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Attention-Deficit/Hyperactivity Disorder (ADHD) and Working Memory in Adults: A Meta-Analytic Review

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Objective: Within the last decade, working memory (WM) has garnered increased interest as a potential core deficit or endophenotype of attention-deficit/hyperactivity disorder (ADHD). The current study is the first meta-analytic review to examine several subject and task moderator variables' (e.g., percent female, diagnostic selection procedure, trials per set size, response demands, type of dependent variable, and central executive [CE] demands) effect on between-group phonological (PH) and visuospatial (VS) WM in adults with ADHD, relative to healthy controls. ***Method:*** Literature searches were conducted using the PsycINFO, Web of Science, and PubMed databases, and yielded 38 studies of WM in adults with ADHD. ***Results:*** Results revealed moderate-magnitude between-group effect sizes (ESs) across both WM domains. In addition, several task-moderating variables explained significant ES variability among PH and VS studies. ***Conclusions:*** Collectively, these findings indicate that WM deficits persist into adulthood and suggest that methodological variability may explicate why WM deficits have not been uniformly detected in previous experimental studies.

Keywords: ADHD, working memory, attention, meta-analysis

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Attention-deficit/hyperactivity disorder (ADHD) is characterized by difficulties with attention, hyperactivity, and impulsivity, and occurs in an estimated 3% to 5% of school-age children (Barkley, 2006). Although initially considered a childhood disorder, examination of ADHD in late adolescents and adults has garnered increased interest over the last decade, with recent epidemiological findings suggesting an estimated 4% to 5% of adults meet criteria for the disorder (Kessler et al., 2006). The increased interest in examining adult ADHD is exemplified in recent proposals to amend the next iteration of the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; American Psychiatric Association, in press) to reflect criteria appropriate for adults with the disorder (Kessler et al., 2010). Presence of the disorder in adulthood is associated with numerous pejorative outcomes, including lower collegiate grade-point averages and decreased graduation rates, greater relationship and marital difficulties, higher divorce rates, increased risk for other comorbid disorders, and lower socioeconomic status relative to nonaffected adults (Barkley, Fischer, Smallish, & Fletcher, 2006; Mannuzza, Klein, Bessler, Malloy, & LaPadula, 1993; Sobanski et al., 2008). Improvements to diagnostic specificity, case conceptualization, and treatment modalities are intrinsically tied to the refinement of existing and emerging ADHD models to reflect the lifelong course of the disorder (Rapport, Kofler, Alderson, & Raiker, 2008).

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Extant models of ADHD emphasize the role of executive functions as either secondary features that result from the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000) defined core deficits (Barkley, 2006), or central core deficits that underlie the ADHD phenotype (i.e., inattention, hyperactivity, and impulsivity; Rapport, Chung, Shore, & Isaacs, 2001). The functional working memory (WM) model of ADHD, for example, hypothesizes that WM deficits serve as a core feature of the disorder (Rapport, Chung, et al., 2001), and affected individuals exhibit increased motor activity relative to typically developing peers in an attempt to increase cortical arousal needed for task demands related to central executive (CE) functioning (Rapport et al., 2009).

The foundation of Rapport and colleagues' (2009) functional WM model of ADHD is derived from Baddeley's (2007) model that suggests WM processes allow for the temporary storage, maintenance, and manipulation of information that is required to guide behavior. The WM model describes a CE and two subsidiary components—the phonological (PH) and visuospatial (VS) storage/rehearsal subsystems. The CE is an attentional controller responsible for overseeing and coordinating the subsidiary systems, focusing attention, dividing attention among concurrent tasks, and protecting temporarily stored information from competing external or internal distracting information (Engle, Kane, & Tuholski, 1999). The PH and VS (also referred to as the VS sketchpad) subsystems are responsible for the temporary storage and rehearsal of verbal and visual/spatial information, respectively.

Extant experimental (Huang-Pollock & Karalunas, 2010; Rapport, Alderson, et al., 2008) and meta-analytic studies (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) have provided strong evidence of WM deficits in children with ADHD, particularly with

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regard to the VS system and the CE. Relatively less is known about WM processes in adults with the disorder, but this warrants examination because of the lifelong trajectory of ADHD symptoms and associated pejorative outcomes in affected individuals. A comprehensive model of ADHD that incorporates both child and adult symptomatology is expected to demonstrate strong predictive validity and to accurately account for phenotypic changes associated with ontogeny (Faraone, Biederman, & Mick, 2006). That is, adults with ADHD often experience continued problems with attention (Wilens, Faraone, & Biederman, 2004) and impulsivity (Hurst, Kepley, McCalla, & Livermore, 2011), but relatively fewer difficulties with hyperactivity (Biederman, Mick, & Faraone, 2000; Faraone et al., 2006; Wilens, Biederman, & Spencer, 2002). Additional research is needed to discern whether or not the expression of ADHD in adolescents and adults is due to common underlying core deficits/endophenotypes (e.g., WM) compared with those observed in studies of children affected with the disorder.

Previous meta-analytic reviews of adults with ADHD have examined WM as a component of overall neuropsychological performance (Hervey, Epstein, & Curry, 2004; Schoechlin & Engel, 2005) or executive functions (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005), but have not examined the WM construct alone. For example, findings from Hervey, Epstein, and Curry (2004) and Schoechlin and Engel (2005) suggest that neuropsychological deficits persist in adults with ADHD, particularly with regard to executive functions and verbal memory. Conclusions from these study findings must be tempered, however, due to the broad range of executive/neuropsychological domains included in both reviews. That is, short-term/WM processes constituted a relatively small proportion of reviewed studies (18%; Hervey et al., 2004) or were not examined independently from other neuropsychological processes, such as long-term memory and attention (Schoechlin & Engel, 2005).

A more recent meta-analytic review examined a broad range of executive and nonexecutive tasks, including Digits Forward and Digits Backward from the Wechsler Adult Intelligence Scale–Revised (WAIS–R; Wechsler, 1981), and found small to moderate effect sizes (ESs) for both backward (ES = 0.44) and forward (ES = 0.29) span tasks (Boonstra et al., 2005) when comparing adults with ADHD to nonaffected peers. Although these findings appear to provide support for persistent short-term/WM deficits in adults with ADHD, conclusions may be premature, due to the use of overly restrictive study inclusion criteria and failure to examine VS processes that are associated with greater ADHD-related deficits (Martinussen et al., 2005). For example, included studies were limited to those that shared task parameters and dependent variables with at least three other studies. This procedure significantly limited the number of included studies and was unnecessary because a strength of meta-analytic reviews is their ability to examine phenomena across relatively heterogeneous methodologies, by means of standardized ES estimates (Lipsey & Wilson, 2001). A more comprehensive review with broader inclusion criteria and examination of both PH and VS modalities is expected to provide more accurate and reliable findings. In addition, the previous review did not examine methodological and sample variables that may serve as potential moderators of between-group differences.

