EFFECTS OF ACUTE CARDIOVASCULAR EXERCISE ON ATTENTION IN PREADOLESCENT CHILDREN

by

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ABSTRACT

The purpose of this study was to assess the influence of an acute bout of cardiovascular exercise on selective and sustained attention in preadolescent children. Secondary aims included determining if gender, baseline physical activity level, or intensity of exercise moderates the relationship between acute exercise and attentional processes. A within-subjects design was used to measure performance on the Conners' Continuous Performance Test (CPT II) following 20 min of sedentary activity (passively viewing a video) and 20 min of cardiovascular (CV) exercise. The CPT II was administered on two different testing days to 26 preadolescent children (age = 10.4 ± 1.16 years; 13 females). Participants wore ActiGraph GT1M accelerometers at the waist during the exercise session, which consisted of a 10-station aerobic circuit, designed to elicit and maintain a cardiovascular response. Testing began once heart rate returned to within 10% of preexercise levels. The Physical Activity Questionnaire for Children (PAQ-C) was administered as a baseline measure of physical activity levels. Average exercise intensities met national guidelines of spending greater than 50% exercise time at moderate to vigorous physical activity (MVPA). Results indicated that CV exercise had no adverse effects on selective or sustained attentional processes. Neither gender nor baseline physical activity level influenced this relationship. To meet daily recommended levels of MVPA, opportunities for CV exercise may be incorporated in the school day without adversely affecting student attention.

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CHAPTER I

INTRODUCTION

The relationship between physical activity and cognitive processes has been well established in adult populations (Colcombe & Kramer, 2003; Hillman, Snook, & Jerome, 2003; Tomporowski, 2003b). Interestingly, researchers have determined that aerobic exercise has a disproportionate benefit on mental processes involving executive functions (Colcombe & Kramer, 2003; Kramer, et al., 1999). Executive functions, also called cognitive control, are higher-order central functions that lend order to thoughts and behaviors. In children, executive functions have been closely associated with academic achievement and independently predict math and reading scores through the school years (Diamond, Barnett, Thomas, & Munro, 2007). Nevertheless, minimal research has examined the effects of exercise on executive functions in children.

Inhibitory control, a core component of executive functions, is believed central to selective and sustained components of attention (Diamond, et al., 2007). Selective attention reflects the ability to discriminate among relevant and nonrelevant stimuli and to filter out the later, whereas the ability to sustain attention is commonly referred to as vigilance (Posner & Boies, 1971). Children often exhibit difficulty with inhibitory control, and recent advances in brain development suggest that a protracted increase in myelination and connectivity in the frontal cortex may account for this (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). A child who cannot effectively inhibit impulsive behavior or shift attention from one task to another is unlikely to remain on task in the classroom and excel academically (St Clair-Thompson & Gathercole, 2006). Thus, optimizing attention in the classroom has practical importance for scholastic performance.

Much of the exercise literature involving children has suffered from inconsistencies in design, and incorporated a considerable variety of cognitive measures and physical parameters (Colcombe & Kramer, 2003; Tomporowski, 2003a). Cognitive benefits of exercise have been identified along variables as far ranging as grade point average and intelligence quotient to verbal tests and academic readiness. A meta-analysis on children's studies concluded that a significant positive association exists between physical activity and cognition, and that this relationship is strongest for elementary or middle school children (Sibley & Etnier, 2003). Furthermore, longitudinal studies in this analysis reported that academic performance improved as time in physical education (PE) increased. Additional studies have found positive relations between aspects of academic performance and physical activity level (Castelli, Hillman, Buck, & Erwin, 2007; Coe, Pivarnik, Womack, Reeves, & Malina, 2006).

Exercise studies incorporating electroencephalography (EEG) as a measure of neuroelectric activity have provided insight into the specific cognitive functions associated with exercise. Numerous EEG studies have identified positive effects of exercise on executive processes in adults (Bixby, et al., 2007; Hawkins, Kramer, & Capaldi, 1992; Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Hillman, Weiss, Hagberg, & Hatfield, 2002; Pontifex, Hillman, & Polich, 2009). Among these are tasks involving inhibition and selective and sustained attention (Colcombe & Kramer, 2003;

Arthur Kramer & Hillman, 2006). Hillman and colleagues (2005) showed similar effects in children, reporting that high-fit children exhibit both faster and more robust neuroelectric indices of attention during executive challenge, as compared to lower fit children.

Importantly, children's studies have almost exclusively examined chronic exercise or overall fitness level in relation to cognition. The immediate effects of exercise have predominantly been explored in adults, yet these findings have profound implications for school-aged children. In recent years, opportunities for physical activity during the school day, namely PE and recess, have been reduced as a result of pressure to raise test scores and adhere to state-mandated academic requirements (Taras, 2005). Ironically, this approach may be counterproductive if these short bouts of exercise during the school day benefit executive functions underlying academic achievement. To date, no reported studies have associated increased PE time with a decline in academic test performance.

In the adult literature, several EEG studies have found that a single bout of cardiovascular (CV) exercise directly benefits neural correlates of attention (Hillman, et al., 2003; Magnié, et al., 2000). Additionally, Tomporowski (2003a) reported that adults were able to attend and respond to task-relevant stimuli more quickly and effectively after an acute bout of exercise than before. Exercise appears to induce transient changes in cognitive functions, directly responsible for the enhanced allocation of attentional resources. On the contrary, Etnier and colleagues (1997) found little support for the benefits of acute exercise on cognition in their meta-analysis. Inconsistencies with study methods, the intensity and duration of physical exercise, and the dependent variables of interest may account for these discrepancies in the literature.

With preadolescent children, the immediate effects of physical activity have primarily been examined in terms of impact on classroom behavior or academic performance. For example, a series of field experiments found school-age children to be more attentive following recess than before (Pellegrini & Bohn, 2005). Others reported enhanced mathematical performance following acute aerobic exercise (Tomporowski, 2003a). After a mere 15 minutes of walking, Caterino and Polak (1999) showed that fourth graders had improved performance on a concentration test. Although these studies all suggest mental benefits from acute exercise, a systematic study of attentional processes has yet to be conducted in children.

