–1003. doi:10.1111/1469-7610.00227
*Saydam, R. B., Ayvasik, H. B., & Alyanak, B. (2015). Executive functioning in subtypes of attention deficit hyperactivity disorder. *Noro Psikiyatri Arsivi*, *52*(4), 386–392. doi:10.5152/npa.2015.8712
*Schachar, R., Chen, S., Crosbie, J., Goos, L., Ickowicz, A., & Charach, A. (2007). Comparison of the predictive validity of hyperkinetic disorder and attention deficit hyperactivity disorder. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, *16*, 90–100. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2242647/pdf/ccap16_2p090.pdf
Schwarzer, G. (2007). meta: An R package for meta-analysis. *R News*, *7*, 40–45.
Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development*, *60*, 973–980. doi:10.2307/1131037
*Siklos, S., & Kerns, K. A. (2004). Assessing multitasking in children with ADHD using a modified six elements test. *Archives of Clinical Neuropsychology*, *19*, 347–361. doi:10.1016/S0887-6177(03)00071-4
*Simone, A. N., Bédard, A. C. V., Marks, D. J., & Halperin, J. M. (2016). Good holders, bad shufflers: An examination of working memory processes and modalities in children with and without attention-deficit/hyperactivity disorder. *Journal of the International Neuropsychological Society*, *22*(01), 1–11. doi:10.1017/S1355617715001010
*Skowronek, J. S., Leichtman, M. D., & Pillemer, D. B. (2008). Long-term episodic memory in children with attention-deficit/hyperactivity disorder. *Learning Disabilities Research & Practice*, *23*(1), 25–35. doi:10.1111/j.1540-5826.2007.00260.x
Sonuga-Barke, E. J. (2003). The dual pathway model of AD/HD: An elaboration of neuro-developmental characteristics. *Neuroscience and Biobehavioral Reviews*, *27*, 593–604. doi:10.1016/j.neubiorev.2003.08.005
Sonuga-Barke, E. J. (2005). Causal models of attention-deficit/hyperactivity disorder: From common simple deficits to multiple developmental pathways. *Biological Psychiatry*, *57*, 1231–1238. doi:10.1016/j.biopsych.2004.09.008
*Soroa, M., Iraola, J. A., Balluerka, N., & Soroa, G. (2009). Evaluación de la atención sostenida de niños con trastorno por déficit de atención con hiperactividad [Assesment of Sustained

Attention of Children with Attention Deficit Hyperactivity Disorder]. *Revista de Psicodidáctica*, *14*(1), 13–27. Retrieved from https://recyt.fecyt.es/index.php/REVP/article/view/6376/5097

*Sowerby, P., Seal, S., & Tripp, G. (2011). Working memory deficits in ADHD: The contribution of age, learning/language difficulties, and task parameters. *Journal of Attention Disorders*, *15*, 461–472. doi:10.1177/1087054710370674

*Spronk, M., Vogel, E. K., & Jonkman, L. M. (2013). No behavioral or ERP evidence for a developmental lag in visual working memory capacity or filtering in adolescents and adults with ADHD. *PLoS One*, *8*, e62673. doi:10.1371/journal.pone.0062673

Sterne, J. A., Becker, B. J., & Egger, M. (2005). The Funnel Plot. In H.R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 73–98). Chichester, UK: Wiley.

Sterne, J. A., & Egger, M. (2001). Funnel plots for detecting bias in meta-analysis: Guidelines on choice of axis. *Journal of Clinical Epidemiology*, *54*, 1046–1055. doi:10.1016/S0895-4356(01)00377-8

Sterne, J. A., Egger, M., & Smith, G. D. (2001). Investigating and dealing with publication and other biases in meta-analysis. *BMJ: British Medical Journal*, *323*, 101. doi:10.1136/bmj.323.7304.101

Sun, X., Zhang, X., Chen, X., Zhang, P., Bao, M., Zhang, D., … Hu, X. (2005). Age-dependent brain activation during forward and backward digit recall revealed by fMRI. *NeuroImage*, *26*(1), 36–47. doi:10.1016/j.neuroimage.2005.01.022

