Effects of Physical Activity on Executive Function of Children with ADHD

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Abstract

Children with ADHD are often described as experiencing deficits in executive function. Two key areas of concern are inhibition, the ability to refrain from a dominant response when needed, and updating, the ability to revise or update incoming information. The purpose of this manuscript is to combine disparate lines of research to help establish a positive link between moderate to vigorous physical activity, executive function, and ADHD. Neuroscience research suggests moderate to vigorous physical activity may increase allocation of attentional resources as evidenced by increases in P3 amplitude and reduce P3 latency in children with ADHD. Intervention studies employing moderate to vigorous physical activity have shown improvements in executive function for children with ADHD. Optimal stimulation and dopamine regulation are suggested as theoretical perspectives for the effects of exercise. Key variables and implications for teachers suggest moderate to vigorous physical activity may provide a quick and effective means of improving executive functioning of children with ADHD in the classroom.

Keywords: ADHD, executive function, physical activity, MVPA

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Core cognitive processes collectively termed ‘cognitive control’ or ‘executive control’ include inhibition, working memory, and cognitive flexibility (Diamond, 2006). The term Executive Function (EF) has been used to describe underlying cognitive processes that drive goal directed behavior and coordinate goal directed activities, such as reasoning, problem solving, and planning (Best & Miller, 2010), capacities allowing a person to be purposeful, independent, self-reliant and maintain an appropriate problem solving set to pursue future goals (Barkley, 2000; Welsh & Pennington, 1988).

ADHD is defined and diagnosed by the presence of observable behaviors representing three areas: inattention, hyperactivity, and impulsivity. Research suggests EF may underlie observed behavioral challenges for this group of children (Berlin, Bohlin, Nyberg, & Janols, 2004; Berlin, Bohlin, & Rydell, 2004; Weyandt, 2005). The purpose of this paper is to combine disparate lines of research to help establish a positive link between moderate to vigorous physical activity, cognitive control/ executive function, and ADHD.

Prevalence of Attention Deficit Hyperactivity Disorder (ADHD) is on the rise, reaching 11% of children in the United States (Visser et al., 2014). In school, children with ADHD are often unable to stay on task, fail to complete academic assignments, or simply fail to turn them in on time (Denisco, Tiago, & Kravitz, 2005). Children with ADHD are more likely to experience school failure, have intellectual impairments, repeat grade levels and score lower on measures of intelligence as compared to typical children (Faraone et al., 1993; Kent et al., 2011). These issues often continue into adulthood, as half of children diagnosed in adolescence continue to meet criteria for ADHD as adults (Lara et al., 2009). Given these numbers, developing effective school-based interventions that positively affect both academic performance and classroom behavior for this population is very important. One intervention that shows promise in the literature is moderate to vigorous physical activity (MVPA) (Taras, 2005; Tomporowski, Davis, Miller, & Naglieri, 2008).

MVPA is physical activity or movement that is aerobic in nature and typically entails an increase in heart rate of 50-85% of maximum through such activities as running, walking or cycling (Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). Recommendations for health benefits suggest school-age youth receive 60 minutes of MVPA per day (Strong et al., 2005). Physiological benefits resulting from regular exercise include diabetes prevention, weight management, and cardiovascular health. In addition to MVPA's impact on physical measures, laboratory based researchers have documented effects on attention to task, cognition, and brain function (Hillman, Erickson, & Kramer, 2008; Mahar, 2011). MVPA has also been shown to improve classroom behavior and academic engagement for children with ADHD, both on and off stimulant medication (Hart & Lee, in review).

Executive Function

Executive function is a construct described in different ways in the literature (Barkley, 2000; Miyake et al., 2000; Pennington & Ozonoff, 1996; Weyandt, 2005), however, one prominent framework suggests EF has three main components: inhibition, updating, and shifting (Miyake et al., 2000). While each variable shares some overlap, analysis by Miyake et al. (2000) demonstrates they are distinct constructs serving differing roles based on specific tasks. *Inhibition* is the deliberate refraining from an automatic, dominant, or strong response when needed (Best & Miller, 2010; Miyake et al., 2000). *Updating* occurs when individuals monitor and/or revise incoming information regarding the current task (Miyake et al., 2000). Updating requires individuals to hold and manipulate information over short periods of time without the aid of external devices or cues (Best & Miller, 2010) and may support the ability to follow directions. *Shifting*, or "attention switching", is the ability to move from one task, rule set, or mental state to another (Miyake et al., 2000). This model, consisting of inhibition, updating and shifting, forms a leading theoretical framework of EF.