A number of proposed mechanisms may underlie the positive relationship between CV exercise and cognition. Animal models, in particular have shown that CV training stimulates cortical capillary supplies, the number of synaptic connections, and the growth of new neurons (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Neeper, Gómez-Pinilla, Choi, & Cotman, 1995; van Praag, Christie, Sejnowski, & Gage, 1999). Consequently, trained animals have a more efficient, adaptive brain, capable of enhanced learning (Colcombe & Kramer, 2003; van Praag, et al., 1999). In humans, exercise influences neurotransmitter and endorphin release, neurotrophic factors, cerebral blood flow, and general arousal of the central nervous system (Brisswalter, Collardeau, & René, 2002; Ferris, Williams, & Shen, 2006; Tomporowski, 2003b). Although the mechanisms are not well understood, these findings lend biological plausibility to observed exercise-related cognitive benefits.

Current research suggests that both gender and general CV fitness levels may moderate the relationship between acute exercise and cognitive processes. Whereas results from some studies suggest that females derive more cognitive benefit than males from exercise (Carlson, et al., 2008; Shephard, 1996), others have either found no difference (Jarrett, et al., 1998), or a larger benefit for males (Tantillo, Kesick, Hynd, & Dishman, 2002). Similarly, findings are mixed regarding the effects of CV fitness on the transient impact of exercise on cognition (see Tomporowski, 2003a for review). These inconsistencies necessitate further investigation into factors that might moderate the relationship between exercise and cognition.

Whether acute CV exercise results in transient benefits to the attention system remains to be explored in children. A better understanding of this relationship has important implications for school programming and the incorporation of physical activity into the school curricula. If a positive relationship between acute exercise and attention were to be illuminated, it may justify time spent away from the classroom in physical activity, and result in more widespread implementation of school activity programs. Ultimately, such actions could lead to more attentive, focused students, with a greater capacity for learning in the classroom. Given declining physical activity levels and growing obesity rates (Boreham & Riddoch, 2001), evidence supporting exercise-induced cognitive benefits may ultimately result in physical benefits as well. Lastly, it may prove advantageous to strategically place periods of physical activity throughout the school day, so as to optimize learning for critical or particularly challenging lessons.

Significance of the Study

The present study was designed to expand upon previous research by examining the effects of acute aerobic exercise on attentional processes in preadolescent children. Selective and sustained attention, as measured by the Conners' Continuous Performance Test (CPT II), were of primary focus. Positive findings would have tremendous implications for performance in the classroom, and ideally enable educators to optimize the learning environment for students. This may include restructuring the school day so as to maximize the transitory benefits of acute exercise. For example, an exercise break could be taken just before a math or reading period, which may be more attentionally demanding to the students. Furthermore, this study seeks to determine if gender or baseline physical activity levels influence the relationship between an acute CV exercise bout and specific components of attention.

Research Questions

This study was designed to investigate the following research questions:

1. What is the effect of an acute bout of CV exercise on selective and sustained attentional processes in preadolescent children?
2. Do the effects of acute CV exercise on attentional processes differ between preadolescent males and females?
3. Do general levels of physical activity influence the effects of acute CV exercise on attentional processes in children?

Hypotheses

The following hypotheses have been proposed for this study:

1. Overall performance on the Conner's Continuous Performance test (CPT II), as determined by the CPT Overall Index, will significantly improve following acute CV exercise, as compared to a sedentary control.
2. Inattention score, as measured by omissions, commissions, hit reaction time (RT), RT standard error, variability, RT by inter-stimulus interval (ISI), and detectability (d') will significantly improve following acute CV exercise, as compared to a sedentary control.
3. Student scores of omissions, commissions, RT, and d' will independently show improvements following 20 minutes acute CV exercise, as compared to a sedentary control.
4. Student vigilance scores, as measured by hit RT and hit RT standard error over block change, will exhibit significant improvements following 20 minutes acute CV exercise, as compared to the sedentary control.
5. Gender will not moderate the relationship between acute CV exercise and components of attentional control.
6. Children who are more physically active will have better performance on the CPT II test following acute aerobic exercise than those children who are generally less active.

Limitations

The following limitations were applied to this study:

1. This study did not account for differences in food consumption, caffeine intake, medications, or sleep.
2. Study participants consisted of a convenience sample.
3. Participants were recruited from a single geographical region; Salt Lake City, Utah.

Delimitations

The following delimitations were applied to this study:

1. Participants all resided in the Salt Lake City, UT area.
2. Participants were 9-12 years of age.
3. Participants in the study were recruited between the fall of 2008 and 2009.

Assumptions

The following assumptions served as the basis of conduct for this study:

1. It is assumed that participants accurately represent a normal population of children between the ages of 9-12 years.
2. It is assumed that participants accurately represent a normal population of 9- to 12-year-old males and females.
3. It is assumed that participants completed the CPT II tests and questionnaire truthfully and to the best of their ability.

CHAPTER II

LITERATURE REVIEW

Overview

One of the greatest challenges teachers face is keeping the attention of their students. Focusing is an especially large challenge for preadolescent children. They are particularly susceptible to the effects of cognitive interference, or distractions, after sustained periods of structured work (Dempster, 1992). This is partly accounted for by the immaturity of a child's nervous system as well as by limited experience. Nevertheless, without a fundamental level of attention, learning may ultimately suffer. To augment learning and achievement gains, steps should be taken to ensure that children's attention is optimized in the classroom. Based on the extant adult literature, there is reason to believe that acute cardiovascular exercise may augment executive functions, including attentional control.

However, there is concern among educators that time taken away from the academic classroom for physical education classes or recess may negatively impact overall academic achievement and standardized test scores. This has resulted in only 50% of schools requiring physical education programs in grades 1 to 5 (Sibley & Etnier, 2003). Some argue that maximizing instructional time is necessary for increasing test scores and that recess only disrupts the work patterns of children, amplifying excitement and inattentiveness (Carlson, et al., 2008; Jarrett, et al., 1998). More research would address this concern and support objectives to maintain or expand children's programs revolving around exercise. To date, researchers have primarily examined exercise-related cognitive benefits in the adult and older adult populations.

Yet, if acute CV exercise promotes attentional processes in children, then it is important that they are given the opportunity to exercise and hence, learn in an optimal attention state. Acute exercise may prove to be a fruitful intervention to optimize school performance and learning. It may be possible to capitalize off transient cognitive gains by strategically placing certain lessons after recess or PE. Furthermore, if exercise were to be more consistently incorporated into the school curriculum, then physical health benefits would also result. This point is of considerable importance, given increased obesity rates and declining physical activity levels among children (Boreham & Riddoch, 2001).

