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Attention Deficit Hyperactivity Disorder (ADHD) is one of the leading childhood psychiatric disorders and is a costly public health problem. ADHD causes multiple impairments and while stimulant medications are effective in treating core symptoms of ADHD, some children are not responsive to medications, there is little known about their long-term effects, and they can cause numerous deleterious side effects. Research suggests that physical activity positively impacts some of the same neurobiological mechanisms that have been implicated in ADHD and may have a particularly beneficial effect for children with ADHD by moderating fundamental cognitive deficiencies and behavioral symptoms that characterize this disorder. One of the primary cognitive impairments in ADHD children is executive function (EF). Children with ADHD consistently perform worse on a range of EF tasks relative to those without ADHD (Wilcutt et al., 2005). There is extensive research to support that physical activity selectively improves EF performance in older adults (Colcombe & Kramer, 2003) and some evidence that it has a small effect on cognition in children (Sibley & Etnier, 2003; Tomporowski et al., 2008). Despite evidence and rationale supporting the potential for physical activity to benefit children with ADHD, there is very little research in this area. Therefore, the purpose of this study was to investigate the extent to which physical activity is associated with ADHD symptoms and EF task performance in children with ADHD. Eighteen boys (*M* age = 10.61, *SD* = 1.50), who had been diagnosed by a medical professional and were currently taking stimulant medication, were recruited from

the community for participation in the study. Children came to the testing site to complete four measures of EF: planning (Tower of London); working memory (Digit Span); processing speed (Children's Colors Trails Test 1 and 2); and inhibition (Conner's Continuous Performance Test, CPT II). Parents completed rating scales (ADHD Rating Scale IV; Behavior Assessment System for Children, 2nd Edition) to assess their child's ADHD symptoms. The most relevant outcome variables from each task and the rating scales were chosen for analysis. Physical activity was measured with an accelerometer (Yamax NL-1000) that participants wore for seven consecutive days providing daily step counts (steps) and minutes per day spent in moderate-to-vigorous intensity physical activity (MVPA). Regression analyses were used with physical activity as a predictor of EF performance and ADHD symptoms. Results revealed that MVPA was a significant predictor of performance on the Tower of London, adjusted $R^2 = .28$, $F\,(1, 16) = 7.61$, $p < .05$. Additionally, although non-significant, correlations for 5 of the other 6 EF outcome measures with both measures of physical activity (steps and MVPA) were in the hypothesized direction, with higher physical activity predictive of better EF performance. There were no significant results for ADHD symptoms. This study provides promising results that physical activity is associated with EF, specifically planning abilities, in children with ADHD. These findings are especially encouraging given that the participants were all receiving medication treatment for ADHD. Given that EF deficits in ADHD children negatively affect their school experience and performance, further research is warranted to examine the impact of physical activity on EF in ADHD children.

ASSOCIATIONS AMONG PHYSICAL ACTIVITY, ADHD SYMPTOMS, AND EXECUTIVE FUNCTION IN CHILDREN WITH ADHD

by

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APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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“To my parents, Mike and Sandy Gapin, for their unwavering faith and support throughout this process. ”

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CHAPTER I

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a behavioral disorder characterized by developmentally inappropriate levels of inattention, impulsivity, and hyperactivity. ADHD affects 3-7% of school-age children, with a boy to girl ratio of approximately 3:1 (American Psychiatric Association (APA), 2000; Barkley, 1990). Children with ADHD have a host of impairments in social, school, and family domains, which place considerable economic burden ($31.6 billion) on school systems, families, and medical professionals (Birnbaum et al., 2005). There is converging evidence that children with ADHD demonstrate poor motor skills, have lower levels of physical fitness, and are at increased risk for obesity in comparison to children without ADHD (Harvey & Reid, 2005; Holtkamp et al., 2004). Stimulant medication is used to treat the core symptoms of ADHD, however, these treatments are not always effective. Therefore, the identification of effective adjunctive treatments is warranted.

The etiology of ADHD is multidimensional and complex. Research has identified several cognitive and neurobiological deficiencies that contribute to the disorder. One prominent theory of the pathophysiology of ADHD emphasizes deficits in behavioral inhibition resulting in impairments in executive function (Barkley, 1997a). Executive functions are defined as the cognitive functions that serve to maintain an appropriate problem-solving set in order to attain a future goal (Welsh & Pennington, 1988). Executive function encompasses cognitive domains that are highly relevant for daily life activities, appropriate behavior, and academic and social function. In essence, they are the functions that result in self-regulation. Neurobiological studies indicate that neurotransmitter imbalances in the brain, decreased levels of brain-derived neurotrophic factor (BDNF), and decreased cerebral blood flow to the prefrontal brain regions also contribute to behavioral features and executive function impairments in ADHD (Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990).

Physical activity has been relatively unexplored as an adjunctive behavioral treatment that could benefit children with ADHD. While there is no direct evidence for a link between physical activity and improvements in ADHD symptoms, physical activity has been found to positively impact many of the same neurobiological and cognitive factors that are implicated in ADHD. There is research to support that physical activity improves executive performance and maintains cerebral structure in older adults (Colcombe & Kramer, 2003). Results from large-scale studies of community-dwelling older adults report beneficial effects of physical activity on cognitive health with the largest effects of physical activity reported for executive control processes (Kramer et al., 1999). Research also consistently demonstrates that physical activity benefits cognitive function and academic performance in children by increasing scores on achievement tests and performance on cognitive tasks (Dwyer, Sallis, Blizzard, Lazarus, & Dean, 2001; Hillman, Castelli, & Buck, 2005; Sibley & Etnier, 2003). Further, research using animal models and recent studies with humans demonstrate that acute bouts of exercise alter neurotransmitter and BDNF levels in the brain, and BDNF has been shown to be important for neuronal growth and health (Meussen & Piacentini, 2001; Winter et al., 2007). Although there is no published evidence related to the potential for physical activity to benefit symptoms of ADHD children, these related outcomes suggest that physical activity may serve as a protective factor for children with ADHD by altering fundamental executive function and neurobiological deficiencies. Thus, regular physical activity may reduce symptom severity and the psychosocial impact of ADHD.

The goal of this study was to collect preliminary data related to the relationship between physical activity, executive function, and behavioral symptoms in children diagnosed with ADHD. It was hypothesized that higher physical activity would be associated with lower ADHD symptoms and with better performance on executive function tasks. This study contributes to our understanding of the relationship between physical activity and the behavioral and cognitive symptoms of ADHD. In addition, the results provide a foundation for research focused on the development and testing of optimal physical activity interventions to improve treatment outcomes. This has important public health implications because limited behavioral strategies and adjunct treatments have been identified to help children with ADHD.

CHAPTER II

REVIEW OF THE LITERATURE

ADHD is one of the leading childhood psychiatric disorders in America and is a costly major public health problem. ADHD affects approximately 3-7% of school age children (American Psychiatric Association [APA], 2000) and successful school outcomes for children with ADHD depend upon the degree to which treatment components meet the needs of a particular child. ADHD is characterized by age-inappropriate symptoms of inattention, hyperactivity, and/or impulsivity which occur for at least six months in at least two domains of life, beginning prior to the age of 7 years (APA, 2000). The Fourth Edition of the Diagnostic and Statistical Manual (DSM-IV) identifies three subtypes of ADHD: inattentive, hyperactive-impulsive, and combined. Numerous impairments in social and school functioning are associated with ADHD such as poor academic performance, disruptive behavior, cognitive deficits, higher frequency of risk taking behavior, increased risk of obesity, and a higher incidence of anxiety and depressive symptoms (Barkley, 1990; Weiss & Hechtman, 1993). ADHD also has long-term negative outcomes for many children, including decreased educational attainment, work performance, and occupational stability (Barkley, 2002; Barkley, Fischer, Smallish, & Fletcher, 2006). Further, there are significant economic implications of ADHD. A child's poor academic performance places a heavy burden on school systems due to an increased need for school services such as individualized education programs, counseling, educational testing, and efforts to address disruptive behaviors (Altemeier &

Horwitz, 1997). The results of medical cost studies are consistent in indicating that children with ADHD have higher annual medical costs than children without ADHD (Guevera, Lozano, Wickizer, Mell, & Gephart, 2001; Swensen et al., 2003, 2004). The estimated total excess cost of ADHD is $31.6 billion thus demonstrating a significant economic burden on medical professionals and families (Birnbaum et al., 2005).

ADHD is most commonly treated through the use of stimulant medications, primarily methylphenidate (e.g., Ritalin) and amphetamines (e.g. Adderall), which are considered to be catecholamine agonists. However, research indicates that for many children a combined treatment approach is the best way to moderate symptoms of ADHD. In the landmark Multimodal Treatment Study of ADHD (MTA) study, the National Institute of Mental Health (MTA Cooperative Group, 1999a, 1999b) examined 579 children between the ages of 7 and 10 years at six sites nationwide and in Canada. The researchers compared the effects of four interventions: a medication-only treatment, a behavioral intervention (direct contingency management and clinical behavior therapy), a multimodal treatment consisting of medication and behavioral intervention, and a no-intervention community care condition (i.e., typical medical care provided in the community). Across all six sites, which varied considerably in terms of sociodemographic characteristics, researchers found that the multimodal treatment and the medication treatment alone worked significantly better than behavioral therapy alone or community care alone at reducing the symptoms of ADHD. Importantly, the study revealed that a lower medication dosage was effective in the multimodal treatment, whereas higher doses were needed to achieve similar results in the medication-only treatment. More recently, the MTA Cooperative group (Jensen et al., 2007) published results from a 36-month follow-up assessment (with 485 of the original 579 children) that demonstrated different treatment outcomes. As opposed to earlier results, at 36 months there was no advantage for any of the treatment groups, yet all children receiving treatment showed improvements from initial baseline measurements.

It is important to note that while stimulant medications have proven efficacious in treating the core symptoms of ADHD in the short-term, there is little known about the long-term effects of medication and there is wide individual variation in therapeutic effectiveness, optimal dosage level, and side effects. The side effects of medication typically include sleep disturbance, appetite suppression, headaches, and stomachaches, which all can negatively influence health outcomes and academic performance (American Association of Pediatrics, 2001). Further, medication does nothing to promote healthy lifestyle behaviors. Previous research has identified desirable characteristics of effective treatments which include that the treatment is socially valid and acceptable (Kazdin, 1989), functionally based (Carr, Robinson, & Palumbo, 1990), applied with a high degree of treatment integrity (Gresham, 1989), and has a benign side effect profile. Physical activity appears to fit these characteristics well and may be an effective adjunctive treatment intervention.

ADHD Mechanisms

Neurobiological factors. Current research suggests that neurobiological factors play an important role in the complex development of ADHD. Models of ADHD posit that a core deficit in frontal lobe function underlies its various cognitive and behavioral manifestations. The fronto-striatal and fronto-parietal networks support an array of executive processes and also underlie motor control, inhibition, and the modulation of reward pathways (Biederman, 2005; Dickstein et al., 2006). More specifically, the dorsolateral prefrontal cortices, anterior cingulate cortices, and associated striatal regions, are frequently cited as central to ADHD dysfunctions (Castellanos & Tannock, 2002; Castellanos et al., 2002; Durston, 2003). Two recent meta-analyses highlight consistencies in hypoactivity and structural differences in individuals with ADHD when compared to controls. Valera, Faraone, Murray, and Seidman (2007) conducted a meta-analysis with 21 studies that compared ADHD children and adolescents (n = 565) to controls (n = 583). Participants ranged in age from 9-15 years (*M* age = 11). Researchers assessed 33 brain regions and found global volumetric reductions in these regions in ADHD subjects compared to the controls (standardized mean difference = 0.41). The largest effects were observed in cerebellar regions (0.67), splenium (0.59), right and total cerebral volume (0.48), and right caudate (0.34). Results of this meta-analysis provide additional support that ADHD pathophysiology may involve the cerebellar-prefrontal-striatal network. Dickstein, Bannon, Castellanos, and Milham (2006) used the activation likelihood estimation meta-analytic technique to summarize the results of 16 studies that compared ADHD patients to controls. Of the 16 studies, 11 of these included children and adolescents and 5 included adults. Results show a consistent pattern of hypoactivity in patients with ADHD compared to controls. This hypoactivity is widespread, affecting the anterior cingulate as well as the dorsolateral, inferior, and orbito frontal cortices. Additional regions affected by ADHD include the basal ganglia and parietal cortices.

The results of several review papers on brain imaging studies in ADHD point to consistent evidence that the total brain volume of children with ADHD is significantly smaller on average than the brain of children without ADHD. For example, Krain and Castellanos (2006) summarized results of MRI studies comparing children with ADHD to controls and found that children with ADHD had cerebral volumes that were 3.2% smaller than the controls and all four brain lobes were equally affected. Bush, Valera, and Siedman (2005) reviewed imaging studies and found that the regions of the prefrontal cortex represented the most structural differences. The authors found changes in the dorsolateral prefrontal cortex, which is a region of the prefrontal cortex that affects vigilance, selective and divided attention, attention shifting, planning, executive control, and working memory (Duncan & Owen, 2000). Additionally, structural differences were found in the ventrolateral prefrontal cortex which is linked to behavioral inhibition and has documented involvement in stop-signal tasks (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003). The most consistent finding in this review for the prefrontal region was hypoactivity in the dorsal anterior cingulate cortex which facilitates complex and effortful cognitive processing and is thought to modulate reward-based decision making, which is particularly important in ADHD. Research also shows that children with ADHD have significantly diminished blood flow to the prefrontal and frontal regions of the brain and their pathways (Sieg, Gaffney, Preston, & Hellings, 1995).

Recently, BDNF has been hypothesized to also contribute to ADHD (Tsai, 2003; 2007). Evidence for this hypothesis comes from research demonstrating that stimulants increase central BDNF, specifically in the midbrain region (Meredith, Callen, & Scheuer, 2002; Nibuya, Morinobu, & Dunman, 1995; Nibuya, Nestler, & Dunman, 1996) and a number of studies demonstrating correlations between genetic variations in BDNF and vulnerability to ADHD (Kent et al., 2005; Lanketree et al., 2004, 2008; Xu X et al., 2005). Further evidence shows that BDNF in the midregion is linked to both differentiation and survival of dopaminergic neurons (Hyman et al., 1991; Knusel et al., 1991), suggesting that BDNF may impact dopaminergic system dysfunctions associated with ADHD.

