The effects of physical activity on attention deficit hyperactivity disorder symptoms: The evidence

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Abstract:

Evidence supports the beneficial effects of physical activity (PA) on cognitive performance and suggests that effects might be particularly large for children. However, limited research has explored PA as a means of managing behavioral symptoms and improving cognitive performance of children with attention deficit hyperactivity disorder (ADHD). The etiology of ADHD and the putative mechanisms for the effects of PA on cognitive performance suggest that PA might be especially important for this population.

Objective

The purpose of this paper is to review the literature regarding the potential of PA for ADHD symptom management, particularly in regard to behavioral and cognitive symptoms.

Methods

Literature was reviewed for published and unpublished research specifically examining the effects of PA on cognitive and/or behavioral symptoms of ADHD. Additionally, potential mechanisms were addressed.

Results

Albeit limited, current research generally supports the potential for acute and chronic PA to mitigate ADHD symptoms.

Conclusion

Given the generally supportive extant literature and the challenges that face children with ADHD, future research exploring the potential of PA with this population is advocated.

Keywords: Exercise | ADHD | Children | Cognition

Article:

Introduction

Both chronic (Etnier et al., 1997) and acute (Brisswalter et al., 2002, Etnier et al., 1997, Lambourne and Tomporowski, 2010 and Tomporowski, 2003) physical activity (PA) have positive effects on cognitive performance. Importantly, evidence suggests that the effect for chronic PA is larger for children (Etnier et al., 1997 and Sibley and Etnier, 2003) and for older adults (Angevaren et al., 2008, Colcombe and Kramer, 2003 and Etnier et al., 1997). Additionally, there is evidence suggesting that the benefits are larger for older adults with cognitive impairment (Heyn et al., 2004) and who are at genetic risk for Alzheimer's disease (Etnier et al., 2007 and Rovio et al., 2005). These findings can be interpreted as supporting the cognitive reserve hypothesis (Scarmeas and Stern, 2003 and Whalley et al., 2004) which suggests that the benefits of PA are greater for those whose cognitive reserves are challenged. Thus, older adults experiencing age-related cognitive decline, older adults at risk for clinical cognitive impairment, and children for whom cognitive reserves are not fully developed are expected to benefit the most from PA. However, although there is a relatively large literature addressing the effects of PA on the cognitive abilities of older adults at risk for cognitive decline (Hamer and Chida, 2009, Heyn et al., 2004 and Lautenschlager et al., 2010), surprisingly little research has explored the potential of PA to have greater benefits for children who have additional challenges to their cognitive reserves. In particular, children with attention deficit hyperactivity disorder (ADHD) experience behavioral and cognitive challenges that might lead them to experience even greater cognitive benefits from PA than do children without ADHD. Further, the etiology of ADHD and the putative mechanisms by which PA impacts cognitive performance suggest that PA might be particularly beneficial for this population. The purpose of this paper is to review the literature regarding the potential of PA for symptom management for children with ADHD.

ADHD characteristics

ADHD is one of the leading childhood psychiatric disorders in America, affecting approximately 3–7% of school-age children (American Psychiatric Association, 2000). ADHD is diagnosed based upon symptoms of inattention, hyperactivity, and/or impulsivity which must occur for at least six months in at least two domains of life and which begin to be observed prior to the age of 7 years (American Psychiatric Association, 2000). These symptoms persist into adulthood and can cause numerous impairments in social, academic, and occupational functioning. Additionally, ADHD behavior is in direct conflict with the demands of the classroom. In the classroom, students are expected to be still and stay seated, pay attention, concentrate, be quiet, and follow directions, which are all central to the learning process (Harlacher et al., 2006). Thus, the classroom environment itself is challenging for children with ADHD to navigate and behavioral symptoms of ADHD may limit a child's ability to be successful in school.

Neurobiological mechanisms of ADHD

The etiology of ADHD is multidimensional and complex. Models of ADHD posit that a deficit in frontal lobe function underlies its various cognitive and behavioral manifestations. In particular, fronto-striatal and fronto-parietal networks are frequently cited as central to ADHD dysfunctions (Castellanos and Tannock, 2002 and Durston, 2003). In a review of studies using a variety of neuroimaging techniques, Bush et al. (2005) reported that the most substantial differences in cerebral structure between ADHD patients and healthy controls were evident in regions of the prefrontal cortex. In particular, results showed hypoactivity and structural abnormalities in the dorsolateral prefrontal cortex, which affects vigilance, selective and divided attention, attention shifting, planning, executive control, and working memory. Additionally, structural differences were found in the ventrolateral prefrontal cortex which is linked to behavioral inhibition as measured by performance on stop-signal tasks. The most consistent finding reported 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.

