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Exercise and Attention-Deficit Hyperactivity Disorder: A Systematic Review

Jason Sarff

St. Catherine University, jasonbsarff@gmail.com

Exercise and Attention-Deficit Hyperactivity Disorder: A Systematic Review

by

Jason B. Sarff, B.A.; J.D.

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Committee Members

Courtney Wells, MPH, MSW, Ph.D., (Chair)
Chelle York, MSW, LICSW
Donna M. Brengman, MSW, LICSW

The Clinical Research Project is a graduation requirement for MSW students at St. Catherine University/University of St. Thomas School of Social Work in St. Paul, Minnesota and is conducted within a nine-month time frame to demonstrate facility with basic social research methods. Students must independently conceptualize a research problem, formulate a research design that is approved by a research committee and the university Institutional Review Board, implement the project, and publicly present the findings of the study. This project is neither a Master's thesis nor a dissertation.

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Abstract

This study examined the role of exercise as a moderator of executive functioning for children with attention-deficit hyperactivity disorder (ADHD). Specifically, the hypothesis that exercise enhances the executive functioning of children with ADHD and promotes enhanced wellbeing was explored. Topics examined included the type of exercise, duration, severity, and other critical factors that play a role in the efficacy of exercise as a possible adjunct intervention for children with ADHD. A systematic review was utilized to identify literature from the SocINDEX and PsycInfo databases, with a variety of search terms utilized to identify articles exploring the impact of exercise on children with ADHD. Results from the study suggest that exercise may positively moderate inhibitory control and other key aspects of executive functioning to aid children with ADHD.

Exercise and Attention-Deficit Hyperactivity Disorder

Data from the Centers for Disease Control and Prevention (CDC, 2016) paints a startling picture of the number of children who are affected by attention-deficit hyperactivity disorder (ADHD). More than six million children in the U.S. have been diagnosed with ADHD. The percentage of children who have been diagnosed with ADHD has increased substantially in recent years, from 7.8% in 2003 to 11% in 2011. Research suggests that boys are two times as likely as girls to have ADHD (American Psychiatric Association [APA], 2013).

While the precise etiology of ADHD is not known (Black & Andreasen, 2014), it is described in the Diagnostic and Statistical Manual (DSM-5) as a neurodevelopmental disorder (APA, 2013). The primary DSM-5 criteria for a diagnosis of ADHD are "inattention and/or hyperactivity-impulsivity that interferes with functioning or development" (APA, 2013, p. 59). Attention, concentration, and impulse control are cognitive functions commonly associated with executive functioning (Piepmeier et al., 2015). Although many children have problems with attention and impulsivity, children with ADHD experience such problems with greater frequency and severity (National Institute of Mental Health [NIMH], 2013).

Finding ways to effectively help children who have ADHD is critically important to social workers. School social workers, clinical therapists, skills workers, and other social work practitioners work daily on behalf of children who are facing challenges resulting from ADHD. Helping people who are vulnerable is a particular value of social workers that is mandated by the National Association of Social Work's (NASW, 2016)

Code of Ethics. Children with ADHD are uniquely vulnerable because of their age and the symptoms of their disorder.

Children with ADHD often face significant challenges and hardships. Children with ADHD are more likely to suffer from low self-esteem, depression, suicidal ideation, and substance use problems (Smith, Molina, & Pelham, 2002; The University of Chicago Medicine, 2010). In addition, children with ADHD often face greater scholastic challenges (e.g. diminished grades, standardized test scores) than children who do not have an ADHD diagnosis (NIMH, 2013).

Despite these challenges, most children who have been diagnosed with ADHD can achieve success at school and enjoy productive lives with effective services and treatment (NIMH, 2013). Best practices for the treatment of ADHD currently call for a combination of medication and behavioral therapy (CDC, 2016). However, many children with ADHD are being treated exclusively with medication (CDC, 2016). In addition, medication has its limitations (Gapin & Etnier, 2010). The utilization of medication, duration of its impact, and extent of its efficacy show meaningful variation (Chang, Liu, Yu, & Lee, 2012; Hoza et al., 2015). Gapin and Etnier (2010) have noted,

> While stimulant medications have proven efficacious in treating the core symptoms of AD/HD 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 (p. 754).

Accordingly, parents, teachers, social workers, and other concerned parties are searching for new ways to help children who have an ADHD diagnosis.

One possible alternative (or supplement) to ADHD medication that has been the subject of research is physical exercise (Piepmeier et al., 2015). An extensive body of research suggests that exercise enhances cognitive functioning (Barenberg, Berse, & Dutke, 2015; Chen, Yan, Yin, Pan, & Chang, 2014). In particular, some research has demonstrated that exercise helps to promote executive functioning (Chen et al., 2014). Accordingly, this study is conducted to examine whether exercise is an effective aid to children with ADHD.

Literature Review

Evidence from research paints a promising, but somewhat clouded picture of exercise as a possible ADHD intervention for children (Piepmeier et al., 2015). Considerable research has demonstrated that exercise enhances certain types of cognitive functioning (Chang & Etnier, 2009). Significantly, exercise and enhanced aerobic fitness may promote increased basal ganglia volume (Chaddock et al., 2010) and cerebral blood flow (Gapin & Etnier, 2010). One limitation of existing research, however, is that few exercise studies have utilized child participants with an ADHD diagnosis (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Piepmeier et al. (2015) have noted:

> [T]here is a paucity of research exploring whether or not exercise may benefit the cognitive performance of children with ADHD. In fact, to date, there have only been a small number of studies that explored the effects of acute exercise on cognitive performance in children with ADHD (p.98).

Despite the need for additional research, however, the limited number of exercise studies that have focused on children with ADHD have yielded promising results (Hoza et al., 2015).

One way to more effectively decipher the utility of exercise as an ADHD treatment is to examine existing research that explores the impact of exercise on executive functioning (Gapin & Etnier, 2010). Given that children with ADHD may struggle due to executive functioning challenges, interventions that aid in the enhancement of executive functioning may prove effective (Gapin & Etnier, 2010). However, a focus on studies that examine the impact of exercise on executive functioning is not without challenges. Issues pertaining to the definition of executive functioning (Etnier & Chang, 2009), intensity of exercise interventions (Chang & Etnier, 2009; Labelle, Bosquet, Mekary, & Bherer, 2013), and the timing of post-test measurements (Hung, Tsai, Chen, Wang, & Chang, 2013) must be explored to clarify the role of exercise as a potential treatment for ADHD.

Defining Executive Functioning

Although research has long confirmed the value of exercise as a means of enhancing certain types of cognitive functioning, the focus on exercise as a possible means of enhancing executive functioning is relatively new (Chang et al., 2014). In addition, much of the research focusing on exercise as a moderator of executive functioning has focused on older adults (Gapin & Etnier, 2010). However, a growing interest in exercise as a possible means of enhancing executive functioning in children has led to a promising field of study in recent years (Chang, Hung, Huang, Hatfield, & Hung, 2014).

Etnier and Chang (2009) have defined executive functioning in the following manner:

> Executive function, also known as controlled cognition, resource-demanding cognition, or executive control, is generally defined as a 'higher level' or 'meta-' cognitive function that manages other more basic cognitive functions (Alvarez & Emory, 2006; Baddeley, 1986; Salthouse, 2007) and the regulation of emotions and attention (Bell & Deater-Deckard, 2007; Blair & Diamond, 2008; Lewis et al., 2008) necessary for purposeful and goal-directed behaviors (p. 470).

Clarifying the role of exercise as a moderator of executive functioning is challenging because exercise studies have often focused on different aspects of executive functioning (Etnier & Chang, 2009). Indeed, there is a certain degree of controversy concerning the proper utilization of the term. Despite the fact that executive functioning includes numerous components that may be differentiated, much of the existing research focuses on one aspect of executive functioning or utilizes highly-generalized conceptions of the term that may create confusion for those attempting to interpret research findings (Etnier & Chang, 2009).

