Activity Level and Phonological Short-Term Memory Processes in Boys with ADHD

Jennifer Bolden, Michael J. Kofler, Mark D. Rapport, Joseph S. Raiker, Megan Carl, Brianna Pollock, & Erin Lunsford

University of Virginia
Curry School of Education
UCF

Introduction

Phonological storage/rehearsal deficits are documented consistently in children with ADHD (cf. Kasper et al., 2012) and are associated with impaired language acquisition, reading comprehension, understanding classroom instructions, and social problems (cf. Bolden et al., 2012). The association between phonological storage/rehearsal deficits and ADHD behavioral symptoms, however, is less well understood.

Three recent studies have failed to find an association between phonological storage/rehearsal deficits and hyperactivity in ADHD using parent/teacher ratings (Martinussen & Tannock, 2006; Willcutt et al., 2005) and actigraphs (Rapport et al., 2009). Recent evidence, however, suggests that this failure may be due to task limitations that result in significant underestimation of ADHD-related phonological storage/rehearsal deficits (Bolden et al., 2012). In addition, no study to date has fractionated phonological storage and rehearsal processes to examine their unique contribution to children's activity level.

The present study used objective measurement of children's activity level while experimentally manipulating demands on phonological storage and rehearsal processes in children with and without ADHD to examine the extent to which either/both processes are involved in ADHD-related hyperactivity.

Figure 1

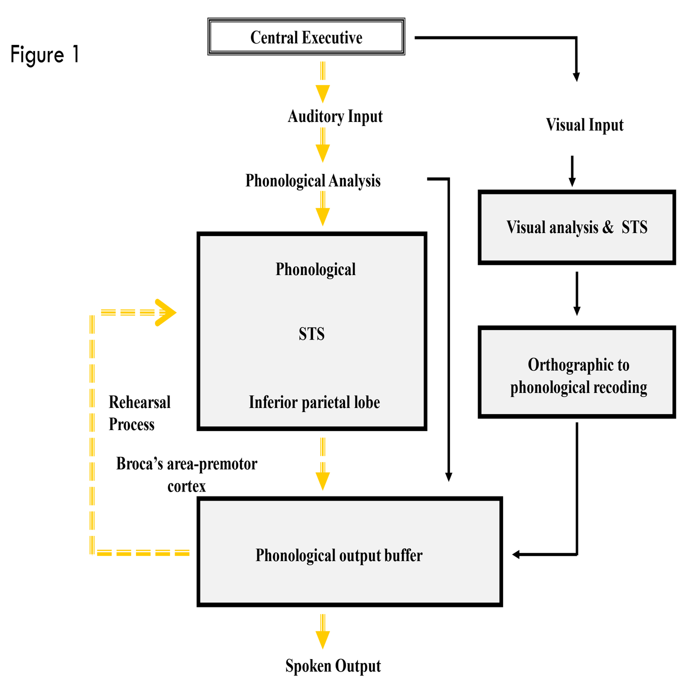


Figure 1. Adapted and expanded version of Baddeley's (2008) phonological working memory subsystem and associated anatomical loci.

Method

Participants

Eighteen children with ADHD and 17 TD children aged 8 to 12 years participated in the study following a comprehensive clinical evaluation (i.e., K-SADS clinical interview, standardized parent/teacher rating scales). The children were recruited by or referred to the Children's Learning Clinic-IV (CLC-IV) through community resources (e.g., pediatricians, community mental health clinics, school system personnel, 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 pro bono comprehensive diagnostic and psychoeducational services. Its client base consists of children with suspected learning, behavioral or emotional problems, as well as TD children (those without a suspected psychological disorder) whose parents agree to have them participate in developmental/clinical research studies. Means, *SDs*, and *F*-values for demographic information are presented in Table 1.