The role of executive function. Executive function involves central control processes such as planning, organizing, shifting and sustaining attention, regulating alertness, facilitating working memory, modulating emotion, and having the ability to self-regulate actions. One comprehensive theory that is well supported in the literature proposes that a fundamental executive function deficit in behavioral inhibition induces secondary executive dysfunction and impaired motor control, resulting in impaired self-regulation of behavior that is the root of ADHD (Barkley, 1997a). More specifically, Barkley's hybrid model of ADHD identifies behavioral inhibition as the primary executive function that is implicated in ADHD (Barkley, 1997a; see Figure 1). Behavioral inhibition is defined as the ability to inhibit a prepotent response, to interrupt an ongoing response, and to maintain interference control (Barkley, 1998). The first aspect, the inability to inhibit a prepotent response, refers to the difficulty of stopping a habitual, dominant response even if it is in one's best interest to suppress that response. The second aspect, the ability to interrupt an ongoing response or response pattern, permits a delay that allows the individual to decide whether to continue responding. This enables the individual to stop ongoing behaviors when they prove unsuccessful or to alter their response following corrective feedback (Dawson & Guare, 2004). Flexibility in ongoing behavior is important because it allows the individual to change his/her behavior as the context of the situation changes. The third aspect, interference control, is an inhibitory process that protects overt and covert behavior from internal and external disruptions and allows for the execution of cognitive functions necessary for self-control (Barkley, 1997b). In summary, behavioral inhibition helps children to think before they act and to determine if and when they will respond. Consequently, deficits in behavioral inhibition prevent and/or interrupt the execution of thoughtful responses.

Collectively, the processes involved in behavioral inhibition influence four categories of executive functions: working memory, self-regulation of affect/motivation/arousal, internalization of speech, and reconstitution. Working memory involves the ability to hold several facts or thoughts in memory temporarily while solving a problem or performing a task. Self-regulation of affect allows individuals to think before responding and attenuates inappropriate responses. It also facilitates internal motivation for the initiation and maintenance of task-oriented behavior. Internalization of speech is the self-talk used to evaluate and direct behavior. This internal dialogue aids in behavior selection that is optimal for attaining goals and plays a critical role in self-regulation. Reconstitution is the analysis and synthesis of information to create a novel response during problem solving. Barkley's model posits that development in these executive functions will result in greater motor control-fluency which produces desired, intentional, and goal-directed behavior (Meaux, 2002). When successive impairments exist in these functions, the consequences are diminished self-control, timing, persistence, flexibility, novelty, and complexity that ultimately disrupt goal-directed motor behavior (Barkley, 1997a). In children these executive function deficits may interfere with the ability to process incoming information while listening to a teacher’s explanation, identify the relevant pieces of information, inhibit irrelevant thoughts and ignore distractions, hold the information in mind while linking it to what he/she already knows about the topic, and staying focused on tasks (Dawson & Guare, 2004).

Most research supports Barkley’s model in ADHD samples, with particularly strong evidence for the components of behavioral inhibition (Pennington & Ozonoff, 1996), working memory (Anastopoulos, Spisto, & Maher, 1994; Zentall & Smith, 1993), poor self-regulation of motivation (Barber, Milich, & Welsh, 1996; Barkley, DuPaul, & McMurray, 1990; Wilkison, Kircher, McMahon, & Sloane, 1995), and motor control (Oosterlaan & Sergeant, 1995; Sergeant, 1995).

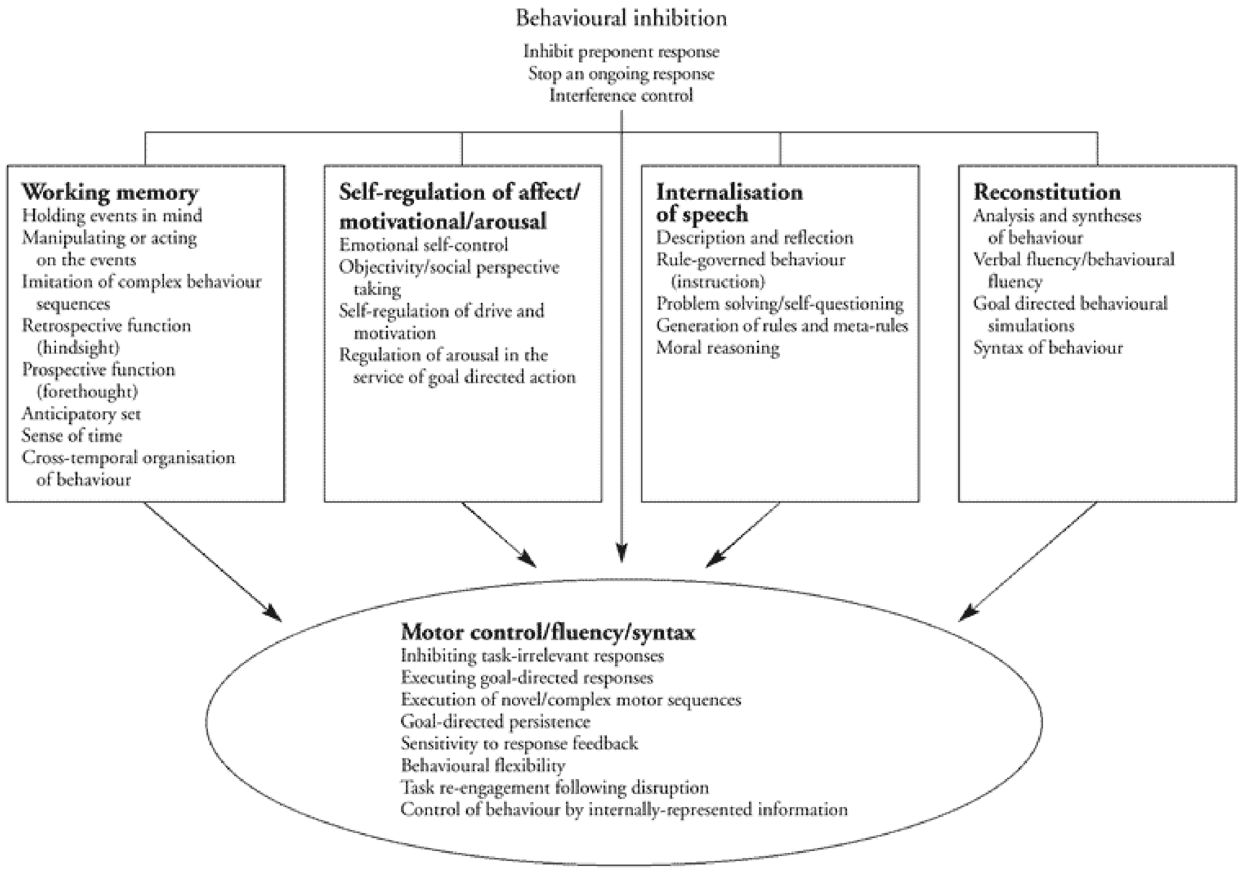

Figure 1. Barkley's Model of ADHD

Evidence supports that these executive function deficiencies seriously impair academic performance resulting in higher school failure and drop-out rates, lead to difficulties in family and peer relationships, and result in low self-esteem well into adolescence and adulthood (Hoagwood, Kelleher, Feil, & Comer, 2000). Research documents that ADHD is characterized by deficits in executive function with ADHD children performing more poorly on a range of executive function tasks relative to control participants (Fischer, Barkley, Smallish, & Fletcher, 2005; Pennington & Ozonoff, 1996; Shallice et al., 2002; Seidman, Biederman, Monuteaux, Weber, & Faraone, 2000). A meta-analysis of 83 studies in which executive function measures had been administered to groups of children and adolescents with ADHD (n = 3,374) and without ADHD (n = 2,969) found that participants with ADHD exhibited significant impairment on neuropsychological measures of response inhibition, vigilance, working memory, and planning with effect sizes generally in the moderate range (0.46–0.49) (Wilcutt et al., 2005). In further support of deficits in frontal lobe function, a recent meta-analysis of 16 neuroimaging studies contrasted patterns of neural activity in children and adults with ADHD (n = 184) and healthy controls (n = 197). This study provides objective evidence of a pattern of frontal hypoactivity in patients with ADHD that is consistent with models implicating frontal lobe dysfunction in ADHD (Dickstein et al., 2006).

While executive function deficits are not the only problems in ADHD children, they contribute significantly to the symptoms of the disorder and are associated with substantial academic deficits (Barkley, Anastopoulos, Guevremont, & Fletcher, 1991; Faraone, Biederman, Lehman, Spencer, Norman, Siedman, et al.., 1993; Fischer, Barkley, Edelbrock, & Smallish, 1990). A recent meta-analysis including 54 studies that examined the effects of ADHD on achievement yielded a large effect (d = 0.75; Frazier, Youngstrom, Glutting & Watkins, 2007). This result indicates that there is a moderate discrepancy between achievement outcomes in ADHD children relative to controls. Therefore, it is important to identify ways to improve these executive function deficits in children, to potentially limit the critical impact on academic and social outcomes.

ADHD Mechanisms and the Potential Role of Physical Activity

Physical activity has been found to positively impact many of the same neurobiological and cognitive factors that are implicated in ADHD. An extensive body of evidence coming from animal models and studies with humans supports this statement.

BDNF. Physical activity triggers the release of BDNF, which enhances cognition by increasing neuronal communication and stimulating the growth of new brain cells. Research with animal models demonstrates that BDNF levels decrease with inactivity, while physical activity significantly increases BDNF within the central nervous system. This increase in BDNF is directly linked to the amount of exercise and is associated with improved performance on cognitive tasks (Cotman & Berchtold, 2002; Neeper, Gomez-Pinilla, Choi, & Cotman, 1995, 1996). Wheel running in rats has also been shown to result in BDNF changes, which are maintained for several weeks without exercise (Cotman & Engesser-Cesar, 2002). Studies with humans have also demonstrated significant increases in BDNF levels following acute exercise in human samples. Serum concentrations of BDNF increased following 30 minutes of moderate intensity exercise in a sample of multiple sclerosis (n = 48) and age-matched controls (n = 20) (Gold, Schulz, Hartmann, Mladek, Lang, Hellweg, et al., 2003). In a sample of fifteen male and female subjects, serum BDNF levels were significantly elevated following 30 minutes of exercise performed at 10% above ventilatory threshold on a cycle ergometer compared to baseline levels (Ferris, Williams, & Shen, 2007). In another study (Rojas et al., 2006) using a sample of 8 male athletes, BDNF serum levels were measured after a 10 minute warm up period followed by a ramp test to exhaustion performed on a cycle ergometer.

BDNF was significantly elevated after the incremental ramp test to exhaustion. A study by Winter et al. (2007) provides good support for the impact of an acute exercise bout on BDNF and catecholamines in relation to vocabulary learning. Researchers assigned 27 healthy male college students into one of three groups: a 15 minute sedentary control group; a 40 min low-intensity running group; or a group performing two high intensity sprints of 3 minutes each at increasing speed. Peripheral levels of BDNF, dopamine, epinephrine, and norepinephrine were measured before and after exercise. The dependent variables included learning speed, and immediate (1 week) and long-term (greater than 8 months) learning of new vocabulary words (using an artificial language). These were assessed immediately after the exercise session, at 1 week, and at 8 months following the acute bout of exercise. Results showed that the high intensity running group learned 20 percent faster compared to the other two groups. Additionally, high intensity exercise elicited the strongest increases in BDNF and catecholamines. When examining the difference between the short-term and long-term effects, the higher BDNF levels during high intensity exercise were associated with more efficient short-term learning and dopamine and norepinephrine levels were associated with more efficient intermediate and long-term learning of new vocabulary. The authors suggest that BDNF and catecholamines may be mediators of the physical activity and learning relationship. Collectively, these results suggest that changes in BDNF may be induced by single bouts of physical activity. These cerebral changes as a result of physical activity function to maintain brain health and improve cognition.

Cerebral structure and function. Animal models show that chronic physical activity results in increased cerebral blood flow (Endres et al., 2003; Swain et al., 2003) and maintenance of cerebral vasculature (Neeper et al., 1995; 1996). Physical activity has also been found to increase angiogenesis (Black, Isaacs, Anderson, Alcantra, & Greenough, 1990) and neurogenesis (Van Praag, Christie, Sejnowski, & Gage, 1999), which enable the brain to operate more efficiently.

In addition to the results of animal studies, there is evidence from human studies which shows that physical activity positively impacts cerebral structure and function. Through the use of functional MRI technology (fMRI), Colcombe et al. (2003) provided neuroanatomical evidence for the protective effects of aerobic fitness on cognitive decline. In a cross-sectional sample of older adults ages (n = 55), cortical tissue density and volume were significantly reduced as a function of cardiovascular fitness, and these reductions were greatest in the frontal, prefrontal, and parietal cortices. Further benefits of physical activity on cerebral structure are demonstrated in two studies by Colcombe et al. (2004). In a cross-sectional study of 41 high-functioning community dwelling older adults (*M* age = 66.23), Colcombe et al. (2004) found greater task-related activity in the frontal and parietal regions in higher fit adults relative to low fit adults. In a follow-up study designed to examine the effects of 6 weeks of aerobic training on cerebral structure and function, 29 healthy community dwelling older adults (ages 58-77) were randomly assigned to either an aerobic training group or a toning and stretching control group (Colcombe et al., 2004). Pre-test and post-test test measures of cerebral activity were assessed using fMRI while participants performed the Erickson Flankers Task. Results showed that those in the aerobic training group demonstrated greater task-related brain activity in the prefrontal and parietal cortices relative to the stretching and control group. Additionally, both studies showed favorable differences in activation of the anterior cingulate cortex for the high fit and aerobically trained groups, which is important for control and regulation of attentional processes.

