Memory Retrieval Deficits in Children with ADHD: The Mediating Role of Working Memory

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MEMORY RETRIEVAL DEFICITS IN CHILDREN WITH ADHD: THE MEDIATING ROLE OF WORKING MEMORY

by

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ABSTRACT

Children with ADHD exhibit impairments in memory retrieval processes that are required for successful performance in a wide range of activities including written and oral expression. There have been few attempts of explaining the relation between these memory retrieval deficits in children with ADHD and specific executive functions such as working memory (WM). The current study investigates the possible mediating effects of the domain general attentional controller (i.e., the central executive) and two domain specific short-term memory stores (i.e., phonological visuospatial short-term memory) on children's memory retrieval ability. Children ages 8-12 (M = 9.37, SD = 1.26) with ADHD (n = 38) and typically developing children (n = 28) completed a counterbalanced series of tasks that were specific to the two WM subsystems (phonological, visuospatial). The Central Executive (CE) portion of WM was estimated using a regression approach to isolate common variance between the PH and VS STM tasks. The Associational Fluency subtest of the Kaufman Test of Educational Achievement (KTEA-II) was used to estimate children's memory retrieval ability. Bias-corrected bootstrapped mediation analyses revealed a significant full mediation effect, wherein the independent and interactive effects of PH STM explained 39% of the diagnostic status to memory retrieval relation. VS STM and CE were not found to be significant mediators of this relation as their 90% CI included 0.0. The present investigation's results lend support that a specific focus on strengthening the WM subsystem, PH STM, may prove beneficial in helping children with ADHD retrieve information from long-term memory and on tasks related to written and oral expression.

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INTRODUCTION

Attention deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder that affects an estimated 5% to 7% of children in the United States (Center for Disease Control and Prevention [CDC], 2018). The disorder is highly heritable and characterized by three primary symptom clusters that involve impairing levels of inattentiveness, hyperactivity, and impulsivity across settings (Diagnostic and Statistical Manual of Mental Diseases, DSM-5, 2013). Children with ADHD are known to face several early life challenges including difficulties with social and academic functioning. Their social/interpersonal difficulties have been studied extensively and typically involve interrupting peers and adults, not waiting their turn, causing disruptions in the classroom, and difficulties in play and peer interaction activities (Kofler et al., 2011). Academically, children with ADHD experience significant difficulties in most core foundational areas including reading (Friedman, Rapport, Raiker, Orban, & Eckrich, 2016), math (Friedman, Rapport, Orban, Eckrich, & Calub, 2018), and written/oral expression even in the absence of a formal comorbid learning disorder (Eckrich, Rapport, Calub & Friedman, 2018; Friedman, et al., 2016).

The reading and math difficulties experienced by children with ADHD have received extensive scrutiny over the past decade and an emerging consensus suggests that they reflect a complex interplay among core foundational learning related skills (e.g., orthographic conversion, appropriate knowledge of and automaticity of grapheme to phoneme conversion) and various aspects of working memory (Friedman et al., 2016). Comparatively less is known regarding their difficulties related to conveying their thoughts orally and in written text which is of central importance because of the myriad ways these fundamental forms of communication contribute to

children's functioning at home, in school, and with friends. The ability to communicate orally nearly always precedes the development of written communication, and early deficits in oral communication among children with ADHD typically include underdeveloped use of proper grammar, syntax, and semantics. These deficits, in turn, contribute to inevitable challenges in written expression in children with ADHD (Eckrich et al., 2018).