Procedure

Phonological memory tasks. Word lists of increasing length (2, 4, and 6 words) were presented to and recalled by children following a brief (3 s) interval to assess their short-term storage capacity while restricting the need to actively rehearse the information. The brief 3 s delay condition was utilized to minimize the reliance on echoic memory (the brief sensory registry for holding acoustic information). Performance scores (% of trials correct) were examined to determine each child's verbal span—defined as the maximum set size at which a child recalls successfully all stimuli in the correct serial order on at least 50% of trials—as recommended by Conway et al. (2005). Word lists at their established span but with extended rehearsal times (12 s, 21s) were used to assess their ability to actively maintain information in the STS. The two extended delay conditions were selected to equate the delay interval between adjacent conditions (i.e., 9 s intervals between 3 s and 12 s, and between 12 s and 21 s) and allow sufficient time to challenge the articulatory (subvocal) rehearsal mechanism based on earlier findings demonstrating that children are able to maintain words by means of covert rehearsal up to 30 s (Bauer 1977). All nine phonological memory measures were counterbalanced to control for order effects.

Control (C) conditions. Children's activity level was assessed while they used the Microsoft® Paint program for five consecutive minutes both prior to (C1) and after (C2) completing the phonological and visuospatial working memory tasks during four consecutive Saturday assessment sessions. The Paint program allows children to draw/paint anything they like on the monitor using a variety of interactive tools, and served as pre and post conditions to assess and control for demand characteristics (e.g., interacting with the same computer in the same room in the same chair), and potential within-day fluctuations in attentive behavior (e.g., fatigue effects).

Activity level. MicroMini Motionlogger® (Ambulatory Monitoring Inc., 2004) actigraphs were used to measure children's activity level (see Figure 2). The acceleration-sensitive devices resemble a wristwatch and were set to Proportional Integrating Measure (low-PIM) mode, which measures the intensity of movement (i.e., quantifies gross activity level). Movement was sampled 16 times per second (16 Hz) and collapsed into 1-minute epochs. Data were downloaded via a hardware interface and analyzed using the Action-W2 software program (Ambulatory Monitoring Inc., 2004) to calculate mean activity frequencies for each child during the control and WM tasks. Children were told that the actigraphs were "special watches" that let them play the computer learning games. The Observer (Noldus Information Technology, 2003) live observation software was used to code start and stop times for each task, which were matched to the time stamps from the actigraphs. Actigraphs were placed immediately above children's left and right ankles using Velcro watch bands. Ankle placement was used in lieu of trunk placement due to the improved sensitivity of the former for detecting movement (Eaton, McKeen, & Saudino, 1996). A third actigraph was placed on children's non-dominant wrist only, because some tasks required hand movement (using the preferred hand), which would have confounded measured activity level across those tasks. Figure 2 depicts a picture of an actigraph used in the present study and a sample histogram of measured voltage over time.

Figure 2. Motionlogger® (Ambulatory Monitoring Inc., 2004) and histogram of measured voltage over time.

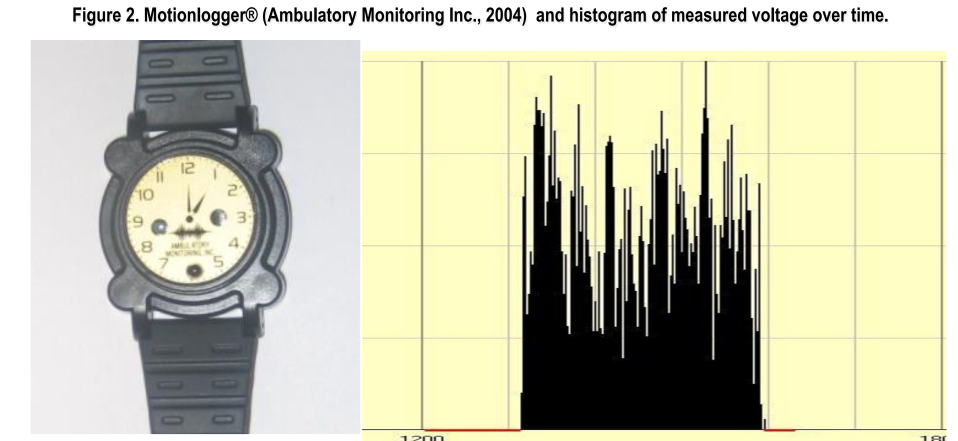


Table 1. Sample and Demographic Variables

Variable	ADHD		Typically Developing		
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	*F*
Age	9.30	1.12	10.21	1.41	4.30*
FSIQ	101.61	13.61	111.73	11.52	5.19*
SES	45.31	10.81	52.60	9.79	4.05
CBCL					
AD/HD Problems	75.22	10.87	57.27	7.69	28.83***
TRF					
AD/HD Problems	65.67	9.63	54.36	5.34	15.52***
CSI-Parent					
ADHD, Combined	76.22	10.11	51.40	12.91	38.39***
CSI-Teacher					
ADHD, Combined	64.00	10.83	51.07	8.45	13.51***