To provide greater clarification, Etnier and Chang (2009) have urged researchers to take a more calculated approach:

> Researchers examining the effect of physical activity on executive function are encouraged to consider the complexity of the executive function construct and to give careful consideration to whether to include multiple measures of executive function to identify the effect on the broad construct of executive function or to

> focus on a specific executive function (e.g., shifting, inhibition, or updating) in their research (Miyake, Emerson, & Friedman, 2000a; Miyake et al., 2000b; Salthouse, 2007) (p.472).

Types of Executive Functioning

Etnier & Chang (2009) have suggested that executive functioning is an "umbrella term" (p.472) for higher-level brain functioning associated with the frontal lobe. Although there are dozens of types of executive functions that have been identified by researchers, the types most commonly examined in exercise studies include inhibition, planning, working memory, and scheduling (Etnier & Chang, 2009). Other types of executive functioning that have served as the focus of exercise research studies include switching, attention, updating, and set-shifting (Biederman et al., 2004; Etnier & Chang, 2009).

Etnier and Chang (2009) have noted that the term inhibition refers to the ability to inhibit a learned or habitual response. Pontifex et al. (2013) have noted that inhibition may be the most critical area of inquiry regarding the potential impact of exercise as a treatment for ADHD. In particular, Pontifex et al. (2013) have observed:

> Research suggests that failures in inhibitory control . . . may represent the core cognitive deficit underlying the manifestation of ADHD. Specifically, a growing body of research has suggested that ADHD-related deficits in inhibitory control are associated with failures in the cascade of processes underlying the stimulus-response relationship, including reductions in the allocation of attentional resources . . . (p. 543).

The other types of executive functioning that have drawn particular interest for their relation to ADHD symptoms include set-shifting, working memory, planning, and attention (Biederman et al., 2004; Gapin & Etnier, 2010; Piepmeier et al., 2015; Pontifex et al., 2013). Accordingly, exercise studies that focus on inhibition individually, or studies that focus on these particular subsets of executive control in an individual or cumulative fashion offer unique insight into the role of exercise as a potential aid to children with ADHD (Etnier & Chang, 2009; Pontifex et al., 2013).

Exercise Procedures

Analyzing the effect of exercise as a moderator of executive functioning is challenging due to the wide range of exercise interventions that have been utilized by research studies (Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010). Exercise interventions have varied by intensity (low, moderate, high intensity), frequency (acute single-bout vs. prolonged exercise regimens), and duration (number of minutes exercise is performed) (Chang & Etnier, 2009; Hung et al., 2013; Labelle et al., 2013).

The concerns about the definition of executive functioning and variations regarding exercise intensity, frequency, and duration cloud the already muddied water of exercise interventions and their potential role as an aid to children with ADHD. A systematic review of the literature is required to analyze the data and decipher themes from the existing literature to provide teachers, school administrators, social workers, and other concerned parties information to facilitate a more thorough understanding of exercise's effectiveness as a possible ADHD intervention.

Accordingly, the purpose of this systematic review is to gather and analyze research findings regarding exercise and ADHD to examine whether exercise is an effective aid to children with ADHD. In addition, the purpose of this research study is to promote a further dialogue about the strategic use of exercise to facilitate the academic success and wellbeing of children.

Conceptual Framework

The conceptual framework for this systematic review was guided by the ecosystems perspective (Berger, 2011) and Maslow's hierarchy of needs (Hutchison, 2011).

Ecosystems Perspective

Urie Bronfenbrenner's ecological-systems approach suggests that human behavior is significantly impacted by the systems and environmental surroundings that people experience (Berger, 2011). Describing the theory, Berger (2011) notes that Bronfenbrenner identified three primary systems that impact human behavior: microsystems, exosystems, and macrosystems.

According to Berger (2011), microsystems refer to an individual's immediate surrounding influences (e.g. family, friends); exosystems refer to larger systems (work or school district); and macrosystems refer to larger value-instilling factors, such as economic (e.g. capitalism), religious, or political institutions. The guiding principle behind the ecological approach is that people are impacted by other people, neighbors, schools, towns, communities, and national systems. In short, people do not live in a vacuum; we each influence one another in some capacity (Berger, 2011).

Similarly, children with ADHD are impacted by their parents, teachers, and schools. Finding the best way to integrate an exercise program at home and school could provide children with the multi-layered assistance they require. Each child's welfare is ultimately the responsibilities of parents, schools, and communities. Examining evidence from the available literature may help parents and schools create exercise interventions to provide children with the assistance they are entitled to receive.

Human Needs Identified by Maslow

Abraham Maslow's hierarchy of needs was instrumental in the conception of this systematic review. Maslow observed that all human beings share certain core or universal needs, ranging from lower needs (physical needs and safety) to higher needs, including love, self-esteem, and self-actualization (Hutchison, 2011). The theory holds that people may not be able to reach the highest level of human achievement until lower needs are satisfied (Hutchison, 2011).

Children with ADHD may find it difficult to reach their full social and educational potential if physiological stressors (e.g. hyperarousal) create difficult challenges (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008). Accordingly, an exercise program that enhances executive functioning for children with ADHD presents an exciting and rewarding focus of study (Budde et al., 2008).

Methods

This study utilized a systematic review to identify and collect data about the impact of exercise on children with ADHD. The study included specific inclusion and exclusion criteria and data collection measures to identify and analyze findings from exercise research studies.

Research Design

This study utilized a systematic review. Milner (2015) has noted, "Systematic reviews are a type of literature review in which authors systematically search for, critically appraise, and synthesize evidence from several studies on the same topic" (p. 89). Systematic reviews are favored in evidence-based practice due to their use of transparent and thorough methods to limit researcher bias (Milner, 2015). A systematic review was chosen for this study to summarize the findings from numerous studies and explain the complex interplay between exercise and ADHD in a concrete and succinct fashion.

An initial cursory review of ADHD literature revealed two central aspects that shaped this systematic review. First, the number of exercise studies that specifically utilized child participants with ADHD was limited (Pontifex et al., 2013). Therefore, a method of expanding the scope of inquiry beyond studies focusing exclusively on the impact of exercise on children with ADHD was required. Second, an initial review suggested that a core component of ADHD is executive functioning challenges (Gapin & Etnier, 2010). Therefore, the focus of this review was expanded to include studies utilizing slightly older participants (maximum mean age 19) and studies highlighting the impact of exercise interventions on executive functioning and other cognitive benefits.

Data Collection and Analysis

Two databases were utilized for this systematic review. The first was the SocINDEX and the second was PsycInfo. SocINDEX was utilized for its inclusion of articles from a variety of social work domains and PsycInfo was utilized for its abundance of research studies that examine cognitive functioning. A variety of searches were performed utilizing combined search terms. Search terms included: exercise and attention-deficit hyperactivity disorder, exercise and ADHD, exercise and executive functioning, and exercise and executive function.

Selection criteria were utilized to ensure that studies most relevant to the study's purpose were identified and included in the review. The term exercise was defined to include all forms of aerobic and resistance exercise of light, moderate, or high-intensity, with the following exception: Studies focused on yoga and tai-chi were excluded from consideration due to their meditative or mindful focus, which may produce distinct outcomes that vary from traditional forms of aerobic or resistance exercises (Netz & Lidor, 2003).

For this review, the maximum mean age of study participants was limited to 19 years to avoid the inclusion of studies focusing on elements commonly associated with aging, such as dementia and early cognitive decline. Literature reviews (e.g. meta-analysis reviews) and cross-sectional studies demonstrating correlational trends were not included in the results section of this study, but such reviews and studies are utilized throughout this review as sources to define terms, elucidate concepts, or otherwise aid in the objectives of this study. The date range for searches was 1994 to 2015. This study was limited to a review of studies described in peer-reviewed articles that included an exercise intervention and incorporated a consideration of the impact of exercise on cognitive functioning.