The primary objective of this study was to determine if a single 20-minute bout of exercise serves to enhance selective and sustained attention in preadolescent children. Comparisons were drawn to each participant's own performance following a sedentary control activity. Finally, this study explored potential gender differences and effects of baseline physical activity levels on the relationship between acute exercise and attention.

Executive Function and Cognitive Development

Executive functions, also called cognitive control, are higher-order central functions that lend order to thoughts and behaviors. Core executive functions are inhibitory control (resisting distractions or temptations), working memory (mentally holding and using information), and cognitive flexibility (adjusting to change or shifting between tasks (Diamond, et al., 2007). Inhibitory control serves as the basis for both selective and sustained attentional processes (Davidson, Amso, Anderson, & Diamond, 2006). Selective attention is credited with enabling people to filter out an abundance of irrelevant sensory input in order to focus on those of importance (Posner & Boies, 1971). It is often viewed as a bottleneck through which only a fraction of sensory input may pass. Inhibition is credited with this "filtering out" of irrelevant stimuli and allows individuals to act on the basis of choice, rather than impulse (Davidson, et al., 2006). As such, inhibitory control typically requires that a strong internal or external pull is overridden in order to properly perform a task. Sustained attention, or vigilance, is generally considered a function of the ability to focus attention over time and discriminate between target and nontarget stimuli.

Compared to healthy adults, children typically exhibit difficulty inhibiting irrelevant stimuli and focusing attention on those of relevance (Bunge, et al., 2002). Recent imaging studies suggest this may be due to immature frontal regions and incomplete myelination (Bunge, et al., 2002; Travis, 1998). It appears maturation follows a developmental trajectory whereby gray matter in areas serving primary functions, such as motor and sensory systems, matures earliest. Prefrontal areas, especially dorsolateral prefrontal areas, associated with executive function and attention are last to mature (Casey, Tottenham, Liston, & Durston, 2005; Gogtay, et al., 2004; Lenroot & Giedd, 2006; Shaw, et al., 2007). Furthermore, the maturational time course among frontal regions is believed to parallel cognitive function (Bunge & Zelazo, 2006; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006). Inhibitory control is among the cognitive abilities to exhibit protracted development (Diamond, et al., 2007).

Critically, the same executive networks underlying inhibition and selective attention that are delayed in childhood appear to benefit most from exercise.

Exercise and Executive Functions in Adults

A positive correlation between physical fitness and cognitive processes has been well established in adults, and especially older adults (Colcombe & Kramer, 2003; Hillman, et al., 2003; Tomporowski, 2003a). However, the most profound benefits have consistently appeared with aspects of cognition involving executive control (Colcombe & Kramer, 2003; Hillman, et al., 2003; Kramer, et al., 1999). Kramer and colleagues (1999) provided strong support for this executive function hypothesis. Participants in this study were assigned to either a 6-month aerobic or nonaerobic exercise program, and at the conclusion, aerobic exercisers exhibited clear improvements on tasks involving executive functions. Negligible effects were seen for tasks that did not emphasize executive functions. Even after accounting for age, education, and IQ, Bixby and colleagues (2007) found that physically active adults (65-92 years) performed significantly better than their sedentary counterparts on executive control tasks. Active older adults also appear to perform better on tasks demanding attentional flexibility than those who do not regularly exercise (Hawkins, et al., 1992).

Other intervention studies have lent support to the executive function hypothesis. Colcombe and Kramer (2003) conducted a meta-analysis on 18 intervention studies targeting healthy, sedentary older adults. Again, fitness training had robust, but selective benefits on executive functions. Using functional magnetic resonance imaging (fMRI), Colcombe et al. (2004) later demonstrated that a 6-month exercise intervention on previously sedentary older adults promotes aspects of the attentional network of the brain. Compared to controls, aerobically trained individuals showed more robust task-related activity in prefrontal and parietal cortices during an inhibitory task. Exercise also modified activity in the anterior cingulate cortex, an area implicated in the regulation and control of behavior. These findings suggest that increased CV fitness may enhance plasticity in the aging brain, particularly in areas responsible for executive function. It is plausible that some of the exercise-induced cellular, molecular, and neurochemical changes observed in animal models (see Mechanisms), may underlie these changes in executive functions.

A subset of research in this area has utilized event-related potentials (ERPs) to quantify neuroelectric responses underlying cognitive processes. Measured with electroencephalography (EEG), ERPs indicate how neural resources are allocated in response to stimuli (i.e., thoughts or perceptions). The P3 component, inherent to every ERP, is believed to indicate executive functions involved in the distribution of attention as well as activation of immediate memory (Magnié, et al., 2000; Pontifex, et al., 2009). Higher P3 amplitudes indicate that a larger population of neurons is recruited to carry out a given task, whereas decreased P3 latency indicates faster processing. Dustman and colleagues (1990) were the first to utilize ERP to demonstrate that enhanced fitness may result in faster executive processing, as determined by reduced P3 latency. Similarly, Hillman and colleagues (2004) showed that habitual physical activity benefits processing speed in older adults, and may also protect against cognitive decline, as measured via P3 latency and amplitude, respectively. Several other ERP studies have indicated analogous exercise-related benefits in older adults (Hillman, et al., 2004; Hillman, Kramer, Belopolsky, & Smith, 2006; Pontifex, et al., 2009).

These initial studies suggest that exercise may serve to minimize age-related cognitive decline, but do not address whether healthy, young adults may reap the same benefits. More recent studies have focused on this question. When compared to their sedentary counterparts, young (19.4 ±.3 years), active individuals showed similar changes in P3 amplitude and latency as older (63.7 ± .9 years) active adults during an executive task (Hillman, et al., 2006). Themanson and colleagues (2008) found that higher levels of CV fitness are associated with increased cognitive flexibility in adults (18-25 years). In further support of the executive function hypothesis, another study found that high-fit individuals (18-23 years) exhibited shorter P3 latency than less-fit people on a go-no/go executive challenge, but not on an oddball task (nonexecutive cognitive task).

(Woo, Roth, Ludlow, Polich & Hatfield, in press).

