Domestic Parent-Child Interaction Problems and Working Memory: The Mediating Role of Inattentive ADHD Symptoms

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DOMESTIC PARENT-CHILD INTERACTION PROBLEMS AND WORKING MEMORY: THE MEDIATING ROLE OF INATTENTIVE ADHD SYMPTOMS

by

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ABSTRACT

The intent of this thesis is to explore the mediating effects of ADHD Inattentive symptoms on domestic parent-child interaction problems and working memory. Inattentive symptoms in children with ADHD are known to cause forgetfulness, slow processing speed, and negative parent-child interactions. Working memory deficits in phonological short term memory and the central executive are also well-established in children with ADHD. However, it is currently unknown to what extent inattentive symptoms are responsible for home behavior problems in conjunction with phonological working memory deficits. The aims are tested using two validated, common clinical questionnaires: The Teacher Report Form and the Home Situations Questionnaire. Additionally, working memory and executive function are tested using a phonological letter-number sequencing task and a visuospatial dot-in-the-box task. Results show that inattentive symptoms mediate the relationship between working memory and parent-child interaction problems. Teacher reports of inattention affect the degree to which the child experiences behavior problems at home, and also affects the phonological working memory system implicated in this behavior. Future directions include using a more diverse sample, investigating a wider range of ADHD symptoms, investigating effects across multiple settings, and exploring possibilities of additional executive functioning mediators.

ACKNOWLEDGMENTS

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INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is an early onset, chronic neurodevelopmental disorder characterized by excessive inattentiveness, gross motor activity, and impulsivity. The disorder affects an estimated 5% to 7% of children in the United States (APA, 2013) at an estimated annual cost of $20.6 billion, the majority of which is spent for special education services and pharmaceutical prescriptions (Bui et al., 2017). ADHD is associated with multiple cognitive, behavioral, and interpersonal deficits that contribute to significant adverse outcomes beginning in childhood and continuing into adulthood.

The interpersonal difficulties experienced by children with ADHD are particularly problematic because they impact their day-to-day functioning across multiple settings including home, school, and in the community. Current research indicates that these difficulties are apparent prior to 6-years of age, as evidenced by teacher ratings of reduced social competence and peer interaction problems in preschool (Pollack, Hojnoski, DuPaul, & Kern, 2016), and continue into later childhood to include difficulties with peer- and parent-child interactions (Tung & Lee, 2014). The difficulties are thought to reflect inadequately developed interpersonal skills, social cooperation, and understanding of social expectations (Merrell & Wolfe, 1998).

The numerous difficulties children with ADHD experience at home are well documented and particularly troublesome given the daily time spent interacting with their caregivers (Altepeter & Breen, 2006). Children with ADHD evoke more negative comments and correctional commands from their parents (Fletcher et al., 1996; Johnston, 1996; Johnston & Jassy, 2007), and require more cues, frequent reminders, and one-on-one supervision when completing daily tasks, activities, and chores in the home setting (Tseng, Kawabata, & Gau

2011). Previous investigations examining parent/child interactions and characteristics in families with children with ADHD relative to families with typically developing (TD) children also reveal that parents of children with ADHD utilize significantly higher rates of negative-reactive parenting behaviors relative to positive parenting strategies (Johnston, 1996). A more recent study by Haack and colleagues (2016) also revealed that children with ADHD exhibited significantly higher rates of inattentive behavior (relative to TD children) while interacting with their parents, which in turn was correlated with lower compliance with parent requests, such as completing homework assignments. In a similar vein, Tripp and colleagues (2007) reported that children with ADHD scored lower on ratings of warmth, engagement, and communication than their TD counterparts, and exhibited more negative interactions with their parents during instances of problem solving.

The well-documented negative parent-child interactions in the home also appear to erode functioning in other environments (e.g., while attending school). For example, Keown (2012) reported that boys with ADHD were more inattentive in school if their mothers displayed low levels of positive regard and fathers displayed low levels of sensitivity while interacting with their child at home. Inattention symptoms of children with ADHD have also been shown to be associated with opposing patterns of effects in their parents. For example, Lifford and colleagues (2008) reported that mother-child rejection behaviors were amplified as a function of higher rates of inattention symptoms in their children, whereas father-child rejection behaviors were related to higher rates of inattention in their children.

Several hypotheses have been offered to explain ADHD-related parent-child relationships at home. The most prominent of these hypothesizes that children with ADHD have inadequately

