Research in Developmental Disabilities 45–46 (2015) 103–109

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Hyperactivity in boys with attention-deficit/hyperactivity disorder (ADHD): The role of executive and non-executive functions

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ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 1 July 2015
Accepted 13 July 2015
Available online

Keywords:
ADHD
Attention-deficit/hyperactivity disorder
Working memory
Executive functions

ABSTRACT

Motor activity of boys (age 8–12 years) with ($n = 19$) and without ($n = 18$) ADHD was objectively measured with actigraphy across experimental conditions that varied with regard to demands on executive functions. Activity exhibited during two *n*-back (1-back, 2-back) working memory tasks was compared to activity during a choice-reaction time (CRT) task that placed relatively fewer demands on executive processes and during a simple reaction time (SRT) task that required mostly automatic processing with minimal executive demands. Results indicated that children in the ADHD group exhibited greater activity compared to children in the non-ADHD group. Further, both groups exhibited the greatest activity during conditions with high working memory demands, followed by the reaction time and control task conditions, respectively. The findings indicate that large-magnitude increases in motor activity are predominantly associated with increased demands on working memory, though demands on non-executive processes are sufficient to elicit small to moderate increases in motor activity as well.

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1. Introduction

Historically, ADHD-related hyperactivity has been viewed as a ubiquitous trait of children with the diagnosis (Rapoport & Benoit, 1975). Porrino and colleagues' (1983) seminal findings, however, challenged this notion by demonstrating that hyperactive boys, compared to matched-healthy classmates, exhibited significantly greater objectively measured motor activity during reading and mathematics classes, but not during lunch/recess and physical education classes. That is, high attentional demands associated with academic work appeared to contribute to increased hyperactivity during waking hours. Parents and teachers also noticed increased motor activity during tasks associated with high cognitive demands (e.g., classwork and homework; Schachar, 1991). More recently, the functional working memory model of ADHD (Rapport, Chung, Shore, & Isaacs, 2001) has attempted to explicate situational variability in ADHD-related motor activity by suggesting hyperactivity serves as a compensatory mechanism by increasing cortical arousal during situations/tasks that place increased demands on working memory (WM) – the temporary storage, maintenance, and manipulation of mental information (Baddeley, 2007).

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http://dx.doi.org/10.1016/j.ridd.2015.07.012
0891-4222/Published by Elsevier Ltd.

The first empirical examination of the relationship between working memory and objectively measured motor activity demonstrated that children with ADHD, relative to typically developing (TD) children, exhibited a disproportionate increase in activity from control to working memory conditions (Rapport et al., 2009). Collectively, these findings, and similar findings in subsequent studies with adults (Hudec, Alderson, Kasper, & Patros, 2013; Lis et al., 2010), support the hypothesis that ADHD-related hyperactivity is functionally related to demands placed on the central executive component of WM, and challenge other prominent models that imply ADHD-related activity is relatively ubiquitous (e.g., Barkley, 1997).

A more recent study tested predictions from inhibition models of ADHD (Barkley, 1997), and specifically, whether varying demands on inhibition processes elicit corresponding changes in motor activity (Alderson, Rapport, Kasper, Sarver, & Kofler, 2012). The study utilized a choice-reaction time (CRT) task, requiring a left/right button press for a corresponding X/O stimulus, and a stop-signal task (SST), requiring inhibition of the prepotent X/O button responses when an auditory tone was presented. A priori, the authors hypothesized that completing a SST would engage children's inhibition system and, consequently, reduce the inhibitory resources available to limit excessive activity. Although results indicated that motor activity was greatest during CRT and SST conditions, relative to a control condition, there was no difference in activity across the CRT and SST conditions. Consequently, Alderson and colleagues (2012) concluded that increased activity during experimental, relative to control, conditions was related to the central executive component of working memory, and more specifically, controlled-focused attention associated with the choice-response paradigm shared by the CRT and SST tasks (Cowan, 1997).