One possible explanation for the oral and written expression deficits that children with ADHD face is memory retrieval (Hajovsky et al., 2017). Retrieval of information from long-term memory (LTM) can involve either semantic or phonemic information. Phonemic information refers to the retrieval of words that begin with the same phoneme (*s*ugar, *s*nail, *s*hip), whereas semantic information refers to the retrieval of words belonging to the same category (e.g., dog, cat, mouse) (Takács et al., 2014). Semantic retrieval from LTM is known to require numerous search strategies in the acquisition of a subset of information from different cues (such as a particular category or prompt). In contrast, associative retrieval is the automated process whereby available cues and information stored in LTM interact. When breaking down associative retrieval into phonemic and semantic information retrieval, there are mixed findings with respect to children with ADHD. For instance, teenagers with ADHD perform worse on phonemic retrieval but not semantic retrieval compared to healthy controls peers. The same study, however, found no differences in retrieval processes for children with ADHD ages eight to twelve (Abreu et al., 2013). In contrast, a study conducted by Hurks et al. (2004) found that children with ADHD produced more errors than healthy control groups on associative retrieval tasks. Overall, children with ADHD are known to struggle in rehearsal as well as memory retrieval processes—more

specifically, retrieval processes as they relate to executive functions (EF) (Pollak, Kahana-Vax, & Hoofien, 2008).

An alternative explanation for the difficulties that children with ADHD have with associative retrieval focuses on their Working Memory (WM) deficits. WM is a limited-capacity cognitive system that allows individuals to store and process new information as well as information held in long-term memory. This tripartite system consists of three primary components (Baddeley, 2007)—a domain general attentional controller referred to as the central executive (CE), and two domain specific, short-term memory subsidiary systems that briefly store and maintain phonological and visuospatial information. The CE has no memory of its own and is responsible for coordinating the temporary storage/rehearsal subsystems, and allows individuals to process, utilize, and/or manipulate stored information needed for complex behaviors such as planning and problem solving (Baddeley, 1983). The visuospatial short-term memory (VS STM) subsystem is responsible for the temporary storage and rehearsal of non-verbal or spatial information, whereas the phonological short-term memory (PH STM) subsystem holds and processes speech-based/verbal information (Rapport et al., 2008). WM impairments in children with ADHD have been consistently found in meta-analytic reviews (Kasper, Alderson, & Hudec, 2012) and research investigations (Kofler, Rapport, Bolden, Sarver, & Raiker, 2009). Due to the WM system being integral to complex behaviors, children with ADHD can face several deficits in scholastic achievement (including mathematics and written expression), and even social problems (Eckrich et al., 2018; Kofler et al., 2011; Friedman, Rapport, Orban, Eckrich, & Calub, 2018; Sarver et al., 2011).

In relation to the current study, past research has identified WM as a predictor for performance on both phonemic and semantic fluency tasks (Stolwyk, Bannichelvam, Kraan & Simpson, 2015). For example, Rende et al., (2002) reported that PH WM performance contributed significantly to children's phonemic/letter fluency performance. VS WM was also found to support semantic/category fluency tasks as it allowed participants to use visualization strategies during word retrieval. Lastly, Rende et al., (2002) reported that associational fluency tasks (phonemic and semantic) relied on common CE processes including in the search for the given retrieval cues (either letter or category). This investigation utilized articulatory suppression, cube comparison and arithmetic switching in order to measure all three components of WM. This differs from the present study as it aims to measure PH STM and VS STM using quite different tasks to do so.

The present study examines children with ADHD and their deficits in associative retrieval which is unique from extant research that focuses primarily on deficiencies related to free recall from STM or phonemic and semantic retrieval alone (Pollak et al., 2008; Takács et al., 2014). Understanding the processes by which retrieval impairments occur may facilitate improvement of oral and written language expression in children with ADHD. A widely used measure of associative retrieval—viz., the associational fluency task—is used in the current study due to its established psychometric properties and measurement of both semantic and phonemic retrieval processes (Kaufman & Kaufman, 2004). One of the two modality specific subsystems, the PH STM, and the CE itself, were hypothesized to mediate the relation between diagnosis of ADHD and their deficits in phonemic and semantic memory retrieval. Conversely, VS STM is not expected to play a mediating role because phonemic and semantic retrieval do not rely on visuospatial ability.