developed interpersonal relationship knowledge and skills (Melnick, 1998; Nilsen, Lizdek, & Ethier, 2015), and this hypothesis is frequently extended to include inadequately developed parenting knowledge and strategies (Johnston & Jassy, 2007; Rajendran, Kruszewski, & Halperin, 2016). A central point of these hypotheses is that strengthening a child's knowledge and repertoire of appropriate social interaction skills and/or teaching parents positive parenting behaviors and strategies are required to remediate parent-child relationship difficulties. In this regard, the gold standard treatment for ADHD—viz., psychostimulants—would be expected to exert little or no effect on parent-child relationships because the medication neither teaches nor strengthens the hypothesized core social skill/knowledge deficits or implements desirable parenting interaction strategies. Barkley (1988) examined the assumptions of the aforementioned hypothesis by observing children with ADHD interacting with their parents under counterbalanced psychostimulant (methylphenidate) and placebo conditions. The authors reported that the mother invoked significantly higher rates of positive comments and fewer negative/controlling comments while interacting with their children under the psychostimulant relative to the placebo condition despite receiving no parent-child training. The aforementioned study was an expansion upon findings from an earlier study by Cunningham and Barkley (1978) using hyperactive twin boys. These findings were interpreted to support an alternative model—the core symptom model—which suggests that core ADHD symptoms of inattention, impulsivity, and excessive gross motor activity are primarily responsible for the strained and often negative interactions between children with ADHD and their parents.

The working memory model proposed by Baddeley (1974) is an alternative theoretical model to account for the well-documented parent-child interaction difficulties at home. Working

memory (WM) is a multi-component, limited-capacity cognitive system responsible for the temporary storage and processing of information used when engaged in reasoning, planning, problem solving, and other complex behaviors. The *working* component of WM (i.e., the central executive [CE]) is responsible for the mental processing of internally-held information using several interrelated processes: updating (replacing memory contents with newer, more relevant information), manipulation/dual processing (processing information while simultaneously storing the same or other information), serial reordering (mentally manipulating the stored information), and interference control (preserving information being processed by inhibiting irrelevant internal and external information from accessing WM). The CE contains no memory of its own—rather, it serves as an attentional controller that oversees the processing, manipulating, and preservation of information held in two, anatomically distinct storage/rehearsal memory systems—the phonological (PH) and visuospatial (VS) short-term memory subsystems that are responsible for verbal and nonverbal information, respectively.

WM has emerged as a possible endophenotype for ADHD based on independent empirical findings demonstrating that children with ADHD evince large magnitude deficits on WM tasks (Kasper, Alderson, & Hudec, 2012) and complementary evidence that WM deficits underlie core and secondary symptoms of the disorder. For example, compelling experimental evidence indicates that CE deficits in children with ADHD fully mediate their excessive gross motor activity (Rapport et al., 2009; Sarver et al., 2013), inattentive behavior (Kofler et al., 2010), impulsivity (Patros et al., 2015; Raiker et al., 2012), inhibitory control (Alderson et al., 2010), and impaired social relationships at school (Kofler et al., 2009).

Collectively, the above findings suggest two possibilities regarding the oft-reported negative and impairing parent-child relationships of children with ADHD at home. WM deficits may adversely affect the quality of their interactions with their parents due to their forgetfulness, need for frequent reminders, and close monitoring (i.e., a direct effect). Alternatively, the effect of WM deficits in children with ADHD may be indirect when interacting with their parents due to expected worsening of core symptoms such as inattention when required to engage in activities such as completing chores, homework, and following directions that increase demands on their limited WM capabilities.

The functional working memory model of ADHD (Rapport et al., 2008) creates three predictions regarding the impact of WM deficits on home behavior problems that can be evaluated empirically. First, WM deficits in children with ADHD may impair their ability to store and recall information related to following parent/guardian directions and processing command cues effectively (Rapport et al., 2008). In this case, central executive and/or phonological system performance deficits are expected to have a direct effect on the severity of home problems. Alternatively, WM deficits may impact home behavior indirectly. This hypothesis is based on previous findings indicating that working memory deficits are related to a worsening in core symptoms such as inattention (Kofler et al., 2010; Rapport et al., 2009). The hypothesized indirect effect would thus indicate that one of the hallmark ADHD symptoms (inattention) that occurs due to working memory failure (e.g., neglecting chores due to an inability to store information when instructions are given by parent) contribute significantly to the home problems experienced by children with ADHD. Finally, home problems experienced by children with ADHD may reflect both direct and indirect effects of working memory.

Collectively, discovering that inattention symptoms strongly influence the severity of domestic parent-child interaction problems independent of working memory influences would support prevailing views that the mechanism by which children with ADHD experience home behavior problems is primarily due to the disruptive nature of core inattentive symptoms, as opposed to the emergence of these symptoms secondary to working memory deficits. Mediation analyses were used in this study to estimate the direct and indirect impact of central executive and phonological storage/rehearsal working memory functioning on cross-informant reports of ADHD symptoms of inattention and severity of problematic home behaviors.

The current study is the first to test empirically whether WM deficits predict the severity of home behavior problems in children with ADHD and TD children, and it is also unique in that it uses teacher ratings of ADHD symptoms to predict behavior in the domestic setting to avoid possible mono-method bias effects. This research is necessary to develop therapeutic strategies that target domestic parent-child behaviors and activities of daily living to minimize deficits and strengthen appropriate behavioral interactions in other areas of daily functioning, such as in school, at work, and in peer interaction.