The present study is unique in its comprehensive review of a broad range of WM tasks across both PH and VS modalities. Findings from previous reviews have been relatively equivocal (Boonstra et al., 2005; Hervey et al., 2004; Schoechlin & Engel, 2005) and warrant further examination, given strong evidence from previous correlational (Alderson, Rapport, Hudec, Sarver, & Kofler, 2010), experimental (Rapport, Alderson, et al., 2008), structural equation model (Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2009), and meta-analytic (Martinussen et al., 2005) studies with children that suggest large magnitude differences between VS and PH deficits. That is, larger magnitude ESs (children with ADHD exhibit poorer performance relative to typically developing children) have been found in the VS subsystem relative to the PH subsystem. Further, the current review is the first to provide a systematic examination of sample (e.g., percent of female participants and diagnostic procedures) and task variable (e.g., trials per set size, response demands, type of dependent variables, and CE demands) moderator effects on adults' WM performance not quantified in previous reviews. Moderating variables warrant scrutiny due to their potential to influence the relationship between independent and dependent variables, with implications for theory development, refinement, and refutation (Holmbeck, 1997). Thirty-eight studies were included in the current review, including 29 studies published since the previous reviews of overall neuropsychological processes and executive functions (Boonstra et al., 2005; Hervey et al., 2004; Schoechlin & Engel, 2005).

Method

Literature Searches

Literature searches were conducted using the PsycINFO, Web of Science, and PubMed databases. The following keywords were used in each search engine: attention deficit disorder, ADHD, hyper* and atten*, each of which was paired with WM, visual span, spatial span, short-term memory (STM), phonological loop, visuospatial, and digit span. An asterisk placed at the end of a root word instructed search engines to look for any derivative of that root word (e.g., atten*: attention). A forward search was conducted using the Social Science Citation Index, and a backward search was completed by examining references cited in included studies.

Inclusion Criteria

All studies included in the review compared the performance of adults (18 years old or greater) with ADHD to healthy controls (HCs) on WM tasks. Articles were included if they utilized a task that required temporary mental storage of verbal or VS information. Additional inclusion criteria required that studies (a) were a published article (e.g., not a dissertation); (b) included between-subjects comparisons; (c) included an HC group and a group identified as ADHD, ADD, ADDH, or hyperkinetic disorder; (d) included independent PH and/or VS scores (rather than one composite score that reflected an aggregate of PH and VS performance; PH and VS WM tasks were defined as any tasks that required temporary storage and rehearsal of verbal and visual/spatial information, respectively); (e) included adequate data to calculate an ES for between-group WM performance differences (e.g., studies were excluded that only reported event-related potentials recorded during WM tasks); and (f) were written in Eng-

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lish. Thirty-eight studies were gleaned from the preliminary broad literature search based on the inclusion criteria described previously (see Table 1). One of the studies required special consideration. Specifically, Brown et al. (2011) included two ADHD groups, with one consisting of individuals that are carriers of the 9R allele. The ADHD group with 9R-carriers was included in the current study.

Next, guidelines were determined a priori to omit data from studies that provided multiple tasks/conditions in a single modality (VS or PH), as including multiple ESs from the same sample risks threats to statistical independence and overweighting findings (Lipsey & Wilson, 2001). Specifically, the first step gave preference to study conditions that provided the most complete data, as incomplete data results in exclusion from later moderation analyses.[1] As a next step, conditions that placed greater demands on WM (e.g., Letter–Number Sequencing; Wechsler, 2008), particularly the CE, were given preference over conditions that reflected simple storage/rehearsal processes (e.g., Digit Span Forward; Wechsler, 2008). This process resulted in 100% agreement between two raters who independently selected study conditions. Finally, studies were selected randomly when task demands were equivalent and none of the a priori selection guidelines provided resolution.

The 38 included studies provided data from 103 tasks/conditions. Fifty-six tasks/conditions were excluded (a list of excluded tasks can be found in the online supplemental materials). Specifically, eight WM tasks were excluded in favor of tasks that included more complete data.[2] Next, data from 33 tasks were excluded in favor of tasks that required greater mental manipulation of information (i.e., greater demand on CE processes). Remaining tasks ($n = 10$) that could not be selected by the above criteria were selected randomly when task demands were equivalent and none of the a priori selection guidelines provided resolution (Barkley & Murphy, 2010; Gropper & Tannock, 2009; Ibáñez et al., 2011; Marx et al., 2010, 2011; Prox-Vagedes et al., 2011; Ross, Harris, Olincy, & Radant, 2000; Rucklidge, Harrison, & Johnstone, 2011; Schweitzer, Hanford, & Medoff, 2006; Torralva et al., 2011). Finally, two studies that reported multiple conditions of a task required special consideration. One study examined the effect of emotional interference on WM by presenting neutral and negative background pictures across conditions of an n-back task (Marx et al., 2011). The neutral-pictures condition was chosen (excluding two emotional interference conditions) because it is most similar to other included n-back tasks. Another study (White, Hutchens, & Lubar, 2005) repeated administrations of the Paced Auditory Serial Addition Task (PASAT) with different interstimulus intervals. The first presentation of stimuli was chosen to remain consistent with other included studies utilizing the PASAT, thus excluding three repeated trials. This decision was based on previous literature that suggests performance on the PASAT is susceptible to practice effects and may be variable across ISIs (Tombaugh, 2006). Table 1 provides a list of included tasks.

Potential Moderators and Coding of Moderators

Informant. Diagnostic information that is used to group participants (e.g., ADHD and HC) may be obtained by self-report, ratings scales, and/or interviews of individuals who have a relationship with the person being tested (e.g., a friend, parent), or a combination of both collection methods (Rapport, Kofler, et al., 2008). Studies of ADHD in adults often rely exclusively on the self-report of participants, perhaps due to decreased cost (e.g., time and effort to contact parents or spouse) and a colloquial belief that adults are reliable reporters of their own emotional and behavioral functioning (Barkley, Murphy, & Fischer, 2008). The most valid diagnostic data collection method, however, includes gathering information from both the individual being tested and a collateral informant (Murphy & Gordon, 1998), as many adults with ADHD exhibit reduced insight regarding their own behavior and an inaccurate recall of their academic, occupational, social, and behavioral history (Sandra Kooij et al., 2008). Studies that rely solely on the self-report of participants to form diagnostic groups are expected to be associated with smaller ESs, due to heterogeneity in self-reported ADHD. Consequently, included studies were coded using a dichotomous moderating variable, *informant*. Studies that diagnosed participants by single report (self- or other-report only) were coded as 0, whereas those that included multiple informants to diagnose participants were coded as 1.