Cognitive Control/ Executive Functioning in Children with ADHD

Children with ADHD exhibit multiple deficits in EF, such as impairments in inhibition, updating, and processing speeds (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Pennington & Ozonoff, 1996; Weyandt, 2005). Using meta-analytic techniques Willcutt et al., (2005) examined 83 studies that utilized measures of EF to assess deficits in individuals with ADHD. Their analysis similarly showed that individuals with ADHD presented with deficits in all areas of EF, with the strongest effect sizes coming from measures of inhibition, updating, vigilance, and planning, all hallmarks of diagnostic criteria for ADHD. These areas align with those proposed by Miyake (2000) with vigilance and planning falling under the larger constructs of inhibition and updating respectively. In synthesizing these deficits, two become particularly clear in students with ADHD: inhibition (Barkley, 2000; Pennington & Ozonoff, 1996; Weyandt, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) and updating (Barkley, 2000; Martinussen et al., 2005; Pennington & Ozonoff, 1996; Schreiber, Possin, Girard, & Rey-Casserly, 2014; Willcutt et al., 2005). Although there is some overlap in the underlying processes, updating and inhibition are distinct and employed differently based on the required task (Best, 2010).

Inhibition, or the ability to interrupt an ongoing dominant response, is a key characteristic of ADHD (Doyle, 2006). For example, while taking a test, a child with ADHD may not be able to refrain from calling out to a friend. Deficits in inhibition can lead to problems listening to instructions, compliance, task completion, and socialization with peers and adults; more serious and even life threatening problems can occur (Glanzman & Sell, 2013). Deferred gratification, and resistance to temptation (i.e., self-control) are also elements of inhibition children with ADHD lack (Barkley, 1997). This deficit in self-control may suggest a cause for the elevated risk of driving infractions and accidents for adolescents and adults diagnosed with childhood ADHD (Thompson, Molina, Pelham, & Gnagy, 2007).

Updating is the second major deficit associated with ADHD. Updating is emerging as one of the primary deficits in children with ADHD and helps explain academic problems observed in this population (Schreiber et al., 2014). Updating is the limited capacity system (i.e., short-term memory) for holding information in the mind and manipulating it to help guide complex behavior without external aids (Barkley, 2000; Best & Miller, 2010; Schreiber et al., 2014). Tasks that necessitate maintaining and manipulating information, such as remembering and manipulating multiple steps of a task, rely on more pre-frontal cortex control and executive involvement (Best & Miller, 2010).

MVPA and EF

Recent years have seen an increased interest in the relationship between physical activity (bodily movement that increases energy expenditure, Darst & Pangrazi, 2009) and cognitive function. It is well documented that bout(s) of MVPA are beneficial to overall brain health, through increased angiogenesis (Ide & Secher, 2000), neurogenesis, hippocampal growth and development (Colcombe, 2006), up-regulation of brain neurotransmitters (Cotman, 2007) and gray matter volume (Erickson et al., 2014). This research foci have grown substantially over the last 25 years since animal researchers (Isaacs et al., 1992) inadvertently discovered associations between MVPA and increased cognition in rodents. This led to a concentration of study designs with human participants (initially with senior adults, to adults, and finally, of late, with children). Although child-based research is the least well established, emerging literature indicates aerobic-based MVPA is linked with high order EF (Diamond, 2006, Chang et al., 2012). A growing body of research examining MVPA and brain function has provided some evidence, primarily in adults (Hillman et al., 2008), that MVPA has a positive impact on both EF and consequential behaviors (Hillman, Castelli, & Buck, 2005; Tomporowski et al., 2008). Although the trigger mechanism for increased EF is unknown, there are some suggestions that attempt to explain the relationship between the two variables.