Catecholamine function. Research suggests that physical activity increases the availability of dopamine and norepinephrine in synaptic clefts of the central nervous system, thus enhancing synaptic transmission. It has been shown in animal studies that neurotransmitter activity, release, and metabolism are influenced by physical activity (Meeusen & De Meirleir, 1995; Meeusen & Piacentini, 2001) and that chronic physical activity produces specific adaptations in neurotransmitter output in rats (Meeusen et al., 1997). For example, following acute bouts of physical activity (treadmill running) in rats, dopamine release (Meeusen &, Piacentini, 2001) and turnover (Hattori, Naoi, & Nishino, 1994) increased in the striatum. Also, treadmill running produced chronic changes in the upregulation of dopamine receptors (MacRae, Spirduso, Walters, Farrar, & Wilcox, 1987). Additional animal research suggests that reductions in anxiety and depression reported by individuals following physical activity may be due to alterations in these neurotransmitters (Brosse, Sheets, Lett, & Blumenthal, 2002; Fulk et al., 2004; Meeusen, Roeykens, Magnus, Keizer, & De Meirleir, 1997).

Evidence for the effects of physical activity on catecholamine function in humans is not as prominent, but a recent study specific to ADHD provides support for increased dopamine activity following acute exercise. Tantillo, Kesick, Hynd, and Dishman (2002) studied the rate of spontaneous eye blinks, the acoustic startle eye blink response (ASER), and motor impersistence among 8-12 year-old children (10 boys, 8 girls) with ADHD after acute exercise at submaximal and maximal intensities. These tasks are related to dopaminergic activity in the brain, specifically in the caudate nucleus. Spontaneous eye blink rates have been used to gauge dopamine levels in ADHD children and are correlated positively with dopamine levels in the caudate nucleus. The caudate nucleus is a region of the brain where morphological differences have been found in the brains of children with ADHD (Taylor et al., 1999; Castellanos et al., 1996; Filipek et al., 1996; Hynd et al., 1990). ASER is a mandatory, automatic contraction of the orbicularis oculi muscle which controls the movement of the eyelids. Motor impersistence is defined as the inability to sustain an act and can be demonstrated in numerous areas of the body such as the limbs, eyes, eyelids, jaws, and tongue (Heilman, Watson, & Valenstein, 2003). In the ADHD child, motor impersistence often involves purposeless movement and fidgeting of hands. The authors hypothesized that physical activity might lead to decreased motor impersistence, increased blink rate, and increased amplitude and decreased ASER latency, thus suggesting that physical activity is helpful in managing ADHD. Results varied by gender and showed that boys with ADHD had an increased spontaneous blink rate and decreased motor impersistence and ASER latency after maximal exercise. Girls with ADHD had increased ASER amplitude and decreased ASER latency after submaximal exercise. These results suggest that the effects of exercise on ADHD are positive, yet affect boys and girls in slightly different ways. One possible reason for these slight differences is that boys have greater dopamine receptor density in the striatum than girls. Therefore, based on these results, the authors concluded that exercise could be used as a "dopaminergic adjuvant" (p.203). Consequently, albeit indirect, this evidence suggests the possibility that for children with ADHD, physical activity may alter neurotransmitter activity, release, and/or metabolism to reduce symptom severity.

Executive function. Although the relationship between physical activity and cognition in ADHD populations has not been explored, there is a large body of evidence that physical activity benefits cognition in older adults and children without ADHD. This evidence provides further support for the potential of physical activity as an adjunctive treatment for ADHD. Results from large-scale studies of community-dwelling older adults report beneficial effects of physical activity on cognitive health (Barnes et al., 2003; Hillman et al., 2006; Lytle et al., 2004; Weuve et al. 2004; Yaffe et al., 2001). The most protective influence of physical activity has been reported for executive control processes (Kramer et al., 1999). Older adults tend to experience substantial declines in executive processes coupled with selectively increased brain tissue loss in the frontal and prefrontal regions of the brain as a function of the aging process. Both cross-sectional and randomized control trials suggest that regular physical activity as well as aerobic fitness may protect older adults from these types of declines. In a meta-analysis of 18 intervention studies, exercise was found to have a significant, positive effect on executive control functions in cognitively normal elderly adults when compared to controls (Colcombe & Kramer, 2003). In an empirical study typical of those included in this meta-analytic review, Kramer et al. (1999) studied the effects of six months of either aerobic training (walking) or anaerobic training (toning and stretching) in 124 sedentary older adults (aged 60-75). They found that aerobically trained subjects improved in tasks requiring executive control processes supported by frontal and pre-frontal cortices, whereas both groups improved on tasks not involving executive control. Collectively, this body of literature suggests that physical activity may selectively improve cognitive processes that are dependent on executive control and frontal/prefrontal brain function.

Based on this evidence it is plausible that physical activity may benefit children with ADHD by positively impacting executive processes. However, no published studies have examined the effect of physical activity on executive functioning in school-age children with ADHD. In an unpublished study, ADHD children who engaged in 40 minutes of cardiovascular exercise per day at 50-75% of their maximum heart rate improved on executive function measures from pre to post-test, as indicated by parent and teacher ratings using the *Behavioral Rating Inventory of Executive Function* (Tette, 2003). It is promising that significant results were achieved, thus warranting further investigation.

Benefits of Physical Activity and Fitness on Children

The mental and physical health benefits of physical activity on children without ADHD are well documented and highlight the potential of physical activity for helping children with ADHD. Children who are physically active have fewer cardiovascular risk factors and behavioral problems in addition to having superior motor fitness, motor skills, and academic achievement as compared to physically inactive peers (Blair & Connelly, 1996). Schools that offer physical activity programs have shown positive effects on academic achievement, including increased concentration; improved mathematics, reading, and writing test scores; and reduced disruptive behavior, even when time for physical activity reduces the time for academics (Symons, 1997). This section summarizes the recent research relative to the benefits of physical activity on cognition, academic performance, and behavior in children. Unfortunately the vast majority of research on physical activity benefits for children, particularly on cognition, has been conducted in children without ADHD. This provides us with a limited view of the ways in which physical activity can impact the lives of ADHD children both cognitively and behaviorally.

Cognition. The strongest support for the relationship between exercise and cognition comes from a meta-analysis including 44 studies (Sibley & Etnier, 2003). Results demonstrated a significant positive effect of physical activity on cognition in children (ES = 0.32, *SD* = 0.27) with larger effects seen in children of elementary (ES = 0.40, *SD* = 0.26) and middle school age (ES = 0.48, *SD* = 0.27). In an earlier meta-analysis by Etnier et al. (1997) including acute, cross-sectional, and experimental designs, a small effect size ($g = 0.36$) was found for chronic physical activity and cognition in children ages 6-13 years.

The most recent evidence supporting the beneficial effects of physical activity on cognition in children was summarized in a review of the literature. Tomporowski, Davis, Miller, and Naglieri (2008) identified four studies examining the effects of chronic exercise programs on cognition. Tuckman and Hinkle (1986) looked at the cognitive effects of a 12-week running program compared to a control group that participated in a standard physical education class (non-aerobic activities only) in 154 children in grades 4-6. Both groups met three times per week for 30 minutes per session. Performance on three cognitive tests measuring perceptual motor skill, visual motor coordination, and creativity (i.e. divergent thinking) were measured at post-test. While there were no effects seen in either exercise group for perceptual motor skill or visual motor coordination, there were beneficial effects on creativity for those children assigned to the running program. Tests of creativity have been reported to measure executive function (Lezak, Howeison, & Loring, 2004; Naglieri & Kaufman 2001; Tomporowski et al., 2008). In a follow-up study conducted by Hinkle, Tuckman, and Sampson (1993), children in eighth grade (n = 85) were again assigned to the same protocols of their previous aerobic running program (treatment group; 8 weeks, 5 times per week) or a standard physical education class (control group) that included only non-aerobic activities like volleyball, table tennis, and badminton. Children in the aerobic running program performed better on tests of creative thinking (creative fluency, creative flexibility, and creative originality) lending further support to the beneficial effects of regular exercise on executive function. Further support comes from a recent randomized controlled trial (Davis et al., 2007) looking at the effects of different doses of exercise on cognitive performance in 94 overweight children (*M* age = 9.2, *SD* = 0.84 years, range 7-11). Children were randomly assigned to one of three conditions: high exercise dose (40 minutes per session), low exercise dose (20 minutes per session), or no-exercise (control). Both exercise conditions were of the same intensity (average heart rate >150 bpm), but varied in duration, and occurred five times per week for 15 weeks. Cognitive performance was measured before and after the 15 weeks using the Cognitive Assessment System (CAS). Of many scale scores provided, the planning scale reportedly reflects executive function processes (Das, 1999). Results showed that exercise training significantly improved scores on the planning scale, however, there was no dose-response relationship. That is, the effect was only seen when examining differences between the control group (no-exercise) and the high dose exercise group. It appeared that 20 minutes was not long enough to elicit effects on cognition in this sample. Of particular relevance to this study is that the statistical analyses were conducted both including and excluding five children in the sample who were diagnosed with ADHD and currently taking medication at the time of cognitive testing. These five children were distributed evenly across groups, and results were similar for both analyses. Although this is a small portion of the sample, it may suggest that beneficial effects can be seen for medicated children with ADHD.

Biological support for the beneficial effects of exercise suggests that exercise induces changes in activation of the frontal lobes, which facilitates mental concentration, planning, decision-making, memory, and creativity (Caterino, 1999). Further, physical activity has been shown to modulate stress and anxiety, which have detrimental effects on learning and memory, and often contribute to behavioral problems (Adlard & Cotman, 2004; Howells et al., 2005). While the precise effects of exercise-related changes in brain function have yet to be determined, some researchers have suggested that systematic physical activity will produce more broad changes in children's brain function than those observed in adults (Hillman et al., 2005).

Academic performance. Further support comes from several randomized controlled trials that have demonstrated beneficial effects of physical activity on academic achievement and/or behavior (Dwyer, Coonan, Leitch, Hetzel, & Baghurst, 1983; Sallis et al., 1999; Shephard, 1997; Shephard, Lavallee, Volle, LaBarre, & Beaucage, 1994). These four large-scale studies explored the effects of increased physical activity during school at the expense of time spent in academics. Results from the majority of these studies found significant improvement in academic achievement with increased physical education time, while only one study found no changes in academic performance with increased physical education time. More recent experimental studies also show beneficial effects of physical activity on academic outcomes. When researchers randomly assigned 214 middle-school children to moderate and vigorous activity groups, they found that those in the vigorous activity group had significantly higher grades after one semester (Coe, Pivarnik, Womack, Reeves, & Malina, 2006).

Several large sample cross-sectional studies also demonstrate a positive effect of physical activity on self-reported grade point average, self-esteem, and self-reported and school administration reported academic achievement (Field, Diego, & Sanders, 2001; Dwyer, Blizzard, & Dean, 1996; Linder, 1999; Tremblay, Inman, & Willms, 2000). Dwyer et al. (2001) measured academic achievement in 8,000 school children ages 7-15 years old and found consistently across age and sex groups that academics were significantly correlated with questionnaire measures of physical activity levels and with performance on a physical fitness test. The California Department of Education (2002) measured performance on the SAT-9 test and on a physical fitness test for 950,000 children in grades five, seven, and nine. Not only did those with higher levels of physical fitness score higher on the SAT-9, but there was a linear relationship between academic achievement and fitness scores, with a particularly strong association in math. In another study, children who engaged in daily physical activity not only showed superior motor fitness and academic performance, but also had a generally better attitude toward school compared to their less active counterparts (Pollatschek & O'Hagan, 1989).

Behavior. The benefits of physical activity on the behavior of children without ADHD are well documented and provide further support for the potential role of physical activity in helping children with ADHD. Several studies in the early 1980s provide preliminary background support for the effect of physical activity on behavioral problems in children. For example, a sample of 12 elementary-aged boys with behavioral disorders engaged in a jogging routine before school for six weeks (Allen, 1980). The boys were randomly assigned to no jogging, or a 5 minute warm-up jog followed by either 5 or 10 minutes of jogging for 3 times per week. Throughout the school day, five types of negative behaviors (hitting/bothering others, name calling/throwing things, yelling/talking out of turn, moving or sitting in appropriately, refusing to cooperate or participate) were recorded and totaled by the classroom teacher for each day of the study. Results showed that there was a 50% reduction in disruptive behaviors on jogging days compared to non-jogging days. The average number of negative behaviors observed on jogging days for the five-minute and ten-minute blocks was 37 and 32 respectively, in contrast to 63 for non-jogging days. The author noted that the fewest disruptions occurred one hour immediately following the jogging activity. Teachers informally reported that children who ran before class exhibited improved attention span and impulse control and a more positive attitude toward school.

In another study with hyperactive boys who were not taking medication, teachers reported less hyperactivity at school following days when the boys ran for 15 minutes after school (Bass, 1985). Another encouraging study tested the effects of running on hyperactivity, impulse control, and medication dosage. A total of fifty-six children 6-13 years old were assigned to complete a running program consisting of a forty-five minute run completed four times per week for twelve weeks. Running decreased hyperactivity and impulsivity, but most notably, those who ran were able to decrease their dose of medication. Upon completion of the study, when children stopped running, their behaviors returned to baseline levels (Shipman, 1985).

A meta-analysis examining the effects of antecedent exercise on disruptive behavior provides additional support for physical activity as a means of influencing behavior in children (Allison, Faith, & Franklin, 1995). Researchers reviewed 16 group studies and 26 single-case studies and found effect sizes of $d = 0.33$ ($SE = 0.08$) and $d = 1.99$ ($SE = 041$), respectively. The largest effects were seen in studies including direct observation and hyperactive participants. Thus, there is evidence that physical activity has a positive impact on behaviors of children in school settings; however, there is no published study in which the relationship between physical activity and behavior has been tested in children who have been clinically diagnosed with ADHD.

One unpublished study has examined the effects of physical activity on clinically diagnosed ADHD children. When examining behavioral symptoms of ADHD, results showed that 40 minutes of exercise 5-7 days/week for six weeks (at >50% VO_{2max}) significantly improved the behavior of ADHD children (n = 13) aged 5-12 years while no improvements were seen in the control group (n = 11) (Wendt, 2000). In summary, these results suggest that physical activity might be an effective supplement to medication to reduce behavioral issues that interfere with learning and academic progress and to directly benefit cognitive performance by ADHD children.