METHOD

Participants

The sample comprised 66 children (boys= 60, girls= 6), between 8-12 years of age (M = 9.37, SD = 1.26) that were recruited via community referral to a children's learning clinic (referral from mental health professionals, pediatricians, school systems, or self-referral). All parents and children provided their informed consent/assent prior to participating in the study, and approval from the university's Institutional Review Board was obtained prior to the onset of data collection. Two groups of children participated in the study: children with ADHD-combined presentation (n= 38), and typically developing (TD) children (n= 28) without a psychological disorder. Children with a history of (a) gross neurological, sensory, or motor impairment by parent report, (b) history of a seizure disorder by parent report, (c) psychosis, autism spectrum, or depressive disorders, or (d) Full Scale IQ score ≤ 85 were excluded.

Group Assignment

All children and their parents participated in a detailed, semi-structured clinical interview using all modules of the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS). The K-SADS assesses on-set, course, duration, severity, and impairment of current and past episodes of psychopathology in children and adolescents based on DSM-5 criteria. Its psychometric properties are well established, including interrater agreement of

0.93 to 1.00, test-retest reliability of 0.63 to 1.00, and concurrent (criterion) validity between the K-SADS and psychometrically established parent rating scales (Kaufman et al., 1997). Thirty-three children meeting the following criteria were included in the ADHD-Combined Presentation group: (1) an independent diagnosis by the directing clinical psychologist using DSM-5 criteria for ADHD-Combined Presentation based on K-SADS interview with parent and child; (2) parent ratings of at least 2 SDs above the mean on the Attention Deficit/Hyperactivity Problems DSM-Oriented scale of the Child Behavior Checklist (CBCL; Achenbach and Rescorla 2001), or exceeding the criterion score for the parent version of the ADHD-Combined Presentation subscale of the Child Symptom Inventory-4: Parent Checklist (CSI-P; Gadow et al., 2004); and (3) teacher ratings of at least 2 SDs above the mean on the Attention-Deficit/Hyperactivity Problems DSM-Oriented scale of the Teacher Report Form (TRF; Achenbach and Rescorla 2001), or exceeding the criterion score for the teacher version of the ADHD-Combined subtype subscale of the Child Symptom Inventory-4: Teacher Checklist (CSI-T; Gadow et al., 2004). The CBCL, TRF, and CSI are among the most widely used behavior rating scales for assessing psychopathology in children. Their psychometric properties are well established (Rapport, Kolfler, Alderson & Raiker, 2008). Twenty-seven children met the following criteria and were included in the typically developing group: (1) no evidence of any clinical disorder based on parent and child K-SADS interview; (2) normal developmental history by parental report; (3) ratings within 1.5 SDs of the mean on all CBCL and TRF scales; and (4) parent and teacher ratings within the non-clinical range on all CSI subscales.

Procedures

The PH WM and VS WM tasks were programmed using SuperLab Pro 2.0 (Cedrus Corporation, 2002) and administered as part of a larger battery that required the child's presence for approximately three hours per session across four consecutive assessment sessions scheduled one week apart. Participants completed the tasks seated alone, approximately 0.66 cm away from a computer monitor, in an assessment room. Performance was monitored at all times by the examiner who was stationed just outside the child's view to provide a structured setting while minimizing performance improvements associated with examiner demand characteristics (Power, 1992). All participants received brief (2–3 min) breaks following each task and preset longer (10–15 min) breaks after every two to three tasks to minimize fatigue. The Kaufman Test of Educational Achievement, second edition (KTEA-II; Kaufman & Kaufman 2004) was administered during two separate weekday testing sessions to minimize fatigue.

Working Memory

Phonological Working Memory (PHWM) The PHWM number-letter reordering task assesses PH WM based on Baddeley's (2007) model, and its cognitive demands require an active interplay between higher-order CE processes (attention and interference control, reordering) and subsidiary PH STM. Children were presented a series of jumbled numbers and a capital letter (all 4 cm in height and width) on a computer monitor. Each distinct stimulus within each of the 24 continuous trials for each set size condition (3, 4, 5, and 6). All children received five practice trials and scored at least an 80% correct prior to engaging in the regular task conditions. Two trained research assistants, blind to diagnostic status and seated out of the child's view, recorded children's verbal responses (heard through headphones) independently on a preformatted response sheet. Inter-rater reliability was 95%; discrepancies were resolved via audio-video review.