Most research suggests MVPA effects neurotransmitter regulation and neurotropic factors that aid brain health. Cotman et al. (2007) suggests Brain-Derived Neurotropic Factor (BNDF), insulin growth factor (IGF), and vascular endothelial-derived growth factor (VEGF), are key growth factors that interact with the brain, and potentiate neurotransmitter release. Cotman et al. (2007) suggest these growth factors mediate effects of MVPA on the brain, enabling growth and longevity of neural connections, more opportunity for wiring of cells, and longer healthy brain lifespan, through protection via a strengthened myelin sheath. Not only does PA encourage neurogenesis, there is also growing literature to suggest MVPA effects the uptake of dopamine, serotonin and norepinephrine (Hillman et al., 2008). These transmitters affect EF by regulating impulsivity, giving the learner improved focus, attention, vigor, and positive self-esteem, important elements in positive mental health. Spina et al. (1992) reported BNDF helps in survival of dopamine neurons, and Sauer et al. (1993) suggested BDNF aids in dopamine function, a regulator of motivation and attention. Mamounas et al. (1995) recognized BDNF promotes survival and growth of serotonin axons (upregulations of serotonin is a common form or antidepressants designed for mood regulation). Both serotonin and dopamine are important neurotransmitters explicitly addressed in mental health literature relating to conditions of attentional and impulsivity deficits, such as ADHD. Cotman et al. (2007) suggested benefits of MVPA on brain health include benefits on learning, depression, neurogenesis (birth of new neurons), and angiogenesis (growth of new capillary blood vessels). They suggested IGF and BDNF mediate behavioral improvements, and IGF and VEGF support exercise induced angiogenesis and neurogenesis, including an interactive cascade of signaling that reduces peripheral risk factors for cognitive decline. Ploughman (2008) suggested exercise may cause changes in behavior, cognition and EF by (a) increasing oxygen saturation in the brain, (b) increasing neurotransmitters such as serotonin and norepinephrine, and (c) up-regulating neurotrophins.

In summary, there is seemingly little consensus regarding underlying mechanisms that may facilitate or inhibit EF. However, it is highly unlikely there is a single source, but instead an interaction or cascade of factors at work. While the conclusions from the research are strong for adult populations (Hillman et al., 2008), an understanding of effects of MVPA on cognition and behavior of adolescent children, particularly those with or at risk for disabilities remains largely unclear (Allison, Faith, & Franklin, 1995; Allison & Keays, 1995; Tomporowski, 2003a).

EF is a construct vital to academic performance (Hillman et al., 2012, St-Clair Thompson & Gathercole, 2006), but there are indications EF skills may be on the decline (Smirnova & Gudareva 2004). This is concerning as EF skills can be a better predictor of school readiness than entry-level reading or math scores (Blair, 2007). In children, the MVPA-EF relationship is not linear in terms of increased cognition. Rather it is multi-factorial, and different cognitive benefits, from MVPA, should be expected. This seems likely related to diverse rates of pre-frontal cortex development in children, especially in terms of plasticity (Shaw et al., 2006), and hippocampus growth (Pfluger et al., 1999). It is salient to suggest however that students who have the most to gain, in terms of fitness levels, and academic performance, gain the most (Phillips et al., 2015).

Yet, there has been little effort to investigate how MVPA relates to cognition and EF of children with special needs (Tomporowski et al., 2008). Although included within samples, data for individuals at risk for or already identified with disabilities have not been disaggregated from typical performing students (Archer & Kostrzewa, 2012; Best, 2010; Chang, Labban, Gapin, & Etnier, 2012; Etnier, Nowell, Landers, & Sibley, 2006; Gapin, Labban, & Etnier, 2011; Taras, 2005; Tomporowski, 2003a; Tomporowski, 2003b; Tomporowski et al., 2008; Welsh & Labbé, 1994). Changes in EF have provided a means for showing effects and benefits of MVPA

(Hillman et al., 2008; Sattelmair & Ratey, 2009). For the purpose of this paper, the few studies that have examined effects of MVPA on EF with students with ADHD come from two bodies of research: those that examine neurological indicators of EF and those that examine behavioral indicators.

Neuroscience Studies and the Impact on EF of Students with ADHD

One means of determining if MVPA affects EF processes is through research that examines event related potential (ERP) data. ERP research involves presenting a stimulus to a participant wearing an array of electrodes on the head and recording electric impulses that occur. The electric impulses produce waves with peaks and troughs that are graphically displayed and compared. Research has identified one element, the P3 waveform, as a possible indicator of attentional, inhibitory, and updating processes (Polich, 2007; Polich & Lardon, 1997). It has been theorized P3 amplitude is sensitive to the amount of attentional resources engaged during task performance (Polich, 2007). That is, the stronger the amplitude of the P3 waveform, the more attentional resources are utilized on a given task. Thus, increases in magnitude are indicative of increased attention and inhibition (Higashiura et al., 2006; Polich, 2007; Yagi, Coburn, Estes, & Arruda, 1999).