The searches yielded a total of 669 identified results. Each of the results were viewed electronically to view the article titles and abstracts. The titles and abstracts were analyzed to determine which articles met the selection criteria guidelines noted herein. Articles excluded for further review included articles with abstracts indicating that the mean participant age was over 19, the study was cross-sectional in nature, the study featured no exercise intervention, the intervention was yoga or tai chi, and articles that were described as literature or systematic reviews. All other articles were downloaded electronically and the body of the article was reviewed further to determine if the study met the criteria noted herein.

A total of 36 articles met the selection criteria for this systematic review. Thereafter, data was collected from the retrieved articles that met the selection criteria.

Data from the retrieved articles were utilized to analyze key variables relevant to the consideration of exercise's impact on cognitive functioning, including the research study's sample size, mean participant age, exercise intensity (low, moderate or high intensity), duration (number of minutes the exercise is performed), and frequency (single-bout, number of days or weeks), and factors emphasizing the results (e.g. type of executive function examined and impact of the exercise intervention).

Protection of Human Participants

This systematic review focused on published, peer-review journals that constituted publically available data. Accordingly, no new research involving human participants was performed for this study and no protection was required.

Results

The results from the studies that met selection criteria for this systematic review suggest a promising, but complex picture of exercise as a possible aid to children with ADHD. The results are divided into four categories to provide greater clarity: 1) Studies Utilizing Child Participants with ADHD; 2) Studies of children without ADHD inclusion criteria; 3) Studies of young adults; and 4) Exercise variables.

Studies Utilizing Child Participants with ADHD

Nine of the 36 studies that met selection criteria for this systematic review included selection criteria that specifically sought the inclusion of children with ADHD. Results from these studies are summarized below, with discussions of inhibitory control and other key domains of executive functioning, followed by a detailed description of the studies.

Inhibitory control. Critically, the studies that focused on children with ADHD provided strong support for the idea that exercise can help children with ADHD improve their level of inhibitory control. Specifically, Piepmeier et al. (2015), Pontifex et al. (2013), and Chang et al. (2012) demonstrated results suggesting that exercise may significantly improve the inhibitory control of children with ADHD. In addition, the findings of Chang et al. (2014) suggested that exercise may enhance the restraint inhibition domain of behavioral inhibition.

Significantly, none of the nine studies focusing on children with ADHD that isolated inhibitory control as a stand-alone variable suggested that exercise does not enhance inhibitory control. However, Silverstein and Allen (1994) did conclude in more general terms that a vigorous-intensity exercise intervention did not reduce the hyperactive behavior of a three-year-old boy with ADHD. Unique factors present in this study may limit its generalizability, however, including sample size (n = 1), exercise intensity (vigorous as opposed to moderate intensity), and the boy's lack of interest in the exercise intervention (he was described as running away from the exercise protocol frequently). However, the research may also point to differences in the developmental trajectory of executive functioning, as preschool children may differ in the ability to enjoy the same cognitive benefits from exercise as older children (Silverstein & Allen, 1994). Critically, the Silverstein and Allen (1994) study was the only study of pre-school age children that met criteria for this systematic review. Accordingly, further research on the utility of exercise as an aid to pre-school children with ADHD is warranted.

Other key domains of executive functioning. Eight of the nine studies focusing on children with ADHD found that exercise improved at least one facet of executive functioning. The four studies noted immediately above suggest the salutary impact of exercise on aspects of inhibitory control. In addition, Hill et al. (2011) found that exercise promoted enhanced attention. Similarly, Hoza et al. (2015) reported findings from parental assessments suggesting that exercise decreased inattentiveness and moodiness (teacher assessments differed, however). Taylor and Kuo (2009) found that a low-intensity walk in a city park facilitated enhanced concentration. However, results from this study suggested the possibility that time spent in nature provided the most critical component of the enhanced concentration. Critically, Pontifex et al. (2013) found that exercise promotes significant enhancements of regulatory processing as well as enhancements to academic performance, including arithmetic and reading.

Despite these favorable results, disparities regarding some domains of executive functioning were present in the studies of children with ADHD. For example, Gapin and Etnier (2010) found that exercise promoted enhanced planning ability, whereas Piepmeier et al. (2015) found no association between exercise and improved planning. Significantly, both studies focused on children with ADHD who were similarly aged. However, all of the 18 participants in the Gapin and Etnier (2010) study were boys, whereas the Piepmeier et al. (2015) study focused on nine male and five female participants.

Another possible explanation for the differing results is the nature of the exercise interventions. Gapin and Etnier (2010) utilized a seven day intervention of moderate to vigorous exercise, whereas Piepmeier et al. (2015) utilized a single bout of exercise of moderate intensity. Individual characteristics of the participants may also provide an explanation for the disparate results. For example, Tine and Butler (2012) tested one aspect of executive functioning (selective attention), and found that children of lower-income parents and children with lower initial pretest scores on this domain of executive functioning enjoyed greater gains. Similarly, some studies have suggested that preexisting levels of fitness (Crova et al., 2014) are key variables to assess.

Set shifting was another executive functioning domain that was marked by disparate results. The findings of Chang et al. (2012) suggest that exercise may enhance set shifting, whereas the findings of Piepmeier et al. (2015) found no similar gains. Both studies focused on a single bout of a moderate-intensity aerobic exercise, with similar types of exercise (cycling versus treadmill). Similar to the analysis above, the Chang et al. (2012) study focused primarily on boys (37 boys, 3 girls), whereas the Piepmeier et al. (2015) study was more evenly mixed (nine boys, five girls). Differences in study methods and individual participant characteristics could also provide explanations for the disparate results (see below for further details).

Study descriptions. Piepmeier et al. (2015) conducted a randomized-control study to determine the effects of exercise on the cognitive performance of children. The researchers noted that prior research suggests the value of exercise as an intervention to improve the cognitive performance of children. Building on existing research, Piepmeier et al. (2015) sought to determine if exercise could provide similar benefits of enhanced cognitive performance to children with an ADHD diagnosis. Specifically, the study focused on the effect of exercise on the executive functioning of children with and without ADHD, including inhibitory control, speed processing, planning, or set shifting functions.

The study participants included 14 students with an ADHD diagnosis and 18 students without ADHD from a private K-12 school, with a mean age of 10.75 years. The study utilized a single-bout (one bout of exercise), moderate-intensity exercise intervention. The intervention consisted of a cycling exercise for a duration of 30 minutes, with 20 minutes of active exercise and five minute periods of warm-up and cool-down.

The exercise intervention facilitated enhanced levels of speed processing and inhibitory control for students with ADHD, but did not facilitate enhanced planning or set-shifting. The findings suggest that a single-bout of moderate exercise may significantly improve inhibitory control, which is essential for children with ADHD. Accordingly, the study suggests the utility of an exercise program to provide coordinated care to students with an ADHD diagnosis.

The second study examined for this systematic review that utilized child participants with an ADHD diagnosis was conducted by Pontifex et al. (2013). The study examined the effect of exercise on the cognitive functioning of children. Specifically, the study utilized a single-bout, moderate-intensity aerobic (treadmill) exercise intervention to examine the effect of exercise on the executive functioning and academic performance of children with and without ADHD. Students in the control group engaged in a reading activity while seated. The study included 20 students (mean age nine years) with an ADHD diagnosis and 20 students without an ADHD diagnosis.

The study revealed that child participants with and without ADHD experienced significant enhancements to their regulatory processing, inhibitory control, and academic performance. Students experienced enhanced cognitive functioning relating to reading and arithmetic. The study constitutes a valuable addition to the existing body of research which suggests that exercise may be utilized as an effective intervention for children with ADHD.