Percent female. The ADHD phenotype frequently presents differently in males and females with ADHD, such that females are more likely to exhibit attention difficulties in the absence of hyperactivity–impulsivity symptoms, which are typically present in males with the disorder (Biederman, Faraone, Monuteaux, Bober, & Cadogen, 2004). Some studies have suggested that males with ADHD also exhibit more severe executive function (e.g., WM) deficits (Seidman et al., 1997) and decreased neural activity in areas of the brain that are related to WM (e.g., prefrontal cortex; Valera et al., 2010), when compared with females with the disorder. Consequently, studies consisting of samples with a large female-to-male ratio are expected to be associated with smaller between-group ESs. The total percentage of females (ADHD group and HC group) included in each study was examined as the continuous moderating variable, *percent female*.

Age. Previous studies indicate that PH and VS WM continues to develop throughout early adolescence and adulthood (Best & Miller, 2010; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Swanson, 1999), until the late 50s or early 60s, at which point it begins to decline (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2011). Studies that included a younger sample of late adolescents or early adults, therefore, are expected to yield larger between-group differences because older adults with ADHD would have had time to "catch up" to nonaffected adults. Consequently, the continuous moderating variable *age* (mean age of the total sample; Alderson, Rapport, & Kofler, 2007; Mann-Wrobel, Carreno, & Dickinson, 2011) was examined to explicate differences in WM capabilities across younger and older adults.

Trials per set size. Studies that utilize relatively few trials are expected to be less reliable relative to studies that use greater numbers of experimental trials (Bland & Altman, 1996). Furthermore, previous research suggests that WM resources are depleted after multiple trials, such that studies with relatively few trials are expected to put fewer demands on WM resources relative to

[1] The weighted regression used to examine potential moderation effects deletes cases listwise so that any missing data from a single study results in exclusion from the analysis.
[2] These tasks are not included in the supplementary table.

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Table 1
Working Memory Studies of Between-Group Comparisons of ADHD and Healthy Control Adults

Study	*N*	Percent female	Mean (SD) Age	Informant	Measure	PH/VS	Trials per set size	Performance metric	Response modality	CE demand	Effect size[a]	95% confidence interval
Gansler et al. (1998)	30 ADHD 10 HC	6.67 30	28.9 (12.5) 35.0 (10.26)	Multiple	Logical Memory I (WMS-R)	PH	2	Stimuli	Recall	Low	−0.011	−0.71, 0.69
Gansler et al. (1998)	30 ADHD 10 HC	6.67 30	28.9 (12.5) 35.0 (10.26)	Multiple	Visual Reproduction I (WMS-R)	VS	5	Stimuli	Recall	Low	0.091	−0.61, 0.79
Ross et al. (2000)	10 ADHD 10 HC	40 40	39.0 (7.0) 38.0 (8.0)	Single	Delayed Oculomotor Response Task	VS	10	Stimuli	Recall	Low	0.416	−0.43, 1.27
Schweitzer et al. (2000)	6 ADHD 6 HC	0 0	28.5 (8.9) 25.7 (5.2)	Multiple	Paced Auditory Serial Addition Task	PH	50	Trials	Recall	High	1.063	−0.07, 2.19
Rapport et al. (2001)	35 ADHD 32 HC	31.43 40.63	32.9 (10.8) 33.2 (13.2)	Multiple	Letter–Number Span	PH	4	Trials	Recall	High	0.244	−0.23, 0.72
Ossmann & Mulligan (2003)	24 ADHD 24 HC	41.67 41.67	19.21 (1.18) 19.42 (1.06)	Single	Reading Span	PH	5	Stimuli	Recall	High	0.302	−0.26, 0.86
Dowson et al. (2004)	19 ADHD 19 HC	21.05 21.05	27.7 (7.1) 29.5 (7.0)	Multiple	Spatial Working Memory (CANTAB)	VS	4	Stimuli	Recall	High	1.115	0.44, 1.79
McLean et al. (2004)	19 ADHD 19 HC	21.05 21.05	27.7 (1.6) 29.5 (1.6)	Multiple	Spatial Working Memory (CANTAB)	VS	4	Stimuli	Recall	High	0.640	0.001, 1.28
Valera et al. (2005)	20 ADHD 20 HC	40 40	34 (11.8) 33 (10.6)	Multiple	2-Back	PH	18	Trials	Recognition	High	0.121	−0.49, 0.73
White et al. (2005)	10 ADHD 10 HC	40 50	29.4 (7.47) 26.8 (7.52)	Single	Paced Auditory Serial Addition Task	PH	50	Trials	Recall	High	2.339	1.23, 3.45
Schweitzer et al. (2006)	16 ADHD 17 HC	35.29 27.78	33.35 (11.45) 31.94 (7.70)	Multiple	Paced Auditory Serial Addition Task	PH	50	Trials	Recall	High	0.803	0.11, 1.50
Chamberlain et al. (2007)	20 ADHD 20 HC	30 30	31.6 (8.33) 30.9 (7.93)	Multiple	Spatial Working Memory (CANTAB)	VS	4	Stimuli	Recall	High	0.867	0.23, 1.50
Clark et al. (2007)	20 ADHD 16 HC	35 12.5	28.0 (8.6) 25.1 (5.4)	Multiple	Spatial Working Memory (CANTAB)	VS	4	Stimuli	Recall	High	0.650	−0.01, 1.31

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Table 1 (*continued*)