Previous investigations of children (Rapport et al., 2009) and adults (Hudec et al., 2013; Lis et al., 2010) have provided support for a functional relationship between increased working memory demands and ADHD-related hyperactivity. A second look at the findings of Alderson and colleagues (2012), however, raises questions about the unexpected magnitude of activity change that occurred in response to relatively few central executive demands (i.e., demands associated with completion of a CRT task). It appears that relatively small processing demands were sufficient to elicit large increases in motor activity from control task levels. Moreover, although Rapport et al. (2009) demonstrated that children with ADHD exhibited disproportionate increases in motor activity during working memory conditions compared to control conditions, variability in the ADHD group's activity across increasing set-sizes (i.e., increasing number of stimuli to recall) was non-significant. These findings were interpreted to suggest WM-related activity changes were due to central executive demands rather than storage/rehearsal processes but, in hindsight, may suggest that any processing demands, beyond those required to attend to a task (e.g., control conditions in Alderson et al., 2012; Hudec et al., 2013; Rapport et al., 2009), account for between and within group variability in activity. Collectively, previous findings support a relationship between working memory demands and ADHD-related motor activity, but no studies to date have examined the specificity of demands on central executive processes in generating activity level changes. Understanding the task/environmental parameters that elicit hyperactive behaviors has important implications for the development and revision of ADHD models, as well as potential treatment and assessment techniques. Consequently, additional studies that examine activity differences across a broad range of executive and non-executive tasks, with varying involvement of central executive processes, are needed.

The current study is the first to examine motor activity in boys with ADHD and typically developing (TD) boys across several experimental conditions that varied with regard to WM demands. Specifically, motor activity during two *n*-back (1-back, 2-back) WM tasks was compared to activity during a CRT task that required fewer central executive processes (Hogan, Vargha-Khadem, Kirkham, & Baldeweg, 2005), and a simple reaction time (SRT) task that involved mostly automatic processing with minimal central executive demands (Dykiert, Der, Starr, & Deary, 2012). A control condition (Rapport et al., 2009) that presumably placed even fewer demands on storage/rehearsal and central executive processes was also included for comparison with experimental conditions.

Boys in the ADHD group were expected to exhibit greater activity across all experimental conditions compared to boys in the TD group, and all children were expected to exhibit increased motor activity during experimental conditions that placed demands on the central executive component of WM (CRT, 1-back, 2-back), compared to the control condition. Additionally, all children were expected to be more active during the 1-back and 2-back tasks compared to other experimental conditions, since the *n*-back paradigm places relatively greater demands on working memory and executive control (e.g., sustained attention, shifting, updating; Jonides et al., 1997) by requiring children to maintain several stimuli in memory, update the series each time a new stimulus is presented, and divide resources between updating new information and responding with a decision about the presented stimulus. It was also anticipated that the ADHD group, relative to the TD group, would exhibit a disproportionate increase in motor activity as demands on central executive processes increased. These predictions were based the working memory model of ADHD (Rapport et al., 2001) and previous findings with children (Alderson et al., 2012; Rapport et al., 2009).

2. Method

2.1. Participants

The sample consisted of 37 boys (19 ADHD, 18 TD) between the ages of 8 and 12 years ($M = 9.91$ years) recruited from a university-based clinic and from the community. Parents/guardians provided informed consent and children provided assent prior to participation in the study. A psychodiagnostic assessment based on gold-standard procedures was completed prior to research testing. The study was approved by the Institutional Review Board prior to the onset of data collection.

2.2. Group assignment

Parents/guardians provided information about developmental, educational, social and medical history in a psychosocial interview and completed a Kiddie Schedule for Affective Disorders and Schizophrenia-Present and Lifetime Version (K-SADS-PL; Kaufman et al., 1997). Socioeconomic status was measured using the Four Factor Index of Social Status (Hollingshead, 1975). Each child was administered the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003) and the Kaufman Test of Educational Abilities, Second Edition (KTEA-II; Kaufman & Kaufman, 2004) to assess current cognitive functioning and academic achievement, respectively. A parent/guardian and a teacher completed standardized rating scales to assess each child's behavior in home and school settings.