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Prevalence of attention-deficit/hyperactivity disorder: A systematic review and meta-analysis. *Pediatrics*, *135*, e994–e1001. doi:10.1542/peds.2014-3482

Tian, F., Yennu, A., Smith-Osborne, A., Gonzalez-Lima, F., North, C. S., & Liu, H. (2014). Prefrontal responses to digit span memory phases in patients with post-traumatic stress disorder (PTSD): A functional near infrared spectroscopy study. *NeuroImage: Clinical*, *4*, 808–819. doi:10.1016/j.nicl.2014.05.005

*Tiffin-Richards, M. C., Hasselhorn, M., Woerner, W., Rothenberger, A., & Banaschewski, T. (2008). Phonological short-term memory and central executive processing in attention-deficit/hyperactivity disorder with/without dyslexia—Evidence of cognitive overlap. *Journal of Neural Transmission*, *115*, 227–234. doi:10.1007/s00702-007-0816-3

*Tillman, C. M., Bohlin, G., Sørensen, L., & Lundervold, A. J. (2009). Intellectual deficits in children with ADHD beyond central executive and non-executive functions. *Archives of Clinical Neuropsychology*, *24*, 769–782. doi:10.1093/arclin/acp075

*Toplak, M. E., Rucklidge, J. J., Hetherington, R., John, S. C. F., & Tannock, R. (2003). Time perception deficits in attention-deficit/hyperactivity disorder and comorbid reading difficulties in child and adolescent samples. *Journal of Child Psychology and Psychiatry*, *44*, 888–903. doi:10.1111/1469-7610.00173

*Toplak, M. E., & Tannock, R. (2005). Time perception: Modality and duration effects in attention-deficit/hyperactivity disorder (ADHD). *Journal of Abnormal Child Psychology*, *33*, 639–654. doi:10.1007/s10802-005-6743-6

*Udal, A. H., Øygarden, B., Egeland, J., Malt, U. F., Løvdahl, H., Pripp, A. H., & Grøholt, B. (2013). Executive deficits in early onset bipolar disorder versus ADHD: Impact of processing speed and lifetime psychosis. *Clinical Child Psychology and Psychiatry*, *18*, 284–299. doi:10.1177/1359104512455181

Wells, E. L., Kofler, M. J., Soto, E. F., Schaefer, H. S., & Sarver, D. E. (2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. *Research in Developmental Disabilities*, *72*, 166–178. doi:10.1016/j.ridd.2017.10.024

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry*, *57*, 1336–1346. doi:10.1016/j.biopsych.2005.02.006

*Willcutt, E. G., Pennington, B. F., Olson, R. K., Chhabildas, N., & Hulslander, J. (2005). Neuropsychological analyses of comorbidity between reading disability and attention deficit hyperactivity disorder: In search of the common deficit. *Developmental Neuropsychology*, *27*(1), 35–78. doi:10.1207/s15326942dn2701_3

*Wu, K. K., Anderson, V., & Castiello, U. (2002). Neuropsychological evaluation of deficits in executive functioning for ADHD children with or without learning disabilities. *Developmental Neuropsychology*, *22*, 501–531. doi:10.1207/S15326942DN2202_5

*Yang, B.-R., Chan, R. C. K., Gracia, N., Cao, X.-Y., Zou, X.-B., Jing, J., … Shum, D. (2011). Cool and hot executive functions in medication-naive attention deficit hyperactivity disorder children. *Psychological Medicine*, *41*, 2593–2602. doi:10.1017/S0033291711000869

*Yang, B. R., Chan, R. C. K., Zou, X., Jing, J., Mai, J., & Li, J. (2007). Time perception deficit in children with ADHD. *Brain Research*, *1170*, 90–96. doi:10.1016/j.brainres.2007.07.021

Yang, Z., Jutagir, D. R., Koyama, M. S., Craddock, R. C., Yan, C.-G., Shehzad, Z., … Milham, M. P. (2015). Intrinsic brain indices of verbal working memory capacity in children and adolescents. *Developmental Cognitive Neuroscience*, *15*, 67–82. doi:10.1016/j.dcn.2015.07.007