METHOD

Participants

The sample was comprised of 60 boys aged 8 to 12 years (M=.53, SD=.50), recruited by or referred to the Children's Learning Clinic (CLC-IV) through community resources (i.e., physician referral, community mental health clinics, school systems, and self-referral). The CLC-IV is a research-practitioner training clinic known to the surrounding community for conducting developmental and clinical child research and providing free comprehensive diagnostic and psychoeducational services. Its client base consists of children with suspected learning, behavioral or emotional problems, as well as children without a suspected psychological disorder (i.e., TD, or typically developing children) whose parents agree to allow them to participate in developmental/clinical research studies. A psychoeducational report was provided to the parents of all participants. All parents and children gave full informed consent prior to participating in the study, and the university's Institutional Review Board granted approval prior to the beginning of data collection. Two groups of children participated in the study: children with ADHD and TD children.

Group Assignment

All children and their parents participated in a detailed, semi-structured clinical interview using all sections of the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Aged Children (K-SADS). The K-SADS assesses onset, course, duration, severity, and impairment of current and past episodes of psychopathology in children and adolescents based on DSM-IV criteria. Its psychometric properties are well established, including interrater agreement of 0.93 to 1.00, test-retest reliability of r= *0.63 to 1.00*, and concurrent (criterion) validity between the K-SADS and psychometrically established parent rating scales (Kaufman et

al., 1997).

Thirty-one boys meeting the following criteria were included in the ADHD-Combined Type group: (1) an independent diagnosis by the directing clinical psychologist using DSM-V criteria for ADHD-Combined Type 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 & Rescorla, 2001), or exceeding the criterion score for the parent version of the ADHD-Combined subtype 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 & 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 et al., 2008). Children who received a diagnosis other than ADHD Combined Type were excluded.

Twenty-nine boys 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 working memory (WM) and central executive (CE) tasks described below were programmed using SuperLab Pro 2.0 (Cedrus Corporation, 2002) and administered as part of a larger battery of assessments that required the child's attendance across four consecutive Saturday assessment sessions that lasted approximately 3 hours each. Participants completed all tasks while seated alone, 0.66 m 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 minute breaks following each task, and longer 10– 15 minute breaks after every two to three tasks to minimize fatigue effects.

Measures

Working Memory (WM) Tasks

The working memory tasks used in the current study are identical to those described by Rapport et al. (2008). Each child received four phonological and four visuospatial tasks (i.e., PH and VS set sizes 3, 4, 5, and 6) across the four testing sessions. The eight working memory set size conditions each contained 24 unique trials of the same stimulus set size, and were counterbalanced across the four testing sessions to control for order effects and potential proactive interference effects across set size conditions (Conway et al., 2005). Five practice trials were administered before each task; children were required to achieve 80% correct before advancing to the full task (Rapport et al., 2008). Previous studies of ADHD and typically developing children reveal large magnitude between-group differences on these tasks (Rapport et al., 2008). The WM tasks also have high internal consistency ($\alpha = 0.81$ to 0.95) in the current

sample and the expected level of external validity (*r= 0.50* to *0.66*) with WISC-III and -IV Digit Span STM raw scores (Raiker et al., 2012). However, for this particular study, only the PH WM components were used because of scarce evidence that supports the role of VS processing in inattentive behavior (Kofler et al., 2010) and because the majority of daily domestic tasks and activities are verbal and do not require robust visual processing.

Phonological Working Memory (PH WM) Task. The PH WM tasks are similar to the Letter-Number Sequencing subtest on the WISC-IV (Wechsler, 2003), and assess phonological working memory based on Baddeley's (2007) model. Children were presented a series of jumbled numbers and a capital letter on a computer monitor. Each number and letter (4 cm height) appeared on the screen for 800 ms, followed by a 200 ms inter-stimulus interval. The letter never appeared in the first or last position of the sequence to minimize potential primacy and recency effects, and trials were counterbalanced to ensure that letters appeared an equal number of times in the other serial positions (i.e., position 2, 3, 4, or 5). Children were instructed to recall the numbers in order from smallest to largest, and to say the letter last (e.g., 4 H 6 2 is correctly recalled as 2 4 6 H). Children completed five practice trials prior to each administration (≥80 % correct required). All children achieved the minimum of 80% accuracy on training trials. Two trained research assistants, shielded from the participant's view, recorded oral responses independently. Interrater reliability was calculated for all task conditions for all children, and ranged from 0.97 to 0.99.

Visuospatial Working Memory (VSWM) Task. Children were shown nine squares arranged in three offset vertical columns on a computer monitor. A series of 2.5 cm diameter

dots (3, 4, 5, or 6) were presented sequentially in one of the nine squares during each trial such that no two dots appeared in the same square on a given trial. All but one dot that was presented within the squares was black; the exception being a red dot that never appeared as the first or last stimulus in the sequence. Children were instructed to indicate the serial position of black dots in the order presented by pressing the corresponding squares on a computer keyboard, and to indicate the serial position of the red dot last.