Nineteen children met the following criteria to be included in the ADHD group: (1) diagnosis by the directing clinical psychologist at the Center for Research of Attention and *Behavior based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5; American Psychiatric Association [APA], 2013) of ADHD-Combined Presentation ($n = 17$) or ADHD-Predominantly Inattentive Presentation ($n = 2$) based on a K-SADS-PL interview with the parent/guardian and child; (2) score on the DSM-ADHD scale of the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001) in the clinically significant range (greater than 2 SD above the mean), or score on the DSM-ADHD scale of the Conners 3-Parent (C3P; Conners, 2009) in the clinically significant range (greater than 1.5 SD above the mean); (3) score on the DSM-ADHD scale of the Teacher's Report Form (TRF; Achenbach & Rescorla, 2001) in the clinically significant range (greater than 2 SD above the mean), or score on the DSM-ADHD scale of the Conners 3-Teacher (C3T; Conners, 2009) in the clinically significant range (greater than 1.5 SD above the mean). Ratings were obtained from parents and teachers to ensure behaviors are present in at least two settings per diagnostic criteria (APA, 2013).

Eighteen children were included in the TD group based on no diagnosis of any clinical disorder based on DSM-5 (American Psychiatric Association, 2013) criteria, normal developmental history, K-SADS-PL clinical interview with parent/guardian and child, and ratings on the CBCL, TRF, C3P, and C3T. Children that presented with a seizure disorder, a history of psychosis, a Full Scale IQ score on the WISC-IV less than 80, and/or evidence of gross neurological, sensory, or motor impairment were excluded from the study. Children discontinued use of psychostimulant medication for 24 h prior to each research session.

2.3. Experimental tasks

2.3.1. Simple reaction time (SRT)

Children were presented a series of 3.8 cm letters that appeared at the center of a 19-in. touchscreen computer monitor. Children were instructed to click the left button of a mouse each time any letter appeared on the computer screen, and to respond as quickly as possible without making mistakes. Each letter disappeared after children responded with the mouse click or after 1000 ms, and was followed by a 1000 ms inter-stimulus interval. Children completed one practice block and three consecutive experimental blocks, with each block consisting of 32 trials.

2.3.2. Choice reaction time (CRT)

Children were shown a fixation point in the center of the computer screen for 500 ms followed by a single green letter (uppercase X or O) for 1000 ms. The Xs and Os appeared with equal frequency throughout the experimental blocks. Children were instructed to respond to each X (left button press) and O (right button press) via a wireless response pad as quickly as possible, without making mistakes. Children complete two practice blocks and eight experimental blocks, with each block consisting of 32 trials.

2.3.3. Working memory tasks

Two *n*-back task conditions were used as measures of WM (Ragland et al., 2002). Task parameters were identical to the CRT task except that 25% of the trials presented red letters. Children were instructed to say "yes" if the red letter was the same as the letter presented *n* stimuli earlier in the sequence, and to say "no" if it was different. Children completed separate 1-back and 2-back conditions. Each *n*-back condition consisted of two practice blocks and eight experimental blocks, with each block consisting of 32 trials (24 green font trials, 8 red font trials).

2.3.4. Control (C) condition

The control condition is identical to the protocol established by Rapport et al. (2009). Measurements of children's motor activity were collected for 5 min while they used the Microsoft Paint program to draw anything of their choice. This computer-based task is expected to place minimal WM demands on participants because they are not required to temporarily store, rehearse, or recall information. Activity from control condition measurements was averaged to create one score.