A large cohort study of over one million participants also identified a clear positive association between CV fitness and cognitive performance. This relationship held true even within monozygotic twin pairs, indicating that non-shared environmental influences accounted for intelligence scores to a greater extent than heritability (Aberg, et al., 2009). Importantly, this study found that CV fitness at age 18 predicted educational achievements later in life. Nevertheless, the paucity of studies with children pales compared to the extant literature on adults and older adults. The following section describes the small, yet variable, body of children's studies designed to assess the relationship between exercise and a range of mental functions.

Physical Activity and Mental Function in Children

To date, researchers have used a considerable variety of dependent measures and physical parameters to assess the relationship between exercise and cognition in children

(Colcombe & Kramer, 2003; Tomporowski, 2003a). Consequently, results have been highly variable, suggesting a modest to moderate association or none at all.

Much of the research in this area has assessed direct measures of academic achievement such as standardized test scores and grade point average. Coe and colleagues (2006) reported increased performance in core academic classes for children who reported more vigorous physical activity outside of school relative to those who reported no physical activity. Similarly, a study examining third- and fifth-grade students found a positive relationship between CV fitness levels and academic achievement (Castelli, et al., 2007). Cardiovascular fitness levels at age 18 have also been able to predict educational achievements later in life (Aberg, et al., 2009).

Sibley and Etnier (2003) conducted a meta-analysis on 44 studies of children and adolescents (ages 4 to 18), and found a significant positive association between physical activity and cognition. The relationship was strongest for elementary or middle school children. Furthermore, three out of four large-scale longitudinal studies examined found that academic performance improved as time in PE increased. Additional studies have found positive relations between physical activity and aspects of academic performance (Field, Diego, & Sanders, 2001); others reported merely a weak relationship (Sallis, et al., 1999). No reported studies have associated increased time in PE with a decline in academic test performance.

Studies examining habitual physical activity in children have also found positive associations with executive control tasks. Following a 15-week aerobic exercise intervention, overweight children (mean age = 9.2 years) improved scores on a standardized executive function test (a portion of the Cognitive Assessment System

(CAS) test) (Davis, et al., 2007). A cross-sectional study by Buck, Hillman and Castelli (2008) found that preadolescent children who were aerobically fit performed better on the Stroop color-word task, commonly used to assess executive function.

Similarly, Hillman and colleagues (2005) measured EEG brain activity in high- and low-fit children and found that high-fit children exhibited larger P3 amplitude, shorter P3 latency, and faster reaction times than less-fit children during a choice-reaction test. These cross-sectional studies suggest that children may derive some of the same executive benefits from cardiovascular fitness as adults. However, all of the aforementioned studies examined long-term effects of exercise. Far less is known about the effects of a single, acute bout of exercise on executive functioning. Even less is known about this relationship in children.

Effects of Acute Exercise on Cognition

The effects of acute exercise on cognition have received significantly less attention than that of cardiovascular fitness or physical activity levels. Additionally, studies have reported considerably mixed findings. Some contend that this is due to inconsistencies in design and the fact that a tremendous range of aerobic activities, exercise intensities, durations, and cognitive assessments has been used (Brisswalter, et al., 2002; Magnié, et al., 2000).

Results from a meta-analysis by Etnier and colleagues (1997) concluded, counter to hypothesis, that acute exercise may provide more benefit to simple reaction time than to more cognitively demanding tasks. Chronic exercise had a stronger relationship with enhanced cognitive abilities. Similarly, Themanson, Hillman, and Curtin (2006) found that attentional control benefited from cardiorespiratory fitness but not acute aerobic exercise (30-minute treadmill running). Another study looked at a different aspect of executive control (task-switching) in children, and found that a 23-minute bout of moderate treadmill walking had no effect on performance (Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008).

Recognizing incongruencies in the literature, Tomporowski (2003b) conducted a review limited to studies involving systemic changes in physiological functions. He reported that adults were able to attend and respond to task-relevant stimuli more quickly and effectively after an acute bout of exercise than before. Furthermore, he concluded that exercise induces transient changes in cognitive functions directly responsible for the enhanced allocation of attentional resources (Tomporowski, 2003b). Tomporowski's exclusion criteria minimized variability among independent variables in the extant literature, and consequently, may have allowed more subtle exercise effects to be exposed.

Additional studies support the notion that transient changes induced by acute exercise benefit executive functions. The use of EEG has proved beneficial in this area of research. For example, Magnié and colleagues (2000) examined neuroelectric changes resulting from a single, maximal cycling bout. The young adults (18-30 years old) participating in their study exhibited increased P3 amplitude and decreased P3 latency following the exercise session. Hillman and colleagues observed this same trend in P3 behavior on adults after a 30-minute bout of self-paced running (2003). Thirty minutes of exercise (cycling) has also been shown to facilitate response speed during a Stroop and a go/no-go task, which both target executive functions (Kubesch, et al., 2003). These studies support the hypothesis that acute exercise may directly benefit attentional processes in the adult population. Yet, the question still remains to be explored in children.

The acute exercise research on healthy children has primarily been interested in determining if short bouts of physical activity within the school curricula negatively impact classroom behavior or academic performance. Fourth graders have been reported to be more on task and less fidgety on days they had a 15- to 20-minute recess than on nonrecess days (Jarrett, et al., 1998). Similarly, on-task behavior improved for a group of third and fourth grade students ($N = 243$) following 10 minute classroom-based physical activities (Mahar, et al., 2006). Studies such as these counter the argument that a break for physical activity leads to more disrupted, less focused students. Tomporowski (2003a) concurs, sighting that physical activity exerts short-term benefits on behavior in healthy children. Even those with behavioral disorders experienced improved classroom behavior after as little as 10 minutes of jogging (see Tomporowski, 2003a).

Only a select few studies have examined the effects of acute exercise on cognitive processes or states potentially underlying academic performance. Budde and colleagues (2008) recruited adolescents (age 13-18 years) and found that a mere 10 minutes of coordinated exercise improved scores on an attention and concentration test, relative to controls. Likewise, 15 minutes of vigorous aerobic exercise improved fourth-grade students' performance on a concentration test significantly more than 15 minutes of stretching (Caterino & Polak, 1999).

Mechanisms

A variety of physiological mechanisms have been proposed to account for the relationship between exercise and cognitive function. These include neurotrophic and growth factor effects, increased neurotransmitter availability, angiogenic effects, general arousal, and structural and functional cortical changes. Some of the proposed physiological mechanisms are more specific to the transient effects of a single exercise bout, whereas others address adaptations from habitual CV exercise. The latter may indirectly underlie benefits seen from acute exercise, particularly if fitness level influences short-term exercise-related cognitive benefits.