Note: ADHD = attention-deficit/hyperactivity disorder; CBCL = Child Behavior Checklist; CSI = Child Symptom Inventory severity *T*-scores; FSIQ = Full Scale Intelligence Quotient; SES = socioeconomic status; TRF = Teacher Report Form.

Table 2. Phonological Short-Term Store

	Phonological Set Size (3-sec Interval)				*F*	Set Size Contrasts
	2	4	6	Group Composite		
	$\bar{X}$ (SD)	$\bar{X}$ (SD)	$\bar{X}$ (SD)	$\bar{X}$ (SE)		
ADHD	37126.79 (15052.45)	44909.48 (11998.33)	42078.95 (14175.56)	41371.74 (2743.87)	2.75	2(3) < 4(3) = 6(3)
TD	26706.76 (15165.07)	26617.90 (11139.31)	35186.61 (15440.93)	29503.76 (3005.76)	5.19*	2(3) = 4(3) < 6(3)
Set Size Composite	32390.41 (15771.68)	36595.13 (14707.55)	38946.07 (14940.17)	--	4.26*	2(3) = 4(3) < 6(3)
Group *F*	3.89	20.28***	1.78	8.50**		
Group Contrasts	ADHD=TD	ADHD>TD	ADHD=TD	ADHD > TD		

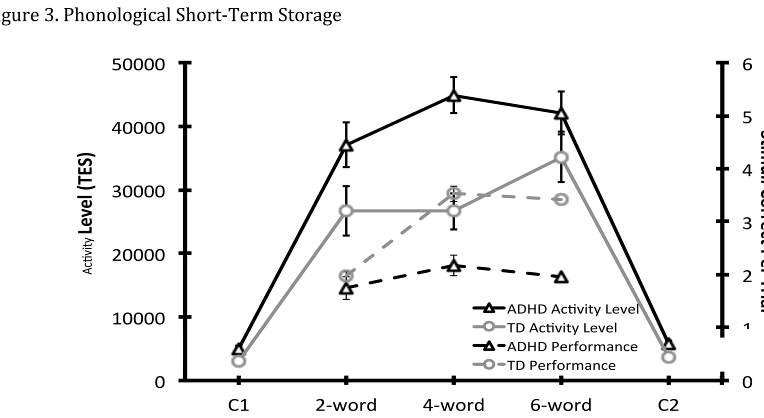
* *p* < .05; ** *p* ≤ .01; *** *p* ≤ .001; PH-Short-Term Store x Group = 3.20, *p* = .048

Table 3. Articulatory Rehearsal Mechanism

	Delay Condition				*F*	Recall Contrasts
	3-s	12-s	21-s	Group Composite		
	$\bar{X}$ (SD)	$\bar{X}$ (SD)	$\bar{X}$ (SD)	$\bar{X}$ (SE)		
ADHD	42270.45 (13340.53)	44316.22 (15445.09)	40046.90 (9778.23)	42211.19 (2742.27)	0.81	3-s = 12=s = 21-s
TD	32541.37 (15391.14)	27521.83 (12178.60)	27479.86 (11089.09)	29181.02 (2919.37)	4.73*	3-s > 12-s = 21=s
Recall Composite	37709.95 (14938.82)	36443.85 (16205.20)	34156.10 (12061.51)	--	1.69	3-s = 12=s = 21-s
Group *F*	3.67	11.44**	11.61**	10.58**		
Group Contrasts	ADHD = TD	ADHD>TD	ADHD>TD	ADHD > TD		