Despite the wealth of evidence suggesting that physical activity has an effect on many of the mechanisms that have been implicated in ADHD, there is only limited research on physical activity levels and ADHD symptoms. Physical activity is a simple, widely available and well-tolerated plausible intervention for ADHD. Moreover, behavioral interventions which might augment the traditional forms of therapy for ADHD are needed. Therefore, research is necessary to describe physical activity levels in children with ADHD and to explore how the level of physical activity is related to symptoms of the disorder.

Summary

In conclusion, animal studies and studies with older adults demonstrate the beneficial effects of physical activity on executive function and cerebral structure and function. Research evidence with children who have not been diagnosed with ADHD also supports the benefits of physical activity for behavior, cognition, and academic performance. Individuals with ADHD can be characterized by deficits in executive function and behavioral symptoms that cause impairment in a host of life domains. The treatments currently used to help ameliorate these deficits are not effective for all sufferers (Barkley, 2006; Rowland, Lesesne, & Abramowitz, 2002) and in many cases provide limited relief from symptoms (MTA Cooperative Group, 2004; National Institute of Health, 1998). Previous research also shows that behavioral therapies are typically not adequate in bringing children into normal ranges of functioning (Antshel & Remer, 2003; Fiore, Becker, & Nero, 1993; Hinshaw, 1994), and medications pose some medical risks and involve numerous side effects (MTA Cooperative Group, 2004; National Institute of Health, 1998; Rowland et al., 2002). Since there are limitations related to the use of current medications and there are documented benefits of physical activity, it is important to identify whether or not physical activity could positively impact executive function and attenuate behavioral symptoms. One unpublished study supports this hypothesis, however, to our knowledge, there is no published study examining this relationship in an ADHD population. This greatly limits our understanding of how to use physical activity effectively to help children with ADHD. The study's goal was to identify the relationship between physical activity, behavioral symptoms, and executive function performance in children with ADHD. This will lead to a better understanding of how physical activity may serve as a useful complementary treatment for ADHD. Further, this research will increase our ability to make the most informed decisions and recommendations concerning potential physical activity intervention strategies.

Consequently, the present investigation explores the relationship between physical activity and behavioral symptoms through accelerometer data, a series of self-report surveys given to the parents of ADHD children, and executive function tasks performed by the ADHD children. By investigating the relationship among these variables, this study addresses an issue that has clear relevance to ADHD treatment approaches. Is physical activity associated with behavioral symptoms in ADHD? Further, is physical activity associated with executive function task performance in an ADHD population? If this preliminary evidence demonstrates that greater physical activity is associated with reduced behavioral symptoms and/or increased executive function performance, physical activity may be further explored as an adjunct treatment for ADHD.

Hypotheses

Relationships between physical activity, executive function, and ADHD symptoms were assessed to provide exploratory evidence regarding the potential effects of physical activity on ADHD symptoms. First, it was hypothesized that higher physical activity would be associated with lower ADHD symptoms (Inattention and Hyperactivity/Impulsivity). Second, it was hypothesized that higher physical activity would be associated with better performance on executive function tasks.

CHAPTER III

METHODS

Overview of Research Design

The overall objective of this study was to identify the degree to which physical activity is associated with behavioral symptoms and executive function task performance in a sample of 20 boys between the ages of 8 and 12 years with ADHD. The relationship between physical activity, executive function and behavioral symptoms was measured using accelerometer data and a self-report questionnaire, self-report surveys completed by the children's parent, and executive function tasks performed by the ADHD children. Children previously diagnosed with ADHD were recruited from the local community and requested to complete testing to assess physical activity, behavioral symptoms, and executive function performance. Importantly, for this study, only ADHD children who were currently taking medication to control their ADHD symptoms were included. Although it is certainly likely that physical activity might be more beneficial to ADHD children who are not currently medicated, the vast majority of ADHD children are medicated and, therefore, we sought to explore relationships between variables in a sample already receiving this form of treatment.

General Procedure

Data was collected in the fall from September through December. An introductory letter was provided that introduced the research study and explained the volunteer parameters, consent and assent, and confidentiality. Testing took place upon one visit to the University of North Carolina at Greensboro Sport and Exercise Psychology Laboratory. Participants were instructed not to engage in structured physical activity within 3 hours of the testing period to reduce the potential impact of acute physical activity on cognitive function. They were also instructed to take their medication as usual. Ethical approval for the study was granted by the UNCG's Institutional Review Board (IRB). The procedures of the study were explained at a developmentally-appropriate level to the child. Prior to participation in the study, parents and children signed informed consent and assent forms, respectively. Following the consent process, the child's height and weight were measured. Parents then completed four questionnaires which took approximately 45 minutes to complete. The first questionnaire, the *General Demographic, ADHD Information, and Physical Activity Questionnaire* assessed the child's current health status, demographics, information pertaining to the ADHD diagnosis (type and age at diagnosis), current medications (including history, type, dose, and frequency), use of supplements for treatment, and presence of comorbid medical conditions. Questions were also asked about the child's and family members' physical activity behaviors. The second questionnaire, *The Physical Activity Questionnaire for Older Children (PAQ-C)*, measured general MVPA over the previous 7 days as well as participation in school and/or organizational sport teams. The parent completed a proxy version of this. The PAQ-C was also given to the child in an interview format on the testing day and a copy was sent home with the parent to return with the accelerometer. The purpose of this was to provide a self-report measure of physical activity in addition to the accelerometer's more objective measure of physical activity. Finally, the parent completed two behavioral and emotional symptom questionnaires relative to his/her child.

While the parent completed the questionnaires, the child completed a series of four executive function tasks. These tasks took about 45-60 minutes to complete. Following the completion of these tasks, the family was given a small payment ($20) and an accelerometer for the child to wear to assess his physical activity during waking hours for a consecutive 7-day period. During the 7-day period the participant was asked to complete a physical activity log. This daily log asked the participant to record if the accelerometer was worn all day, if the child completed any physical activities while the accelerometer was off, and if any activities were performed that may not have been recorded by the accelerometer (e.g., bike riding, swimming, skateboarding). After the 7 days, the researcher collected the accelerometer, the PAQ-C, and the physical activity log from the participant who subsequently received a second payment ($30). The division of the payments was to facilitate compliance with the study protocol and the return of the accelerometer to the research team. Parents were called once a day for the duration of the study in order to ensure that their child was wearing the accelerometer correctly and adequately, there were no questions/concerns about its use, and they were completing the daily physical activity log.

Sample Recruitment and Selection

Twenty children diagnosed with ADHD were identified and recruited to participate in the study through flyers placed at local ADHD clinics, medical providers, specialty ADHD schools, and various support agencies that have direct connections to individuals identified with ADHD. Advertisements were also placed in local newspapers. Flyers stated: “the purpose of this research is to investigate the relationship between physical activity and AD/HD symptoms in children.” In order to be included in the study participants had to be diagnosed with ADHD by a medical professional and currently taking medication to treat ADHD symptoms. As a result of the higher prevalence rate of ADHD in boys relative to girls and because behavioral and cognitive symptoms vary significantly as a function of gender, only boys were included in this study in order to limit variability in the sample.

Descriptive Measures

General demographic, ADHD information and physical activity questionnaire. This questionnaire assessed: demographics (age, gender, and combined family income), medications and supplements used to treat ADHD, ADHD diagnosis type, age at diagnosis, and physical activity patterns of both the child and the parent or primary caregiver. This questionnaire took 10-20 minutes to complete. There were some additional items, based on questions designed for the National Children and Youth Fitness Studies I and II (Ross & Gilbert, 1985; Ross & Pate, 1987), asking parents to compare their own, their significant other’s, and their child’s physical activity to others of the same age/sex. Parents were also asked “In the typical week, on how many days does your child get exercise that causes rapid breathing and a fast heart rate for 30 continuous minutes or more?” and “In the typical week, on how many days do you and, if applicable, the other caregiver in the family get exercise that causes rapid breathing and a fast heart beat for 30 continuous minutes or more?” The participant would respond for him/herself and, if part of a two-parent family, indicate the answer to this question for the other parent. The questionnaire also included some researcher generated open-ended questions regarding the child's and parents/caregivers' physical activity behavior in addition to perceptions of how physical activity influences their child's ADHD symptoms. These were exploratory and used for descriptive purposes only. These questions included:

1. Very broadly, have you noticed a difference in ADHD symptomology when your child is regularly involved in physical activity and/or organized community/school sports? If yes, please describe these differences. Are they positive or negative?
2. When your child is regularly involved in physical activity and/or organized/community sports, do you notice a difference in his/her symptoms of inattention? If yes, please describe these differences. Are they positive or negative?
3. When your child is regularly involved in physical activity and/or organized/community sports, do you notice a difference in his/her symptoms of hyperactivity? If yes, please describe these differences. Are they positive or negative?
4. When your child is regularly involved in physical activity and/or organized/community sports, do you notice a difference in his/her symptoms of impulsivity? If yes, please describe these differences. Are they positive or negative?

5. When your child is regularly involved in physical activity and/or organized/community sports, does that impact academic performance at school? If yes, please describe.

Physical Activity Measures

New Lifestyles NL-1000 accelerometer. The Yamax accelerometer is made in Japan and marketed in the United States under a different name (New Lifestyles Digiwalker, NL-1000) and previous models of this brand have been extensively validated in the literature (Vincent, Pangrazi, Raustorp, Tomson, & Cuddihy, 2003; Schneider, Crouter, & Bassett, 2004). The NL-1000 counts total steps, MVPA time accumulation, and includes an internal clock and 7 day memory function. Because the accelerometer has an internal clock, it automatically resets each day. Therefore, the accelerometers were sealed so that they could not be accidentally reset and to reduce potential reactivity (Vincent & Pangrazi, 2002). Reactivity with pedometer and accelerometer use occurs when the testing process itself influences behavior. For example, if the child receives the accelerometer on the first day and wants to see if the activity count goes up when he walks, runs, jumps, etc., higher numbers may be recorded based on these experimentations. Reactivity was thus reduced by sealing the accelerometers so the participants could not see the display. Accelerometers were fastened to the waistband of children's pants or shorts in line with the right knee and each accelerometer included a security strap to ensure it stayed in place and was not lost during data collection. Children were instructed to put on the accelerometer when they woke up in the morning and to take it off at bedtime. They could only remove it for bathing, swimming, and sleeping. A detailed list of instructions, including diagrams of how to wear the accelerometer correctly based on the manufacturers' instructions, were given to each participant. Physical activity data was collected for 7 days since this has been found to exceed the requisite length of time (4 days) to measure habitual physical activity in children (Durant et al., 1992; Janz, Witt, & Mahoney, 1995; Trost, Pate, Freedson, Sallis, & Taylor, 2000). Additionally, 7 consecutive days was selected because previous literature has found differences in activity levels between weekend days and weekdays (e.g. Duncan, Schofield, & Duncan, 2006; 2007). Therefore, all participants were instructed to wear it on both weekends and weekdays. Upon collection of the accelerometers, steps and MVPA time accumulation were recorded.

Physical Activity Questionnaire for Older Children (PAQ-C) (Crocker, Bailey, Faulkner, Kowalski, & McGrath, 1997). This questionnaire measures general MVPA during the school year over the previous 7 days in children between 8 and 14 years of ages (grades 4 to 8). The self-administered questionnaire consists of eight items to be completed by the child. Questions are worded at a developmentally appropriate level. A total of nine questions are used and each PAQ-C statement is scored on a five-point scale, with higher scores indicating higher levels of activity. Physical activity is described as sports, games, or dance that make you breathe hard, make your legs feel tired, or make you sweat. The first question is an activity checklist consisting of common sports, leisure activities and games, plus room for other activities. A primary purpose of this item is to act as a memory cue. Six questions assess activity in physical education classes, recess (removed for secondary school students), lunch, right after school, in the evenings, and on the weekend. These serve as memory cues to aid in physical activity recall. One question asks which statement “describes you best for the past 7 days,” with five statements describing low activity levels to high activity levels. One question asks the child to report how frequently he or she did physical activity for each day of the week. The PAQ-C has been found to be moderately significantly related to other physical activity measures (self-report, motion sensor, and recall interview) in boys and girls 8-14 years old as reported in two studies (combined N = 186) (Kowalski, Crocker, & Faulkner, 1997). A summary score is calculated by averaging the values of 1 to 5 obtained on each of the nine items. A score of 1 indicates low physical activity, whereas a score of 5 indicates high physical activity. Parents completed the PAQ-C on two occasions: once on the day of the cognitive testing and then again after the 7-day period for which the accelerometer was worn. The children were administered the PAQ-C in interview format on the day of cognitive testing. To assess whether the nine items that were used to create the physical activity score formed a reliable scale, Cronbach's alpha was computed. The alpha for the nine items for the second parent completion was 0.78, which indicates that the items form a scale that has reasonable internal consistency reliability. Similarly, the alpha for the child’s completion (0.70) indicated good internal consistency, and the 0.63 alpha for the first parent’s completion indicated minimally adequate reliability.

Daily physical activity log. Because accelerometers do not pick up all types of activities (i.e., skateboarding, swimming), a daily activity log was also given to the participants so that they could record these types of activities. This log also asked them to record if the accelerometer was left off for any period of time and what the child did during the time the accelerometer was off. These daily logs were returned with the accelerometer. For participants that listed additional activities on these logs, the specified physical activity was found in *The Compendium of Energy Expenditures for Youth* (Ridley, Ainsworth, & Olds, 2008). For all physical activities that were listed and had a MET value > 3.0 (indicative of moderate physical activity; Ridley, Ainsworth, & Olds, 2008), the number of minutes the child was engaged in the activity was added to that day's activity minutes. For any activities in which it may have been questionable that the activity was engaged in at a moderate intensity for the entire duration of time listed, 50% of the time recorded was added to that day's total minutes and then included in the MVPA calculations for each participant. This 50% value was used to ensure that time spent in physical activity would not be inflated.