Previous studies have reported strong reliability and validity of the PH WM task, evidenced by high internal consistency (r = 0.82 to 0.97) and significantly large correlations (r = 0.50 to 0.71) with an established measure of Working Memory (i.e., WISC-IV Working Memory Index), respectively (Alderson et al., 2015; Raiker et al., 2012).

Visuospatial Working Memory (VSWM) The VSWM task is based on Baddeley's (2007) model, and its cognitive demands require an active interplay between upper level CE processes (i.e., attentional control and interference control, reordering) and subsidiary VS STM processes. Children were shown nine 3.2 cm squares arranged in three vertical columns on a computer monitor. The columns were offset from a standard 3 x 3 grid to minimize the likelihood of phonological coding of the stimuli (e.g., by equating the squares to numbers on a telephone pad). A series of 2.5 cm diameter dots were presented sequentially in one of nine squares during each trial, such that no two dots appeared in the same square on a given trial. All but one dot presented within the squares was black— the exception being a red dot that was counterbalanced across trials to appear an equal number of times in each of the nine squares, but never presented as the first or last stimulus to minimize primacy and recency effects. Children were instructed to respond by pressing the corresponding squares on a modified computer keyboard, and to re-order the dot locations by indicating the serial position of the black dots in the order presented followed by the serial position of the red dot last.

Five practice trials were administered before each PH and VS WM task (80% correct required). Each task involved 24 unique trials of the same set size, for eight total task conditions (set size 3–6, separately for PH and VS). Both tasks were independently counterbalanced across the four weekly assessment sessions, such that children received one PH and one VS task per

session. Presentation rate was 800 ms per stimuli (200 ms inter-stimulus interval) for all PH and VS task variants. Evidence for reliability and validity of these WM tasks includes high internal consistency ($\alpha = 0.82$), and demonstration of the expected magnitude of relations (Swanson & Kim, 2007) with established measures of short-term memory (WISC-IV Digit Span raw scores: $r = 0.58$).

Central Executive (CE) Working Memory CE Working Memory functioning was estimated at each set size using the regression approach described by Rapport et al., (2008). Due to no one task/measure being able to provide a true estimate of CE ability, VSWM scores were regressed onto PHWM scores and PHWM scores onto VSWM scores. These scores were combined via factor analysis in order to achieve an estimate of CE functioning.

Associational Fluency The measure of associational fluency for this study came from the Kaufman Test of Educational Achievement, second edition (KTEA-II). The KTEA-II is a measure of overall educational achievement for those age four to twenty-five. The reading-related subtest, associational fluency, score was considered by itself for this study's associational fluency dependent variable measure. The subtest required children to name as many words as they could that belonged to a specific semantic category (beginning with a letter, or a category such as animals) in sixty seconds.

RESULTS

Preliminary Analysis

All independent, dependent, and mediating variables were screened for multivariate outliers using Mahalanobis distance tests ($p < 0.001$) and univariate outliers as reflected by scores exceeding 3.0 SDs from the mean in either direction. No significant outliers were identified. As expected, scores on the parent and teacher behavior rating scales were significantly higher for the ADHD group relative to the TD group. Children with ADHD and TD children age 8-12 did not differ on age ($p = 0.15$), SES ($p = 0.20$), or FSIQ ($p = 2.18$). Sample and demographic variable can be found in Table 1.

Table 1 Sample and Demographic Variables

	ADHD		TD		Total	
	Mean	*SD*	Mean	*SD*	*t*	Cohen's *d*
Age	9.34	1.30	9.40	1.22	0.15	0.05
SES	52.38	8.02	53.09	12.35	0.20	0.07
FSIQ	105.21	11.04	110.67	9.55	2.18	3.83
CBCL AD/HD Problems	10.97	2.79	2.73	3.81	-9.93*	2.47
TRF AD/HD Problems	18.79	5.14	3.69	5.56	-11.39*	2.72
CSI-P: ADHD, Combined	37.24	8.76	9.70	9.60	-12.21*	3.00
CSI-T: ADHD, Combined	34.44	10.13	7.59	7.94	-12.17*	2.95
Associational Fluency	-0.21	0.94	0.28	1.03	1.97	0.50
Phonological STM Factor Score	-0.36	1.07	0.49	0.64	3.99	0.96
Visuospatial STM Factor Score	-0.21	0.92	0.28	1.06	1.95	0.49
Central Executive STM Factor Score	-0.44	0.87	0.59	0.86	4.79	1.19