2.4. Activity measurement

2.4.1. Motor activity

Actigraphs provide an objective metric of motor activity (i.e., frequency, intensity, and duration of finite motor movements) by recording changes in acceleration 16 times per second (Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006; Tryon, 2005). Actigraphs are associated with improved reliability and validity, compared to subjective ratings and other objective methods (e.g., pedometers, infrared motion analysis), and are particularly suited to studies of ADHD (see Rapport, Kofler, & Himmerich, 2006 for a review of activity measurement and use with ADHD populations). The current study utilized MicroMini Motionlogger® (Ambulatory Monitoring Inc., 2010) actigraphs, which are similar in appearance to wristwatches. The actigraphs were attached with a Velcro strap immediately above children's left and right ankles, and were worn during all tasks. Activity measurements from the children's wrists were not included, as the tasks required the children to use both hands to respond. That is, inclusion of actigraph data from either wrist was expected to confound the overall activity measurements with task-related movement (e.g., button presses). Both actigraphs were set on the Proportional Integrating Measure (lo-PIM) mode, which provides a measure of children's movement intensity (i.e., gross activity level). Recorded movement was aggregated into 1-min epochs for analysis (Rapport et al., 2006). For each child, a total extremity score (TES; Rapport et al., 2009), a measure of overall movement, was calculated by summing the mean activity level (i.e., epochs) from the left and right ankle sites during each task.

2.5. Procedure

Children completed three laboratory-based research sessions that lasted approximately 3 h each to allow for breaks between tasks and for administration of additional experimental tasks as part of a larger study. Children completed all tasks seated alone on a swivel chair positioned approximately 0.7 m from a computer monitor. The session administrator remained in the room during practice trials but was not present during experimental trials. All experimental tasks were counterbalanced to control for order and carryover effects, but control tasks were always administered to begin and end the research session. Children were offered breaks between tasks or as requested.

3. Results

3.1. Data screening

3.1.1. Power analyses

G*Power software (v. 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007) was used to determine the number of children required to reliably detect differences with a repeated measures ANOVA. A Cohen's d effect size (ES) of 1.02 was used based on Alderson and colleagues (2012) previously reported ES of between-group (ADHD and TD) activity differences during a CRT task (Alderson et al., 2012). Based on an ES of 1.02, alpha of 0.05, power equal to 0.80, and 2 groups and 5 repetitions, 22 total children were needed to reliably detect between-subject differences, and 8 children were needed to reliably detect within-subject and interaction effects. The current study includes 37 children.

3.1.2. Outliers

Dependent variables were screened for univariate outliers using a criterion of at least 3.29 standard deviations greater than or less than the mean for each group, corresponding to a p-value of .001 (Tabachnick & Fidell, 2001). No outliers were identified.

3.2. Preliminary analyses

The sample was comprised of 81.1% Caucasian, 8.1% Biracial, 5.4% Hispanic, 2.7% Asian, and 2.7% Native American children. All parent and teacher rating scale scores were significantly higher for the ADHD group relative to the TD group (see Table 1). There were no between-group differences in racial composition ($\chi^2(4) = 2.44$, $p = .655$), age ($t(35) = .120$, $p = .905$), intellectual functioning ($t(35) = 1.97$, $p = .056$), or socioeconomic status ($t(34) = 1.28$, $p = .211$). Consequently, these variables were not included as covariates in any of the subsequent analyses. Group means and standard deviations for these variables are provided in Table 1.

3.3. Group by task comparison of motor activity

A 2 × 5 mixed-model ANOVA was conducted to examine differences in motor activity across conditions (Control, SRT, CRT, 1-back, 2-back) and between groups (ADHD, TD). There were significant main effects for group ($F(1,35) = 5.93$, $p = .020$) and condition ($F(4,140) = 14.23$, $p < .001$), but the interaction between condition and group was not significant ($F(4,140) = 1.33$, $p = .263$). Results are depicted in Table 1 and Fig. 1. Children in the ADHD group, compared to children in the TD group, exhibited significantly greater activity across conditions.