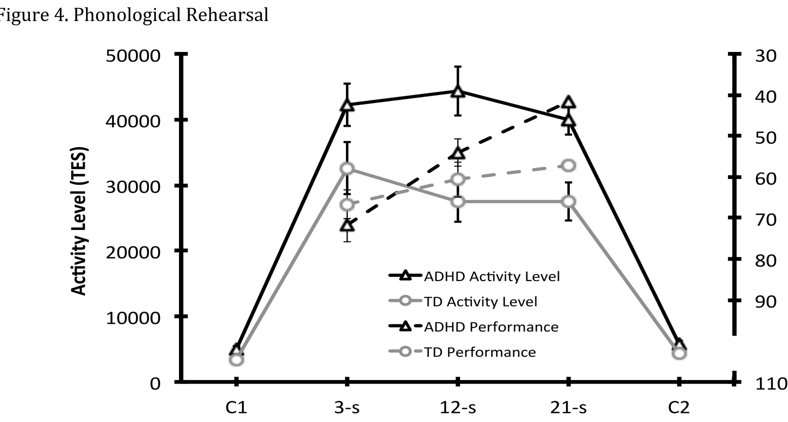
* *p* < .05; ** *p* ≤ .01; *** *p* ≤ .001; Phonological Rehearsal x Group = 1.59, *p* = 0.21

Figure 3. Phonological Short-Term Storage



Activity level (solid lines) and performance (dashed lines) during the pre (C1) and post (C2) control conditions and three phonological storage set sizes (2-word, 4-word, and 6-word conditions. Activity level reflects total extremity score (TES) across the non-dominant wrist and both ankle actigraphs. Performance reflects the percent of words recalled correctly. Triangles = Children diagnosed with ADHD; Circles = Typically developing children.

Figure 4. Phonological Rehearsal



Activity level (solid lines) and performance (dashed lines) during the pre (C1) and post (C2) control conditions and three phonological delay conditions (3-s, 12-s, 21-s). Activity level reflects total extremity score (TES) across the non-dominant wrist and both ankle actigraphs. Performance reflects the percent of words recalled correctly. Triangles = Children diagnosed with ADHD; Circles = Typically developing children.

Results

Impact of phonological storage on activity level.

The 2 (ADHD, TD) x5 (C1, PH 2-, 4-, 6-word conditions, C2) Mixed-model ANOVA revealed significant main effects for set size, group, and the interaction (Figure 1a). Children with ADHD moved significantly more than TD children during the 4-word condition (*ES*=1.24), but not the 2-word or 6-word conditions (both *p*>0.06). Activity level increased in children with ADHD between the 2-word and 4-word conditions (*ES*=0.58), and remained stable across the 4-word and 6-word conditions (*p*=0.15). TD children were more active during the 6-word condition relative to the 4-word (*ES*=0.64) and 2-word conditions (*ES*=0.55).

Impact of rehearsal duration on activity level.

The rehearsal demands independent of storage deficits was examined by setting each child at their individual phonological span, defined as maximum set size at which a child recalls at least 50% of the stimuli correctly as recommended by Conway et al., (2005), and examining changes in performance associated with increased delay (i.e., 12-*s* and 21-*s* delay conditions relative to the 3-*s* delay). The 2x5 (C1, 3-, 12-, and 21-second delay conditions, C2) Mixed-model ANOVA revealed significant main effects for delay, group, and the interaction (Figure 1b). Children with ADHD moved significantly more than TD children during the 12- and 21-second delay conditions (both *ES*=1.04) but not the 3-*s* delay condition (*p*=0.07). Rehearsal delay did not significantly impact activity level for children with ADHD (all *p*>0.58), whereas TD children exhibited decreased motor activity during the 12-s (*ES*=0.36) and 21-s (*ES*=0.38) delay intervals relative to the 3-*s* delay interval.

Discussion

Children with ADHD and typically developing children both evinced similar magnitude increases in activity level as a function of increasing storage demands; however, this increase occurred at lower cognitive loads for children with ADHD relative to TD children. These findings are consistent with the smaller capacity phonological storage system available to children with ADHD, and suggest that previous failures to find a relationship between phonological memory and activity level may have been attributable to task limitations (Bolden et al., 2012).

After controlling for phonological storage capacity, motor activity in children with ADHD was unaffected by increasing rehearsal duration, whereas TD children became moderately less active during the longer delay conditions. Given that these rehearsal delays differentially impact recall performance for children with ADHD (Bolden et al., 2012), these findings suggest that high levels of motor activity may impede rehearsal of phonological information across an extended delay.