Study	*N*	Percent female	Mean (SD) Age	Informant	Measure	PH/VS	Trials per set size	Performance metric	Response modality	CE demand	Effect size[a]	95% confidence interval
Hale et al. (2007)	10 ADHD 10 HC	10 10	34.9 (8.12) 27.0 (4.14)	Single	Modified Digit Span Backward	PH	3 to 5	Trials	Recall	High	−0.242	−1.08, 0.60
Lampe et al. (2007)	22 ADHD 20 HC	36.36 70	29.95 (8.2) 28.7 (6.9)	Single	Digit Span Backward (WMS-R)	PH	2	Trials	Recall	High	0.491	−0.11, 1.09
Ehlis et al. (2008)	13 ADHD 13 HC	30.77 38.46	29.8 (8.0) 26.8 (3.6)	Single	2-Back	PH	12	Trials	Recognition	High	0.513	−0.24, 1.27
Marchetta et al. (2008)	20 ADHD 136 HC	25 38.2	29.95 (5.22) 30.13 (4.79)	Multiple	Auditory Verbal Learning Task	PH	1	Stimuli	Recall	Low	0.873	0.40, 1.35
Gropper & Tannock (2009)	16 ADHD 30 HC	37.5 56.67	21.34 (2.59) 22.48 (2.68)	Single	Paced Auditory Serial Addition Task	PH	60	Trials	Recall	High	0.998	0.37, 1.63
Gropper & Tannock (2009)	16 ADHD 30 HC	37.5 56.67	21.34 (2.59) 22.48 (2.68)	Single	Spatial Span Backward (CANTAB)	VS	1 or 2	Stimuli	Recall	High	0.708	0.09, 1.32
Laasonen et al. (2009)	30 ADHD 40 HC	40 50	31.6 (8.17) 37.15 (11.7)	Single	Letter–Number Sequencing (WAIS-III)	PH	3	Trials	Recall	High	0.201	−0.27, 0.67
Pollak et al. (2009)	30 ADHD 30 HC	43.33 43.33	25.1 (2.4) 25.0 (3.5)	Single	Computer-Based VS Working Memory Task	VS	Variable	Trials	Recall	Low	1.077	0.54, 1.61
Wolf et al. (2009)	12 ADHD 12 HC	0 0	22.2 (4.4) 21.6 (4.7)	Multiple	Cognitive Activation Task	PH	28	Trials	Recognition	High	0.262	−0.51, 1.04
Wolf et al. (2009)	12 ADHD 12 HC	0 0	22.2 (4.4) 21.6 (4.7)	Multiple	Corsi Block Tapping Backward	VS	2 or 3	Trials	Recall	High	−0.107	−0.88, 0.67
Agay et al. (2010)	13 ADHD 16 HC	53.8 37.5	33.2 (8.6) 32.4 (7.7)	Single	Digit Span Backward (WAIS-R)	PH	2	Trials	Recall	High	0.223	−0.49, 0.94
Barkley & Murphy (2010)	143 ADHD 108 HC	32 53	32.4 (10.9) 36.4 (12.0)	Multiple	Digit Span Backward (WAIS-III)	PH	2	Trials	Recall	High	0.220	−0.03, 0.47
Barkley & Murphy (2010)	143 ADHD 108 HC	32 53	32.4 (10.9) 36.4 (12.0)	Multiple	Complex Figure Task (LAMB)	VS	1	Stimuli	Recall	Low	0.081	−0.17, 0.33
Boonstra et al. (2010)	49 ADHD 49 HC	46.94 46.94	38.7 (9.7) 38.1 (9.3)	Single	Letter–Number Sequencing (WAIS-III)	PH	3	Trials	Recall	High	0.625	0.22, 1.03

(*table continues*)

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Table 1 (*continued*)

Study	*N*	Percent female	Mean (SD) Age	Informant	Measure	PH/VS	Trials per set size	Performance metric	Response modality	CE demand	Effect size[a]	95% confidence interval
Boonstra et al. (2010)	49 ADHD 49 HC	46.94 46.94	38.7 (9.7) 38.1 (9.3)	Single	Visual Memory Span Backward (WMS-R)	VS	2	Trials	Recall	High	0.415	0.02, 0.81
Burgess et al. (2010)	20 ADHD 23 HC	40 43.47	20.1 (1.8) 19.0 (0.9)	Multiple	Digit Span Backward (WAIS-III)	PH	2	Trials	Recall	High	0.638	0.03, 1.24
Burgess et al. (2010)	20 ADHD 23 HC	40 43.47	20.1 (1.8) 19.0 (0.9)	Multiple	Spatial Span Backward (WMS-R)	VS	2	Trials	Recall	High	0.577	−0.02, 1.18
Dige et al. (2010)	69 ADHD 66 HC	59.42 66.67	31.81 (9.36) 37.09 (12.33)	Single	Dichotic Memory Test	PH	8	Stimuli	Recall	Low	1.382	1.01, 1.76
Lis et al. (2010)	20 ADHD 20 HC	35 35	37.3 (8.3) 37.5 (9.2)	Single	1-Back	VS	600	Trials	Recognition	High	0.489	−0.13, 1.11
Marx et al. (2010)	20 ADHD 20 HC	0 0	24.22 (5.62) 25.26 (5.91)	Single	2-Back	PH	60	Trials	Recognition	High	0.343	−0.27, 0.95
Valera et al. (2010)	43 ADHD 49 HC	47.72 53.06	36.8 (11.0) 32.5 (10.1)	Single	2-Back	PH	18	Trials	Recognition	High	−0.148	−0.55, 0.26
Aycicegi-Dinn et al. (2011)	13 ADHD 19 HC	38.46 36.84	28.31 (6.89) 27.11 (7.77)	Single	Letter–Number Sequencing Task	PH	4	Trials	Recall	High	0.795	0.08, 1.51
Aycicegi-Dinn et al. (2011)	13 ADHD 19 HC	38.46 36.84	28.31 (6.89) 27.11 (7.77)	Single	Paper-and-Pencil VS Working Memory Task	VS	14	Stimuli	Recall	Low	0.858	0.14, 1.58
Barkley & Fischer (2011)	52 ADHD 73 HC	16.36 6.67	26.8 (1.4) 27.0 (0.9)	Multiple	Simon Game	VS	2	Stimuli	Recall	Low	0.610	0.25, 0.97
Brown et al. (2011)	32 ADHD 12 HC	48.5 50	33.7 (10.5) 30.7 (9.1)	Single	2-Back	PH	18	Trials	Recognition	High	0.230	−0.42, 0.88
Finke et al. (2011)	30 ADHD 30 HC	40 40	35.5 (9.49) 35.96 (10.39)	Multiple	Whole-Report Task	PH	16	Stimuli	Recall	Low	1.883	1.28, 2.49
Ibáñez et al. (2011)	10 ADHD 10 HC	10 10	33.1 (3.42) 33.3 (3.64)	Multiple	Letter–Number Sequencing (WAIS-III)	PH	3	Trials	Recall	High	1.197	0.28, 2.11
Ibáñez et al. (2011)	10 ADHD 10 HC	10 10	33.1 (3.42) 33.3 (3.64)	Multiple	Spatial Working Memory (IFS)	VS	4	Trials	Recall	High	0.948	0.06, 1.84

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Table 1 (*continued*)

Study	*N*	Percent female	Mean (SD) Age	Informant	Measure	PH/VS	Trials per set size	Performance metric	Response modality	CE demand	Effect size[a]	95% confidence interval
Marx et al. (2011)	39 ADHD 40 HC	43.59 52.5	28.5 (6.3) 24.9 (4.6)	Single	2-Back	PH	14	Trials	Recognition	High	0.473	0.03, 0.92
Prox-Vagedes et al. (2011)	13 ADHD 13 HC	53.85 53.85	31.2 (NR) 32.2 (NR)	Single	Continuous Word Recognition Task	PH	90	Trials	Recognition	High	−0.392	−1.14, 0.36
Rucklidge et al. (2011)	14 ADHD 14 HC	35.71 42.86	37.5 (9.56) 31.4 (14.27)	Multiple	Number–Letter (WRAML-II)	PH	1 to 5	Trials	Recall	Low	0.217	−0.50, 0.94
Rucklidge et al. (2011)	14 ADHD 14 HC	35.71 42.86	37.5 (9.56) 31.4 (14.27)	Multiple	Design Memory (WRAML-II)	VS	5	Trials	Recall	Low	−0.324	−1.05, 0.40
Torralva et al. (2011)	16 ADHD 15 HC	62.5 46.67	46.6 (14.2) 43.9 (19.8)	Single	Letter–Number Sequencing (WAIS-III)	PH	3	Trials	Recall	High	1.022	0.29, 1.75
Torralva et al. (2011)	16 ADHD 15 HC	62.5 46.67	46.6 (14.2) 43.9 (19.8)	Single	Rey Complex Figure Test	VS	1	Trials	Recall	Low	−0.208	−0.90, 0.48
Rohlf et al. (2012)	37 ADHD 32 HC	5.41 6.25	21.66 (2.98) 22.45 (2.96)	Single	Digit Span Backward (WAIS-German)	PH	2	Trials	Recall	High	0.725	0.24, 1.21