Note: ADHD: attention deficit/hyperactivity disorder; TD: Typically Developing; FSIQ: Full-Scale Intelligence Quotient; SES: Socioeconomic status; CBCL: Child Behavior Checklist; TRF: Teacher Report Form; CSI-P: Child Symptom Inventory: Parent severity raw scores; CSI-T: Child Symptom Inventory: Teacher severity raw scores; STM: Short-Term memory

Simple Mediation Models

Zero-order intercorrelations between all factor scores were computed and are shown in Table 2. Separate simple mediation models were tested to examine the extent to which WM variables attenuated the relation between diagnostic status and memory retrieval as measured by associational fluency. Mediation analyses were completed using bias-corrected bootstrapping to minimize Type II error as recommended by Shrout and Bolger (2002). Bootstrapping was used to establish the statistical significance of all total, direct, and indirect effects. All continuous variables were standardized z-scores based on the full sample to facilitate between-model and

Table 2. First-Order Correlations

Diagnostic Status(TD = 0, ADHD = 1)								
Age	-.10							
Gender(Boy = 1, Girl = 2)	-.04	.00						
SES	-.04	-.15	.00					
FSIQ	-.26*	-.09	-.19	.31				
Central Executive	-.51**	.52**	.05	-.10	.21			
PH STM	-.42**	.20	.01	-.02	.26*	.69**		
VS STM	-.24	.53**	.06	-.12	.00	.63**	-.13	
Associational Fluency	-.24*	.09	-.18	.21	.40**	.15	.33*	-.16

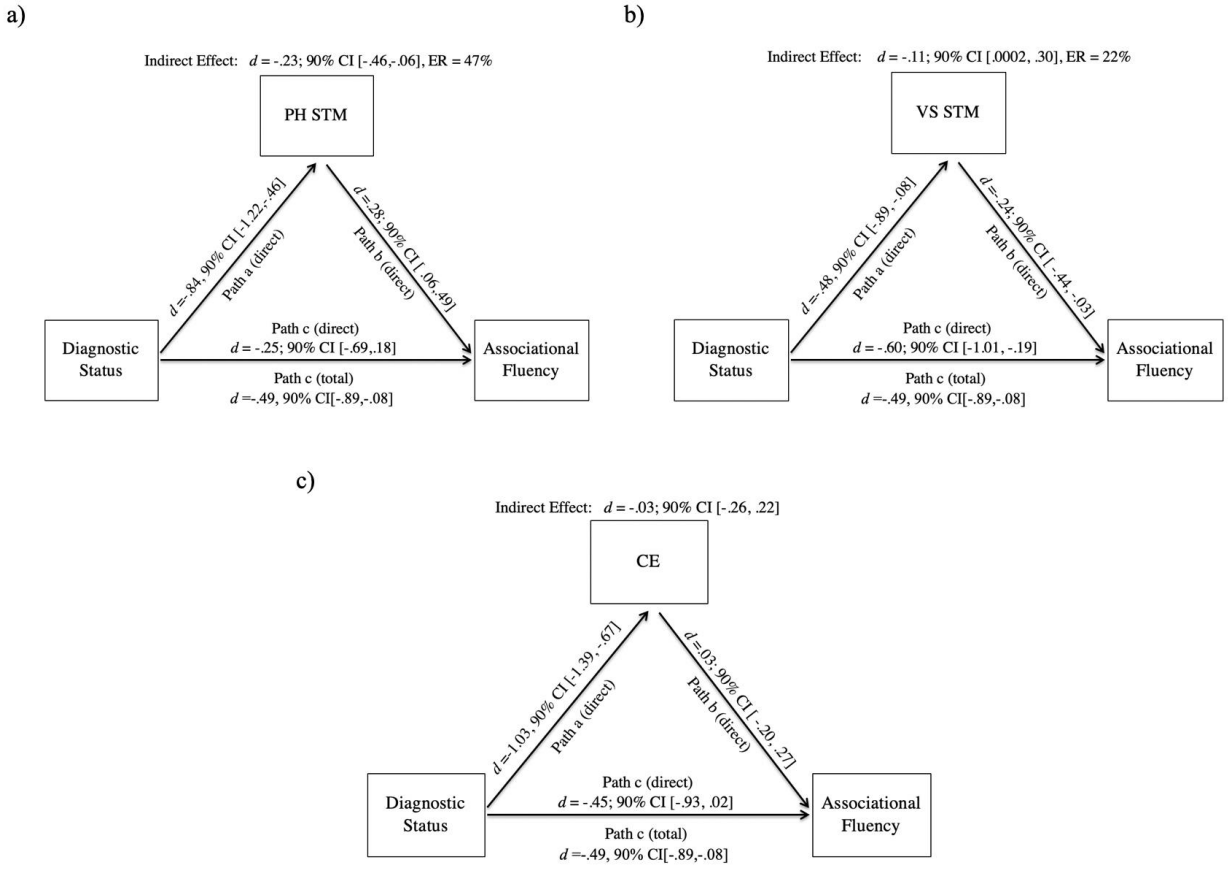
Note: ADHD: attention-deficit/hyperactivity disorder; PH STM: phonological short-term memory; SES: Socioeconomic status; FSIQ: Full-Scale Intelligence Quotient; TD: Typically Developing; VS SM: Visuospatial short-term memory. Correlations reflect Pearson's correlation coefficients. Correlation is significant based on $p < .05$.