Clear patterns of findings in the animal literature demonstrate biochemical, cellular, and molecular changes in response to exercise interventions. These studies suggest mechanisms that may underlie certain changes seen in humans. Among these are an increase in neurochemicals known to augment neuron proliferation and survival: brain-derived neurotrophic factor (BDNF), insulin-like growth factor 1 (IGF-1), serotonin, and reduced corticosteroid levels (Carro, Trejo, Busiguina, & Torres-Aleman, 2001; Cotman & Berchtold, 2002; Cotman, Berchtold, & Christie, 2007; van Praag, et al., 1999). In mice, exercise has also been shown to enhance learning and induce neurogenesis in the hippocampus (van Praag, et al., 1999).

The neurotrophin, BDNF is increasingly recognized for its role in plasticity and the health of neurons. It has been credited with supporting the function of glutaminergic neurons in the brain, stimulating neurogenesis, and improving learning and mental function (Cotman & Berchtold, 2002). Voluntary exercise appears to increase levels of BDNF and other growth factors in mice (Cotman & Berchtold, 2002). However, studies suggests these benefits may not be limited to animals, as 30 minutes of moderate cycling has been shown to significantly increase serum levels of BDNF in humans (Ferris, et al., 2006; Gold, et al., 2003). Furthermore, BDNF appears to have a direct impact on gene expression and may consequently explain some of the long-term benefits and plasticity associated with fitness (Cotman & Berchtold, 2002; Cotman & Engesser-Cesar, 2002).

The role of neurotransmitters may also be central to the effects of exercise on cognition. Importantly, neurotransmitters are particularly sensitive to acute physiological change, and are thus believed to play a considerable role in the transient cognitive changes associated with exercise. The catecholamines (epinephrine, norepinephrine, and dopamine) and serotonin appear to be critical components.

In humans, it is well documented that epinephrine and norepinephrine levels increase during exercise, particularly at its onset (see Etnier, et al., 1997). Epinephrine may have a direct impact on cognitive function via increased neurotransmitter availability, particularly acetylcholine and gamma-aminobutyric acid (GABA) (Wenk, 1989). Hence, the benefits of acute exercise on cognition may be partly explained by the fact that increased levels of epinephrine help mobilize glucose and enhance neurotransmitter availability. Furthermore, it is plausible that repeated acute bouts of exercise might chronically augment these effects as well as neurotransmitter levels (R Dustman & White, 2006). Serotonin, levels of which rise following acute exercise, has been identified as beneficial to mood, self-esteem, and impulse control. Though less substantiated by research, serotonin may serve to induce a relaxation state where concentration is enhanced (Tomporowski, 2003a).

Exercise research on Attentional Deficit Hyperactivity Disorder (ADHD), classically associated with reduced dopamine levels, has shed insight into the mechanisms potentially involved with attention. Tantillo, Kesick, Hynd and Dishman (2002) targeted the effects of acute exercise on the dopamine system in children by measuring the acoustic startle eye blink response (ASER). The ASER, sensitive to dopamine agonists, was faster with reduced latency following a bout of treadmill walking at 65-75% VO^2 max. Tantillo and colleagues suggested that acute exercise may have efficacy in treating ADHD symptoms, via its impact on dopamine. Although the focus of the present study is a healthy population, these results aid in understanding the mechanistic effects of exercise on the attention system.

Animal studies have been able to more directly assess exercise-induced changes in dopamine levels, finding that acute treadmill running acutely increases dopamine release and turnover in the striatum of rats (MacRae, Spirduso, Cartee, Farrar, & Wilcox, 1987; Tantillo, et al., 2002). Using positron emission tomography (PET), Aalto and colleagues (2005) were able to provide direct evidence for use of the dopaminergic system in healthy humans during executive tasks. Dopamine release, measured via receptor availability, increased during both a verbal working memory and sustained attention task. If a short bout of CV exercise has the ability to increase dopamine availability, the attention system may directly benefit.

Increases in cerebral blood flow may also account for exercise-induced changes in the brain. Research on humans has shown that chronic exercise not only maintains cerebral blood flow in older adults (Rogers, Meyer, & Mortel, 1990), but increases it (Jørgensen, Perko, & Secher, 1992; Jørgensen, Perko, Hanel, Schroeder, & Secher, 1992). More precisely, it is the substrates (namely glucose and oxygen) carried by this blood flow that is believed to benefit cognitive processes. In the animal literature, acute exercise has also been shown to increase cerebral blood flow as a result of increased metabolic demands. For example, transient increases in localized cerebral glucose use have been found in response to acute exercise (Vissing, Andersen, & Diemer, 1996), and long-term CV exercise has resulted in increased angiogenesis (Black, et al., 1990) in rats. However, it is not clear whether localized changes in cerebral blood flow during exercise extend beyond regions involved with motor, sensory, and autonomic control (Dishman, et al., 2006).

General arousal theories provide yet another plausible explanation to account for transient cognitive effects brought about by CV exercise. A short bout of exercise stimulates the central nervous system, and may serve to enhance certain types of information processing (see Tomporowski, 2003a). Such increased general arousal may be reflected in the observations that P3-exercise effects occur in a global fashion, across cortical sites (Magnié, et al., 2000; Polich & Kok, 1995).

Recent neuroanatomical evidence from human populations has associated structural and functional changes in the brain with cardiovascular fitness. Using magnetic resonance imaging (MRI), Colcombe et al. (2003) showed age-related declines in cortical density to be attenuated as a function of cardiovascular fitness. Significantly, the areas exhibiting the most substantial reduction in decline included the parietal, frontal, and prefrontal cortices (Colcombe, et al., 2003). The frontal and prefrontal regions, in particular, are believed to be critical players in supporting executive functions. Using functional MRI, Colcombe and colleagues have also linked aerobic training to differences in cortical activation during an inhibitory task. Aerobic training was found to increase activation in prefrontal and parietal cortices, and decrease activity in the anterior cingulate cortex (ACC) (Colcombe, et al., 2004). Significantly, the ACC is believed most involved with conflict monitoring and signal adaptation in the attentional system.