Note. All studies were between-group comparisons of ADHD and healthy control adults. Number of females reported as percentage. ADHD = attention-deficit/hyperactivity disorder; CANTAB = Cambridge Neuropsychological Test Automated Battery; HC = healthy/normal control; IFS = INECO Frontal Screening; LAMB = Learning and Memory Battery; Multiple = multiple diagnostic/grouping sources; NR = not reported; PH = phonological; SD = standard deviation; Single = single diagnostic/grouping source; VS = visuospatial; WAIS = Wechsler Adult Intelligence Scale; WMS-R = Wechsler Memory Scale-Revised; WRAML = Wide Range Assessment of Memory and Learning.
[a] Positive effect size reflects poorer performance (lower accuracy or greater errors) by the ADHD group.

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studies with many trials (Burton & Daneman, 2007), and a relatively larger number of trials requires participants to extract information from their storage/buffer (primary memory) and an additional search process (secondary memory; Unsworth & Engle, 2006). Consequently, studies that rely on relatively few trials per set size (*set size* refers to the number of stimuli/targets presented in a trial) may not effectively capture between-group WM differences and are expected to find smaller between-group ESs relative to studies that included a greater number of trials per set size (Rapport, Alderson, et al., 2008). A dichotomous moderating variable, *trials per set size*, was created by categorizing studies that included fewer than 10 trials per set size as "low" (coded as 0) and studies that included 10 trials per set size or greater as "high" (coded as 1). The cut point for the high–low division was determined a priori based on a previous finding that suggests the slope of learning and memory performance changes after approximately 7 to 10 trials (Stepanov, Abramson, Wolf, & Convit, 2010).

Response modality. Extant literature has identified separate cognitive processes associated with recognition and recall tasks (Kahana, Rizzuto, & Schneider, 2005), which are correlated with distinct brain structures such as the anterior cingulate, thalamus, globus pallidus, and cerebellum (Cabeza et al., 1997). Recall tasks, relative to recognition tasks, are expected to place greater demands on WM due to the need for increased effort and self-initiation processes, compared with the simpler task of choosing a stimulus among a group of options (recognition task; Baddeley, Chincotta, Stafford, & Turk, 2002; Craik & McDowd, 1987). Consequently, studies that utilize recognition tasks are expected to find nonsignificant or smaller ESs relative to studies that utilize recall tasks, due to less demand placed on the WM system. *Response modality* (i.e., recognition or recall) was therefore examined as a potential moderating variable, with tasks categorized into those that required recognition (0) and those that required recall (1).

Performance metric. WM performance accuracy is typically defined as either total correct trials or total correct stimuli, with the number of total correct trials currently being the most frequent approach to measuring WM performance. Examination of total correct trials as a dependent measure, however, may not provide the most valid measure of participants' WM abilities because the procedure (a) does not detect partial recall of stimuli (e.g., 90% correct recall of stimuli within a trial is treated the same as 0% recall of stimuli within a trial, as both responses result in a score of 0), and (b) discontinuing a task after a predetermined number of incorrect trials (e.g., after two incorrect trials on digit span tasks) may discard potential correct answers on subsequent trials and consequently underestimate one's WM ability (Conway, Cowan, & Bunting, 2001). That is, external variables such as outside distractions and poor motivation may result in an individual meeting discontinuation criterion for a WM task before they have exhibited their maximum WM potential. To determine the effect of variability in dependent variable operational definitions, the moderating variable *performance metric* was created by coding studies as trials correct (0) or stimuli correct (1).

CE demand. Current studies examining WM typically use tasks that require temporary storage, maintenance, and manipulation of PH or VS information as measures of WM (Luciana, Conklin, Hooper, & Yarger, 2005; Passolunghi & Mammarella, 2010). Examples of these tasks include Digit Span-Backward and Letter–Number Sequencing from the Wechsler scales (Wechsler, 2008) and Finger Windows-Backward from the Wide Range Assessment of Memory and Learning (WRAML-2; Sheslow & Adams, 2003). Previous experimental (Lambek et al., 2011; Rucklidge & Tannock, 2002; Toplak, Rucklidge, Hetherington, John, & Tannock, 2003; Willcutt et al., 2001) and meta-analytic (Martinussen et al., 2005; Willcutt et al., 2005) reviews have adopted this rationale to examine the difference between tasks that provide a measure of storage and those that require manipulation (i.e., involve the CE). The latter tasks are frequently categorized as WM, as they require the participant to remember stimuli and later recall the stimuli in a different pattern than the original presentation. The moderator variable *CE demand* was created by dichotomously coding studies as 0 (no manipulation requirement) or 1 (required manipulation).

ES Estimation

ES estimates were computed using Comprehensive Meta-Analysis Version 2 (CMA; Borenstein, Hedges, Higgins, & Rothstein, 2005) software and reflect the magnitude of difference between adults with ADHD and healthy control adults. Positive ESs indicated better WM performance for the control group relative to the ADHD group. PH and VS ES estimates were computed separately because extant research supports two distinct modalities based on neuroimaging (Fassbender & Schweitzer, 2006), neuroanatomical (Smith, Jonides, & Koeppe, 1996), neuropsychological (Baddeley, 2007), and factor analytic (Alloway, Gathercole, & Pickering, 2006) findings. Further, combining PH and VS data to calculate one ES would omit data, as only one data point could be used for each study (Lipsey & Wilson, 2001). Hedges's (1982) *g* ESs were used to correct for the upward bias of studies with small sample size (Lipsey & Wilson, 2001). To further correct for sample size differences, studies were weighted by their inverse variance weights. ESs are classified as small (ES $\leq$0.30), medium ($0.30 < \text{ES} < 0.67$), or large (ES $\geq$0.67), whereas an ES of zero indicates no difference between means (Lipsey & Wilson, 2001). All ESs were computed using means, standard deviations, and sample sizes, with the exception of the ES obtained from one VS study (Ibáñez et al., 2011), which was computed from sample size and *p* value. Eight studies reported errors instead of accuracy data for their dependent measure, so the direction of the ES of the latter studies was reversed to provide uniform ES data (e.g., an ES of −0.38 was changed to 0.38).

Data Analysis

Homogeneity analyses. A *Q* test was performed on each outcome variable (i.e., PH and VS) to examine the distribution of ESs from the included studies. A significant *Q* rejects the assumption of homogeneity and supports the examination of potential moderator effects (Lipsey & Wilson, 2001).