Gapin and Etnier (2010) provided additional support for the role of exercise as a means of enhancing the executive functioning of children with an ADHD diagnosis. The researchers studied the effects of exercise on 18 child participants with an ADHD diagnosis. The study utilized a moderate to vigorous exercise intervention over a period of seven days which was measured by an accelerometer. All of the child participants were boys, with a mean age of 10.61 years. Two factors that make the Gapin and Etnier (2010) study unique are the duration of exercise which was monitored (seven days, as opposed to single-bout interventions) and the inclusion of child participants with ADHD who were taking medication. All of the 18 child participants had been prescribed ADHD medications. Accordingly, the study provides valuable insight to those who wish to study whether exercise can be used as an adjunct to pharmaceutical interventions. The results are promising, with demonstrated gains by the child participants in enhanced planning ability, a core component of executive functioning (Gapin & Etnier, 2010).

Hoza et al. (2015) added significant value to the existing body of ADHD-specific research with their study of exercise as a moderator of executive functioning in children. The study benefitted from a large sample size (n = 202), which included 94 children who were identified as ADHD at-risk youth (significant observed DSM-IV criteria) and 108 child participants without ADHD. Compared to many studies that focus on single-bouts of exercise, Hoza et al. (2015) utilized a 12-week exercise intervention of moderate to high intensity. The study's findings indicate that an extended exercise program for young children (mean age 6.83 years) can yield positive results, as the study's participants who were ADHD at-risk experienced reduced inattentiveness and moodiness, as observed by parents. However, teacher observations did not observe similar cognitive functioning enhancements. Of note, the study also found by means of chance (control intervention) that a sedentary art program prior to the start of school may also have provided limited cognitive rewards to children with ADHD.

Chang, Hung, et al. (2014) conducted a study consisting of 30 participants with ADHD. Half of the participants were placed in an exercise intervention and the other half were placed in a non-exercise control. The exercise intervention consisted of moderate-intensity aquatic exercise and a set of coordinated exercises. The total duration of the exercise intervention was eight weeks, with twice-weekly swimming lessons lasting 90 minutes. Final data from 27 participants (23 male, 4 female, mean age 8.44 years) were utilized to determine that the exercise intervention enhanced executive functioning, including the restraint inhibition aspect of behavioral inhibition. Significantly, the authors expressed the notion that behavioral inhibition may constitute the most significant challenge to children with ADHD.

Chang, Liu et al. (2012) focused on the impact of a single bout of moderate-intensity aerobic exercise on children with ADHD. The study included 40 children (37 boys, 3 girls, mean age 10.43) with ADHD who were divided into an exercise intervention group (n = 20) and a control group (n = 20) that watched a video. The children who performed a treadmill exercise demonstrated improved executive functioning, including enhanced inhibition and set shifting. The researchers opined: “The tentative explanation for the exercise effect may be the allocation of attention resources, influences of dorsolateral prefrontal cortex, and induction of exercise-induced dopamine” (p. 234).

Hill, Williams, Aucott, Thomsom, and Mon-Williams (2011) conducted a study that examined results from 552 child participants (257 female, 295 male, mean age 9.8 years). More than half of the children presented with some ADHD symptoms, with 54 children showing “Clinical symptom level” (p. 633) and 261 children showing “Subclinical symptom level” (p. 633) symptoms. The children were placed into a two-week intervention that called for one week of class-based exercise and one week without an exercise intervention. The groups were counterbalanced, with one group exercising the first week and the other group exercising the second week. The daily class exercise lasted a duration of 10-15 minutes and was designed to promote moderate intensity exercise, including jumping and jogging in place. The children performed a comprehensive cognitive battery of tests. The researchers described the tests as “mental tracking tasks” (p. 631), which included (amongst other cognitive skills), children’s ability to shift attention.

The researchers found “In week 2 the exercising group significantly outperformed the non-exercising group (3.85 [CI 0.26-7.44])” (p. 633). The researchers noted that the confidence levels should be considered when assessing the strength of the results. A noteworthy finding was that body mass index, ADHD symptomology, and sex did not impact the nature of the improvements facilitated by exercise. In addition, the researchers described the study participants as constituting a “diverse socio-economic population” (p. 633). Accordingly, the researchers concluded, “Our findings suggest that any such programmes may be as usefully applied to whole groups of children as to selected individuals with recognized attention difficulties” (p. 634).

Taylor and Kuo (2009) conducted a study of 17 child participants (15 boys, 2 girls, mean age 9.23) to determine how physical settings impact the attention levels of children with ADHD. Specifically, the 17 children with ADHD each took three guided walks in a city park, downtown area, and residential area. Each area was described as “well-kept” (p. 402). The results of a test of concentration revealed that children experienced significantly more enhanced levels of attention after the walk in the city park, prompting the researchers to suggest that time spent in nature can uniquely enhance the attention of children with ADHD. Significantly, each of the three 20-minute walks were performed at a “relaxed pace” (p. 404) and results from the city walk were comparable to the effects of methylphenidate medication.

Silverstein and Allison (1994) conducted a single-participant study with a three-year-old boy with ADHD to determine if exercise was an effective intervention to reduce ADHD symptoms. The child participant was enrolled in a 20-minute jogging intervention (vigorous intensity, 65%-80% maximum heart rate) for a duration of several weeks. The child was taking a prescribed medication for ADHD and the study called for a review of the efficacy of medication versus an exercise and placebo intervention. The results suggested that exercise resulted in higher amounts of hyperactive behavior than the medication or placebo interventions.

Studies of Children without ADHD Inclusion Criteria

A total of 25 child studies that did not include ADHD-specific inclusion criteria were reviewed in conjunction with this systematic review. Results from the studies suggest considerable cause for optimism.

A total of 19 of the 25 studies specifically found that exercise enhanced some aspect of executive functioning. In addition, three of the remaining five studies demonstrated results suggesting that an exercise program might provide significant value to children with ADHD. Specifically, Hillman et al. (2009) found an association between fitness and enhanced executive functioning; Cooper et al. (2012) found that exercise facilitates certain domains of general cognitive functioning; and Stroh et al. (2009) found an association between fitness and enhanced executive functioning, but did not find that a single-bout of exercise facilitated enhanced cognitive functioning.

Only three of the 25 studies did not provide results finding some positive impact of exercise on executive functioning, and two of the three studies had unique purposes and methodologies that limit their generalizability with respect to the purpose of this systematic review. Specifically, Soga et al. (2015) found that study participants who were tested five minutes after a single bout of exercise did not yield enhancements in executive functioning. Tomporowski et al. (2008) found that a single bout of exercise did not promote enhanced task switching. However, the study focused on task switching. Huertas et al. (2011) found that exercise did not enhance the executive functioning of their study participants. However, the study participants were tested during exercise, as opposed to after exercise.

Study descriptions. Eom et al. (2014) conducted a study designed to determine if exercise could enhance the executive functioning of children with epilepsy. The study's 10 participants (mean age 9.7 years) completed a five-week exercise program, which consisted of twice-weekly supervised exercise sessions of three hours (two 90-minute sports activities) and a recommended period of exercise at home totaling 10-15 minutes. The study found that participants who participated in the exercise intervention experienced significant enhancements in attention (sustained, divided, visual, and audio attention) and psychomotor speed. While it is difficult to determine if the study's findings concerning children with epilepsy are generalizable to children with ADHD, the study provides additional support to the existing body of research suggesting the efficacy of exercise as a positive moderator of executive functioning.