In further support of deficits in frontal lobe function, a recent meta-analysis (Dickstein et al., 2006) of 16 neuroimaging studies contrasted patterns of neural activity in children and adults with ADHD and healthy controls. This review also supported a pattern of frontal hypoactivity in ADHD consistent with models implicating frontal lobe dysfunction in ADHD. Additionally, fMRI studies have identified that children with ADHD have significantly diminished blood flow to the prefrontal and frontal regions of the brain (Seidman et al., 2005 and Sieg et al., 1995) and reduced activation in prefrontal and striatal areas of the brain for behavioral control tasks (Konrad et al., 2006). These regions are involved in attention, working memory, response inhibition, and planning and these functions have been identified as the core cognitive deficits relevant to children with ADHD (Barkley, 1997 and Biederman, 2005). These regions are also associated with the regulation of catecholaminergic pathways important for motor and impulse control and cognitive functions, and there is evidence that individuals with ADHD do not release and reload these catecholamines effectively (Madras et al., 2005).

More recently, brain derived neurotrophic factor (BDNF) has been identified as a potential mechanism that is important in the etiology of ADHD (Tsai, 2007). BDNF is a member of the neurotrophin family and is involved in neurodevelopmental processes that are responsible for the survival and growth of neurons. BDNF is linked to both differentiation and survival of dopaminergic neurons which are linked to impulse regulation (Hyman et al., 1991 and Knusel et al., 1991), suggesting that BDNF may impact dopaminergic system dysfunctions associated with ADHD. Animal research demonstrates that stimulants increase BDNF expression, (Meredith et al., 2002 and Nibuya et al., 1996) and a number of animal studies have found correlations between genetic variations in BDNF and vulnerability to ADHD (Lanktree et al., 2008 and Xu et al., 2007).

Cognitive performance

Research consistently documents that ADHD is characterized by deficits in executive function (EF) with ADHD children performing more poorly on a range of EF tasks relative to control participants (Pennington and Ozonoff, 1996 and Shallice et al., 2002). EF is defined as the cognitive abilities that maintain an appropriate problem-solving set in order to attain a future goal and is thought to be highly relevant for daily life activities, appropriate behavior, and academic and social functions. More specifically, EF is a non-unitary construct that has been operationalized in the PA literature as consisting of planning, scheduling, inhibition, and working memory (Etnier and Chang, 2009 and Tomporowski et al., 2008) and that has been shown in adults (Miyake et al., 2000) to include the abilities of set-shifting (changing attention from irrelevant to relevant information), inhibition (consciously suppressing a prepotent response), and updating (which is related to working memory). In the classroom, EF deficits may interfere with the ability to process incoming information while listening to a teacher, to identify relevant information, to inhibit irrelevant thoughts, to hold information in mind while linking it to other relevant information, and to stay focused on tasks (Dawson and Guare, 2004). Clearly, these deficits could then impact a child's ability to reach his/her potential.

Wilcutt et al. (2005) meta-analytically reviewed 83 studies in which EF measures were administered to children and adolescents with ADHD and without ADHD. They found that participants with ADHD exhibited significant impairment on response inhibition, vigilance, working memory, and planning with effect sizes generally in the moderate range (0.46–0.49). While EF deficits are not the only cognitive and behavioral problems in ADHD children, they contribute significantly to the symptoms of the disorder and are associated with substantial academic deficits. Academic deficits in ADHD have been documented in a recent meta-analysis (Frazier et al., 2007). The analysis yielded a large effect ($d = 0.75$) indicating that there is a large discrepancy between achievement outcomes in ADHD children relative to controls. Given the likely impact of academic performance on a child's ability to reach his/her potential, understanding ways to improve the cognitive abilities (and perhaps most importantly the EF abilities) of ADHD children is critically important.

ADHD mechanisms and the potential role of PA

The potential of PA as a treatment for ADHD is supported by the fact that in animal studies and in studies with older adults, PA has been found to positively impact many of the same neurobiological factors that are implicated in ADHD. For example, recent animal models show that PA results in increased cerebral blood flow (Endres et al., 2003 and Swain et al., 2003). Additionally, PA increases the availability of dopamine and norepinephrine in synaptic clefts of the central nervous system (Fulk et al., 2004). Further, there is evidence that PA results in changes in cerebral structure that are expected to be important for cognitive performance (van Praag, 2008). These changes include the maintenance of cerebral vasculature and an increase in angiogenesis and neurogenesis, which all serve to enhance neuroplasticity and positively influence cognitive abilities. There is also evidence that PA increases BDNF in rodents (Cotman and Berchtold, 2002). In humans, research with older adults has shown that participants who are more aerobically fit or who participate in a physical activity program show benefits in cerebral structure (Colcombe et al., 2003 and Colcombe et al., 2006) as evidenced by reductions in cortical tissue density and volume. Additionally, there is greater brain activity within regions associated with behavioral conflict and attentional control processes (Colcombe et al., 2004).