Moderator analyses. A mixed effects weighted regression approach using SPSS 18.0 for Windows was adopted to provide a measure of overall fit (Q_R), as well as an error/residual term (Q_E). Both statistics are distributed as chi square. A significant Q_R indicates that the model accounts for significant variability among ESs, whereas a significant Q_E indicates that the residual variance is greater than what is expected from random study-level sampling error (Lipsey & Wilson, 2001). The weighted regression provides

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incorrect standard errors and *p* values, as the method for assigning degrees of freedom are different for meta-analyses (Borenstein et al., 2005). Consequently, beta weights from each regression were corrected and compared with a *z* table to determine if the moderator was statistically significant (Guy, Edens, Anthony, & Douglas, 2005; Lipsey & Wilson, 2001).

Results

Overall ES Summary

Thirty tasks provided sufficient information to compute ESs for PH performance. The mean ES of PH performance between ADHD and healthy control adults was 0.55 (95% CI [0.36, 0.74]), and indicates that adults with ADHD exhibit moderate PH short-term/WM deficits relative to normal controls. The distribution of ESs was heterogeneous, Q (29) = 96.92, $p < .001$, ranging from −0.39 to 2.34, and is shown in Table 2 as a stem-and-leaf plot. A stem-and-leaf plot functions as a histogram turned on its side. It summarizes the distribution of data and provides specific information about individual data. ESs are arranged by place value such that digits in the left column represent the stem, whereas digits in the right columns represent the leaf. For example, the ESs of .63 and .64 are represented as .6 in the left column (stem), and 3 and 4 in the right columns (leaf), respectively. All ESs fell within three standard deviations of the mean ES for PH, suggesting the heterogeneity was not due to outliers. A *Fail-safe N* analysis (Rosenthal, 1995) indicated that an unlikely 763 studies would be needed to reduce the confidence interval of the ES to include zero. In addition, a rank correlation (Kendall's tau) test for publication bias was not significant (p = .27).

Table 2
Stem-and-Leaf Plot of PH Working Memory Effect Sizes

Stem	Leaf					
2.3	4					
2.2						
2.1						
2.0						
1.9						
1.8	8					
1.7						
1.6						
1.5						
1.4						
1.3	8					
1.2	0					
1.1						
1.0	0	2	6			
.9						
.8	0	0	7			
.7	3					
.6	3	4				
.5	1					
.4	7	9				
.3	0	4				
.2	0	2	2	2	3	4	6
.1	2					
.0						
−.0	1					
−.1	5					
−.2	4					
−.3	9					

Note. PH = phonological.

Eighteen tasks provided sufficient information to compute ESs for VS (see Table 3). The mean ES of VS between ADHD and healthy control adults was 0.49 (95% CI [0.30, 0.68]), and indicates that adults with ADHD demonstrate moderate VS deficits relative to normal controls. The distribution of ESs was heterogeneous, Q (17) = 34.68, $p < .01$, ranging from −0.21 to 1.12, and is shown in Table 3 as a stem-and-leaf plot. All ESs fell within three standard deviations of the mean ES for VS, suggesting the heterogeneity was not due to outliers. The *Fail-safe N* analysis indicated that 207 studies would be needed to reduce the confidence interval of the ES to include zero, and a rank correlation test for publication bias was not significant (p = .38).

Moderator Variables

PH WM. The results of the mixed effects, weighted regression analysis indicates that the model explains a significant proportion of the variability across the PH ESs, Q_R = 24.86, df = 7, $p < .001$, and accounts for 51% of the variability. Studies that used a greater number of trials per set size (z = 3.56, $p < .001$) and used recall rather than recognition tasks (z = 4.15, $p < .001$) were significantly associated with larger ESs. Percent female, age, informant, performance metric, and CE demand were not significant predictors of PH ESs (all ps > .05). The sum-of-squares residual, Q_E = 23.70, df = 22, p = .36, was not significant, indicating that unexplained variability was not greater than would be expected from sampling error alone, and suggesting the overall model is a good fit (Field & Gillett, 2010; see Table 4).

VS WM. The results of the mixed effects, weighted regression analysis indicate that the model explains a significant proportion of the variability across the VS ESs, Q_R = 17.97, df = 6, p = .006, and accounts for 65% of the variability. Studies that examined correct stimuli (rather than trials; z = 2.10, p = .04) and placed greater demands on the CE (z = 2.53, p = .01) were associated with larger ESs. The variables informant, percent female, age, and trials per set size were not significant moderators of VS ES variability (all ps > .05). Response modality was not included in the regression due to insufficient variability (i.e., all but one included task used recall as the response modality). The sum-of-squares residual, Q_E = 9.54, df = 10, p = .48, was not significant, indicating that unexplained variability was not greater than would be expected from sampling error alone and suggesting the overall model is a good fit.

Best-Case Estimate

Best-case estimation involves solving each regression equation with the moderator values that are considered best practice based on previous research (Lipsey & Wilson, 2001). Examples of best-practice experimental variables include a fewer number of females, younger age, use of collateral informants for symptom report, larger number of trials per set size, recall tasks, stimuli correct as the dependent measure, and mental manipulation of PH or VS information. Although percent female and age were not significant moderators, they were included in the best-case estimate because they were part of the original regression equations, and are

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Table 3
Stem-and-Leaf Plot of VS Working Memory Effect Sizes

Stem	Leaf		
1.1	2		
1.0	8		
.9	5		
.8	6	7	
.7	1		
.6	1	4	5
.5	8		
.4	2	2	9
.3			
.2			
.1			
.0	8	9	
−.0			
−.1	1		
−.2	1		
−.3	2		

Note. VS = visuospatial.

weighted accordingly (i.e., a small amount) by their beta weights. Neither variable is expected to contribute meaningfully to the overall best-case estimates. Solving the regression equations obtained from the moderation analysis yielded ES estimates of 1.22 for VS and 1.44 for PH, suggesting that exceptionally large ESs are expected when using best-practice moderating variables.

Finally, an overlap statistic (OL%; Zakzanis, 2001) was calculated to examine the amount of expected overlap in WM performance between the ADHD group and HC group, if the best-case methodology is used. Given the best-case estimate, the VS WM performance of adults with ADHD is only expected to overlap the performance of HC adults by approximately 38%. In addition, there is approximately an 80% chance that the VS performance of adults with ADHD will be below the mean score of adults in the HC group. The overlap of PH WM performance between adults with ADHD and nonaffected adults is expected to be approximately 32%; however, there is an estimated 84% chance that adults with ADHD would exhibit PH WM performance that is below the average score of nonaffected adults.