Hillman, Buck, Themanson, Pontifex, and Castelli (2009) conducted research to determine if a single-bout of aerobic exercise could enhance the cognitive control and academic ability of preadolescent children. The child participants (n = 20) had a mean age of nine and a half years and completed an acute-bout, moderate-intensity, aerobic exercise intervention (treadmill walking) lasting 20 minutes. The child participants who performed the exercise intervention achieved improved marks on a reading achievement test. In addition, the children who exercised demonstrated increased response accuracy on a cognitive test and increased P3 amplitude, which many researchers associate with executive functioning (Hillman et al., 2009).

Cooper et al. (2012) focused their efforts on the effects of exercise on 45 adolescents (mean age 13.3 years). Utilizing an exercise consisting of 10-minutes of shuttle runs with 30 second breaks between each run, the researchers noted that adolescents exposed to the exercise intervention showed improved cognitive functioning in several cognitive domains. One strength of the study is the discussion, which speculates that disparities amongst exercise studies may potentially be explained by the duration, severity, and cool-down period allowed prior to cognitive testing. Specifically, the researchers opined that exercise causes cognitive arousal with a stimulating effect on executive functioning, whereas fatigue from significant exercise (e.g. intensity or duration) may encumber some aspects of cognitive functioning. The researchers concluded that schools may benefit from the creation of exercise programs specifically tailored to the needs of students.

Budde et al. (2008) added to the body of existing research with their study of 115 child participants (mean age 14.98 years) who completed a moderate-intensity exercise intervention. The study's findings suggest that a single-bout of moderate-intensity exercise may enhance concentration and attention.

Jager, Schmidt, Conzelmann, and Roebers (2014) conducted a study with a sample size of 104 participants (54.8% girls, 45.2% boys, mean age 7.9 years). Half of the study participants took part in a 20-minute exercise intervention that utilized a combination of aerobic exercise (e.g. running) and a cognitive task (e.g. listening to a song and following directions). The participants who performed the exercise intervention achieved significantly higher levels of inhibition, but did not achieve enhanced ability regarding updating or shifting. The researchers noted that exercise may enhance executive functioning by altering cortisol levels.

Chen et al. (2014) focused on third grade and fifth grade students to determine if an acute bout of moderate jogging for 30 minutes could stimulate enhanced executive functioning. The randomized-control study included results from 34 third-grade students (16 girls, 18 boys) and 53 fifth-grade students (26 girls, 23 boys, 4 absent). The results suggest that an acute bout of aerobic exercise (jogging) facilitated enhanced executive functioning, including improved inhibition, working memory, and shifting in both age groups. The researchers noted that the exercise intervention included a social aspect and a more cognitively demanding aspect than standard stationary bicycle interventions because the child participants jogged on a field with other students. The researchers suggested the possibility that socialization and increased cognitive demands might have provided an additional aid to cognitive functioning beyond the benefits of the more commonly utilized stationary bicycle interventions.

Chang, Tsai, Chen, and Hung (2013) conducted a study of 26 child participants (13 boys, 13 girls, mean age 7 years) to examine the impact of an eight-week soccer intervention. Child participants in the exercise group played soccer twice weekly for 35 minutes (low to moderate intensity). The results demonstrated that students who played soccer for eight weeks showed improved performance on an inhibitory control task. The researchers discerned no significant difference between low and moderate-intensity exercise (soccer), concluding that both spurred enhanced executive functioning at levels that were approximately equal.

Pirrie and Lodewyk (2012) examined the impact of an aerobic exercise intervention on the cognitive functioning of students from an elementary school (22 boys, 18 girls, mean age 9.75 years). The students who participated in a one-hour physical education class performed approximately 20 minutes of moderate-to-vigorous exercise consisting of a variety of tasks, including hopping and moving to designated locations to perform cognitive tasks. The results revealed that the exercise intervention facilitated enhanced planning. More specifically, the researchers noted that planning implicates various aspects of executive functioning that promote problem solving and behavioral regulation. The researchers noted:

> These skills are important for success in the learning environment, but also for the child's mental health in general as they interact with their environment. Thus the inclusion of an acute PA in the school day may lead to physical and mental health benefits (p. 96).

However, the study also revealed less positive results. The researchers noted, "No improvement was observed for attention, stimulus processing, or successive processing"

(p. 93). Accordingly, Pirrie and Lodewyk (2012) opined that the nature of the exercise intervention may have imposed some limitations. Specifically, the researchers noted the exercise intervention may have been too strenuous due to its inclusion of a period of high-intensity exercise, and they suggested the possibility that a more coordinative and cognitively demanding exercise intervention may have more effectively enhanced the above-noted aspects of executive functioning.

Vazou and Smiley-Oyen (2014) examined the impact of an acute-bout of exercise on the executive functioning of children (35 participants, mean age 10.5 years). The exercise intervention consisted of various coordinative exercises of moderate to vigorous intensity for a duration of 10 minutes. The results revealed that children who performed the exercise intervention enjoyed improved inhibitory control, but no positive impact was derived for working memory or cognitive flexibility.

Krafft et al. (2014) examined the impact of an eight-month afterschool exercise program on the “white matter integrity (WMI)” (p.1) of children between the ages of eight and 11 (approximate mean age of 9.5 years). Child participants were divided into an exercise intervention (*n* = 10) and a sedentary control group (*n* = 8). The exercise intervention consisted of daily aerobic activities, including jumping rope and tag for 40 minutes (161 heartbeats per minute average). The results suggested that higher levels of attendance in the afterschool exercise program was associated with increased WMI. The researchers noted, “In the overall sample, increased WMI was associated with improved scores on a measure of attention and improved teacher ratings of executive function” (p.1).

Crova et al. (2014) conducted a study of 70 children (mean age 9.6 years) to examine the associations between fitness and two aspects of executive function: working memory and inhibitory control. In addition, the study considered the impact of complex coordinative skills and cognitive demands on executive functioning.

The study found significant differences between fit and unfit children for inhibitory control (fitness associated with greater inhibitory control), but no significant differences for working memory. Children were divided into a traditional physical education class and an enhanced education class that utilized a six-month tennis intervention. The researchers concluded, "Overweight children, compared to their lean peers, showed a higher improvement of inhibitory ability after the intervention period, but only if they were involved in the enhanced PE programme . . . (p.208). Accordingly, the study provides at least two critical insights to the body of existing research. First, coordinative and cognitively challenging exercise might provide a better avenue for enhancing children's executive functioning than more basic exercise interventions (e.g. stationary bicycles or treadmills). Second, children who are overweight might receive more of a benefit from specialized exercise interventions than their higher-fit peers.

Hillman et al. (2014) utilized a randomized-control trial involving 221 children (age seven to nine years) who were divided into a nine-month, afterschool exercise intervention and a wait-list control. Children in the exercise group performed moderate-to-vigorous aerobic activities for a minimum of 70 minutes. The afterschool program was offered 150 of 170 school days. Children in the exercise program exhibited enhanced executive functioning, including improved inhibition and cognitive flexibility. The researchers noted, "The provision of a 9-month randomized controlled PA intervention . . . significantly improved brain and behavioral indices of executive control" (p. 1068). Accordingly, the researchers warned that school policies that reduce children's physical activity may have adverse educational outcomes given the positive association between executive control and math and reading proficiency.

Anderson-Hanley, Tureck, and Schniederman (2011) conducted two pilot studies to examine the effectiveness of exergaming to promote cognitive functioning and decrease repetitive behaviors observed in children with autism. Pilot study one enlisted 12 participants with autism spectrum disorders (mean age 14.8 years, eight boys, six girls) in a "Dance Revolution (DDR)" (p. 129) exergaming intervention. Pilot two enlisted 10 children with autism spectrum disorder (mean age 13.2 years, all boys) in a second exergaming intervention (cyber cycling).