There is also evidence that PA benefits cognitive function in general and EF specifically, thus providing indirect support for the hypothesis that PA may impact the cognitive symptoms of ADHD. There are a number of studies providing evidence that chronic PA benefits EF in older adults (Colcombe and Kramer, 2003) and there is more limited evidence that chronic PA benefits the cognitive performance of children (Tomporowski et al., 2008). When reviewed meta-analytically (Sibley and Etnier, 2003), results from acute, chronic, and cross-sectional studies demonstrated an overall significant positive effect of PA on cognition in children (ES = 0.32) with larger effects seen in children of elementary (ES = 0.40) and middle school age (ES = 0.48). Similarly, in an earlier meta-analysis by Etnier et al. (1997), a small effect size (g = 0.36) was found for chronic PA and cognition in children ages 6–13 years.

Current research on PA and ADHD

Despite the evidence suggesting that PA is a plausible treatment for children with ADHD, there is a paucity of research examining the impact of PA on ADHD behavioral symptoms, underlying mechanisms, or cognitive performance.

Behavioral symptoms

The evidence regarding the effects of PA on behavioral symptoms is often indirect because it comes from studies testing the effects on the broader construct of behavioral disturbances. Thus, although the effects in these studies were reported for behaviors that are relevant to ADHD, the findings may not generalize to children with ADHD. There are some studies that have actually tested the effects of PA in children with ADHD, but these studies are limited in number, have not all been published, often lack a control group, and typically do not include a clinically diagnosed sample. Although the findings of these studies must be viewed with caution because of their obvious limitations, given the dearth of published high-quality empirical evidence these studies are described to provide an indication of the extant literature.

Several studies in the early 1980s provide preliminary background support for the effect of PA on behavioral problems (broadly defined) in children. Allen (1980) tested the effects of a 6 week jogging program on 12 boys with behavioral disorders. The boys were randomly assigned to one of three conditions: no jogging or a 5 minute warm-up jog followed by either 5 or 10 min of jogging 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 a 50% reduction in disruptive behaviors on jogging days compared to non-jogging days. The author noted that the fewest disruptions occurred 1 h 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 chronic exercise study that was conducted with learning-disabled children, Bass (1985) compared student classroom behavior on days that students ran with days they did not run. Results showed that five of six children demonstrated reduced problems in attention span and three of six showed reductions in problems with impulse control on running days. Another study in the classroom setting tested the effects of running on hyperactivity, impulse control, and medication dosage (Shipman, 1985). Children (n = 56, ages 6–13 years) were assigned to a running program 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. It is important to note that this study did not include a control group, thus findings should be interpreted with caution. A meta-analysis examining the effects of chronic aerobic exercise on disruptive behavior provides additional support for PA as a means of influencing behavior in children (Allison et al., 1995). Results from 16 group studies and 26 single-case studies yielded effect sizes of $d = 0.33$ and $d = 1.99$, respectively. The largest effects were seen in studies including direct observation and hyperactive participants.

More recently, PA was shown to be effective in increasing on-task behavior in the classroom by children in kindergarten through fourth grade (Mahar et al., 2006). Classrooms were randomly assigned to the PA program or to no PA. PA was based on the Energizers program which consists of 10 minute bursts of PA interspersed throughout the day. Those classrooms receiving PA showed improvements in on-task behavior following PA. On task behavior was defined as "verbal or motor behavior that followed the class rules and was appropriate to the learning situation." (p. 2088). Even though this study did not include children diagnosed with ADHD, it is of particular relevance because maintaining these types of behaviors is problematic for children with ADHD.

There are three unpublished studies and one published study that report on the impact of PA on behavior specifically in children with ADHD. Gapin and Etnier (2010b) surveyed 68 parents of children diagnosed with ADHD and found that a significantly greater percentage of parents reported positive effects of regular PA on symptoms broadly (54%), for inattention (63%), and for hyperactivity (53%). Tette (2003) investigated the effects of exercise on EF in primary school children ($n = 28$). Children were assigned to either an exercise treatment group or a control group for 8 weeks. Parents and teachers were asked to complete the Behavioral Rating Inventory of Executive Function (BRIEF) pre and post-tests. The BRIEF assesses executive functioning in the home and school settings. Results showed that children in the treatment group improved on BRIEF ratings from pre- to post-test. Wendt (2001) found that ADHD children ($n = 13$) participating in a regular exercise program for 6 weeks showed significant improvements in behavior as compared to ADHD children placed in a control group that received no exercise ($n = 11$). Although the results of these unpublished studies suggest that PA may benefit the behavioral symptoms of children with ADHD, it must be remembered that they are unpublished and, therefore, have not gone through the peer review process to insure their quality. In the only published study that we are aware of which examined the effects of PA on behavior in a clinically diagnosed sample of ADHD children (all of whom were medicated), McKune et al. (2003) demonstrated that behavior, as measured by parent ratings on the Conners Parent Rating Scale, improved after a 5 week exercise program. These findings suggest that it is important to examine chronic PA as a potential way to mitigate behavioral symptoms of ADHD.