Lastly, additional data from the animal literature has shown that CV training enhances learning and induces neurogenesis in the hippocampus (van Praag, et al., 1999). Combined with the previously mentioned angiogenic effects of exercise, trained animals have the cumulative benefits of a more adaptive, efficient brain, capable of enhanced learning. It is possible that such exercise-related mechanisms may enhance neural plasticity in developing brains—inherently characterized by adaptability to the environment. However, a neuroimaging study has never been conducted to assess the fitness effects on cognition during development. Although exercise-related plasticity reflects long-term adaptations to exercise, structural and functional cortical changes may influence acute cognitive responses to exercise as well.

Role of Fitness Level on the Acute Effects of Exercise

This study was also designed to examine whether baseline physical activity levels influence the short-term impact of acute exercise on attention. As discussed, benefits from exercise in the animal literature include increases in neurotrophic factors (Cotman & Engesser-Cesar, 2002), increased cerebral blood flow, and the development of capillaries, synapses and nerves in the brain (Lazarov, et al., 2005; van Praag, et al., 1999). Whether such chronic changes in the brain may alter the relationship between acute exercise and executive functions remains to be determined.

It is possible that repeated bouts of acute exercise, known to increase levels of epinephrine and norepinephrine, might result in lasting changes to available neurotransmitters (Dustman & White, 2006). In other words, repeated, acute bouts of exercise may have a cumulative effect leading to the chronic augmentation of neurotransmitter mobility. Changes in cerebral blood flow, induced by long-term exercise, may also enhance oxygen transport to brain tissues (Black, et al., 1990; Isaacs, Anderson, Alcantara, Black, & Greenough, 1992). This oxygen supply is critical for the metabolism and delivery of neurotransmitters such as dopamine, norepinephrine, and serotonin. Consequently, subsequent acute exercise bouts may cause a more robust neurotransmitter response. An intervention study imparted support to this notion, incorporating individuals 28 ± 8 years old (Greiwe, Hickner, Shah, & Holloszy, 1999). After a training-induced rise in VO^2 max, acute exercise (at 65-85% VO^2max) significantly increased plasma norepinephrine levels more so than before the training.

Yet, scientific opinions conflict regarding the influence of general fitness on the impact of acute exercise on cognition. Some contend that the short-term benefits of exercise on cognition are observed independently of general fitness level, partly because of exercise-induced central arousal (see Brisswalter, et al., 2002). Magnié and colleagues (2000) supported this, finding no significant interactive effects of fitness level on the P3 and N4 ERP components following acute exercise. Conversely, Tomporowski's review (2003a) cited studies supporting the opposite claim. He reported that fitness level did appear to influence the effects of acute exercise on cognition, and cited several theorists' predictions that increased physical fitness will enhance an individual's cognitive response to acute exercise. Further research, particularly in children, is needed to determine if differences in habitual activity level play a role in the more transient cognitive changes believed to be induced by acute CV exercise.

Gender Differences

Whether or not gender differences play a role in the relationship between exercise and cognition remains to be determined. Following long-term exercise intervention programs, several studies have shown that girls' grades benefit more so than boys' (Carlson, et al., 2008; Shephard, 1996). Carlson and colleagues (2008) found that as time spent in PE increased, females improved in reading and math whereas boys were unaffected. Performance on a concentration test also improved more so for females than males (Caterino & Polak, 1999). Observed gender differences may be attributable to lower baseline fitness levels for some females. Additionally, some have theorized that estrogen may positively impact BDNF (Cotman & Berchtold, 2002). A meta-analysis by Colcombe and Kramer (2003) found the largest benefits of exercise on cognition in studies with more than 50% female participants. These studies were conducted on adult or post-menopausal populations. The present study should reflect minimal hormonal influence, given the targeted age group.

Certainly, not all studies examining gender have found enhanced benefit of exercise among females. Jarrett and colleagues (1998) found that boys and girls became equally less fidgety and more on task in the classroom following recess. Another study examined a population of children with ADHD, and found that an acute bout of exercise benefited boys more so than girls (Tantillo, et al., 2002). These inconsistent findings necessitate further exploration into the influence of gender on the association between exercise and attention in healthy children.

Summary

Although researchers have acquired considerable understanding into the effects of exercise on cognition in older populations, little is known about this relationship in preadolescent children. The extant literature suggests that some of the benefits in executive function, found to correlate with physically active lifestyles, may also result from single bouts of cardiovascular exercise. It remains to be determined if such a correlation translates to attentional processes in children. If transient effects of cardiovascular exercise were found to benefit attentional processes, it would hold both scientific and applied importance. Such findings would justify time spent away from the classroom, exercising, and potentially result in more widespread implementation of school physical activity programs. Ultimately, such actions could lead to more physically fit, focused students, with a greater capacity for learning in the classroom.

CHAPTER III

METHODS

The primary purpose of this study was to determine whether an acute bout of cardiovascular exercise affects selective components of attention in preadolescent children. Secondary aims of this study were to determine if gender or baseline physical activity levels influences the relationship between acute exercise and attention. This chapter describes the participants, methodological procedures, instrumentation, and statistical analysis included in this study.

Participants

This study was conducted with a convenience sample of 26 volunteers (10 ± 1.2 years; 13 females). Recruitment methods primarily consisted of flyers in local recreation centers and consenting elementary schools. Children with physical ailments or injuries that would have hindered their ability to complete the 20-minute exercise session were excluded. Before participating, all volunteers provided written informed assent and the rsearch staff obtained parental or guardian consent. This study was approved by the University of Utah's Institutional Review Board. The results from one male were excluded from analysis as he was subsequently diagnosed with Attention Deficit Hyperactivity Disorder (ADHD). Consequently, statistics were run on 25 children.

Procedures

Children (aged 9 to 12) were randomly assigned to one of two initial treatments (exercise or attention control), which were counterbalanced so that half of the participants began with the exercise session and the other half began with the sedentary session. At a later testing date, the treatment conditions were reversed, such that every participant was tested under both treatment conditions. Each session lasted 1-1.5 hours, and the two sessions were spaced at a maximum of 4 weeks apart.

On both testing days, participants began with a 12-minute mental task that consisted of computing paper and pencil mathematical problems. Problems were taken from the Flash Kids Harcourt Family Learning workbook entitled *Math Skills: Grade 4*. Children were encouraged to accurately complete as many problems as possible. This mental task was designed to normalize differences in mental stimulation prior to the intervention segment. The primary investigator also took baseline heart rate manually during this period. Following the mental task, children proceeded with another peer to either the 20-minute exercise protocol or the placebo control.