ERP research with typical college and elementary-age students has shown differences in P3 amplitude after performing MVPA, suggestive of an increase in attentional resources during tasks (Hillman et al., 2009; Hillman, Snook, & Jerome, 2003; Kamijo et al., 2004; Magnié et al., 2000). Prior research suggests reductions in P3 latency in response to presented stimuli represent mental function speed, in that shorter latencies are related to superior cognitive performance, or improvements in updating (Polich, 2007; Yagi et al., 1999). Again, with non-ADHD participants, reductions in P3 latency suggest improved mental processing speed (Hillman et al., 2009; Hillman et al., 2003; Magnié et al., 2000).

Three studies have examined MVPA effects on P3 waveform in students with ADHD (Table 1). The first study examined magnitude and latency of P3 to assess changes in EF for participants with ADHD (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Forty children ages 8 - 10 participated in a single bout of treadmill running at a moderate pace (65-75% maximum heart rate) for 20 minutes. Participants then performed an Eriksen Flanker task to measure changes in P3 magnitude and latency. The Eriksen Flanker task is a response inhibition task that assesses the ability to suppress a dominant response in favor of a target response (Eriksen & Eriksen, 1974). After exercise, increased arousal levels were observed, including areas implicated in EF, compared to a non-exercise (i.e., seated reading) condition. More specifically, there was an increase in P3 amplitude and a decrease in P3 latency at all recording sites after the exercise phase only. Additionally, participants exhibited greater response accuracy after MVPA. Results support previous research, and extend it to an ADHD population, suggesting a single bout of MVPA has an enhancing effect on allocation of attentional resources (P3 amplitude) and improved processing speed (P3 latency). Drollete et al. (2014) combined data from the above study (Pontifex et al., 2013) and an earlier study (Hillman et al., 2009) to compare ADHD and non-ADHDparticipants. Results are distinctive in demonstrating that children with ADHD showed a differential effect from a single bout of MVPA. These data suggest children who have reduced inhibitory control may benefit more than their typical peers after a single bout of MVPA (Drollette et al., 2014).

Table 1
ADHD ERP Studies

Study	n	Age	Task	EF	MVPA	Dur	P3 Findings
Chuang et al. (2015)*	19	8-12	-Go/No-Go	-RI	Treadmill	30	-Latency
Hillman et al. (2014)**	221	7-9	-Eriksen Flanker Task -Color Shape Task	-RI -U	Aerobic games	70m	+ Magnitude - Latency
Pontifex et al. (2013)	40	8-10	-Eriksen Flanker Task	-RI	Treadmill running	20m	+ Magnitude - Latency

Note. RI=Response Inhibition. U=Updating. S=Shifting. Dur=Duration of exercise
*Chuang et al. did not look at P3 but rather CNV **ADHD comprised 43% of sample.

A second study consisted of a 9 month randomized controlled physical activity intervention with 222 seven to nine year old children. Results showed only the MVPA intervention group (n=109) increased P3 amplitude and decreased P3 latency after exercise (Hillman et al., 2014). Taken as a whole for both children without ADHD as well as children with ADHD, data from the P3 waveform suggest MVPA increases allocation of attention resources (magnitude), mental functioning (latency), and response accuracy related to superior cognitive abilities, that results in enhanced attention.

A third more recent study looked at contingent negative variation or CNV. This is partially related to motor preparation and is represented by a negative deflection prior to the P3 positive wave form, and has been used in similar research on response inhibition (Luck, 2014). This study suggests children ages 8-12, with a 30 minute bout of treadmill running supported appropriate response preparation and helped maintain stable motor preparation prior to a go/no-go task (Chuang, Tsai, Chang, Huang, & Hung, 2015).

Intervention Studies and the Impact on EF

In addition to evidence provided by neuroscience studies, a search of the literature identified eleven classroom intervention studies that document effects of MVPA on EF in children with ADHD (Table 2). These studies examined variables such as participants' ages, stimulant medication use, and types of tasks used to measure the two key variables related to EF: inhibition and updating.