Table 1

Physical Activity Variables Used in Statistical Analyses

Instrument	Description	Scores
NL-1000 Accelerometer	Accelerometer that measures steps, distance, and activity minutes for up to 7 days	Average daily step counts (steps) Average minutes per day of moderate-to-vigorous intensity activity (MVPA)
PAQ-C	Self-report physical activity questionnaire designed for children in grades 4-12	Mean Score (range 1-5; low activity-high activity)
Physical Activity Log	Daily record of accelerometer use including physical activities engaged in while monitor was off or that it may not pick up	Minutes spent in moderate intensity physical activities while off or for activities that it would not record (e.g. biking)

ADHD Behavioral Symptoms

*The Behavior Assessment System for Children, 2nd edition, Parent Rating Scale (*BASC-2 PRS, Reynolds & Kamphaus, 2004). The BASC-2 PRS was used to measure the "presence and severity" (Reynolds & Kamphaus, 2002, p. 180) of emotional and behavioral symptoms associated with ADHD within the past 6 months at home and in the community. Research demonstrates that this assessment system has been successful in the process of diagnosing ADHD and in differentiating between subtypes of ADHD (e.g. Doyle, Ostrander, Skare, Crosby, & August, 1997; Ostrander, Weinfurt, Yarnold, & August, 1998; Pizzitola-Jarratt, Riccio, & Siekierski, 2005; Vaughn, Riccio, Hynd, & Hall, 1997).

The BASC-2 PRS item types are rating scales with the respondent circling one of four choices: *N*-behavior never occurs, *S*-sometimes occurs, *O*-often occurs, and *A*-almost always occurs. The measure includes nine clinical scales: Aggression, Anxiety, Attention Problems, Atypicality, Conduct Problems, Depression, Hyperactivity, Withdrawal, Somatization; and three adaptive scales: Adaptability, Social Skills, and Leadership. Composite scores are also calculated in three domains: Externalizing Problems (Hyperactivity, Aggression, Conduct Problems); Internalizing Problems (Anxiety, Depression, Somatization); and Adaptive Skills (Adaptability, Social Skills, Leadership, Activities of Daily Living, Functional Communication). Additionally, a broader Behavioral Symptoms Index (BSI) is obtained through scores on the Atypicality, Aggression, Hyperactivity, Anxiety, and Depression subscales. The BASC-2 PRS is scored using computerized software that calculates T-scores of the individual scales and the composites. Higher scores reflect more problems and scores >65 are considered high risk. For purposes of examining ADHD symptoms, only the Attention and Hyperactivity scores were used for analysis.

The ADHD Rating Scale-IV (Du Paul, Power, Anastopoulos, & Reid, 1998). The ADHD Rating Scale-IV is a reliable and easy-to-administer instrument both for diagnosing ADHD in children and for assessing treatment response. The scale contains 18 items that are directly linked to DSM-IV diagnostic criteria for ADHD. Participants must “Circle the number that best describes your child’s home behavior over the past 6 months.” Response range from 0 = *never* to 3 = *very often*. Three scores are derived from the scale. Nine items are summed to form the raw scores for the Inattention subscale and nine items are summed to form raw scores for the Hyperactivity-Impulsivity subscale. A total raw score is also calculated from all of the items. Raw scores are then converted into percentile scores based on the participant’s age and gender. Three percentile scores were used in the analyses: Inattention, Hyperactivity, and Total. An index of symptom severity can be utilized by summing up the number of items for which participants circled a 2 or a 3 for both subscales.

Table 2

ADHD Behavioral Symptoms Variables Used in Statistical Analyses

Instrument	Description	Scores
BASC-2 PRS	Parent Rating Scale measuring severity of emotional and behavioral symptoms relative to ADHD	T-scores for Hyperactivity and Inattention
ADHD Rating Scale- IV	Parent Rating Scale to aid in diagnosis of ADHD	Percentile scores for Inattention, Hyperactivity and Total scale

Executive Function Measures

The following neuropsychological tests aimed at assessing executive functions were administered to each child and the order of administration was randomized. All of these tests have acceptable validity and reliability when administered to children ages 8-12 years. A summary of the executive function variable scores can be found in Table 3.

Inhibition. The Conners' Continuous Performance Test (CPT-II Version 5.1 for Windows; Conners, 2004) is a computerized, 14-minute, visual performance task in which the participant must respond repeatedly to non-target figures (capital letters) and then inhibit responding whenever the infrequently presented target figure appears (the letter X). The target letter X appears approximately 10% of the time. The test was presented exactly as described in the manual and was presented using a laptop computer. The total time for the test was about 20 minutes, including explanation of instructions, a brief practice test to ensure the participant understood the instructions, and then the test itself. The participants were told to press the space bar when they saw a letter, except when they saw the letter X. When they saw a letter X they were instructed to not press the space bar. The entire test is segmented into six blocks. Each block contains three sub-blocks, which allows the examiner to assess changes in responses and vigilance across the duration of the test. Each sub-block contains 20 trials (letter presentations) for each inter-stimulus interval. The inter-stimulus intervals (ISIs) are 1, 2 and 4 seconds with a display time of 250 milliseconds. The presentation order of the different ISIs varies between blocks. The CPT II produces a number of outcome variables, but for the purposes of this study, only results for Omissions and Commissions were used. Omissions represent the number of targets the participant fails to respond to (not hitting the space bar when a letter that is not an X is presented) and are an index of inattention. Commissions refer to the number of times a participant responds to the non-target stimulus (letter X) as it appears on the screen. Commissions are reflective of impulsivity. Both omission and commission scores were converted to age and gender appropriate T-scores for use in analysis. Higher T-scores are indicative of worse performance.

Planning. The Tower of London (TOL) 2nd edition (Culbertson & Zillmer, 2005) requires the child to copy a modeled pattern of three colored beads (red, blue, green) in as few moves as possible. The test includes two wooden boards (one for the examiner and one of the participant) on which three pegs of descending height are mounted (see Figure 2; Mitchell & Poston, 2001).

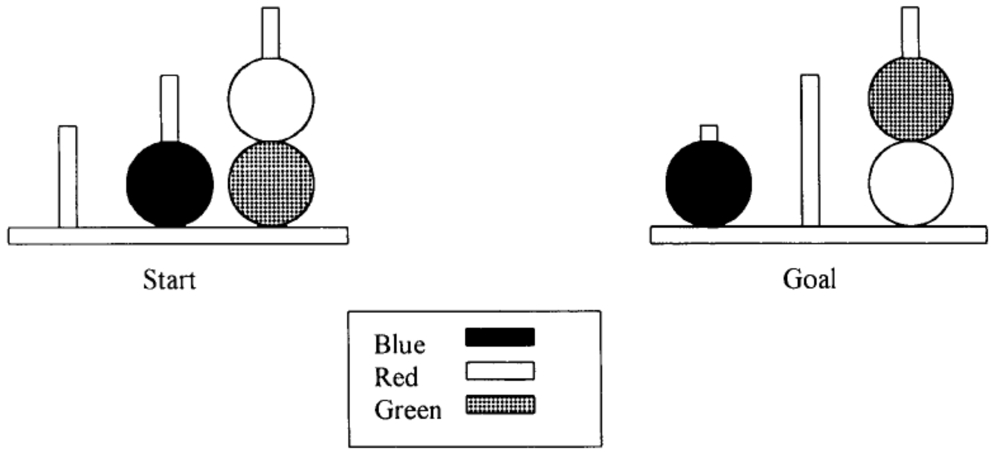

Figure 2. An example of a five move Tower of London task. *Note*. From "Effects of Inhibiting of Response on Tower of London Performance" by C.L. Mitchell and C.S. Poston, 2001. *Current Psychology, 20*, p. 166.

Three beads are placed in a "start position" on the participant's board. The examiner places the beads in a pattern on his/her board and the participant is asked to replicate that pattern on his own board. There are 10 patterns with increasing difficulty for participants to complete. Participants had 2 minutes to replicate each pattern. Each problem has a minimum required amount of moves ranging from 3 to 7. For example, the first problem could be solved using only 3 moves while the last problem required 7 moves to replicate the pattern. Any moves taken beyond the minimum required amount of moves are indicative of less efficient planning ability. There are two rules the participants must follow: 1) they can only move one bead at a time and 2) they cannot overload a peg (e.g. place two beads on a peg that clearly only holds one). For the purposes of this study, two main scores were used: Total Move Score (TMS) and Total Correct Score (TCS). The TMS is the sum of all moves taken in order to solve the problems that exceeded the minimum required move score. For example, if the child took 9 moves to solve a problem with a minimum required move score of 6, the computed TMS score would be 3. Higher TMS raw scores (lower percentile scores) represent less efficient planning abilities. The TCS score indicates how many of the ten problems were solved in the minimum number of moves. Both TMS and TCS scores were converted to percentile scores for analysis.

Working memory. The Digit Span (DS) subtest of the WISC-IV (Wechsler, 2003) is a widely used, standardized memory task. The DS Forward and Backward tests were used for this study. For the DS Forward, the experimenter first reads a series of “blocks” of digits (ranging from two to nine digits, e.g. 4-5-2) with a speed of 1 second per digit to the child. The child must repeat the numbers in the correct order. After a correct response, a new, longer sequence is given; after an incorrect response, respondents are given another sequence of the same length to attempt. The score was the total number of correctly repeated digit blocks. Following completion of all of the forwards trials, the child is then asked to repeat new blocks of digits but in the opposite order (DS Backwards). For example, if the examiner says 4-5-2, then the correct response would be 2-5-4. The same administration and scoring procedure is followed for both tests. The DS is sensitive to deficits in attention and executive functioning, and researchers have recommended that it be used in diagnosing ADHD (Hale, Hoeppner, & Fiorello, 2002). This task requires verbal material to be held in mind across delay intervals and imposes a demand for organizing the material in some way to more easily restate the material when called on to do so. A total scaled score including both DS Forward and Backward, adjusted for age and gender, was used for the analysis.

Processing speed. The Children’s Color Trails Tests 1 and 2 (CCTT 1 & 2; Llorente, Williams, Satz, & D'Elia, 2003) closely resemble the Children's Trail Making Test A & B (TMT A & B; Reitan & Herring, 1985) and provide measures that have a minimal reliance on language skills. Test 1 is similar to TMT A and requires the connection of one set of encircled numbers (1-15) in ascending order by drawing a line from one circle to the next. Even numbers are printed in a yellow background while odd numbers are printed in a pink background. The Children's Color Trails Test 2 is similar to TMT B. In this test there are two sets of encircled numbers (1-15), with one set printed in a pink background and another set printed in a yellow background. The child must draw a line connecting the numbers in ascending order, alternating between pink and yellow circles while disregarding the numbers with inappropriate color sequencing (e.g. connecting a pink 1 to a yellow 2; then a yellow 2 to a pink 3; then from a pink 3 to a yellow 4; and so on). A number sequence error occurs if a child does not go in proper number sequence (e.g. connects number 3 to number 5). A color sequence error occurs if the child ascends in the correct order (e.g., connects number 1 to number 2) but does not alternate colors (e.g. connects a yellow 1 to a yellow 2 instead of a yellow 1 to a pink 2). The participant is asked to complete the sequences in as little time as possible. Outcome variables used in this study included Test 1 and 2 time scores (percentiles) and the interference score (Llorente et al., 2003). Completion time scores are the total amount of time to complete each test and the interference score is the difference in performance between Test 2 and Test 1 divided by Test 1. Other published CCTT dependent variables (e.g., color and number sequencing errors, prompts, near misses) were not used in the study due to their infrequency in this sample precluding valid statistical analyses.

Table 3

Executive Function Variable Scores Used in Statistical Analyses

Instrument	Description	Scores
CCTT (1&2)	Processing Speed	Test 1 and Test 2 T-scores
Digit Span	Working Memory	Total Digit Span Scaled Score
Tower of London	Planning	Percentiles for Total Move Score and Total Correct Score
CPT II	Inhibition	Omissions T-score Commissions T-score

Note. CCTT = Children's Color Trails Test; CPT II = Conners' Continuous Performance Test

Treatment of Accelerometer Data

Initially all accelerometer values for each participant were examined to assess the incidence of missing data. Of the 20 participants, all provided at least 2 days of accelerometer data (11 recorded 7 days, 4 provided 6 days, 3 provided 5 days, and 2 recorded 2 days). Data were reduced to include only those cases with at least 5 days of accelerometer data. Five days was chosen because previous studies have found that accelerometer/pedometer data is of sufficient reliability when collected for at least 3-4 days in children ages 7-15 years (Rowe, Mahar, Raedeke, & Lore, 2004; Strycker, Duncan, Chaumeton, Duncan, & Toobert, 2007; Tudor-Locke et al. 2004); yet 4-5 days appears to be the necessary time period to obtain a more adequate measure of physical activity patterns in children Grades 1-6 (alpha coefficient of 0.80; Trost et al., 2000). Additionally, data was further reduced by removing any data for single days in which less than 1,000 steps were recorded. This cut point was chosen because it has been used in previous research to identify physical activity outliers in younger age groups (Tudor-Locke, Giles-Corti, Knuiman, & McCormack, 2008). A total of three days of data that had less than 1,000 steps were removed among all participants. Consequently, based on these inclusion criteria, only 18 participants were included in the final sample due to incomplete accelerometer data. All reported accelerometer totals and averages reflect physical activity on at least 4 week days and at least 1 weekend day (17 of the 18 participants recorded activity for both weekend days). This is important because previous research documents increased reliability (Masse et al., 2005; Rowe et al., 2004; Tudor-Locke et al, 2004; Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005) and reduced bias (Duncan et al., 2006) when pedometers/accelerometers are used on both weekdays and weekends. Total steps for included days was computed and an average steps/day variable was calculated by summing the total steps and dividing by the number of days the included in this summation (Strycker et al., 2007; Tudor-Locke et al., 2008). The same process was followed for calculating values for total and average MPVA.

Treatment of PAQ-C Data

Since the PAQ-C was administered to both parent and the child, correlations were used to determine which completion(s) of the PAQ-C measures would be used in further analyses. Since the child completion and parent completion were significantly moderately correlated ($r=.53$, $p<.05$), and because the PAQ-C has not been adequately validated as a proxy measure, only the child's completed version was used in further analyses.