Discussion

Collectively, findings from the current study yielded significant between-group ESs of 0.55 and 0.49 for PH and VS studies, respectively, and indicate that adults with ADHD performed moderately worse than nonaffected adults across both domains. These findings, particularly with regard to the ES associated with the PH system, are larger[3] compared with the small ES estimates (0.29 to 0.44) reported in Boonstra et al.'s (2005) previous meta-analysis, and may reflect one or more methodological differences between the reviews. For example, the ES estimates provided by Boonstra and colleagues were derived from only three studies, as opposed to 38 studies examined in the current meta-analysis, and examination of fewer studies is expected to deflate the overall ES estimates by increasing error (Lipsey & Wilson, 2001). Another potential explanation for the discrepancy of findings between the reviews relates to Boonstra et al.'s exclusive use of forward and backward span tasks, which likely placed minimal demands on the CE component of WM (Engle, Tuholski, Laughlin, & Conway, 1999). In contrast, the current study included a broad range of WM tasks, such as letter-number sequencing, sentence span, and n-back paradigms that require frequent attentional shifts between concurrent processing of new information and rehearsal of information temporarily stored in the PH and VS buffers (Cantor, Engle, & Hamilton, 1991; Engle, Kane, et al., 1999; Rosen & Engle, 1997).

The ES estimates obtained in the current study are also incrementally larger compared with PH ESs (PH storage ES = 0.47, 95% CI [0.36, 0.59]; PH CE ES = 0.43, 95% CI [0.24–0.62]) reported in the most recent meta-analytic review of WM in children with the disorder (Martinussen et al., 2005). Although previous literature has demonstrated evidence that executive function impairments persist into adulthood (Boonstra et al., 2005; Hervey et al., 2004; Schoechlin & Engel, 2005), this finding was relatively surprising due to a preponderance of evidence that suggest *DSM–IV–TR* (American Psychiatric Association, 2000) defined core ADHD-related symptoms often attenuate after adolescence (Faraone et al., 2006). That is, Rapport, Alderson, et al.'s (2008) model suggests that attention deficits, hyperactivity, and impulsivity reflect secondary features of ADHD that are downstream of WM deficits, and consequently implies that age-related attenuation of these secondary symptoms is expected to parallel similar changes in WM functioning (i.e., yield smaller ESs with adults compared with children). Consequently, at first glance, these findings appear to contradict predictions from Rapport and colleagues' model. However, the discord between persistent WM impairments and age-related attenuation of ADHD symptoms may reflect topographical changes in the adult ADHD phenotype (Mick, Faraone, Biederman, & Spencer, 2004) and/or learned compensatory strategies that minimize impairments associated with cognitive dysfunction (Frazier, Youngstrom, Glutting, & Watkins, 2007). For example, whereas children with ADHD may struggle to stay on-task and seated during school (and display persistent secondary symptoms), adults with the disorder may seek occupations that allow them to ambulate and switch tasks when desired (which would manifest as an attenuation of secondary symptoms). A more likely explanation, however, may be provided by comparing the current review's VS ES estimate (Cohen's d = 0.50) to the larger VS ESs (VS storage ES = 0.85, 95% CI [0.62, 1.08]; VS CE ES = 1.06, 95% CI = [0.72, 1.39]) reported in Martinussen and colleagues' (2005) review of children. Previous experimental studies have suggested that the CE and VS system, more so than the PH system, is predominantly associated with ADHD-related hyperactivity (Rapport et al., 2009), behavioral disinhibition (Alderson et al., 2010), attention deficits (Kofler, Rapport, Bolden, Sarver, & Raiker, 2010), and social skills impairments (Kofler et al., 2011). Consequently, the smaller VS ES obtained in the current review of adults relative to the previous review of children appears to parallel the ontological–phenotypic changes observed in adults with the disorder (Biederman et al., 2000), and is consistent with previous findings that suggest CE and VS deficits, rather than PH deficits, are more closely tied to ADHD-related secondary symptom presentation (e.g., hyperactivity).

[3] Recalculating the current study's ESs as Cohen's d to compare across reviews yielded PH and VS ESs of 0.56 and 0.50, respectively.

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Table 4
Weighted Regression Model and Moderating Variables For PH and VS

	PH			VS		
	Q	*df*	*p*	*Q*	*df*	*p*
Regression	24.86	7	.001	17.97	6	.006
Residual	23.70	22	.363	9.54	10	.482
R^2	0.51			0.65		
Moderator variables	β[a]	*z*	*p*	β[a]	*z*	*p*
Constant	−.627			.663		
Informant	−.151	−.841	.400	−.224	−.902	.367
Percent female	−.001	.165	.869	−.007	−1.147	.252
Age	−.002	−.101	.919	−.011	−.760	.447
Trials per set size	.859	3.556	.000	.166	.598	.550
Response modality	1.143	4.148	.000	—	—	—
Performance metric	.292	.991	.322	.385	2.095	.036
CE demand	−.110	−.373	.709	.442	2.531	.011

Note. β = standardized beta weight; CE = central executive; df = degrees of freedom; PH = phonological; $Q = \chi^2$ value; R^2 = variance accounted for by the model; VS = visuospatial; $z = z$ value.
[a] Represents the standard deviation change in the dependent variable per each standard deviation change in the independent variable.

Several methodological variables were examined to determine if they significantly moderated the magnitude of between-group ESs on WM tasks. For instance, PH studies that used recall tasks were associated with larger between-group differences relative to those that used recognition tasks. This finding was expected due to recall tasks' greater demand on effortful cognitive processes compared with recognition tasks that allow participants to select the correct choice among an array of stimuli (Cabeza et al., 1997; Kahana et al., 2005).

PH studies that included a greater number of trials were associated with larger between-group differences, which parallels findings from previous research that indicates a positive relationship between reliability and the number of experimental trials included in the WM task (Bland & Altman, 1996). In addition, this finding suggests WM demands may have a cumulative effect on performance, such that WM resources become progressively depleted with subsequent trials (Burton & Daneman, 2007), and implies that the clinical and experimental utility of examining ADHD-related performance deficits on many standardized span tasks (e.g., WAIS-IV Digit Span; Wechsler, 2008) may be ineffective.

VS studies that examined an aggregate of correct trials as a dependent measure, relative to studies that examined stimuli correct, were associated with smaller magnitude ESs. This finding is consistent with a priori predictions and previous research that suggests trial-level analyses may underestimate WM performance, due to discontinue rules that may end a task before a participant's full potential is evaluated (Conway et al., 2001).