Children in both pilot studies were subjected to executive functioning tests following a control condition (watching a video) and separate testing after the exergaming interventions. The results from the study suggest that exercise reduced repetitive behaviors and enhanced executive functioning measured by a "Digit Backwards" (p. 133) test. The results also revealed pretest and posttest improvements in tests associated with inhibitory control and task switching. However, the participants did not show improvements in these areas that reached statistical significance when compared with the participant gains in the control condition.

The researchers noted that the two exergaming interventions that were utilized involved more aerobic activity potential than some common exergames (e.g. tennis, bowling) that focus on limited arm or hand movements. Also noteworthy was the fact that the children from the study engaged in the exercise for the full 20-minute duration of the intervention, possibly demonstrating a level of interest or enjoyment. The DDR intervention included dancing on a mat that had sensors, creating an interactive effect with the game. The cyber cycling intervention included a stationary bike connected to a videogame called *Dragon Chase*. "The object of the videogame is to move, by pedaling and steering, around an open landscape, chasing floating coins and dragons, and earning points based on speed and color matching" (p.133). One limitation noted by the researchers was a lack of a quantitative measure of exercise intensity.

Similarly, Best (2012) conducted a study to assess the viability of exergaming to promote the cognitive functioning of children. The study focused on 33 child participants between the age of six and 10 years (20 boys, 13 girls, mean age 8.1 years) to examine the impact of an exergaming intervention that promoted moderate intensity exercise for a period of 20 minutes, with periodic rest breaks. The results demonstrated that a single bout of moderate intensity exercise (exergaming) promoted enhanced performance on a test of "visuospacial" (p. 1507) capacity, a type of executive functioning that promotes enhanced attention.

Stroh et al. (2009) conducted an "event-related potential (ERP)" study to examine components of ERP (P3, CNV, and N2) that have associations with executive functioning. Specifically, the study focused on 35 participants, age 13 to 14, to examine whether physical fitness and exercise influence ERP components associated with the executive function of adolescents. After determining the fitness levels of the participants and conducting an exercise intervention, the researchers concluded that physical fitness was associated with indicators of improved executive control, but an acute bout of moderate-intensity exercise (stationary bike) did not have a significant impact on cognitive processes.

Lakes et al. (2013) conducted a study to focus on the types of exercise that might be most effective in helping children enhance their levels of executive functioning. Enlisting the help of an ethnically diverse group of child participants from a public middle school in Southern California, the study tested 60 seventh-grade students (approximately one-half girls and one-half boys) at baseline and at the end of the nine-month intervention.

One group was placed in the more standard physical education class that met five days per week, and the Taekwondo group consisted of two days of Taekwondo classes and three days of the standard physical education class. The same physical education instructor that taught the students in group one also taught the students in the Taekwondo group for three days. However, the Taekwondo lessons were provided by Taekwondo master instructors who placed an emphasis on self-control and respect in addition to performing a variety of Taekwondo movements and activities. Students did not engage in sparring, but did have an opportunity to advance and earn Taekwondo belts throughout the process. Results from the study suggested that students in the Taekwondo intervention enjoyed greater gains in inhibitory control on parent-scored observations than students who were not in the Taekwondo intervention.

Huang et al. (2015) conducted a study to examine the impact of obesity and exercise interventions on the cognitive functioning of children. The study examined 115 child participants (59 girls, 56 boys, mean age 12 years) who were divided into two randomly assigned groups. One group with 59 participants took part in a six-week daily camp intervention that included health education and approximately 90 minutes of moderate to vigorous physical activity. Participants in the camp intervention continued with a 46-week family intervention which included one physical exercise day and four meetings with the parents to promote healthy dietary habits and exercise. The second group consisting of 56 child participants utilized a six-week intervention that included one weekly exercise activity for a duration of two hours. The program also included one parent meeting to facilitate healthy exercise and dietary habits.

Children from both groups were tested to determine the impact of the interventions on physical fitness and multiple aspects of executive control. Participants from the daily camp intervention performed better on measures of physical fitness at the end of the program than the child participants from the non-camp intervention.

The researchers utilized the "Behavior Rating Inventory of Executive Function (BRIEF)" (p. 2102), which includes two indexes: the "Behavioral regulation index (BRI)" (p. 2103) and the "Metacognition index (MI)" (p. 2103). The BRI tests emotional control, inhibition, and shifting. The MRI tests critical components of executive functioning including working memory, planning, and organization. The results demonstrated that the more physically fit children from the daily camp intervention performed better on the BRI scales, but the only significant difference were tests measuring emotional control (no significant differences in shifting or initiation). The results from the MI scale showed the more physically fit children from the day camp intervention may enjoy benefits in the areas of "personal monitoring" (p. 2106) and "work-checking-habits" (p. 2106). No differences were observed between the two groups with regard to planning and organization.

The researchers also utilized the "Stroop Color and Word Test (SCWT)" (p.2102) to measures inhibition and selective attention. The testing at six and 52 weeks discerned no significant differences between the child participants from both groups.

Huertas, Zahonero, Sanabria, and Lupianez (2011) conducted a study that assessed data from 18 male participants (mean age 17 years) who were experienced and expert cyclers. The participants performed cognitive testing after no exercise and during acute bouts of moderate exercise (ergometer cycling), and intense exercise (ergometer cycling). The study was distinctive because it tested participants while they were still exercising to focus on cognitive effects occurring during exercise.

The researchers suggested that attention should not be viewed as a unitary concept. Accordingly, attention was divided into the subparts of "alerting, orienting, and executive control" (p. 649). The 18 participants performed cognitive testing after rest, moderate exercise, and high-intensity exercise (ergometer cycling). The results suggested that both exercise interventions (moderate and high intensity) resulted in improved reaction time performance on a cognitive demand task. However, the researchers found no change to orienting or the executive control components of attention, and concluded that the exercise interventions resulted in a "reduced alerting effect" (p. 658).

Chaddock-Heyman et al. (2013) conducted a study that focused on the effects of a nine-month exercise program on children's cognitive functioning. Specifically, 23 children between the age of eight and nine years were divided into an after-school exercise intervention (*n* = 14, 7 boys, 7 girls) and a wait-list intervention (*n* = 9, 6 girls, 3 boys) in which students did not participate in the after-school program. The after-school program facilitated an average of 76.8 minutes of moderate to vigorous exercise that included aerobic, resistance, and motor skills activities). The program also included a healthy snack and an education component that focused on promoting positive health habits.

The research was facilitated by the use of magnetic resonance imaging (MRI) to study the impacts of the exercise intervention on cognitive functioning. The researchers did not detect significant changes to brain functioning in the anterior cingulate cortex (ACC) from pre-test to post-test for children in either group. However, “the results . . . showed decreases in fMRI brain activation in the right anterior prefrontal cortex coupled with within-group improvements in performance on a task of attentional and interference control” (p. 1). The researchers noted, “These results suggest that physical activity during childhood may enhance specific elements of prefrontal cortex function involved in cognitive control” (p. 1). Finally, the researchers concluded, “The results of the present study . . . suggest plasticity of the right anterior prefrontal cortex with prolonged physical activity participation” (p. 11).

Drollete et al. (2014) conducted a study that examined children’s performance on a test of inhibitory control and utilized neuroimaging to monitor the children’s “Event-related brain potentials (ERPs)” (p. 53), including P3 and N2 amplitudes. The researchers noted that P3 and N2 amplitudes are believed to provide indicators associated with inhibitory control functioning. The study utilized 40 child participants (27 male, 13 female, mean age 9.7 years) and examined the impact of a single bout of treadmill walking at moderate intensity for 20 minutes. The study was unique for its focus on children who were deemed high functioning and lower functioning in inhibitory control.

The results suggested that children who exhibit lower levels of inhibitory control may experience greater benefits in inhibitory control from a single bout of moderate exercise than children with higher levels of inhibitory control.