Statistical Analyses

All statistical analyses were conducted using SPSS 16.0 (SPSS Incorporated, Chicago, IL). Preliminary statistical analyses were first performed on all the physical activity, ADHD symptom, and executive function measures to provide descriptive statistics for the sample. To clarify the nature of the hypothesized relationships, additional statistical analyses were conducted for exploratory purposes only. T-tests were conducted to determine if those individuals who had scores ≥ 6 (cut point for more severe symptomology) on either the Inattention or Hyperactivity-Impulsivity subscales of the ADHD Rating Scale were significantly different on executive function performance and physical activity (steps, MVPA, PAQ-C). Since the children were diagnosed by different medical professionals, this provides further information about the relationship between physical activity and symptom severity. Bivariate correlations were conducted to assess the relationship among the objective (accelerometer) and subjective (PAQ-C) physical activity measures.

Next, in order to examine the predictive relationships proposed in the study hypotheses, regression analyses were used (see Table 4 for a summary). In the first set of regressions, physical activity was used to predict executive function performance. Because this study was one of the first to be done in this area and the design was exploratory in nature, a separate regression was used with each physical activity variable (steps, MVPA, PAQ-C) as a predictor of each executive function outcome measure. In the second set of regressions, physical activity was used to predict ADHD symptoms. Again, because of the exploratory aims of the study, a separate regression was used with each physical activity variable as a predictor of each ADHD symptom variable (see Table 4 for a summary). Adjustments to alpha were not made and alpha was .05 for all analyses.

Table 4

Linear Regression Analyses Used to Test the Hypotheses of the Study

Hypotheses	Predictors	Criterion	Criterion variable used
#1	Physical Activity (steps, MVPA, PAQ-C)	ADHD Symptoms	1) ADHD Rating Scale Inattention 2) ADHD Rating Scale Hyperactivity subscale 3) ADHD Rating Scale Total 4) BASC-2 Inattention 5)BASC-2 Hyperactivity
#2	Physical Activity (steps, MVPA, PAQ-C)	Executive Function	1)Tower of London TMS Percentile 2) Tower of London TCS Percentile 3) CCTT 1 Time Percentile 4) CCTT 2 Time Percentile 5) CPT Omissions T-score 6) CPT Commissions T-score 7) DS Total Scaled Score

CHAPTER IV

RESULTS

Descriptive Results

Participants. The final sample consisted of 18 male children ranging in ages from 8 to 12 years with a mean age of 10.61 years (*SD* = 1.50). Descriptive information including age, height, weight, BMI, race, grade in school, and combined family income for the sample are summarized in Table 5.

ADHD characteristics. Based on parent report, all participants were previously diagnosed with ADHD by a medical professional. When possible, parents provided documentation from their physician/health care professional regarding ADHD diagnosis. Descriptive information (based on self-report) for ADHD type (predominately inattentive, predominately hyperactive, or combined) and age when diagnosed with ADHD are presented in Table 6. All participants were currently using stimulant medications, either methylphenidate or amphetamine, for treatment of ADHD and had been taking these medications for a period of 6 months or longer. On the testing day all children had taken their medication as prescribed. While all of the children were taking medication on the days they participated in the study, three used medication on weekdays only, and 15 used medication daily. Seventeen of the 18 participants took medication once per day, while one took medication twice per day. Two participants reported using melatonin as a sleep aid, and three others reported using omega 3 supplements in the treatment of ADHD in addition to their stimulant medication. According to parent self-reports, 45% of the children were diagnosed with at least one comorbid disorder; 55% reported no comorbidities.

Table 5

Descriptive Information for Demographics of the ADHD Sample

	Total Sample (N = 18)		
	M	*SD*	*Range*
Age	10.61	1.50	8-12
Height (in)	56.75	4.27	50-66
Weight (lbs)	87.82	19.77	55.7-125.2
BMI	19.07	4.27	13.13-26.41
Ethnicity	Frequency	%	
Caucasian	13	72.2%	
African American	5	27.8%	
Grade			3-8
3	2	11.1%	
4	2	11.1%	
5	4	22.2%	
6	5	27.8%	
7	4	22.2%	
8	1	5.6%	
Combined Family Income (n = 17)			
<$25,000	1	5.9%	
$25,000-$49,999	2	11.8%	
$50,000-$74,999	2	11.8%	
$75,000-$99,999	4	23.5%	
>$100,000	9	47.1%	

Table 6

Frequency Counts and Percentages for Self-Reported ADHD Type and Age at Diagnosis

	Frequency	Percent
ADHD Type (*n* = 15)		
Predominately Hyperactive-Impulsive	5	33.3%
Predominately Inattentive	2	13.3%
Combined Type	8	53.3%
Age at Diagnosis (*n* = 18)		
3	2	11.1%
4	1	5.6%
5	1	5.6%
5.5	2	11.1%
6	3	16.7%
6.5	1	5.6%
7	4	22.2%
7.5	1	5.6%
8	3	16.7%

ADHD symptoms. Descriptive information for the ADHD Rating Scale is provided in Table 7. Table 8 includes descriptive information for the severity counts, i.e. the number of times a participant circled a response of 2 or 3 for items. Higher Scores are indicative of worse symptoms. The percentiles reported reflect age-adjusted scores.

Table 7

Descriptive Information for the ADHD Rating Scale

	Total Sample (*N* = 18)		
	M	*SD*	*Percentile Mean (SD)*
Inattention *Range 0-27*	14.78	4.29	87.28 (7.85)
Hyperactivity-Impulsivity *Range 0-27*	11.39	5.74	77.89 (26.39)
Total Score	26.17	8.93	86.11 (12.24)

Table 8

Means and Standard Deviations for Severity Counts on the ADHD Rating Scale

	Total Sample (*N* = 18)	
	M	*SD*
Inattention Severity Count	4.89	2.40
Hyperactivity-Impulsivity Severity	3.28	2.44

Subtypes can be assigned based on the number of symptoms reported, with children displaying six or more symptoms of Inattention and six or more symptoms of Hyperactivity-Impulsivity classified as Combined Type, children with six or more symptoms of Inattention and fewer than six symptoms of Hyperactivity-Impulsivity classified as Predominantly Inattentive Type, and children with fewer than six Inattention symptoms and six or more Hyperactivity-Impulsivity symptoms classified as

Predominantly Hyperactive-Impulsive Type. When using these guidelines for the ADHD Rating Scale, 15 of the 18 children were identified, via parent self-report, as having one of the three types of ADHD: Combined (n = 2), Predominately Inattentive (n = 8), or Predominately Hyperactive-Impulsive (n = 5). Further, the developmental deviance of these symptoms can be confirmed by scores above the 93rd percentile (Du Paul et al., 1998). When assessing scores as percentiles, 10 of the 18 scored above the 93rd percentile on either the Attention (n = 5) or Hyperactivity subscales (n = 5). It is important to note that this rating scale was completed based on symptoms the children experience while on medication.

For physical activity, none of the t-tests were significant, p>.05, indicating that those scoring $\geq$6 were not significantly different regarding physical activity compared to those who scored <6. For executive function measures, separate t-tests were run for each executive function test (Digit Span, Tower of London, CPT, and CCTT). For the CPT, the t-test revealed significant differences for Omissions, t (14) = -2.173, p = .011 and no significant difference for Commissions, t (16) = -0.26, p = .80. For the Digit Span, the t-test was not significant, t (16) = 1.42, p = .175. The t-test for the Tower of London TMS variable was also not significant, t (16) = .219, p = .829. However, the t-test for the Tower of London TCS was significant, t (15) = -2.39, p = .03. For the CCTT, only the Time 1 score was significant, t (16) = 2.42, p = .028. The Time 2 score and Interference Index were not significant (p_s > .05).

Means for the Hyperactivity and Attention subscales of the BASC-2 PRS were 56.22 (7.95) and 62.17 (3.87), respectively. Higher scores are indicative of worse symptoms. Means and standard deviations for all subscales are reported in Table 9 for descriptive purposes only, but were not included in further analyses.

Table 9

Means, Standard Deviations, and Ranges for the BASC-2PRS Subscales and Composites (Represented as T-scores)

	Total Sample (N = 18)		
	M	*SD*	*Range*
Externalizing Composite	54.78	8.81	39-72
Hyperactivity	56.22	7.95	42-72
Aggression	52.94	8.28	39-68
Conduct Problems	53.56	12.76	39-83
Internalizing Composite	48	7.79	34-63
Anxiety	47.44	9.88	31-66
Depression	50.06	7.38	39-64
Somatization	47.5	8.54	37-62
Behavioral Symptoms Index	55.39	5.68	47-70
Atypicality	52.83	8.58	41-71
Withdrawal	50.44	35-82	11.75
Attention	62.17	3.87	52-68
Adaptive Skills	41.28	7.93	32-56
Social Skills	40.89	9.53	26-60
Leadership	43.83	7.99	34-65
Activities of Daily Living	38.22	8.12	25-56
Functional Communication	45.17	8.42	34-63

Note. Higher mean scores are indicative of worse symptoms.

Executive function performance. Descriptive information (M ± SD) for executive function outcome variables can be found in Table 10.

Table 10

Descriptive Information for Executive Function Measures

	Total Sample (*N*=18)	
	M	*SD*
CPT		
Omissions (T-score)[a]	50.06	9.10
Commissions (T-score)[a]	49.19	11.10
Tower of London		
Total Move Percentile	34.28	31.19
Total Correct Percentile	35.78	31.74
Digit Span	11.06	4.24
CCTT		
Test 1 (T-score)	38.83	12.87
Test 2 (T-score)	40.78	10.57

Note. [a] Higher means are indicative of worse performance. CPT = Conner's Continuous Performance Test; CCTT = Children's Colors Trails Test

Physical activity measures. Descriptive information (*M* ± *SD* and range) for the PAQ-C and the accelerometer data including total and average steps per day, total and average minutes per day, and weekend and weekday average steps and minutes can be found in Table 11.

Table 11

Descriptive Information for the Accelerometer Data and PAQ-C

	Total Sample (N = 18)		
	M	*SD*	*Range*
Average Steps Per Day	9,437.61	3,072.46	4,581-16,795
Average Minutes Per Day (MVPA)	38.47	17.56	19-71
Weekday Average Steps	9,163.41	3,314.23	3,096-17,380
Weekend Average Steps	9,633.53	4,074.9	1,653-17,234
Weekday Average Minutes	39.58	19.67	17-78
Weekend Average Minutes	35.33	18.52	9-71
PAQ-C *Range 1-5*	2.79	0.52	1.77-3.84

Note. PAQ-C = Physical Activity Questionnaire for Older Children.

Physical activity survey items. For the open-ended questions, parents were asked if, when their child was physically active, they noticed a difference in ADHD symptoms in several categories: broadly, and separately for symptoms of inattention, hyperactivity, and impulsivity. If a difference was reported (participants marked “yes”), then they were asked to indicate how and whether the difference was positive or negative. When assessing the parents’ views about symptoms at a broad level, 10 of the 17 respondents reported that regular physical activity did not produce a difference in symptoms. Of the remaining 7 that reported physical activity impacted symptoms broadly, 6 indicated that physical activity had a positive effect. Of those that reported their child experienced symptoms of inattention (n = 14), eight reported no difference and six reported a positive difference in symptoms. For participants that reported their child experienced symptoms of hyperactivity (n = 15), seven reported no difference and eight reported a positive effect of physical activity on hyperactivity symptoms. Of the 14 participants who reported that their child experienced symptoms of impulsivity, 10 reported no difference and four reported a positive difference in symptoms.

Regression Analyses

Associations among physical activity variables. Bivariate correlations were conducted to assess the relationship among physical activity variables. Results showed that steps and MVPA were significantly correlated, $r = .78$, $p < .001$. Correlations were not statistically significant between steps and the PAQ-C ($r = .40$, $p = .10$) or the MVPA and the PAQ-C ($r = .30$, $p = .23$).

Associations among body mass index, physical activity, ADHD symptoms, and executive function variables. There was a significant negative relationship between BMI and self-reported physical activity ($r = -.72$, $p = .002$). Participants with higher physical activity levels had a lower BMI. However, there was no significant association between BMI and accelerometer data. BMI was also not correlated with the executive function variables ($r_s = .10\text{-}.40$, $p > .05$) or any of the ADHD symptom variables ($r_s = .01\text{-}.14$, $p > .05$).

Associations between the predictor and criterion variables. Bivariate correlations were conducted for ADHD symptoms (as measured by the BASC-2 PRS and ADHD Rating Scale) and the physical activity measures (see Table 12). There were no significant correlations between physical activity and ADHD symptoms. Correlations should be in the negative direction such that higher physical activity is associated with lower symptom scores.

Table 12

Correlation Matrix for the ADHD Symptoms and Physical Activity Measures

Measure	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Steps	_ _						
2. MVPA	.78	_ _					
3. PAQ-C	.40	.30	_ _				
4. RS IA Percentile	-.02	.01	.29	_ _			
5. RS H-I Percentile	.00	.00	.35	.61**	_ _		
6. RS Total Percentile	-.03	.02	.33	.83**	.91**	_ _	
7. BASC IA	.19	-.36	.24	.44	.30	.35	_ _
8. BASC H	.21	-.01	.31	.70**	.60**	.72**	.62**

Note. RS IA = ADHD Rating Scale Inattention; RS H-I = ADHD Rating Scale Hyperactivity-Impulsivity; RS Total = ADHD Rating Scale Total; BASC IA = BASC Attention Subscale; BASC H = BASC Hyperactivity Subscale; MVPA = minutes of moderate-to-vigorous intensity activity; PAQ-C = Physical Activity Questionnaire for Older Children. * $p < .05$ ** $p < .01$

Bivariate correlations were also conducted for each executive function test and measures of physical activity (see Table 13). Correlations between physical activity variables and the Tower of London measures revealed a significant correlation between MVPA and TMS, $r = .57$, $p = .01$. Correlations between physical activity variables and Digit Span, CPT, and CCTT Test 1 and Test 2 were not statistically significant. Correlations, except for the Commissions and Omissions measures, should be positive, with greater physical activity associated with better executive function performance. The correlations between physical activity and Omissions and Commissions should be in the negative direction, with higher physical activity associated with lower scores. The majority of the correlations were positive and in the hypothesized direction with higher physical activity scores associated with better executive function performance.