Working Memory Factors. Estimates of CE and PH working memory were computed at each set size using the latent variable procedure described by Rapport et al., (2008) as recommended (Swanson & Kim, 2007). This process involves regressing the PH WM onto the VS WM task for each set size condition and regressing VS WM onto PH WM for each set size condition. Shared variance at each set size reflects the domain-general CE and unique variance reflects PH STM and VS STM as depicted in Figure 1. Latent factors were created for each construct (CE, PH) using scores at each of the four set sizes via principle components factor analysis. The CE and PHWM latent factors alone were utilized in this study due to the aforementioned theoretical constraints.

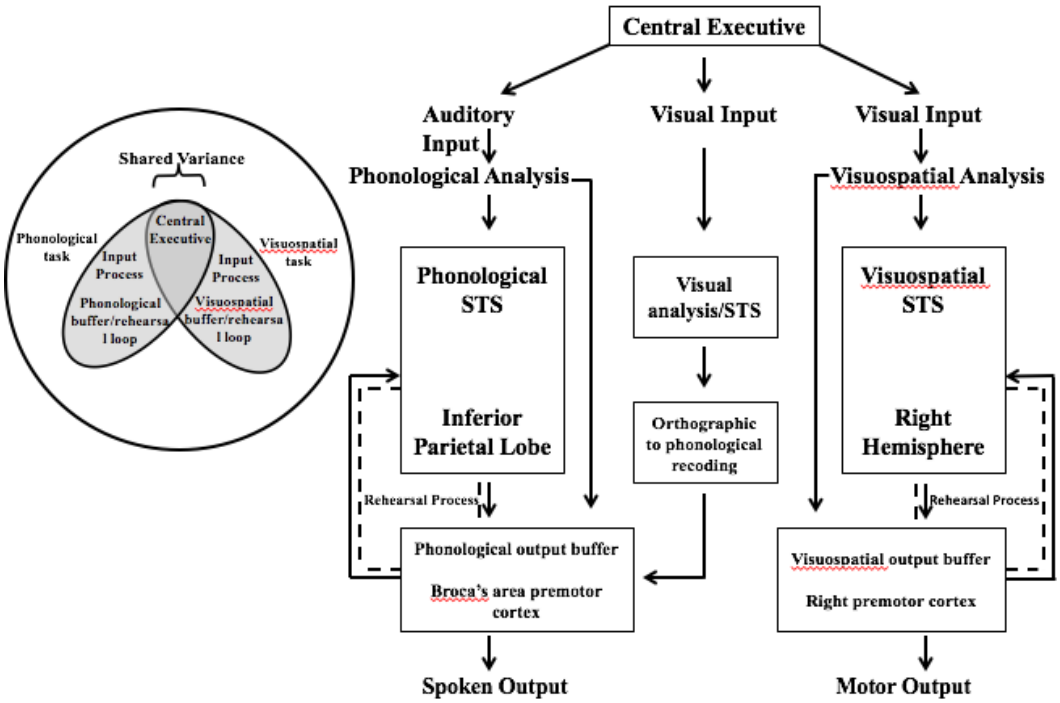

Figure 1: From Rapport, Alderson et al. (2008): Adapted and expanded version of Baddeley's (2007) working memory model and associated anatomical loci. The insert shows the component processes related to the phonological (PH) and visuospatial (VS) tasks. STS= short term store. Reprinted and expanded with permission from the author.

Domestic Parent-Child Interaction Problems. The Home Situations Questionnaire (HSQ; Altepeter & Breen, 1981) measures the number and severity of parent-child related home behavior problems based on parent report. The HSQ consists of 20 one-line descriptions of various home situations within the home environment that involve parents' interaction with their child (e.g., at mealtimes, getting dressed, when washing/bathing, and chores at home). Parents indicate whether a problem behavior occurs in the situation by circling 'yes' and 'no' and rate the severity of the problem using a 9-point Likert scale from (1) *mild* to (9) *severe*. The psychometric properties of the HSQ are well-established, including high internal consistency (α=

0.82 to 0.87) and 2-week test-retest reliability for number of problems (*r=.89*) and severity (*r=.83*) (Altepeter & Breen, 1989). For the purposes of the current study, the total severity of problems was used as the primary raw scores for all items on the HSQ.

ADHD Clinical Core Symptoms

Teacher ratings of children's ADHD symptoms were measured by the Teacher Rating Form (TRF) Inattentive symptom subscale (Achenbach & Rescorla, 2001). The TRF was used in order to reduce the possibility of mono-instrument bias for models predicting home behavior problems from ADHD symptoms, such as the occurrence of illusory correlations when the same subscales on similar rating scales are compared. The TRF assesses symptoms of childhood psychopathology based on DSM-IV criteria. The psychometric properties of the teacher version are well established, including high internal consistency (α= .73 to .94) and 2 to 4-week test-retest reliability (*r=.86*) (Achenbach & Rescorla, 2001). Each item is rated for severity on a 4-point Likert scale (0=never to 3=very often).

Measured Intelligence Children were administered the Wechsler Intelligence Scale for Children (WISC-III or WISC-IV) to obtain an overall estimate of intellectual functioning based on each child's estimated Full Scale IQ (FSIQ; Weiss., et al. 2016). The changeover to the fourth edition was due to its release during the course of the data collection and was used to provide parents with the most up-to-date intellectual evaluation possible.

