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

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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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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.