within-model comparisons and allow unstandardized regression coefficients (*B* weights) to be interpreted as Cohen's *d* effect sizes when predicting dichotomous grouping variable (Hayes, 2009). The PROCESS script for SPSS (Hayes, 2014) was used for all analyses, and 10,000 samples were derived from the original sample (n= 66) by a process of resampling with replacement (Shrout & Bolger, 2002). Effect ratios (indirect effect divided by total effect) were calculated to estimate the proportion of each significant total effect that was attributable to the mediating pathway (indirect effect). Ninety percent confidence intervals were selected over 95% due to concerns that the latter is less conservative in determining full vs. partial mediation. Briefly, the narrower 90% confidence interval is less likely to include 0.0, and therefore is likely to result in a more conservative conclusion regarding the magnitude of the relation between diagnostic status and associational fluency after accounting for the mediator. In contrast, the wider 95% confidence

interval increases the likelihood that the confidence interval for direct effect will include 0.0, indicating that diagnostic status and associational fluency are no longer related significantly after accounting for the mediator (Shrout & Boulger, 2002).

Examination of the total effect of diagnostic status (ADHD, TD) on associational fluency for all models revealed a significant relation (*d*= -0.49, CI = -.089, -0.08), such that a diagnosis of ADHD was associated with medium effect size associational fluency differences prior to accounting for potential mediators. CE was not a significant mediator of the diagnostic status to associational fluency relation (90% CI included 0.0). In contrast, VS STM was a significant, partial mediator (*d*= 0.11, CI = .0002, 0.30) and accounted for 22% of the variance of the diagnostic status to associational fluency relation. PH STM was a significant, full mediator (*d*= -0.23, 90% CI= -0.46, -0.06) and accounted for 47% of the variance of the diagnostic status to associational fluency relation. The schematics depicting these three mediation models can be seen in *Figure 1*.

Figure 1. Simple Mediation Models



Note: CI: confidence interval (90%), ER: effect ratio, PH STM: phonological short-term memory, VS STM: Visuospatial short-term memory, CE: Central Executive. Schematics depicting the effect sizes, and standard errors of the total, direct, and indirect pathways for the mediating effect of (a) Phonological short-term memory (b) Visuospatial short-term memory, and (c) Central Executive. Cohen's d for the direct and total effect pathways reflects the impact of ADHD on Associational Fluency scores before (total effect) and after (direct effect) taking into account the mediating variable.