Table 13

Correlation Matrix for the Executive Function Variables and Physical Activity Measures

Measure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1.Steps	_ _								
2.MVPA	.78	_ _							
3. PAQ-C	.40	.30	_ _						
4. Digit Span	.31	.37	-.29	_ _					
5. TOL TMS	.45	.57*	.15	.26	_ _				
6. TOL TCS	.21	.18	.32	-.32	.63**	_ _			
7. CCTT 1	.41	.36	.18	.07	.34	-.19	_ _		
8. CCTT 2	.35	.45	.07	.67**	.39	.-.22	.47*	_ _	
9. Omissions[a]	.12	-.11	-.12	-.42	-.17	.23	-.18	-.47	_ _
10. Commissions[a]	.23	.25	-.16	-.11	-.25	-.32	.19	.01	.32

Note. [a] = lower score equals better performance and a negative relationship is expected to be observed. MVPA = minutes of moderate-to-vigorous intensity activity; PAQ-C = Physical Activity Questionnaire for Older Children; TOL TMS = Tower of London Total Move Score; TOL TCS = Tower of London Total Correct Score; CCTT = Children's Color Trails Test. * $p < .05$ **p < .01

Since only the TOL TMS was significantly correlated with MVPA, a linear regression analysis was used to test the study hypothesis that physical activity would be a significant predictor of TOL TMS. The regression analysis of MVPA on TOL TMS revealed a significant effect, adjusted $R^2 = .28$, $F\ (1, 16) = 7.61$, $p < .05$. This effect indicates that MVPA was a significant predictor of planning ability, with 28% of the variance in TMS explained for by physical activity. Higher physical activity was associated with lower total move scores.

CHAPTER V

DISCUSSION

Research exploring the nature of the relationship between physical activity, behavioral symptoms, and executive function in ADHD children is limited. Therefore, the purpose of this study was to begin to describe these relationships and to identify the extent to which physical activity may influence behavioral symptoms and cognition in children with ADHD.

Summary of the Findings

Results indicated that MVPA was predictive of better performance on the Tower of London measure of planning. Although non-significant, physical activity was associated with better performance on the majority of other measures of executive function. Results also indicated that there were no significant associations between physical activity and behavioral symptom measures. However, the relationships were in the hypothesized direction with children who engaged in more physical activity characterized by less severe symptomology.

This is the first study to look at the relationships between objective measures of physical activity, executive function performance, and behavioral symptoms in boys diagnosed with ADHD. The results are important given that ADHD children experience executive function impairments, have difficulty managing their symptoms, and current pharmacological treatments for ADHD vary in effectiveness and come with numerous side effects. Thus, this study provides much needed preliminary support for further investigation into the potential benefits of physical activity on executive function and behavioral symptoms in ADHD children.

Associations Among Physical Activity Variables

No significant relationships were found between accelerometer data and self-report physical activity data. The low to moderate observed correlations between the measures are consistent with those in a recent review of convergent validity demonstrating that self-report measures of physical activity were only weakly correlated with data from objective monitors of physical activity (median r = 0.33; Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002) and were even lower in a recent study by Rowe et al. (2004; r = 0.08 for boys). In an analysis of studies using larger sample sizes and older children (8^{th}-11^{th} grades), the correlation between the Previous Day Physical Activity Recall (PDPAR; Weston, Petosa, & Pate, 1997) and pedometer data was much higher (r = 0.77) (Sirard & Pate, 2001). It is precisely because of such documented inconsistencies such as these in the literature, that research regarding physical activity assessment should include a combination of objective and subjective measurements for optimum accuracy (Tudor-Locke, Williams, Reis, & Pluto, 2004).

Physical Activity and ADHD Symptoms

Correlations between physical activity and ADHD symptoms were rather low and not significant, however, they were in the hypothesized direction, with higher levels of physical activity associated with lower symptom severity. Therefore, the results of this study are promising considering that they were found in a small, medicated sample of ADHD children. Since the rating scales were completed at the time the child was on medication, it is likely that the medication mitigated presence and/or severity of the symptoms. Given the results of an extensive review on the effects of medication among ADHD children, medication showed reductions in hyperactivity and inattention symptoms of up to 60-75% of children, yet positive effects on cognition were not as likely (Swanson et al., 1993). Several reviews examining the effects of various medication treatment strategies in children with ADHD have reported an average effect size of $d = 0.80$ for symptoms and $d = 0.30$ for achievement related outcomes (Conners, 2002; Kavale, 1982; Klassen, Miller, Raina, Lee, & Olsen, 1999; Swanson et al., 1993). If the correlations presented in this study are converted to *d*'s (see Cohen, 1988 for formula), physical activity has a medium effect for executive function measures (average $d = 0.70$) and a small effect on ADHD symptoms (average $d = 0.30$). These findings are clinically meaningful and suggest that physical activity may provide moderate benefits for cognitive outcomes and small benefits for symptoms. Further, this information may be relevant for the design of future physical activity interventions involving medicated children that may want to direct their focus on cognition, rather than ADHD symptoms.

Although there were no significant relationships between physical activity and the ADHD symptom measures, responses from survey questions provide some support that regular physical activity can positively impact ADHD symptoms. When asked if physical activity impacted symptoms broadly, almost half (45%) of the parents in this study reported positive effects such as “Generally symptoms diminish when he gets a lot of physical activity;” “less antsy;” and “built up energy seems to be released and ‘freedom’ of anxiety comes and he is able to relax to watch TV etc.” Similarly, for symptoms of inattention specifically, participants reported positive effects with statements such as "able to sit down [and] focus on [the] task better;" "attention span is longer;" and "more focused." For symptoms of hyperactivity, this sample reported positive effects such as "better at directing energy" and "less hyper and can relax." With impulsivity symptomology, participants reported such positive effects as "when activity is limited, is more impulsive and picks at and annoys his siblings more" and "if he has been more active and gotten energy out, he tends to respond and act more calm." Even if physical activity helps for a small percentage of the population that is also on medication, this lends support to the use of physical activity in conjunction with medication.

Physical Activity and Executive Function

Physical activity has been associated with better performance on tasks of executive control for older adults (Kramer et al., 1999; Colcombe & Kramer, 2003) and children (see Tomporowski et al., 2008 for a review). The data reported in this study are at least partially consistent with these findings. Physical activity was found to be a significant predictor of TOL TMS, which is a measure of planning and problem solving ability. This is an important finding since planning has been identified as one of the more consistent executive function impairments in children with ADHD (Wilcutt et al., 2005). In their meta-analysis comparing ADHD and non-ADHD children on executive performance, Wilcutt et al. (2005) reported effect sizes ranging from d = 0.51-0.69 for tower tasks. Pennington and Ozonoff (1996) found the greatest effects (d = 1.08) for planning measures in their comparison of children with and without ADHD. The correlations for the TOL TMS and TOL TCS in this study yield a comparable effect size of $d = 1.4$ and $d = 0.40$, respectively (see Cohen, 1988 for conversion formula). Planning has also been shown to be sensitive to the influence of exercise in children without ADHD (Carlson, 2005; Davis et al., 2007). For example, in a recent study examining the effects of exercise on cognition in children, Davis et al. (2007) assessed a variety of cognitive measures, yet those in the exercise group performed better only on the planning measure (the Cognitive Assessment System) than children in a non-exercise control group. In addition, the fact that this study found physical activity to be a significant predictor of TOL performance despite children being on medication is promising and provides support for further investigation of the effects of physical activity on executive function.

While analyses revealed that MVPA was only significantly associated with TOL TMS, relationships for 5 of the other 6 executive function variables were in the hypothesized direction, indicating that higher physical activity may be associated with better executive function performance on TOL, CCTT 1 & CCTT 2, Digit Span, and CPT Commissions. Similar results were found for steps with 6 out of 7 correlations in the hypothesized direction. Higher physical activity was associated with better executive function performance (TOL, CCTT 1 & CCTT 2, Digit Span, and CPT Commissions). Further, the small to moderate correlations observed in this study are consistent with the small effect sizes previously reported when examining the impact of physical activity on executive function (Etnier et al., 1997; Tomporowski et al., 2008). The only measure for which a positive relationship was not observed was CPT Omissions. The lack of support for the relationship between physical activity and the CPT Omissions measure could be due to the measure's lack of sensitivity in this particular sample. In general, the lowest correlations were observed for both of the CPT measures. These very low correlations, and thus lack of support for the relationship with physical activity, were most likely because these are directly assessing the core symptoms of ADHD: inattention and impulsivity, which are most likely to diminish with medication (Barkley, 1998). Similarly, the fact that the observed correlations between physical activity and ADHD symptoms were lower, as a whole, compared to those observed between physical activity and executive function measures, is consistent with this argument.

It is well documented that ADHD children can be characterized by executive function impairments (Wilcutt et al., 2005). However, there is conflicting evidence as to what aspects of executive function are affected across ADHD. The variability of scores on executive function measures in the current sample is not surprising given that previous research demonstrates considerable variability in ADHD children. That is, while it is well understood that executive function impairments exist, the precise nature of these impairments has not been well established (Kempton et al., 1999; Nigg et al., 2005; Pennington & Ozonoff, 1996). There does not seem to be a single primary executive function deficit in ADHD and it is likely that general executive function in ADHD may not be compromised, yet specific aspects of it are. The data herein, coupled with these inconsistencies in the literature, provide further support that executive function tasks should be examined separately, rather than broadly (as with composite scores), in understanding their relationship with and sensitivity to physical activity.

More recent developments in the study of executive function in ADHD include the notion that executive function alone may not be enough to explain ADHD. In other words, children with ADHD may be experiencing other cognitive and neurobiological deficits as a result of their disorder that would benefit from physical activity. Executive function may just be one of several components involved in the neuropsychology of ADHD. As Wilcutt et al. (2005) concluded in their meta-analysis, "Taken together, these results clearly indicate that EF [executive function] weaknesses are significantly associated with ADHD …they are neither necessary nor sufficient to cause all cases of ADHD" (p.1342-1343). Considering this, it would be useful to examine the relationship between physical activity and other aspects of cognition in children with ADHD.

Interpretation of Physical Activity Behavior

PAQ-C. The average activity score for the PAQ-C (*M* = 2.79, *SD* = 0.52) within this sample is comparable to scores reported in studies of children without ADHD. Previous studies with boys yield a range of mean activity scores from 2.3-3.10 (e.g., Ball, Marshall, & McCargar, 2003; Mahon, Anderson, Hipp, & Hunt, 2003; Muratova, Islam, Demerath, Minor, & Neal, 2001; Welk, Wood, & Morss, 2003).

NL-1000 accelerometer data. This sample of boys 8-12 with ADHD were considerably less active (*M* steps = 9,437) than boys within similar age ranges in the majority of other studies (e.g., Duncan, Schofield, & Duncan, 2006, 2007; Laurson et al., 2008; Tudor-Locke et al., 2006; Vincent & Pangrazi, 2002). However, a few studies (Ozduba, Corbin, & Le Masurier, 2006; Rowe et al., 2004) have reported lower step counts (8,000-10,000) that are more similar to the results of this sample. The accelerometer used in the current study was different than models used in these previous studies, however, a recent review of 13 models of pedometers and accelerometers found the one used for this study (the NL-1000) to be comparable, so it is unlikely that the use of a different model could account for the lower activity levels in this sample (Schneider, Crouter, & Bassett, 2004). The low activity levels in this sample were surprising given that participants were aware that the study involved examining relationships among physical activity and ADHD symptoms. If anything, we expected to recruit children who were biased toward the potential positive effects of physical activity, and thus more active compared to children of the same age.

While an adult requirement of 10,000 steps/day in order to maintain physical health (Iwane, Arita, Tomimoto, Satani, Matsumoto, Miyashita et al., 2000; Schneider, Bassett, Thompson, Pronk, & Bielak, 2006; Tudor-Locke & Bassett, 2004; Welk, Differding, Thompson, Blair, Dzuira, & Hart, 2000) has been recommended by health professionals, a consensus has still not been reached on recommended steps per day for children. It appears, from the few daily step counts that have been suggested, that children require more steps than adults. Based on pedometer measurements from a sample of 711 boys and girls ages 6 to 12, Vincent and Pangrazi (2002) recommended 13,000 steps/day for boys. The value of 13,000 steps on at least 5 days of the week was published in a report in 2001-2002 by the President’s Challenge Physical Activity and Fitness Awards Program (President’s Council on Physical Fitness and Sports, 2001). Only 2 of the 18 participants in this study met these current guidelines for steps/day suggesting that this sample is not active enough to achieve adequate health benefits.

Additionally, more recently, Tudor-Locke et al. (2004) recommend a daily cut point of 15,000 steps for boys ages 6 to 12 years old. Any children falling short of this amount are more likely to be classified as overweight or obese. However, if BMI is a factor accounting for differences in steps per day among children it does not appear to be operational in the current sample. The results of this study do not support this classification as only four participants were overweight or obese (age and sex specific BMI $\geq 85^{th}$ percentile; Centers for Disease Control and Prevention, 2000). Step ranges have been most recently established for adults that enable researchers to more easily classify individuals into activity level categories: sedentary = < 5000 steps/day; low active = 5000 to 7499 steps/day, somewhat active = 7500 to 9999 steps/day, and active = ≥ 10,000 steps/day (Tudor-Locke & Bassett, 2004). Considering these recommendations, the current sample (*M* = 9,624) would be considered "somewhat active." However, as Vincent and Pangrazi (2002) suggest, it may not be feasible to set a single daily standard for children as their physical activity patterns are so highly variable. For example, for the highest active participant in this study, steps = 16,795 and the lowest active participant recorded steps = 2,743. These individuals are well above and well below the recommended 12,000 range for children. If the goal is to encourage children to be physically active and healthy, there may need to be multiple standards that children can strive for in order to help them set realistic goals and not become discouraged.

When examining MVPA, the Healthy People 2010 report recommends 60 minutes per day for children and adolescents (US Department of Health and Human Services). This sample falls short of this recommendation (*M* MVPA = 38.47). When using the 60 minutes cut point, only 3 of the 18 participants recorded greater than 60 minutes of physical activity per day.