RESULTS

Preliminary Analysis

All independent and dependent variables were screened for univariate outliers reflected by scores that exceed the mean by 3.5 standard deviations in either direction, as recommended by Tabachnik and Fidell, (2007). There were no outliers identified.

Scores on the HSQ and TRF scales were significantly higher for ADHD children than TD children (see Table 1), suggesting significant between-group differences as expected. Boys with ADHD and TD boys differed slightly on age (p=.05) and FSIQ (p=.05). Age was not examined as a covariate because it was not a significant covariate for any of the model's dependent variables. FSIQ was not examined as a covariate because it shares significant variance with WM, and would result in removing substantial variance associated with working memory from working memory (Miller & Chapman, 2001). Consistent with past studies (Rapport et al., 2008), between-group differences in FSIQ were tested by removing reliable variance associated with CE (factor described above) from FSIQ and then examining between-group differences in FSIQ without the influence of CE. Results revealed that between-group differences in this residual FSIQ score were not significant (p=.85).

Table 1 Sample and Demographic Variables

Variable	ADHD		Typically Developing				
	$\bar{X}$	*SD*	$\bar{X}$	*SD*	*t*	*F*	Cohen's *d*
Age	9.35	1.06	9.99	1.43	-1.99*	3.95*	0.51
FSIQ	104.74	9.86	110.28	11.32	-2.02*	4.09*	0.52
FSIQres	-0.02	0.95	-0.03	1.05	-0.19	0.04	0.05
TRF Inattention Subscale	16.77	6.32	4.31	5.89	7.89***	62.28***	2.04
HSQ Severity Raw Score	77.06	38.06	10.66	13.95	8.85***	78.37***	2.29
Phonological WM Factor Score	-0.55	0.97	0.59	0.63	-5.35***	28.60***	1.38
Phonological STM Factor Score	-0.37	1.08	0.40	0.74	-3.22**	10.36**	0.83
Central Executive Factor Score	-0.58	0.91	0.62	0.68	-5.78***	32.75***	1.48

ADHD Attention Deficit Hyperactivity Disorder, *FSIQ* Full Scale Intelligence Quotient, *FSIQres* Full Scale Intelligence Quotient with Working Memory Removed, *TRF* Teacher Report Form: Inattention Subscale Raw Scores, *HSQ* Home Situations Questionnaire: Problem Severity Raw Scores, *STM* Short Term Memory. *p≤0.05, **p≤0.01, ***p≤0.001

Tier I: Intercorrelations

Intercorrelations between all factor scores were calculated using bias-corrected bootstrapping with 90% confidence intervals. All variables were significantly interrelated as expected (see Table 2). As follows, both WM components, Home Behavior Problem Severity, and ADHD Inattention Symptoms were retained in Tier II.

Table 2 Zero Order Correlations

	1	2	3	4
1. Central Executive				
2. Phonological STM	0.64**			
3. Phonological WM	0.95**	0.85**		
4. Inattentive Symptoms	-0.47**	-0.29*	-0.44**	
5. Home Behavior Problem Severity	-0.39**	-0.30*	-0.39**	0.52**

STM short term memory, *WM* working memory. *p≤0.05, **p≤0.01, ***p≤0.001

Tier II: Mediation Analyses

A mediation model was tested to examine the extent to which the significantly related Tier I ADHD Inattentive symptom construct accounted for the relationship between Phonological WM and Home Behavior Problems. All analyses were completed using bias-corrected bootstrapping to minimize Type II error as recommended by Shrout and Bolger (2002) and 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 allow between and within-model comparisons (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 = 60) by a process of resampling with replacement (Hayes, 2014; 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). β-weight effect sizes, standard errors, indirect effects, and effect ratios are shown in

Figure 2. β-weights were used instead of Cohen's *d* because the independent variable is not dichotomous. 90% confidence intervals were used instead of 95% confidence intervals because the former are more conservative for evaluating mediating effects (Shrout & Bolger, 2002).

Phonological Working Memory. Examination of the total effect (Fig. 2, path c) revealed that Phonological Working Memory (PHWM) was significantly related to parent severity ratings of Home Behavior Problems (β= −0.39). Boys with ADHD demonstrated large magnitude parent-rated domestic home behavior problems prior to accounting for the potential mediating role of inattentive symptoms. In addition, PHWM exerted a direct effect on ADHD Inattentive Symptoms (β = -0.44), with lower phonological working memory performance associated with increased severity of home behavior problems and ADHD Inattention symptoms. Teacher rated ADHD Inattention symptoms also predicted Home Behavior Problems (β = 0.43). The full mediation model indicated that PHWM exerted a significant indirect effect (β = -0.19) on Home Behavior Problems through its impact on ADHD Inattentive symptoms. The direct effect of PHWM on Home Behavior Problems was not significant after accounting for the indirect effect (p = 0.11). Examination of the effect ratio (ER) revealed that the indirect effect accounted for 49% of the total effect of PHWM on Home Behavior Problems (ER = 0.49). This pattern was consistent across the separation of CE (ER = 0.51) and PH (ER = 0.47) working memory components.