Underlying mechanisms

Although sparse, a few studies have been conducted to test the effects of PA on mechanisms that underlie ADHD. Wigal et al. (2003) observed that children with combined type ADHD (have both inattention and hyperactivity–impulsivity symptoms) exhibited a smaller increase in catecholamines in response to acute exercise as compared to healthy, age-matched controls. This decreased reactivity lends indirect evidence to the notion that ADHD is related to a catecholamine dysfunction, perhaps within the hypothalamic–pituitary axis. Tantillo et al. (2002) used indirect measures (spontaneous eye blink rates and acoustic startle eye blink response) to assess dopaminergic response to acute exercise in children with ADHD. Results suggested that cerebral dopamine levels increased following a single session of exercise.

Cognitive performance

There are two studies that report on the effects of PA on cognitive performance of children with ADHD. Gapin and Etnier (2010a) examined the relationship between chronic PA and EF performance in boys diagnosed with ADHD. Participants performed cognitive tasks and then were asked to wear an accelerometer for one week to assess regular PA. Results indicated that greater moderate-to-vigorous PA was predictive of better performance on four EF tasks. The largest results were seen for the Tower of London planning task; however, children that were more physically active also performed better on tasks assessing working memory, inhibition and information processing speed.

In an acute exercise study, Medina et al. (2009) examined the impact of high intensity PA on sustained attention in boys diagnosed with ADHD. Participants performed high intensity exercise on a treadmill for 30 min and sustained attention was tested pre and post exercise. Results showed that there was a significant increase in sustained attention following exercise, irrespective of medication use. More specifically, children improved on response time and vigilance while decreasing impulsivity. Despite these promising results, there is a lack of research examining the effects of a single session of PA on cognition in children with ADHD. The extant literature suggests that acute PA may be particularly beneficial for children diagnosed with ADHD.

Conclusions

There is evidence, albeit limited, that PA has a positive impact on behaviors of children in school settings and that PA can benefit the behavioral symptoms and cognitive performance of children with ADHD. These results suggest that PA might be an effective supplement to medication to reduce behavioral impairments that interfere with learning and academic progress and to directly benefit cognitive performance by ADHD children. PA may also be used for those children that do not respond to medication treatments or wish to seek alternative forms for treatment. As a whole, the few studies that have been published in this area tend to focus on changes in behavior accrued through PA and, surprisingly, there is a paucity of research devoted to the benefits of PA on cognition in individuals with ADHD. Yet, PA as a tool to manage symptoms and benefit cognitive performance (and academic achievement) is often promoted in the media and anecdotally by parents, teachers, school administrators, and medical professionals without much direct evidence. Clearly, more research is needed to validate these claims. That being said, given the preliminary evidence that exists, the overlap in the mechanisms underlying ADHD, and the effects of PA on cognitive performance in the general population, future research exploring the acute and chronic effects of PA on children with ADHD is warranted.

In particular, future studies should be designed to extend our understanding of the effects of both acute and chronic PA on the behavioral and cognitive symptoms of ADHD. Future research with acute exercise is necessary to ascertain the reliability of the effects reported in our pilot study. Additionally, for both acute and chronic paradigms, more experimental studies using clinically diagnosed populations will enable researchers to make the most informed decisions and recommendations concerning potential PA intervention strategies. These studies need to include more rigorous designs and achieve adequate power. Future research should also aim to include other EF tasks than those used previously. This would help elucidate the EF tasks that are most sensitive to PA in this particular population and provide insight as to how performance on these tasks may impact ADHD children in the classroom. Lastly, it would be valuable to explore the effects of PA on behavior and cognition in children with ADHD who are not currently receiving medication treatment for ADHD. While our research has focused on PA as a potential complementary treatment for ADHD, it would be useful to determine if PA can be used as an alternative form of treatment. Anecdotally, some parents choose not to medicate their children while others have difficulty finding a medication that does not produce harmful and/or uncomfortable side-effects. For these individuals, research would be particularly beneficial in elucidating the effects of PA irrespective of medication use.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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