Table 2
ADHD Intervention Studies

Study	n	Age	Task	EF	MVPA	Dur	Findings
Chang et al. (2012)	40	8-13	-Stroop -WCST	-S -RI	Treadmill running	30m	-Positively impacting set shifting and response inhibition
Chang et al. (2014)	27	5-10	-Go/No-Go	-RI	Swimming	90m	-Significant improvements in inhibition control

Gapin & Etnier (2010)	18	8-12	-Tower of London -CPT-II -Digit Span	-U -RI	Overall activity levels	NA	-Significant predictor of planning and inhibition
Gawrilow et al. (2013)	47	8-13	-Go/No-Go	-RI	Trampoline Jumping	5m	-Improved inhibition and increased sustained attention
Kang et al. (2011)	28	6-10	-Trail Making -Digit Symbol	-U -S	Varied activities	90m	-Improved updating, shifting, and social skills
Memarmoghaddam et al. (2016)	40	7-11	-Go/No-Go -Stroop	-RI -S	Varied activities	90m	-Improved inhibition and behavioral inhibition
Medina et al. (2010)	25	7-15	-CPT-II	-S -RI	Treadmill running	30m	-Decreased impulsivity, increased surveillance, improved reaction times.
Pan et al. (2015)	30	7-12	-Stroop -WCST	-RI -S	Table Tennis	70m	-Tentative evidence of improvements
Piepmeier et al. (2015)*	32	K-12 m= 10.7	-Tower of London -Stroop -Trail Making	-U -S -RI	Stationary bike	30m	-Improvement in speed of processing, inhibitory control. -No improvement in planning or set shifting.
Smith et al. (2013)	16	5-8	-Game: Red Light/Green Light	-RI	Varied activities	26m	-Improvements in Response Inhibition
Verret et al. (2010)	21	7-12	-Test of Everyday Attention	-U	Aerobic games	45m	-Improved information processing and visual search

Note. RI=Response Inhibition. U=Updating. S=Shifting. Dur=Duration of exercise *only 14 of the 32 participants had a diagnosis of ADHD

Exercise produced effects that are robust across many variables. Participants ranged from 5-18 years, and all demonstrated a positive shift in elements of EF. However, one pilot study showed only tentative benefits; the table tennis intervention used in this study was sustained over multiple weeks, but there was little indicative of MVPA reflecting a difference from the other studies included (Pan et al., 2015).

Also noteworthy is the effects of MVPA are independent of effects of stimulant medication. In a clinical setting, 25 children diagnosed with ADHD participated in a single episode of MVPA and demonstrated significant improvements in response time and on measures of shifting and inhibition (Medina et al., 2010). Participants in this study taking stimulant medication had similar results to those who were not taking the medication. To further examine the role of stimulant medication, a randomized controlled trial involving 28 children with ADHD had all medication naive participants start taking stimulant medication at the onset of the study (Kang, Choi, Kang, & Han, 2011). Results showed only the MVPA intervention group improved on measures of shifting and updating. These results suggest MVPA benefits can be supportive and similar to those of stimulant medication. Across studies, various tasks were used to assess changes in EF, but most tended to be clinical research tools (e.g. Stroop task, Wisconsin Card Sorting Task, Tower of London Task). The variables highlighted help to emphasize potential differences in the areas of inhibition and updating.

Inhibition. Nine of eleven studies used tasks related to inhibition. For example, Chang and colleagues (2012) asked children with ADHD ages 8-13 years to participate in treadmill running for 30 minutes. These researchers found children had an improved allocation of attentional resources as assessed by measures of inhibition after exercise (Chang, Liu, Yu, & Lee, 2012). Perhaps the most significant applied finding from this study was that a single 5-minute bout of MVPA improved EF. In a similar study, children with ADHD jumped on a mini-trampoline for 5 minutes at a vigorous rate (Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2013). This single 5 minute bout of MVPA resulted in improved response inhibition and fewer errors on a sustained attention task. In a descriptive study, Gapin and Etnier (2010) found overall activity levels predicted children's planning (a sub-component of updating) and response inhibition. This study did not alter activity levels but used accelerometer data from 18 children ages 8-12 to determine how well MVPA predicted improvements in EF. Results suggested MVPA improved EF in both children without disabilities and those with ADHD (Piepmeier et al., 2015). A final study in this area looked at response inhibition, and found a selected exercise program was effective for children with ADHD (Memarmoghaddam, Torbati, Sohrabi, Mashhadi, & Kashi, 2016).