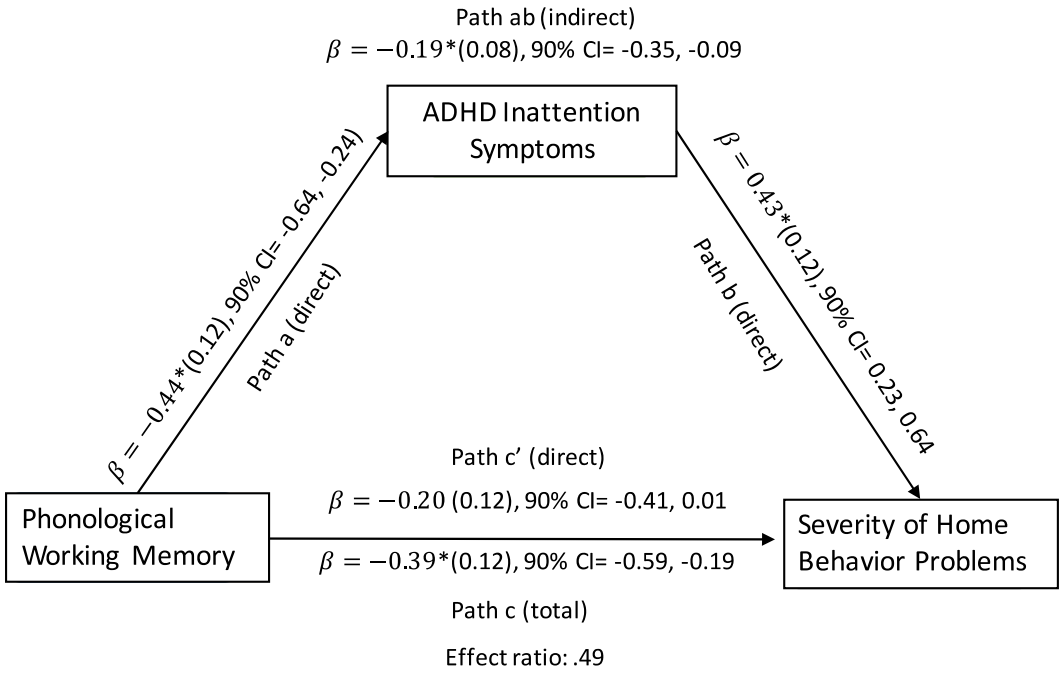

Figure 2: CI=Confidence Interval. Schematic depicts the effect sizes, standard errors, and β coefficients of the total, direct, and indirect pathways for the mediating effect of phonological working memory, which consists of the phonological short term memory and central executive, on severity of home behavior problems. β-weights in the c and c' pathways reflect the effect of phonological working memory on home behavior problem severity before (path c) and after (path c') taking the mediator into account. β-weight (effect size) is significant based on 90% confidence intervals that do not include zero (Shrout & Bolger, 2002).

Tier III: Model Separation

A final set of analyses were conducted to separate the components of Phonological WM (CE and PH STM) and examine their significant indirect effects on Home Behavior Problem severity ratings. The indirect effect and error ratio in Tier II indicated that ADHD Inattentive symptoms are a partial mediator that moderately attenuates the relationship between the Phonological WM system and the severity of parent-rated home behavior problems in children.

Central Executive (CE). Examination of the total effect (Fig. 3a, path c) indicated that CE performance exerted a significant effect on parent-rated Home Behavior Problem severity ratings (β = -0.39). CE also had a direct effect on teacher-rated ADHD Inattention Symptoms (β =-0.47),

with lower CE performance associated with an increased severity of Home Behavior Problems and Inattention symptoms rated by different informants. Inattention symptoms also predicted Home Behavior Problems (β = 0.43). Interpretation of the full mediation model indicated that CE had a significant indirect effect (β = -0.20) on Home Behavior Problems through its impact on ADHD inattentive symptoms. The direct effect of CE on Home Behavior Problems was not significant after accounting for the indirect effect (p = 0.14). Examination of the effect ratio (ER) revealed that the indirect effect accounted for 51% of the total effect of CE on severity of Home Behavior Problems (ER = 0.51).

Phonological Short Term Memory (PH.) The total effect of PH performance (Fig. 3b, path c) on parent-rated Home Behavior Problem severity scores indicated that PH task performance exerted a significant effect on the latter (β= -0.29). PH STM also had a direct effect on teacher-rated ADHD Inattention Symptoms (β = -0.29), with lower PH performance associated with increased severity of Home Behavior Problems and Inattention symptoms rated by different informants. Inattention symptoms also predicted Home Behavior Problems (β = 0.48). Interpretation of the full mediation model indicated that PH had a significant indirect effect (β = -0.14) on Home Behavior Problems through its impact on ADHD inattentive symptoms. The direct effect of PH on Home Behavior Problems was not significant after accounting for the indirect effect (p = 0.19). Examination of the effect ratio (ER) revealed that the indirect effect accounted for 47% of the total effect of PH on severity of Home Behavior Problems (ER = 0.47).