Children who proceeded to the exercise protocol were assigned an ActiGraph (AG) GT1M accelerometer and instructed how to wear it. The accelerometers were fastened by an elastic belt to the participant's right hip. Next, the participants were taken through the aerobic circuit (detailed below) and provided with a demonstration when necessary. The primary investigator was present at all times to ensure safe use of equipment and to provide verbal encouragement. The sedentary condition consisted of passively watching a 20-minute, age-appropriate video: "Food, Diet, & Exercise, volume XXI," distributed by the Library Video Company.

After the 20-minute intervention period, participants walked to a quiet room for administration of the Conner's Continuous Performance Test II (CPT II). Prior to test administration, children were asked to sit quietly until manually measured heart rate returned to within 10% of baseline levels. After 5 minutes, all childrens' heart rates met these criteria. The primary researcher instructed the children on the CPT II task, provided a 60-second practice trial, and remained in the room for the duration of the 14-minute task. In addition, participants were asked to complete the Physical Activity Questionnaire for Older Children (PAQ-C) to provide a baseline measure of physical activity level (details below).

Experimental Design

A repeated measures crossover design was employed in this study to examine change in attentional test scores between the experimental and control conditions. Each child served as his or her own control. Counterbalancing of the control and exercise sessions was employed to minimize potential practice and order effects.

Instruments

Survey of Physical Activity Level

The Physical Activity Questionnaire for Older Children (PAQ-C) (see Appendix A) was used to assess general physical activity levels (Crocker, Bailey, Faulkner, Kowalski, & McGrath, 1997). The PAQ-C is a self-administered, 7-day recall instrument that has been validated as a physical activity assessment tool in children, grades 4 through 8 (Kowalski, Crocker, & Faulkner, 1997). Activity scores for each of the nine questions were averaged to determine the PAQ-C activity summary score, which is scaled from 1-5, with a summary score of 5 indicating the highest level of physical activity. Children were encouraged to be as accurate as possible in completing the PAQ-C and were assured that they were not being graded or scored on their answers. One-week test-retest reliability has been determined for both males (r = 0.75) and females (r = 0.82) (Crocker, et al., 1997).

Conners' Continuous Performance II Test

The Conners' Continuous Performance II test (CPT II) was chosen for the present study because it is readily administered to children and provides behavioral measures of response inhibition, vigilance, and selective attention. The CPT II test is a form of a Go/NoGo task with a 14-minute duration. The subject is asked to quickly respond to "Go" trials by pressing a key in response to letters other than "x." For the "NoGo" trials, the letter "x" is presented, and subjects must inhibit a response. Because the CPT II has many more "Go" (approximately 90% of stimuli) than "NoGo" trials, responding, rather than inhibiting, is made prepotent. The index of inhibitory control (i.e., inhibition of a prepotent response) is the number of mistaken responses (commission errors) a subject makes on NoGo trials (Aron & Poldrack, 2005). The CPT II program incorporates a 60-second practice exercise to ensure that the respondent fully understands the task prior to proceeding.

The standardized, computer-administered CPT II consists of 6 blocks, each with 3 subblocks, containing 20-letter presentations (360 trials in total). The order in which the three different subblocks were presented varied among blocks. The only difference between subblocks is that the program varied the time between letter presentations by 1-second, 2- second, and 4-second intervals. This variable interstimulus interval (ISI) is valuable, as it allows for evaluation of a participant's ability to adjust to a changing tempo and task demands. The display time for each letter is 250 milliseconds (C. Conners, Epstein, Angold, & Klaric, 2003).

For every respondent, the CPT II generates a comprehensive report including raw scores and T-scores of 12 parameters as well as an overall index of test performance. The 12 CPT II measures are: hit reaction time (RT), RT standard error (RT_SE), omission errors (missed targets), commission errors (false hits), variability, detectability (d'), response style (B), perseverations, hit RT by block change, hit RT_SE by block, hit RT by ISI change, and RT_SE by ISI change (see Appendix B for glossary of CPT II measures). The Confidence Index (CI) is a general indicator of performance on the CPT II and is calculated through discriminant function analysis. Because the CPT II is often used for clinical purposes with ADHD populations, the CI provides a percentage value to help evaluate the degree of fit to the profile of clinical or nonclinical respondents.

The CPT II identifies eight performance measures that may be simultaneously considered as a summary measure of inattention. These inattention measures include: omission errors, commission errors, hit RT, hit RT standard error, variability, detectability (d'), and both hit RT and RT SE by ISI. Vigilance, or the ability to sustain attention, is captured by the two CPT statistics, hit RT by block and hit RT SE by block. By examining these two parameters of vigilance, it is possible to determine if a person is systematically responding slower or faster as the test progresses through the six blocks.

Studies support both the reliability and validity of the CPT II. Strong split-half reliability for the CPT II has been identified for d' (r = .83), omissions (r = .94), commissions (r = .83), standard error (r = .87), beta (r =.73), and hit reaction time (r =

.95) (Spreen & Strauss, 1998). Test-retest reliability for the various CPT performance measures range between .55 and .84 over an average 3-month interval (Conners, 2005). Furthermore, data support the notion that there is little to no practice effect for the CPT II (Conners, 2005; Spreen & Strauss, 1998). Studies have also shown the CPT II to be a valid measure of attention in respondents 6 years of age and older. The CPT II Overall Index has been shown to positively correlate with parent and teacher ratings of attention (Conners, 2005). Additionally, the Diagnostic and Statistical Manual of Mental Disorders (DSM) IV Inattentive Symptoms subscale correlated significantly with the CPT II Overall Index ($r = .33$, $p < .05$).

Aerobic Circuit

An aerobic circuit consisting of 10 stations (see Appendix C) was arranged inside the provided gymnasiums. The circuit was designed to elicit and maintain a cardiovascular response. Children were encouraged to complete as many cycles of the circuit as possible in the allotted 20-minute time period, at a moderate to heavy exercise intensity. A brief walk to a water fountain was taken at the halfway point. Simple props including ropes, cones, and an agility ladder were incorporated, and motivational techniques included music and verbal encouragement from the primary investigator. Accelerometers, as outlined below, were employed to measure intensity of exercise.