Post hoc pairwise comparisons across conditions using Fisher's LSD indicated that children were significantly more active during the SRT ($p < .001$, 95% CI [−7204.51, −2356.10], $d = 0.66$), CRT ($p = .002$, 95% CI [−8542.70, −2207.72], $d = 0.58$), 1-back ($p < .001$, 95% CI [12795.66, −6451.40], $d = 1.00$), and 2-back ($p < .001$, 95% CI [−13559.97, −7177.49], $d = 1.11$) conditions, compared to the control task. Further, children were more active during the 1-back task compared to the CRT ($p = .047$, 95% CI [52.18, 8444.46], $d = 0.36$) and SRT ($p = .003$, 95% CI [1801.44, 7884.10], $d = 0.48$) tasks, and during the 2-back task compared to the CRT ($p = .001$, 95% CI [2184.63, 7802.41], $d = 0.43$) and SRT ($p < .001$, 95% CI [2949.93, 8226.91], $d = 0.56$) tasks. No differences in motor activity were observed between the SRT and CRT tasks ($p = .705$, 95% CI [−2573.57, 3763.38], $d = 0.07$) or between the 1-back and 2-back tasks ($p = .684$, 95% CI [−2944.59, 4434.99], $d = 0.06$).

Table 1
Means and SDs of demographic, assessment, and activity data..

	ADHD (n = 19)	TD (n = 18)			
	M (SD)	M (SD)	χ^2	t	F
Racial composition (% of group)			2.44		
Caucasian	84.22	77.78			
Hispanic	5.26	5.56			
Native American	5.26	11.1			
Asian	0	5.56			
Biracial	5.26	0			
Age in years	9.88 (1.63)	9.94 (1.26)		0.12	
WISC-IV: Full Scale IQ	99.26 (8.41)	107.11 (15.03)		1.97	
Socioeconomic status[a]	47.11 (7.40)	51.39 (12.15)		1.28	
CBCL – DSM-ADHD[b]	67.16 (7.67)	50.94 (1.92)		−8.71***	
TRF – DSM-ADHD[b]	64.95 (7.44)	51.94 (3.72)		−6.66***	
C-3: Parent – ADHD total[b]	80.32 (8.71)	52.44 (8.88)		−9.63***	
C-3: Teacher – ADHD total[b]	76.21 (9.61)	50.11 (11.46)		−7.52***	
Control condition TES	12,800.37 (6745.86)	6810.44 (3068.09)			
Simple reaction time TES	15,565.04 (8398.70)	13,606.37 (7820.49)			
Choice reaction time TES	18,483.40 (12,600.38)	11,877.82 (9889.92)			
1-Back TES	23,484.90 (12,466.29)	15,372.96 (10,501.87)			
2-Back TES	24,307.28 (12,681.22)	16,040.97 (9190.06)			
Condition					14.23***
Group					5.93*
Group × condition					1.33

Note. ADHD = Attention-deficit/hyperactivity disorder; C-3 = Conners-3; CBCL = Child Behavior Checklist; TD = typically developing; TES = total extremity score; TRF = Teacher Report Form; WISC-IV = Wechsler Intelligence Scale for Children-Fourth Edition.
[a] Scores are based on the Four Factor Index of Social Status (Hollingshead, 1975).
[b] T-score values are reported for this scale.
* $p < .05$.
*** $p < .001$.