Updating. Updating and monitoring of working memory representations is the second major deficit in EF for children with ADHD (Best & Miller, 2010; Schreiber et al., 2014). Improvement in updating was demonstrated in three studies (Chang, Liu, et al., 2012; Kang et al., 2011; Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2010). In one study, children diagnosed with ADHD participated in a 10 week MVPA program, and showed improvements in updating, including enhanced information processing and faster visual search, leading to improvements in sustaining attention (Verret et al., 2010). Significant to educators, both parents and teachers reported enhanced behavior after physical activity. Similarly, latency of responding was reduced on an updating task compared to the non-MVPA control group in two additional studies (Chang, Liu, et al., 2012; Chang, Hung, Huang, Hatfield, & Hung, 2014). A study conducted in Korea found a 6-week program of MVPA for children with ADHD, compared to a non-MVPA ADHD control group, improved updating as measured with a trail-making task (Kang et al., 2011). Results of these studies suggest MVPA improved measures related to updating for children with ADHD.

Theoretical Implications

Taken together these intervention studies show MVPA can improve measures of EF and improve classroom behavior. These studies corroborate neuroscience studies showing MVPA can improve measures of updating and inhibition: the two major deficits of EF for children with ADHD. Given these observations, an understanding of the mechanism(s) that govern effects of MVPA on EF is important for theory, intervention development, and future research.

Optimal stimulation theory (OST) has been suggested as a theoretical framework for examination of MVPA for students with ADHD (Allison et al., 1995; Lufi & Parish-Plass, 2011). According to OST, individuals engage in operant responses in order to regulate incoming stimulation (Leuba, 1955). Much like a thermostat regulates the temperature of a home, individuals engage in behavior to self-regulate levels of stimulation. When stimulation levels are low, the individual engages in behavior until an optimal level of stimulation has been reached.

Zentall (1975, 2005) has proposed that individuals with ADHD require higher levels of stimulation and habituate to stimulation more quickly than typical individuals. The relatively high levels of behavior observed in individuals with ADHD may function to increase the amount of stimulation and move the student into a homeostatic state of arousal. Students with ADHD who are asked to perform tasks that require little movement and high levels of sustained attention, such as those experienced in many classrooms, may act out/act inappropriately to increase their stimulation to a level that allows them to function optimally (Zentall, 2005, 1975; Zentall & Zentall, 1983). The positive effects observed in this population after MVPA may be a more appropriate means of increasing the level of stimulation to an optimal point. Thus, when a student returns to the classroom after MVPA she/he is better able to attend to the task without exhibiting stimulation seeking behaviors that may be inappropriate for a given setting.

OST suggests typically functioning students are nearer the optimal range and will therefore exhibit smaller benefits concerning behavior. Research has shown effects of exercise are stronger for students who are on task the least and exhibit more inappropriate behavior in the classroom (Drollette et al., 2014; Mahar, 2011). These findings could explain the consistently positive effects seen in studies that examined children with ADHD compared with typical students.

Similarly, in support of OST, on a neurochemical level dopamine may provide an explanation for the effects of MVPA for children with ADHD. There is evidence dopamine is related to attention and regulation in the prefrontal cortex (Glanzman & Sell, 2013). Dopamine is also associated with reward and motivation behavior as well as self-control (Arias-Carrión & Pöppel, 2007; Robbins & Arnsten, 2009), all areas of concern for students with ADHD. Children with ADHD exhibit lower baseline levels of dopamine (Levy, 1991). Thus, low levels of dopamine for children with ADHD may correlate with their limited self-control and inappropriate behavior. MVPA increases production of dopamine, which results in increased levels of dopamine delivered to synapses (McMorris, Collard, Corbett, Dicks, & Swain, 2008). As children with ADHD participate in MVPA, their levels of dopamine may increase leading to a more optimal state of functioning as OST suggests.

Intervention Implications

Research suggests students with ADHD benefit from MVPA (Archer & Kostrzewa, 2012; Grassmann, Alves, Santos-Galduróz, & Galduróz, 2014). Unfortunately, 81.5% of schools in the U.S. exclude students from physical activity for inappropriate behavior (Lee, Spain, Burgeson, & Fulton, 2007). Furthermore, opportunities to participate in physical activity have been reduced in schools to increase instruction time (Marshall & Hardman, 2000; Pellegrini & Bohn, 2005). In contrast to reducing activity levels to make additional time for academic tasks, increasing levels of physical activity may increase academic engagement and reduce problem behavior. Time away from academics while engaged in MVPA has been shown to not adversely affect academic performance (Dwyer, Coonan, Leitch, Hetzel, & Baghurst, 1983; Sallis et al., 1999; Trudeau & Shephard, 2008). In fact, MVPA has been associated with better grades (Taras, 2005; Trudeau & Shephard, 2008). Improvements seen in grades may be a result of the improvements in EF for children with ADHD. Results of this review suggest physical activity may be one possible solution for improving EF deficits in children with ADHD.