The final task-related moderator, CE demand, was examined to determine if greater demands on the CE component of WM account for heterogeneity of between-group differences across studies. In contrast to previous meta-analytic reviews that examined storage and CE tasks independently (Boonstra et al., 2005; Martinussen et al., 2005), the current study used moderator analyses to determine if CE demands influence the magnitude of between-group differences. This approach was adopted due to inconsistent reification of WM across published studies (Engle, Tuholski, et al., 1999) and consideration of Baddeley's (2007) WM model, which suggests the temporary storage and rehearsal of PH and VS information serves as a component (buffer) of WM rather than a separate STM process. Our finding that VS tasks with greater mental manipulation demands were associated with larger ES estimates is consistent with previous studies of children that suggest inattention (Kofler et al., 2010), disinhibition (Alderson et al., 2010), hyperactivity (Rapport et al., 2009), and social skills (Kofler et al., 2011) difficulties are predominantly attributable to the CE component of WM. The nonsignificant moderation effect of CE demand on PH ES estimates likely reflects the greater role of CE processes on the VS system (Alloway et al., 2006), and is consistent with previous experimental findings in children (Rapport et al., 2009).

It is worth noting that, in addition to CE demand, several of the moderating variables yielded conflicting results between PH and VS modalities. For instance, trials per set size (i.e., a higher number of trials) and response modality (i.e., recall tasks) both significantly predicted PH WM between-group differences but did not predict VS WM differences. The significant influence of moderators on only a single modality may be related to limited variability in some VS tasks' moderator values relative to those in PH tasks, and vice versa. For example, only three VS tasks included a high number of trials. Similarly, performance metric (i.e., stimuli correct or trials correct) significantly moderated between-group differences across the VS tasks but not the PH tasks. In this case, only five PH tasks used stimuli correct as the dependent measure.

Overall, none of the examined subject variables significantly moderated the magnitude of between-group ESs on WM tasks. For instance, PH and VS studies were examined to determine if the use of a second informant for group classification was associated with larger between-group differences relative to studies that exclusively relied on self-report of symptoms. The current study's null finding is inconsistent with previous research that suggests collateral informants (e.g., parents and spouses) of current and childhood symptoms improve diagnostic validity (Sandra Kooij et al., 2008). Similarly, studies that included relatively fewer females

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were expected to yield larger between-group differences, as some previous research suggests that executive function (e.g., WM) deficits in females are less severe relative to deficits observed in males (Seidman et al., 1997). Sex ratio of included samples, however, did not significantly moderate between-group VS or PH differences, which is consistent with Valera and colleagues' (2010) finding of nonsignificant WM performance differences between male and female adults, but inconsistent with their finding of disproportionate right frontal, temporal, subcortical, left occipital, and cerebellar underactivity in males with ADHD. A closer examination of three reviewed studies that examined sex as a covariate revealed relatively equivocal results, such that one study found that men performed significantly better than women during PH WM tasks (Schweitzer et al., 2006), whereas the other two studies did not suggest performance differences between the two sexes (Boonstra, Sandra Kooij, Oosterlaan, Sergeant, & Buitelaar, 2010; Gropper & Tannock, 2009). Collectively, these findings suggest further research is needed to explicate the discrepancy between significant sex-related differences reported in individual studies and the current null meta-analytic findings.

Despite previous findings that suggest WM continues to develop after adolescence, the included samples' mean age did not significantly moderate the magnitude of between-group effects across either PH or VS studies, consistent with the findings of Finke et al. (2011), and suggests that younger adults with ADHD do not experience disproportionate WM deficits relative to older adults with the disorder. This somewhat surprising finding may be due to the restricted range of age scores that resulted from using an aggregate score that reflected studies' overall mean age. Individual examinations of the effect of age on WM functioning in adults with ADHD may detect significant effects when a broader age range is examined. Alternatively, this null result may reflect a limitation of the meta-analytic strategy. That is, the relationship between age and WM is likely quadratic in adults, such that WM is expected to improve until around age 60, at which point it begins to decline (Dobbs & Rule, 1989). Additional experimental research is needed to further explicate this finding.

As a last step, the current study solved the regression equations (one for each outcome variable, PH and VS) with moderator values considered best practice according to empirical research. Collectively, studies that use multiple informants, fewer females, younger adults, greater numbers of trials, recall tasks, require mental manipulation of temporarily stored information, and measure stimuli correct as a dependent variable are expected to yield exceptionally large PH (ES = 1.44) and VS (ES = 1.22) ESs and suggest that 80% to 84% of the ADHD group's WM performance is expected to fall below the mean of the HC group. Collectively, these findings suggest that most adults with ADHD are expected to exhibit some PH or VS WM impairment relative to nonaffected adults, given the best-case methodological procedures are utilized, and provide evidence for WM as a core deficit or central feature of the disorder. It is noted, however, that the best-case ES estimates are only hypothetical estimates, and future research that implements best-case practices is necessary before conclusions can be made. Further, these findings do not suggest that WM tasks should be used for diagnostic purposes, as fewer than 80% to 84% of adults with ADHD are expected to exhibit WM deficits to a degree that is typically considered clinically significant (e.g., greater than 1.5 *SD*s from the mean).

Although the current study provides several unique contributions to the literature, a few limitations warrant consideration. For example, the current review broadly defined studies as having a high CE demand if they required any mental manipulation of temporarily stored information (e.g., backward span tasks). A more rigorous operational definition that emphasizes attentional shifts between stimuli and the processing component of the task might have improved power to predict between-study ES heterogeneity (Engle, Kane, et al., 1999). In addition, although both regression models were determined to be a good fit, based on the procedural recommendations of Field and Gillett (2010), all nonsignificant findings should be interpreted with caution. Regardless, the current study was able to account for 65% and 51% of VS and PH ES heterogeneity, respectively. Considered within the context of nonsignificant residuals for each regression, it is unlikely that increased power from additional studies would reveal additional moderating effects. Another potential limitation is that the restricted age range may limit the current study's ability to detect age-related differences in WM performance, as well as its ability to generalize to an older adult population. Lastly, one article in the current meta-analysis (Valera et al., 2010) reported 34% sample overlap with another included study (Valera, Faraone, Biederman, Poldrack, & Seidman, 2005), which potentially threatens statistical independence and overweighting of the findings. However, it is not likely that the results are significantly affected by the sample overlap, given the large number of studies included in the meta-analysis.

Collectively, findings from the current study indicate that the well-documented WM deficits observed in children (Alderson et al., 2010; Rapport, Alderson, et al., 2008) persist into adulthood, consistent with the lifelong trajectory of the disorder (Barkley et al., 2008), and provide support for WM as a core feature (Rapport, Alderson, et al., 2008) or endophenotype (Castellanos & Tannock, 2002) of ADHD. Future experimental, quasi-experimental, correlational, and structural equation model studies that examine additional task and subject moderating variables would expand the field's understanding of ADHD-related WM deficits. For instance, variability in stimuli event rate may influence demands on the CE by increasing or decreasing interference, thus making rehearsal more or less difficult. Further, the significant moderators and examination of best-case estimation procedures in the current study suggests that future WM studies would benefit from careful scrutiny of subject and task variables that may significantly impact interpretations of findings. A follow-up inspection of studies included in the current review revealed that relatively few utilized the best combination of subject and task variables (see Table 1), and likely explains why WM deficits are not uniformly detected in some recent experimental studies (e.g., Lambek et al., 2011).

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