4. Discussion

The current study sought to explicate the relationship between working memory and motor activity reported in previous studies (Alderson et al., 2012; Hudec et al., 2013; Rapport et al., 2009) by examining motor activity across tasks that varied with regard to demands on non-executive and executive processes. As predicted, greater activity was observed for children in the ADHD group compared to children in the TD group, consistent with previous studies utilizing objectively measured motor activity (Alderson et al., 2012; Rapport et al., 2009). It is noted that the moderate magnitudes (d = 0.61–0.74) of the current study's between-group activity differences on WM tasks was considerably smaller relative to previous findings (e.g., d = 1.13, Alderson et al., 2012; d = 1.78, Rapport et al., 2009). This discrepancy may be related to previous studies' inclusion of actigraph data from the non-dominant hand/wrist, which may contain activity associated with task responses (i.e., button

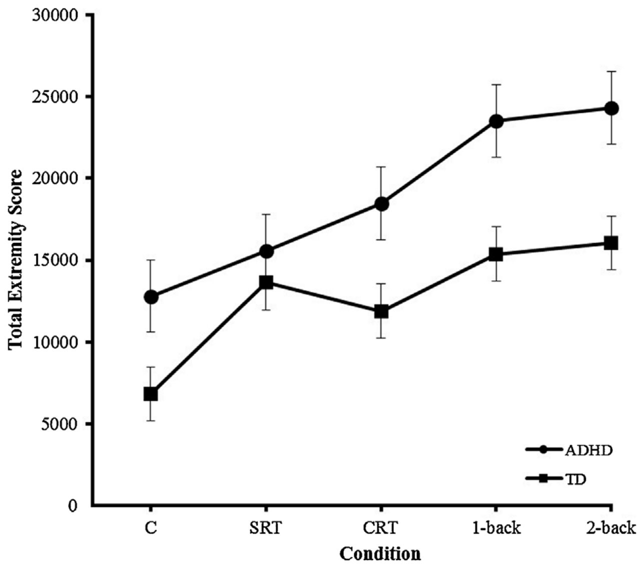

Fig. 1. Total extremity scores during control and experimental task conditions. Error bars represent standard error. ADHD = attention-deficit/hyperactivity disorder; C = control; CRT = choice reaction time task; SRT = simple reaction time task; TD = typically developing.

presses) that is not reflective of gross motor movements. It is also possible that activity associated with the hand/wrist measurement site may be more sensitive to between-group differences, which would contribute to larger between-group differences when aggregated total extremity scores are computed.

Examination of within-group activity changes across conditions revealed that children were more active during SRT, CRT and *n*-back tasks compared to the control condition, which placed minimal working memory demands on the children (Alderson et al., 2012; Rapport et al., 2009). The significant increase in activity from the control to SRT condition was surprising and suggests that minimal attentional and visual processing demands are sufficient to elicit increases in motor activity across children with and without ADHD. Further, the comparable motor activity observed during the SRT and CRT tasks was unexpected. A priori, we predicted that motor activity would increase during the CRT task, relative to the SRT task. This prediction was based on Alderson and colleagues (2012) previous finding of a large magnitude (Cohen's $d = 3.02$) increase in activity from the control condition to the CRT condition, as well as expectations that the CRT task places greater demands on the central executive component of WM compared to the SRT task. Overall, it appears that the small magnitude activity increase from control to SRT and CRT conditions resulted from processes associated with stimulus detection and motor responses (i.e., processes associated with SRT and CRT), rather than stimulus categorization and response selection (i.e., processes uniquely associated with CRT).

Next, we predicted that children would exhibit the greatest amount of activity during the *n*-back tasks, which were expected to place the highest demands on central executive processes. Consistent with this prediction, children's activity significantly increased from the SRT and CRT tasks to the 1-back and 2-back tasks. Even more, the magnitude of activity change from the control condition to the 1-back ($d = 1.00$) and 2-back ($d = 1.11$) conditions was larger than all other within-group effects, suggesting that motor activity was most pronounced when tasks placed high demands on WM. Collectively, while it appears that non-executive processes may contribute to changes in activity, the current findings emphasize the substantial role of executive processing demands in motor activity increases, and also provide support for a functional relationship between hyperactivity and increased task/situational demands on WM (Rapport et al., 2001).