Because there has been limited research with objective physical activity monitors in ADHD children, and no known published step counts or activity minutes, no comparisons of this sample's characteristics can be made to other samples. Only one study measured physical activity by pedometer use in a group of boys with ADHD relative to controls. Results showed that those with ADHD were significantly more active (Perrino, Rapoport, Behar, Ismond, & Bunney, 1983) but specific step counts were not provided.

There are numerous possibilities for the low physical activity levels in this sample. First, with such a small sample size it is plausible that we only obtained data from those children who were less active. If a larger sample of children had been used we may have seen a greater number of more active children.

While not explored in this study, it is possible that characteristics of ADHD influenced participation in physical activity. That is, because individuals are experiencing functional impairments they are less likely to be active. It is a common misconception that, because a core feature of ADHD is hyperactivity, ADHD children are more likely to move around often and accumulate more physical activity. However, as mentioned previously, a review of studies examining movement skill performance and physical fitness in children with ADHD found converging evidence that they suffer from poor physical fitness and movement skill problems, even while on stimulant medication (Harvey & Reid, 2003). Also, a few studies have examined physical fitness in ADHD children and all found lower levels of physical fitness in children with ADHD when compared to children without ADHD (Ballard, 1977; Boileau, Ballard, Sprague, Sleator, & Massey, 1977; Harvey & Reid, 1997). Of particular importance, is that children with ADHD often lack social skills and consequently experience difficulties when interacting with peers. As a result of these difficulties, they may be less drawn to, or less willing to engage in structured and unstructured play activities. It is also important to note that all children in this sample were on medication for treatment of ADHD, therefore side effects of medication (stomachaches, headaches, sleep disturbances) could potentially negatively influence physical activity participation.

A final explanation for low physical activity is that family or peer physical activity behavior could be influencing child physical activity levels. From the self-report data in this study, children who were more active also had parents who reported more days per week of being active themselves. A recent review of 60 studies examining physical activity correlates in children (ages 4-12) found that parental participation in physical activity and parental support were positively associated with children's physical activity (Van der Horst, Paw, Twisk, & Van Mechelen, 2007). There is also evidence that the association is the strongest for active parent support (participating in physical activity with the child) compared to verbal support/encouragement (Sallis, Prochaska, & Taylor, 2000). In the current sample, only half of parents indicated that they were active at least 3 days per week.

Limitations

There are several limitations associated with the present study. A major limitation of this study is that all children were on medication and this makes it difficult to interpret the findings because it is unclear to what extent the medication impacted the variables of interest: physical activity behavior, executive function performance, and symptoms. The core symptoms of ADHD and many of the executive function measures are sensitive to drug effects (Barkley, 1998), suggesting that the participants in this study might have performed worse on measures of executive function and presented with more severe symptomology had they participated in the study while off their medication. This element makes it hard to draw firm conclusions. However, significant results were found indicating that physical activity may provide some benefit above and beyond that provided by medication. Therefore, it is important to replicate this study in ADHD children on medication and to extend this research to non-medicated ADHD children. In addition, results should be compared to children without ADHD to determine if ADHD children benefit differently, or to a greater extent, from regular physical activity.

The findings of this study are based on a small sample size, which most likely affected the power to detect significant relationships in this group of ADHD children. A sample size (based on the average r obtained) of n = 46 participants for executive function measures and n = 169 participants for symptom measures would be needed to achieve adequate statistical power (power = 0.80, alpha = .05) The fact that the majority of findings were in the hypothesized direction suggests that the results would be statistically reliable with a larger sample size. Further, various clinicians performed the child's ADHD diagnosis and it was not possible to ascertain the consistency in the diagnostic procedures employed in making the diagnosis between participants. Additionally, with respect to diagnosis, it is not known if the diagnosis of ADHD conformed to the guidelines outlined in the *DSM-IV*. Ideally, this would have been standardized. Further, children were diagnosed with different types of ADHD (predominately inattentive, predominately hyperactive-impulsive, or combined), some had comorbid disorders, and medication characteristics were not controlled. Each child was using one of two different types of stimulant medication and there were likely disparities in the effectiveness of, and side effects from, the medications. However, it is important to point out that despite the heterogeneity of the sample, a significant relationship between physical activity and planning was observed. Lastly, the sample is not representative of socioeconomic status, geographic region, race, or gender. Therefore, these results may not be generalizable to the ADHD population as a whole.

Another limitation is that, because symptoms were based on severity counts and rating scales by a single informant only, the results must be interpreted cautiously (Du Paul et al., 1998). Typically, both teacher and parent rating scales (often including both parent reports) are used in the diagnostic process to capture the child's symptoms while at home and during the school day. It is possible that teacher ratings may have shown a different picture and/or symptoms could actually be much worse than parents are reporting.

Measuring physical activity comes with many inherent limitations, as there is no gold standard for its measurement. The NL-1000 and PAQ-C were considered as appropriate for providing an indication of an overall level of physical activity in children ages 8 to 12. This researcher is confident that the patterns of physical activity observed in the current investigation were real and not a reflection of measurement error associated with these tools. Further, by providing both subjective and objective measures of physical activity, this more accurately captures the child's physical activity patterns. Additionally, all participants completed the study during the school year within a two-month time period, which helps to reduce variability in the findings but which might not be reflective of the child's physical activity patterns across the entire year. The PAQ-C was developed to assess general levels of physical activity and did not provide an estimate of caloric expenditure or specific frequency, time, and intensity information. Further, the PAQ-C does not discriminate between specific activity intensities, such as moderate and vigorous activities. However, we countered this by measuring MVPA via the accelerometer.

Because this study is correlational in design, it precludes us from determining any sort of causal relationship between physical activity, ADHD symptoms and executive function performance. However, this study did provide preliminary evidence for the nature of these relationships and provides a foundation and rationale for future investigation, particularly utilizing experimental designs to test for causal relationships.

Additionally, because of the correlational design, it is possible that characteristics of ADHD such as the presence of comorbid disorders (particularly learning disabilities), and effectiveness of treatment may be contributing to the observed relationship. For example, it is possible that the unknown presence or the degree of severity of comorbid disorders, rather than physical activity, could have resulted in better executive function performance in this sample. Consequently it is important to accurately identify comorbid disorders in future samples and examine the extent to which other characteristics of ADHD may impact executive function performance and behavioral symptoms in children.

Recommendations for Future Research

Overall, it is possible that few significant relationships were observed because of small sample size and the low physical activity levels in this sample. Future research efforts should focus on recruiting children with higher levels of physical activity and compare executive function performance between high and low active groups as categorized by current health recommendations.

Most importantly, it would be useful to examine the impact of physical activity in a non-medicated sample. First, some studies show improved performance on executive function tasks for those with ADHD while on medication, suggesting that the medication normalizes executive function deficits (Kempton, Vance, Maruff, Luk, Costin, et al., 1999; Konrad, Gunther, Hanisch, & Herpertz-Dahlmann, 2004; Vance, Maruff, & Barnett, 2003). Similarly, when compared to non-medicated participants with ADHD, those on medication perform better on executive function tasks (Kempton et al., 1999; Mehta et al., 2000; Semrud-Clikeman et al., 2006). Based on this evidence, it is necessary to see if physical activity has a larger effect when children are not medicated. It is also important to compare the effects of physical activity in non-medicated and medicated samples of ADHD children. While it is this researcher’s belief that physical activity can help in addition to medication, it is possible that it does not provide any additive benefits. If this were the case, physical activity could still be used to help those for which medication may not be a viable treatment option. As mentioned previously, medication may be ineffective for 25-40% of children (Swanson et al., 1993) or produce deleterious side effects that interfere with numerous life domains. If physical activity can be established as a helpful method for those children independent of medication, this would provide strong support for its adoption as a treatment tool for those that are non-responsive to, or cannot tolerate, medication. One of the challenges inherent in executive function testing of children off-medication is that other ADHD symptoms (behavioral in nature) may interfere with the child's capacity to perform the tasks. Another challenge in testing children off medication is accounting for their medication history. The long-term effects of children on medication are not well-established. A recent study found that children who had a history of medication and were taken off medication (for 24 hours) did not experience deficits in measures of cognitive or behavioral functioning (Semrud-Clikeman, Pliszka, & Liotti, 2008). That is, the improvements in functioning were maintained even after the medication had cleared from the child's system, suggesting that children may still experience the positive effects of the medication even while not taking it at the time of neuropsychological assessment. However, it is not known how long these improvements can be sustained.

Finally, because the literature on physical activity and executive function supports a positive relationship for chronic exercise, this study focused on looking for associations with the idea that regular physical activity (i.e. chronic physical activity) would be related to executive function. The promising results obtained in this study provide a foundation for exploring the influence of chronic physical activity on executive function in ADHD children and provide the impetus for a more in-depth look at this relatively unexplored area of research. The results suggest that a logical future step would be the design of a chronic physical activity intervention to assess the extent to which a regular aerobic exercise program may benefit symptoms and executive function in children with ADHD. Since the long-term goal of this line of research is to design and implement a physical activity intervention to mitigate ADHD impairments in children, it is necessary to elucidate the sensitivity of executive function to physical activity in this particular group of children. Replication of the current findings in larger sample sizes, coupled with experimental studies, will enable researchers to make the most informed decisions and recommendations concerning potential physical activity intervention strategies.

In conclusion, the findings suggest that physical activity may have positive implications for executive function performance and symptoms specific to children diagnosed with ADHD. The results presented here inform the recommendation of examining the potential effects of chronic exercise in ADHD populations. It is our hope that since physical activity is a simple, widely available, and well-tolerated plausible intervention for many other clinical populations, it may be used as a complementary treatment for ADHD.

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APPENDIX

APPENDIX A: CONSENT FORMS

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
CONSENT TO ACT AS A HUMAN PARTICIPANT

Project Title: Associations among physical activity, ADHD symptoms, and executive function in children with ADHD
Project Director: Jennifer Etnier

Participant's Name:

Description and Explanation of Purpose and Procedures: The purpose of this study is to investigate the relationship among physical activity, ADHD symptoms, and executive function in children with ADHD. You will be asked to complete questionnaires designed to gather information about your child’s physical activity behavior, ADHD diagnosis, ADHD symptoms, and demographic and medical information. The questionnaires will take you approximately 30-45 minutes to complete. While you are completing these questionnaires your child will complete a series of 4 cognitive tasks which will take approximately 45-60 minutes to complete. If you and your child complete these questionnaires and tasks you will receive $20. You will also be given the opportunity to spend 30 minutes with your child using the play equipment in the gymnasium at no cost to you. Upon leaving UNCG you will be given a pedometer, which is a device that measures physical activity, with instructions on how to use it. You will also be given a stamped envelope addressed to UNCG. Your child is to use the pedometer according to the instructions for a period of 7 consecutive days. You will be called on a daily basis at a regularly scheduled time during the 7 day period to ensure appropriate and adequate use of the pedometer and to make sure there are not questions or concerns related to its use. After these 7 days you will mail the pedometer back to UNCG. Upon receipt of the pedometer you will receive a $30 payment in the mail.

Additionally the researchers on this project will have access to your UNCG ADHD clinic records, specifically your child’s ADHD diagnosis and results from your recently completed ADHD evaluation to supplement the data collected in this study.

Potential Risks and Discomforts: Some questions asked via the questionnaires and/or on the cognitive tests could make some participants feel uncomfortable or cause mild distress. However, the measures used are all instruments commonly used in this type of work. The researcher has been trained in administering the questionnaires and data collection procedures.

Potential Benefits: The intended benefit for participants in this study is an increased self-knowledge and heightened awareness of the possible effects of physical activity on ADHD symptoms. Additionally, your participation in this study will significantly enhance our understanding of the relationship between physical activity and behavioral and cognitive symptoms in ADHD in children.

Consent: By signing this consent form, you agree that you understand the procedures and any risks and benefits involved in this research for you and your child. You are free to refuse to participate or to withdraw your consent to participate in this research at any time without penalty; your participation is entirely voluntary. Your privacy will be protected because you and your child will not be identified by name as participants in this project.

The University of North Carolina at Greensboro Institutional Review Board, which ensures that research involving people follows federal regulations, has approved the research and this consent form. Questions regarding your rights as a participant in this project can be answered by calling Mr. Eric Allen at (336) 256-1482. Questions regarding the research itself will be answered by Jennifer Etnier by calling (336) 334-3037 or by email to jletnier@uncg.edu. Any new information that develops during the project will be provided to you if the information might affect your willingness to continue participation in the project. By signing this form, you are affirming that you are 18 years of age or older and are agreeing to participate in the project described to you by Jennifer Etnier.

During or after your involvement in this project, you may become aware of other research studies being conducted in the AD/HD Clinic that may be of interest to you. Several such projects are currently underway, investigating: Genetic basis of AD/HD; AD/HD symptoms in elementary school girls; Maternal depression and parenting stress; Risk and protective factors associated with comorbid depression in youth with AD/HD, and; Dyadic coping among adults with AD/HD. These studies use many of the same behavioral data collection procedures. Should you decide to participate in any of these other projects, behavioral data collected from this project can be shared with the other research project in order to spare you the trouble of having to repeat the same data gathering procedures. Only the behavioral data common to each project will be shared, and data will only be shared with projects for which you have given written consent.

__________________________________ _______________

Participant's Signature Date

CHILDREN'S ASSENT FORM

Project Title: Associations among physical activity, ADHD symptoms, and executive function in children with ADHD

We are doing a study to try to learn about people who exercise. We are asking you to help because we don't know very much about how exercise can help kids your age.

If you agree to be in our study, we are going to ask you to complete some thinking activities on paper and on the computer. These will take about 45-60 minutes for you to finish. You and your parent will receive $20 for this. You will also be asked to wear a small object that measures your movement for 7 days. You and your parent will receive $30 after the 7 days.

You can ask questions at any time about this study. Also, if you decide at any time not to finish, you may stop whenever you want.

Signing this paper means that you have read this or had it read to you and that you want to be in the study. If you don't want to be in the study, don't sign the paper. Remember, being in the study is up to you, and no one will be mad if you don't sign this paper or even if you change your mind later.

Signature of Participant ____________________ Date _____________

Signature of Investigator ____________________ Date ____________