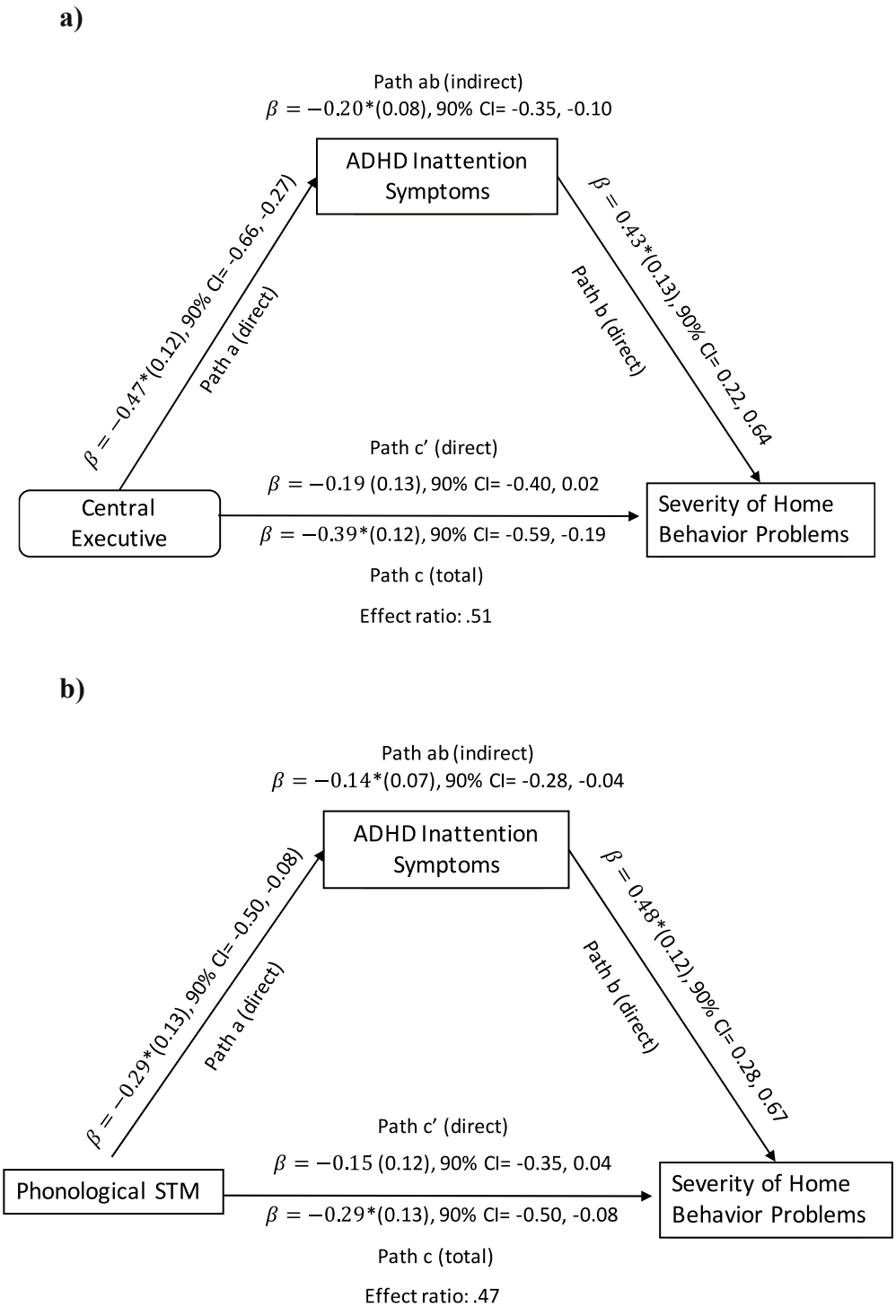

Figure 3: CI= Confidence Interval, STM= short term memory. Schematics depicting the effect sizes, standard errors and β coefficients of the total, direct, and indirect pathways for the mediating effect of (a) central executive, and (b) phonological short-term memory on home behavior problem severity. β-weights for the c and c' pathways reflect the impact of ADHD inattentive symptoms.

DISCUSSION

The current study is the first to examine the direct and indirect impact of specific working memory component processes on domestic parent-child behavior problems in children with ADHD and typically developing children. A bias-corrected bootstrapping procedure was used to examine interrelationships among the overall phonological system of working memory, two primary components of phonological working memory (central executive and phonological storage/rehearsal) and cross-informant reports of ADHD inattentive symptoms and home behavior problems. Results revealed an interactional pattern among the two working memory components and children's home behavior problems. The overall phonological working memory system, which includes the central executive and phonological STS, did not have a direct effect on home behavior problems after accounting for the mediator. This relationship was fully attenuated by the robust indirect effect of the phonological working memory system on home behavior problem severity through its impact on inattentive ADHD symptoms.