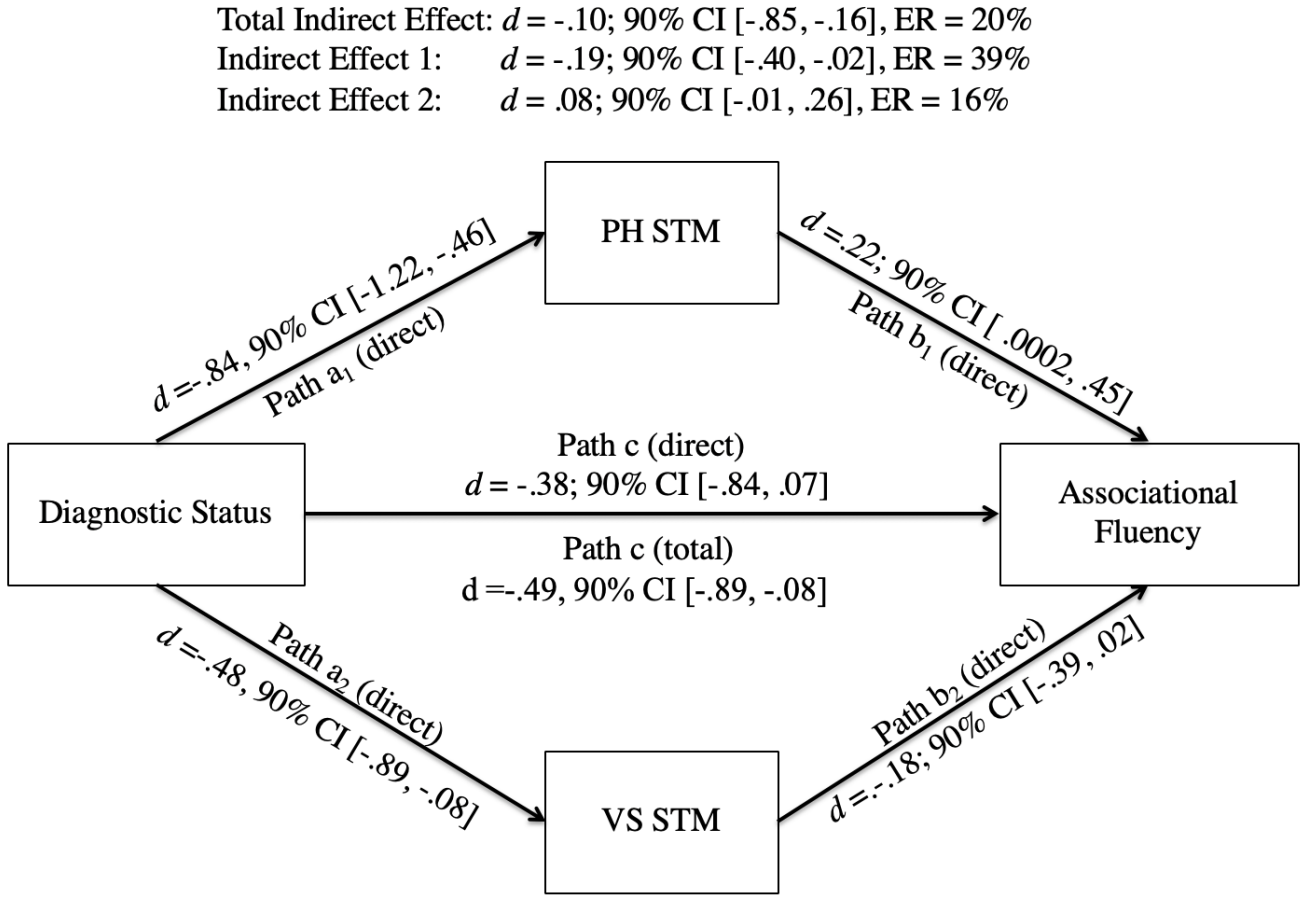
Parallel Mediation Model

A parallel mediation model that included both PH STM and VS STM was used to determine whether PH STM and VS STM would each remain a significant mediator of the relation between ADHD diagnosis and poor performance on the associational fluency task when modeled together (i.e., estimates the meditational effect of each variable while holding the other constant).