The researchers noted studies of children with ADHD that are suggestive of the unique benefits of exercise for children with ADHD. Contrary to some of the other studies noted herein, Drollete et al. (2014) noted, “By contrast, no behavioral modulation was observed for the higher-performing group” (p. 59). Accordingly, the researchers concluded, “Taken together, such findings suggest that single bouts of moderate intensity exercise may have a disproportionate benefit to children characterized by lower inhibitory control capacity” (p. 60).

Davis et al. (2011) conducted a study that assessed data from 171 child participants who were identified as sedentary and overweight (56% girls, 61% “Black” (p. 92), 39% “White” (p. 39), mean age 9.3 years). Children were placed in a low dose, high dose, and no dose exercise intervention that lasted for approximately three months. Children participated in an after school exercise program on school days. The low dose program called for 20 minutes of exercise and the high dose program called for 40 minutes of exercise, with a break in between two 20-minute exercise sessions. The exercise consisted of a variety of activities that elicited “vigorous movement” (p. 92), including running, soccer, jumping rope, and “modified basketball” (p. 92). In addition, Davis et al. (2011) conducted a substudy of 20 participants to perform pretest and posttest brain scans.

The results from the study suggest that sedentary and overweight children enjoyed enhanced executive functioning as a result of the exercise interventions, with a particular dose-response that indicated that the higher dose intervention (40 minutes) produced greater cognitive gains. Critically, the study found improvements to math performance, but not reading performance. In addition, brain scans revealed increased activity in the prefrontal cortex from pretest to posttest. The researchers noted the significance of the findings, “the high-dose condition resulted in mean Planning scores 3.8 points, or a quarter of a standard deviation . . . higher than the control condition” (p. 96). Significantly, the researchers noted, “Demographics did not contribute to the model . . . Therefore, the results may be generalized to overweight Black or White 7- to 11- year olds” (p. 96). The researchers suggested that the findings regarding math improvements were “remarkable” (p. 96) and suggested that education leaders should take note of the results to enhance student outcomes.

Tomporowski, Davis, Lambourne, Gregoski, and Tkacz, (2008) conducted a study of 69 child participants (33 girls, 55% African American, 45% “Caucasian” (p. 500), mean age 9.2 years) to examine the impact of exercise on task switching, a type of executive functioning. The children were defined as sedentary and overweight. Children performed cognitive testing after an exercise and non-exercise intervention. The exercise intervention consisted of a single bout of moderate-intensity treadmill walking for 23 minutes. The results indicated that a single bout of treadmill walking did not promote improved task switching. The researchers noted, “Several studies have failed to detect changes in switch-task performance following acute bouts of exercise” (p. 504).

Kubesh et al. (2009) conducted a study of 81 seventh-grade students (40 girls, ages 13-14 years) who were divided into a 30-minute intervention group, five-minute intervention group, and a no-exercise intervention group. The 30-minute aerobic exercise intervention included a variety of activities, including simple running, zigzag running, jumping, as well as back and abdominal exercises. The five-minute exercise intervention included jogging in place and a variety of motions, including boxing maneuvers, raising the knees, and waiving to others.

The results from the 30-minute exercise intervention revealed improvements in the ability to maintain “on-task attention” (p. 240) when faced with distraction. The 5-minute exercise intervention did not promote enhanced inhibitory control. Moreover, the research revealed that enhanced working memory, behavioral inhibition, and cognitive flexibility were not demonstrated in a dots test that focused on 30 trials per each condition tested, as compared with more favorable results demonstrated in a flanker test that included 55 trials for each tested condition. The researchers suggested that they would include a greater number of trials in the dot tasks to discern if an increased number of trial (and duration of testing) alters the results.

One critical component of the research article was the author’s hypothesis that exercise-induced increases in serotonin production may provide some of the explanation for the positive impact of exercise on cognitive functioning. The researchers noted that increased serotonin following exercise reaches its peak benefit within a 10-minute period following the cessation of exercise. The researchers noted that physical fitness levels may be more critical to enhancing student’s executive functioning and suggested daily exercise programs.

The researchers noted it is a mistake to incorporate exercise programs at the end of the day: “Our study provides arguments for an increase in PE and suggest that PE should be scheduled before important subjects like mathematics and not at the end of the school day, as is often the case" (p. 240). Finally, the researchers suggested that students who are subjected to high-intensity exercise should be "well-trained" (p. 240), suggesting the importance of daily physical education classes.

Tine and Butler (2012) conducted a study of 164 students in grades six and seven, with ages ranging from 10 years and four months to 13.5 years. One of the purposes of the study was to determine if exercise helps students from low-income families more or less than children from high-income families. Students were divided into separate groups that included an exercise intervention and an intervention that called for the viewing of a video. The exercise intervention consisted of a single-bout aerobic exercise for a duration of 12 minutes: Students ran on an indoor track at their target heart range (70-80% maximum heart beats).

The results demonstrated that a single-bout of aerobic exercise facilitated statistically significant enhancement of selective attention for both higher and lower-income students. Contrary to the hypothesis of the researchers, children from low-income families did not have lower scores on a test of selective attention than their higher-income peers at the time of the original pretests. However, posttest results found that the exercise intervention led to "significantly greater improvement" (p. 829) for the children of lower-income families when compared to children from higher-income families. The researchers noted with optimism: "The finding that lower-income children saw such large improvements in their selective attention skills poses acute bouts of exercise as a promising intervention for schools serving lower-income communities" (p. 830). Moreover, the researchers highlighted the critical role of selective attention as a salutary influencer of reading and math proficiency. One final aspect of the study that warrants mention is the finding that children who performed lower in selective attention in the pretest experienced greater advances in selective attention than students who rated higher in selective attention at the time of pretesting.

Contrary to many of the favorable results, Soga, Shishido, and Nagatomi (2015) conducted two sets of tests that failed to demonstrate similar cognitive gains resulting from exercise. The first test was designed to determine the effect of exercise on executive functioning during exercise, and the second focused on the executive functioning of study participants measured five minutes after the exercise intervention. Fifty-five adolescents (mean age 15.6 years) from Japan were asked to perform a single-bout, moderate aerobic exercise. The study demonstrated no evidence of enhanced executive functioning five minutes after the completion of the exercise intervention.

Studies of Young Adults

Two studies utilizing young-adult participants (age range 18-19 years) without ADHD were reviewed in conjunction with this systematic review that met selection criteria. Results from the studies of young adults provide additional evidence suggesting the promise of exercise as a positive modulator of executive functioning. Both studies found that exercise facilitated enhanced executive functioning in at least one domain.

Study descriptions. Luft, Takase, and Darby (2009) conducted a study of 30 athletes (23 males, 7 females, mean age 18.5 years) who were members of sports teams. The participants performed baseline cognitive testing after a 24-hour period without exercising and again after an exercise intervention. The participants then exercised on a treadmill for approximately 20 minutes until “voluntary exhaustion” (p. 187) to measure "maximum oxygen consumption" (p. 187). The study focused on numerous cognitive domains beyond executive functioning. Notable for this reviews focus on executive functioning was the study's finding that intense exercise for "elite level athletes" (p.189) resulted in increased speed of performance on a test of working memory.

Holzapfel et al. (2015) enlisted 48 participants (20 female, 28 male) with Down Syndrome (DS) who were divided into a no exercise intervention (mean age 17 years), standard cycling intervention (mean age 18.4 years) and "Assisted Cycling Therapy (ACT)" (p. 261) intervention. The exercise interventions lasted for eight weeks and included 30-minutes of cycling three times per week. The ACT intervention differed from the standard cycling intervention because it utilized a stationary bike with a mechanical motor that helped the children pedal the bike. Accordingly, the ACT intervention resulted in more vigorous exercise (the cadence was increased throughout the weeks until it reached 60% of the "age-predicted maximal heart rate" (p. 264).