Upon separation of the domain-general central executive and the phonological short term storage/rehearsal, these two components of phonological working memory showed a more limited, yet distinct relationship with children's home behavior problems. The central executive and phonological storage/rehearsal component's relationships to children's home behavior problems both occurred indirectly through inattention. The central executive component's contribution was stronger than the phonological STS contribution, which is consistent with previous research about ADHD and executive function deficits in daily activities (Barkley & Murphy, 2011). Findings suggest that the central executive and phonological STS are both fully mediated by inattention symptoms in relation to home behavior problems.

The finding that the phonological working memory system demonstrated indirect effects on home behavior problems through its impact on inattentive symptoms was consistent with previous studies indicating that deficits in working memory components, particularly deficits in CE processes, negatively impact children's inattentive behavior (Kofler et al., 2010).

The finding that WM central executive processes contribute to children's inattentive behavior—and in doing so, negatively impact their parent-child relationships—is consistent with past research demonstrating a robust relationship between central executive deficits, inattentiveness (Kofler et al., 2010), and excessive gross motor activity (Rapport et al., 2008). In those studies, central executive deficits were related functionally to direct observations of decreased visual attention and higher rates of actigraph-measured motor activity in children with ADHD relative to typically developing children. Thus, the process by which central executive deficits impact parent-child interactions in children with ADHD appears to reflect the behavioral outcome of being unable to maintain a focus of attention on information within working memory while simultaneously updating information from multiple, on-going events and social cues occurring within the environment. In other words, the inability to hold and process information effectively creates a world in which they must act quickly and without forethought to compensate for the rapid rate at which mental representations fade. This prediction is consistent with observations and anecdotal reports of children with ADHD interacting socially; they typically speak and act hastily before an intended verbalization or action fades from memory, rather than listening to and observing what others are saying and doing, or they are forgetful and often distracted easily from tasks.

The distinct indirect effects associated with the phonological system merit consideration. The phonological storage/rehearsal component's unique contribution to children's inattentive behavior problems, which in turn adversely influence their parent-child relationships, could be due to any of three related processes associated with this component: an extremely rapid decay of information held in the store, deficient rehearsal processes, and/or a greater vulnerability to interference effects (i.e., irrelevant thoughts replacing what is stored currently in working memory). Deficits in any of the three processes would make it very difficult to engage in the listen-and-wait and attentive behaviors required for productive parent-child interactions (Rapport et al., 2008).

The indirect effects of working memory explained a substantial percentage of the effect in parent-reported home behavior problems (Effect ratio range= 0.47- 0.51). Nevertheless, significant unexplained variance remained across models since the total model effect ratios only accounted for about half of the variance across the models, indicating that other processes and mechanisms are implicated in the domestic parent-child interaction problems experienced by children with ADHD. It is possible that behavioral control affects the severity of home behavior problems, since children with ADHD have been found to be rated as having more behavior control deficits and metacognitive problems by parents in contrast to typically developing children (Schroeder & Kelley, 2008). However, executive functions are a more general construct described in the literature that is separate from the working memory model. Behavioral control in relation to ADHD-related working memory difficulties remains to be investigated.

As mentioned earlier, the hypothesis that the negative interactions between children with

ADHD and their parents results from inadequate knowledge on the part of parents and underdeveloped interpersonal skills in children is a possible explanation (Tripp et al., 2007; Lifford et al., 2008). However, interactions between parent and child improve under psychostimulant conditions (Cunningham & Barkley, 1978; Barkley, 1988), suggesting that a core symptom model explanation would better suit the relationship. Additional factors, such as children's insufficient interpersonal and emotional regulation abilities (Melnick, 1998) and parental psychopathology, including parental ADHD, (Wymbs, Wymbs, & Dawson, 2015; Nilsen, Lizdek, & Ethier, 2015) have been shown to contribute to the home behavior problems experienced by children with ADHD. However, the extent to which these difficulties are secondary to ADHD-related working memory deficits remains unknown.

The unique contribution of the current study was the investigation of the interrelationships among working memory processes, ADHD behavioral symptoms, and domestic parent-child interaction in children with ADHD and typically developing children. Several caveats require consideration when interpreting the present findings despite these and other methodological refinements (e.g., working memory component and bootstrapped mediation analyses). Experimental replications with larger samples that include females, older and younger children, and other ADHD subtypes besides the combined subtype are needed to assess the generalizability of the highly controlled laboratory experiments with stringent inclusion criteria. Furthermore, this study utilized one subscale measure of ADHD symptoms (inattention), and future studies that examine inattention and hyperactive/impulsive symptoms concurrently as double mediators with home behavior problems are necessary to fully understand the extent to which ADHD symptoms contribute to the relationship between phonological working memory

components and home behavior problems. Furthermore, future studies that breakdown CE processes (updating manipulation/dual processing, serial reordering, and interference control) and examine each in relation to parent-child interaction problems would be beneficial to target treatment towards specific functions of CE that show deficits. Future studies that also use longitudinal methodology or concurrently manipulate working memory demands while observing children's and parents' interactions across different settings are needed to further clarify the complex interactions among working memory deficits, ADHD symptoms, and domestic behavior problems.

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