One study used a unique task that may help teachers to measure improvement in inhibition and self-control in a school setting. This research had young children with ADHD in grades K-3 participate in an eight-week intervention (Smith et al., 2013). In each session, children completed 26 minutes of aerobic games (e.g. tag). To assess changes in EF researchers had the children play a recess game of Red light/Green light. This task showed measurable improvements in response inhibition. For teachers, this is particularly noteworthy as a task to observe, in their own setting, the effectiveness of MVPA for students with ADHD.

Early intervention is important, and results showing children as young as 5 years old improved EF is one reason to consider early adoption of having children with ADHD participate in MVPA (Chang et al., 2014; Smith et al., 2013). Additionally, the finding that students already taking medication still benefit from participating in MVPA is particularly promising (Kang et al., 2011; Medina et al., 2010). In some instances use of stimulant medication in conjunction with behavioral supports allows for a reduction in dosage of medication while maintaining maximum behavioral benefits (Carlson, Pelham, Milich, & Dixon, 1992; Fabiano, Pelham, Gnagy, Burrows-MacLean, & al, 2007). Research is needed to identify if MVPA can be combined in a similar fashion. Perhaps addition of MVPA with stimulant medication may support a reduction in medication dosage while maintaining behavioral benefits.

Given the deficits in EF experienced by children with ADHD, MVPA provides teachers with a user-friendly approach to positively impact EF for this population. Consider the following typical scenario. A teacher asks students to return to their seats, get out their books, turn to page 21, and read to the end of the chapter. Minutes pass and as the teacher circulates around the room, she finds the student with ADHD sitting with a closed book doing nothing, having only remembered the first of several instructions. Similarly, a student may blurt out answers in class at inappropriate times. These applied examples of updating and inhibition are common problems faced in classrooms every day. Teachers may find MVPA an efficient and cost-effective method for improving EF of students with ADHD. A recent meta-analysis that synthesized data for children with ADHD suggests short, variable intensity exercises that are frequent and varied provide optimal improvements in behavior and academic engagement (Hart & Lee, in review). The current paper taken together with the findings of Hart and Lee suggest MVPA can improve EF for children with ADHD in as few as five minutes by using a variety of exercises ranging in intensity, duration, and frequency.

It appears symptoms of ADHD decline as children move into adulthood; yet 15% of adults age 25 continue to meet diagnosable criteria, and 65% meet a definition of ADHD in partial remission (Faraone, Biederman, & Mick, 2006). Further, in a ten year follow-up study 78% of participants reported a persistence in symptoms and functional impairments into early adulthood (Biederman, Petty, Evans, Small, & Faraone, 2010). Some of these symptoms include lower educational attainment, lower job performance and potential firing, fewer close friends, and increases in sexually transmitted diseases (Barkley, Fischer, Smallish, & Fletcher, 2006). Given the potential for lifelong impairment, promotion of MVPA as an ameliorative intervention is easy to justify, particularly when MVPA has been shown to be effective for both children (Memarmoghaddam et al., 2016) and adults with ADHD (Den Heijer et al., 2017).

Conclusion

Children with ADHD experience deficits in EF, with two key deficits being inhibition and updating. Research using event related potentials has shown children with ADHD increase P3 amplitude and reduce P3 latency, suggestive of increased allocation of attentional resources. Intervention studies using MVPA with children with ADHD have shown improvements in EF, particularly in inhibition and updating. Increases in dopamine levels, after participating in MVPA, may support OST as a theoretical perspective for the effects of exercise. MVPA may serve to improve classroom behavior for children with ADHD. In summary, there is evidence MVPA can be effective at improving EF resulting in improved inhibition, updating and shifting; leading to improvements in behavior and academic engagement for children with ADHD. Those improvements may also carry over to improved outcomes in adults above and beyond the physiological benefit of participating in a program of MVPA.

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