It is noted that the ADHD group was not disproportionately more active compared to the TD group as central executive demands increased, which differs from previous findings (Rapport et al., 2009). The discrepancy, however, may be due to between-study variability in demands associated with the current study's *n*-back WM tasks, relative to Rapport and colleagues measure of WM. For example, *n*-back tasks involve a recognition-based paradigm, whereas the Rapport and colleague's study used a recall-based working memory task. Findings from a recent meta-analytic review of children with ADHD suggest that recognition-based WM tasks are less sensitive at detecting between-group differences in affected children (Kasper, Alderson, & Hudec, 2012). Moreover, the *n*-back tasks used in the current study may not have placed sufficient demands on the central executive (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Kane, Conway, Miura, & Colflesh, 2007) to elicit the same magnitude of ADHD-related activity change observed in the study by Rapport et al. (2009). Nevertheless, the current findings appear to provide at least partial support for Rapport and colleagues' (2001) functional WM model of ADHD. That is, although a disproportionate increase in activity by children with ADHD during WM conditions (1-back, 2-back) would have provided the clearest evidence of the relationship between WM demands and ADHD-related hyperactivity, the significant between- and within-group main effects may account for the disruptive motor activity exhibited by children with ADHD that is observed in school and home settings. Specifically, increases in ADHD-related activity during tasks with minimal, or fewer, executive demands (e.g., fast-paced video games) may be observed with objective measurement but remain within "normal" or expected levels under subjective observation by parents or teachers. However, during tasks involving greater executive demands (e.g., math homework), activity may become elevated beyond the subjective threshold for typical behavior and, consequently, be perceived as excessive or hyperactive among children with ADHD. In contrast, TD children's activity may increase proportionately to children with ADHD during tasks with high executive demands yet still be perceived as within normal, age-appropriate limits. In other words, children with ADHD begin with higher levels of activity (during situations with low demands), but they may not be perceived as hyperactive until facing a situation with greater executive demands, in which all children become more active but only children with ADHD surpass what constitutes "normal" or acceptable activity for the context according to observers. This emphasizes the need for objective measurement techniques both experimentally and diagnostically, since ratings may misrepresent the child's level of activity when based on subjective definitions of hyperactivity that can vary by culture and by rater.

The current study contributes to the field's understanding of working memory deficits in children with ADHD and offers a unique examination of the role of non-executive processes in ADHD-related motor activity. A few limitations, however, warrant consideration. The ADHD group was comprised of a heterogeneous group of children diagnosed with the ADHD-Combined and ADHD-Predominantly Inattentive Presentations, which may have deflated overall activity measurements and diminished between-group effects. Future investigations are necessary to determine if the effects are more robust when the combined presentation of ADHD is examined alone. Further, the current sample included only males. Additional studies are needed to determine if the findings generalize to females with the disorder.

4.1. Conclusion

Collectively, findings from this study suggest that high demands on executive processes are not necessary to elicit activity changes in children, although motor activity is greatest during tasks involving demands on working memory. Objective activity measurement appears to provide a reliable metric to compare children with ADHD and non-affected peers, suggesting potential utility as a tool for clinical diagnosis. A large standardization sample of activity by children with and without ADHD on a standardized task/s would be necessary, however, to develop normative comparisons and clinical cutoffs. Nevertheless, such metrics might ultimately contribute to improved diagnostic accuracy by reducing the influence of subjective ratings. Investigations of motor activity and working memory demands in real-life settings are necessary to test the ecological validity of the current and past findings. In addition, while the current and past findings suggest that both affected and healthy children exhibit increased activity associated with increased cognitive demands, it is not clear whether or not a reciprocal relationship is present (i.e., whether or not increased activity improves cognitive performance). It is possible, and consistent with Rapport et al.'s (2008) model, that allowing children with ADHD to move freely may enable them to compensate for deficits that result in academic and social impairment. Undoubtedly, further research in this area is needed.

Acknowledgement

This research was supported by a grant (HR11-034) from the Oklahoma Center for the Advancement of Science & Technology. The data presented, the statements made, and the views expressed are solely the responsibility of the authors.

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