The obtained results (see Figure 2) revealed that only PH STM remained a significant mediator (*d*= -0.19, ER= 39%) when modeled in parallel with VS STM, (i.e., the 90% CI for the VS STM mediator included 0.0), which indicates that the previous reported VS STM mediation effect reflects an epiphenomenon[1].

[1] Epiphenomena effects reflect a situation in which two variables are correlated and significant mediators when modeled separately, but only one is a true mediator of the relation and the other a correlated process that arises from but does not causally influence the process; cf. Hayes 2018, for an expanded discussion.

Figure 1 Parallel Mediation Model



Note: CI: confidence interval 90%; ER: effect ratio; PHSTM: Phonological Short-Term Memory; VSSTM: Visuospatial Short-Term Memory. Effect sizes, and standard errors of the total, direct, and indirect pathways for parallel mediation of PHSTM and VSSTM on the relationship between Diagnostic Status and Associational Fluency. Indirect Effect 1: Mediating effect of PHSTM independent of VSSTM on associational fluency. Indirect Effect 2: Mediating effect of VSSTM independent of PHSTM on associational fluency. Total indirect effect: collective influence of both mediation pathways.

DISCUSSION

Children with ADHD exhibit a wide range of impairments that affect their overall quality of life including significant deficits in written and oral expression. The extent to which specific cognitive abilities, such as WM, contribute to these deficits in children with ADHD was the focus of the present study. It was hypothesized that PH STM and CE would be significant mediators of this relation as the associational fluency task is phonologically based, and CE processes are required when completing a majority of WM tasks. VS STM, on the other hand, was hypothesized to not be a significant mediator of the ADHD to associational fluency relation because it was assumed to require little involvement in the associational fluency task.

Planned, simple mediation analyses were conducted to elucidate the extent to which VS STM, PH STM, and CE independently mediated the diagnostic status to associational fluency relation. In support of the hypothesis, PH STM was found to be a full mediator of the relation while surprisingly, VS STM was found to be a partial mediator. Contrary to my hypothesis, CE was not found to be a significant mediator of the diagnostic status/associational fluency relation.

A planned parallel mediation analysis was conducted subsequently to determine the extent to which PH STM and VS STM were significant mediators when modeled concurrently (i.e., examining the effect of each variable while holding the other constant). PH STM alone was found to be a significant mediator, which indicates that the VS STM mediator effect reported earlier represents an epiphenomenon (i.e., was a significant mediator when modeled separately due to the correlation with PH VS).

These findings support extant research conducted by Rende et al., (2002), as PH STM was found to play a role in the associational fluency task. The present investigation is different from

past research as WM was fractionated to measure the anatomically distinct PH STM and VS STM from the domain-general CE. The CE had a nonsignificant contribution to the diagnostic status/associational fluency relation, which is somewhat unexpected. However, this could reflect methodological and age difference between the current study and past studies investigating the phenomenon. For example, in the study conducted Rende et al., (2002), the CE was found to be involved in similar verbal fluency tasks in a neurotypical, adult population but only when it came to set shifting. Also, they utilized an arithmetic switching task for this measure. The present investigation's results lend support that a specific focus on the WM periphery system, PH STM, in memory retrieval interventions for children with ADHD could be helpful in overall performance in memory retrieval, as well as other tasks related to written and oral expression.

Limitations

The present investigation's inclusion of children, ages 8-12, with ADHD combined type without comorbid learning disorders and other psychopathy may lead to a generalizability of this population. Future studies may benefit from a larger and more diverse samples that include adolescents with ADHD, children with comorbities, specifically children with disorders where WM performance deficits are suspected-e.g. anxiety (Tannock et al., 1995) and a wide range of developmental disabilities.

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