The results suggested that children in the ACT intervention showed greater improvements in executive functioning – including planning – than the children who engaged in the standard cycling or no exercise intervention (which the researchers referred to as "voluntary cycling (VC)" (p. 261).

Exercise Variables

Short-Term and Long-Term Exercise. The results suggest that short-term and long-term exercise interventions promote enhanced executive functioning. Reviewing the data from this study, 23 of the 36 studies that met selection criteria utilized a short-term exercise intervention (defined as lasting seven days or less), with 19 of the 23 short-term interventions utilizing a single bout of exercise. Data from the study revealed 13 of the 36 studies that met selection criteria were long-term exercise interventions (defined as one month or more for the purpose of this study).

Results from the short-term interventions were positive. A total of 17 of the 23 short-term exercise interventions demonstrated enhancements to at least one domain of executive functioning. In addition, Hillman et al. (2009), Cooper et al. (2012), and Stroh et al. (2009) offered promising results suggestive of a positive effect of exercise on general cognitive domains or positive associations between fitness and executive functioning. Huertas (2011), Tomporowski (2008), and Soga (2015) were the three short-term exercise interventions that did not provide promising results. However, important factors distinguished these studies from the majority of studies that did offer promising results.

Tomporowski was a targeted study focusing on impact of exercise on task switching. Factors that distinguished Huertas (2011) from some of the other studies included the timing of the cognitive testing (performed while the participants were exercising), mean age of participants (17 years), duration of the intervention (the number of minutes varied by participant), and participant characteristics (expert cyclers). The Soga (2015) study might be distinguished by the age of its participants (15.6 years). In addition, the researchers suggested that the amount of time they allowed to elapse between the cessation of exercise and the start of testing (5 minutes) were less than some of the other studies that found more favorable results (Soga, 2015).

Results from the long-term interventions were also positive, with 12 of the 13 long-term interventions demonstrating enhancements to at least one domain of executive functioning. Silverstein and Allen (1994) was the only long-term exercise intervention that did not yield promising results. Significantly, the child participant was three years old, indicating that further study of preschool-aged children may be warranted to determine if exercise impacts extremely young children in a unique fashion. As previously noted, however, the child's disengagement from the exercise intervention and the size of the study's sample (n = 1) also limit the study's generalizability.

Participant Age. Results from this study suggest that the age of children may play a role in the impact of exercise as a moderator of cognitive functioning. Of the four studies that did not yield promising results in this study, three of the four were outliers in terms of age. Silverstein and Allen (1994) had the youngest participant (age 3), whereas the participants in the Stroh (2009) and Soga (2015) studies were older than the participants of most studies, with mean ages of 17 and 15.6 years respectively. However, conclusions should be drawn with caution as distinguishing factors of these studies have been noted herein that extend beyond differences of mean participant age. Moreover, several studies for this review featured older teens and young adults that yielded results suggesting that exercise can improve the executive functioning of older children and young adults.

Exercise Intensity. Significantly, only two of the 36 studies were identified by the research authors as including low-intensity exercise. Chang, Tsai et al. (2013) tested participants separately for a low and moderate intensity exercise intervention and found that both exercise intensities yielded enhanced executive functioning. Significantly, the researchers found no difference in the results between the low and moderate-intensity interventions, suggesting that even a low-intensity exercise intervention could yield positive results. Similarly, Taylor and Kuo (2009) found that a low-intensity nature walk yielded positive results. However, the impact of nature as an independent moderator of executive functioning was suggested by the study's findings.

Also significant was the lack of studies that were labeled by researchers as exclusively vigorous or high-intensity. Davis et al. (2011) described their intervention as one eliciting vigorous movement, and Silverstein and Allen (1994) utilized vigorous exercise. The results from Davis et al. (2011) suggested that vigorous movement promoted executive functioning, whereas the results from Silverstein and Allen (1994) suggested no positive gains from vigorous exercise.

Most of the studies that met selection criteria for this review utilized moderate or moderate-to-vigorous exercise. Specifically, 13 of the 36 studies featured moderate-intensity exercise interventions, and another eight of the studies featured exercise labeled by the researchers as moderate-to-vigorous intensity. Two of the 13 studies with moderate-intensity exercise interventions did not yield promising results, whereas the results from each of the eight studies featuring moderate-to-vigorous exercise suggested enhancements to executive functioning.

Discussion

Implications for Social Work Practice

Social workers have a responsibility to help the vulnerable (NASW, 2016), including children who experience academic or social challenges as a result of ADHD. The results of this study provide strong evidence that exercise may provide considerable benefit to children with ADHD.

The findings from this systemic review suggest that exercise can positively influence children with ADHD in two significant fashions. First, evidence from this study suggest that single bouts of aerobic exercise may enhance the executive functioning of children with ADHD. Significantly, findings from this review suggest that single bouts of exercise may facilitate enhanced attention and inhibitory control, which some experts define as the most essential factor of ADHD (Pontifex et al., 2013).

Second, evidence from this review suggests that physical fitness – promoted by regular exercise – may enhance the executive functioning of children with ADHD, and may alter brain volume and structure in a salutary manner. Taken together, studies examined for this review of short and long-term exercise interventions suggest that exercise may positively influence several additional domains of executive functioning, including working memory, switching, and planning.

In addition to the benefits of exercise as an independent moderator, several additional positive moderators of ADHD were discovered inadvertently in the course of this review that warrant mention. The Taylor and Kuo (2009) study suggests the positive impact of nature as an independent moderator of executive functioning for children with ADHD. The Lakes et al. (2013) study utilized a taekwondo intervention that utilized self-control, respect, and opportunities to acquire ascending levels of taekwondo belts that may have facilitated an enhanced sense of mindfulness, purpose, self-esteem, and self-efficacy. In addition, several of the exercise interventions facilitated increased social interaction, which may have contributed to the positive impact of the interventions.

Implications for Policy

Several of the studies reviewed for this systematic review suggest that exercise interventions may improve children's academic achievement, including math and reading comprehension. Many of the research authors strongly promoted the view that exercise programs should be expanded within schools to promote the academic and social wellbeing of children. Some of the studies suggested that children with ADHD may experience more significant gains than students without ADHD, but it is noteworthy that findings from this review suggest that students with and without ADHD will benefit from an increased promotion of physical fitness programs within schools.

Finally, several of the studies examined for this review suggested that stationary bikes or treadmill interventions can provide cognitive benefits, but others highlighted the unique potential of exercise interventions utilizing complex cognitive and coordinative skills. Taken together, these results provide strong justification for the promotion of exercise interventions in schools and suggest possible starting points for consideration of the types of interventions that might provide considerable benefits to students.

Implications for Research

Despite the significant body of evidence suggesting that exercise interventions can provide tremendous benefits to children with ADHD, gaps in the existing body of research require additional attention. Specifically, additional research is required to determine the optimal timing of exercise interventions that are utilized in schools. Additional research contrasting the impacts of different forms of complex coordinate exercises (e.g. soccer versus tennis or team sports) should be performed to provide additional guidance to schools, parents, and other interested parties who want to create the most effective exercise interventions. Confounding variables, such as medication, social interaction, mindfulness, and nature exposure should be isolated within studies to obtain an enhanced understanding of the factors that promote the wellbeing of children with ADHD.

Strengths and Limitations

Systematic reviews have strengths and limitations. One limitation of this review was its lack of focus on qualitative data, which frequently provides a deeper understanding of concepts (Monette, Sullivan, DeJong, & Hilton, 2014). A second possible limitation was the inclusion of search criteria that included general cognitive domains in addition to the more specific domains of executive function. The strength of the current study is its ability to summarize large amounts of data to provide greater clarity concerning the effectiveness of exercise as a potential ADHD treatment.

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