Accelerometers

To control for variations in physical exertion during the aerobic circuit and objectively measure intensity, ActiGraph (AG) GT1M accelerometers were used. Studies show that AG accelerometers provide a valid assessment of physical activity in youth

(Janz, 1994; Treuth, et al., 2004; Trost, Rosenkranz, & Dzewaltowski, 2008). The AG is a small (3.8 x 3.7 x 1.8 cm), lightweight (27g) accelerometer designed to measure vertical accelerations ranging from 0.05-2.00 g. It has a frequency response of 0.25-2.50 Hz. In order to capture the intermittent activity patterns of children, a 30-second sampling interval, or epoch, was used (Trost et al., 2008). At the end of each epoch, the summed value, or activity count, is stored in AG memory and then reset for the next epoch. Electronic output from the AG was provided in terms of these activity counts. The number of recorded activity counts reflected the frequency and magnitude of the vertical accelerations sensed by the accelerometer.

Age appropriate cut-points for the 30-second epochs were then applied to the data to determine percent time in light (400-1599 counts), moderate (1600-4099 counts), and vigorous (≥ 4100 counts) physical activity during the 20-minute period (Puyau, Adolph, Vohra, & Butte, 2002). The accelerometers were numbered and linked to each participant by name and downloaded to a computer at the end of each testing session.

Statistical Analysis

All data analyses were run using the SPSS Software Version 17.0 (SPSS Inc., Chicago, IL). A 2 (intervention: aerobic, sedentary) x 2 (male, female) mixed factorial doubly multivariate design was used to ascertain treatment differences in CPT II performance, specific to inattention. Dependent variables included in the analysis were: omission errors, commission errors, hit RT, hit RT standard error, variability, detectability (d'), hit RT by ISI and RT SE by ISI. Similarly, treatment differences on measures relevant to vigilance (hit RT by block change and RT SE by block change) were also submitted to a doubly multivariate ANOVA. To assess baseline physical activity (as measured by PAQ-C) and intensity of exercise (as measured by ActiGraph accelerometers) as possible moderator variables, each was controlled for in the analysis.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter describes the overall results and includes the findings from CPT II measures specific to inattention and vigilance. Statistical computations utilized are identified for all analysis. Additionally, a discussion is included that addresses both significance of these findings as well as plausible explanations.

Composite Inattention and Vigilance Measures

Means and standard deviations for all CPT II variables are reported in Table 1. Data were screened for missing values and outliers, and also tested for normality. Six subjects had missing values for exercise intensity, due to technical difficulties with the accelerometers. Nearly all of the CPT II measures recorded from the child diagnosed with ADHD were outliers, so that participant's data were excluded from analysis. Lastly, results from two participants were outliers only for perseverative errors, variability, hit RT SE, and RT ISI.

The CPT II test identifies the following eight measures as particularly strong indicators of inattention: omissions, commissions, hit RT, hit RT SE, d', variability, RT ISI, and SE ISI. No order effect was indicated for the inattention measures (p = .67), therefore a 2 (intervention: aerobic, sedentary) x 2 (male, female) doubly multivariate analysis of variance (ANOVA), incorporating these eight inattention variables, was

Table 1. Group means of raw CPT II measures following 20-minute exercise or sedentary session.

CPT II measure	**Exercise mean ± SD**	**Sedentary mean ± SD**
Omission errors	6.6 ± 6.3	8.8 ± 8.6
Commission errors	24.4 ± 9.3	25.4 ± 7.3
Reaction time (RT)	369 ± 65.7	369 ± 52.7
RT Standard error	9.6 ± 4.3	8.7 ± 3.6
Variability	19.4 ± 11.3	15.1 ± 8.8
Detectability (d')	.311 ± .35	.276 ± .29
Beta (response style)	.56 ± .49	.54 ± .35
Perseverative errors	4.2 ± 5.3	6.5 ± 7.1
RT by block change	.015 ± .026	.008 ± .04
SE by block change	.05 ± .1	.046 ± .12
RT by ISI	.098±.05 .086	± .06
RT SE by ISI	.16 ± .19	.11 ± .15
Confidence Index	61.7 ± 18.5	64.3 ± 19.3

conducted. Results revealed no significant effects of exercise intervention (p = .351) or gender (p = .085) on the composite score of inattention. A gender effect was suggested for several individual measures of inattention. Compared to males, females had fewer errors of omission (3.8 vs. 10.2), higher detectability scores (0.423 vs. 0.192), and lower standard errors of RT (8.6 vs. 9.9). However, there was no gender by intervention effect, indicating that the effects of exercise on inattention were not moderated by gender.

Vigilance measures, which consisted of hit reaction time by block change and hit standard error by block change, were also examined for an order effect and none was found (p = .83). Thus, a 2 (intervention: aerobic, sedentary) x 2 (male, female) doubly multivariate ANOVA was also utilized to assess vigilance. Results revealed no significant findings.

Normalized CPT II Measures

In addition to the raw performance scores on the 12 primary CPT II measures, the CPT II program also converts these raw scores to *T*-scores. *T*-scores represent the performance of the individual taking the test relative to the population average of a normative group who are of the same gender and age group. A *T*-score of 50 represents the average for the normative group. Lower *T*-scores indicate better performance, with a standard deviation of 10. Average *T*-scores across CPT II measures for both exercise and control sessions are displayed in Figure 1. Doubly multivariate analysis of variance (ANOVA), identical to that conducted for raw scores, were also conducted for these *T*-score values of inattention and vigilance measures. No significant differences were found for either variables or the interaction of session and gender.

Baseline Physical Activity and Exercise Intensity

A summary table of PAQ-C scores as well as time spent in light, moderate, and vigorous activity is provided in Table 2. Males reported significantly higher PAQ-C scores than females ($t(23) = 2.441$; $p = .02$), 3.5 and 3.0, respectively on a scale of 1-5 (5 indicating the most physical activity). When these baseline physical activity scores were controlled for, there was no effect on either the inattention or vigilance measures. Similarly, exercise intensity had no effect on either of these attentional measures. Importantly, average exercise intensity did meet the national recommendation that 50% of PE exercise time be spent in moderate to vigorous physical activity (MVPA) (U.S. Department of Health and Human Services, 2000).

CPT II Confidence Index

The CPT II test recommends using the Confidence Index (CI) as an indicator of overall performance on the attention test. The program uses a discriminate function

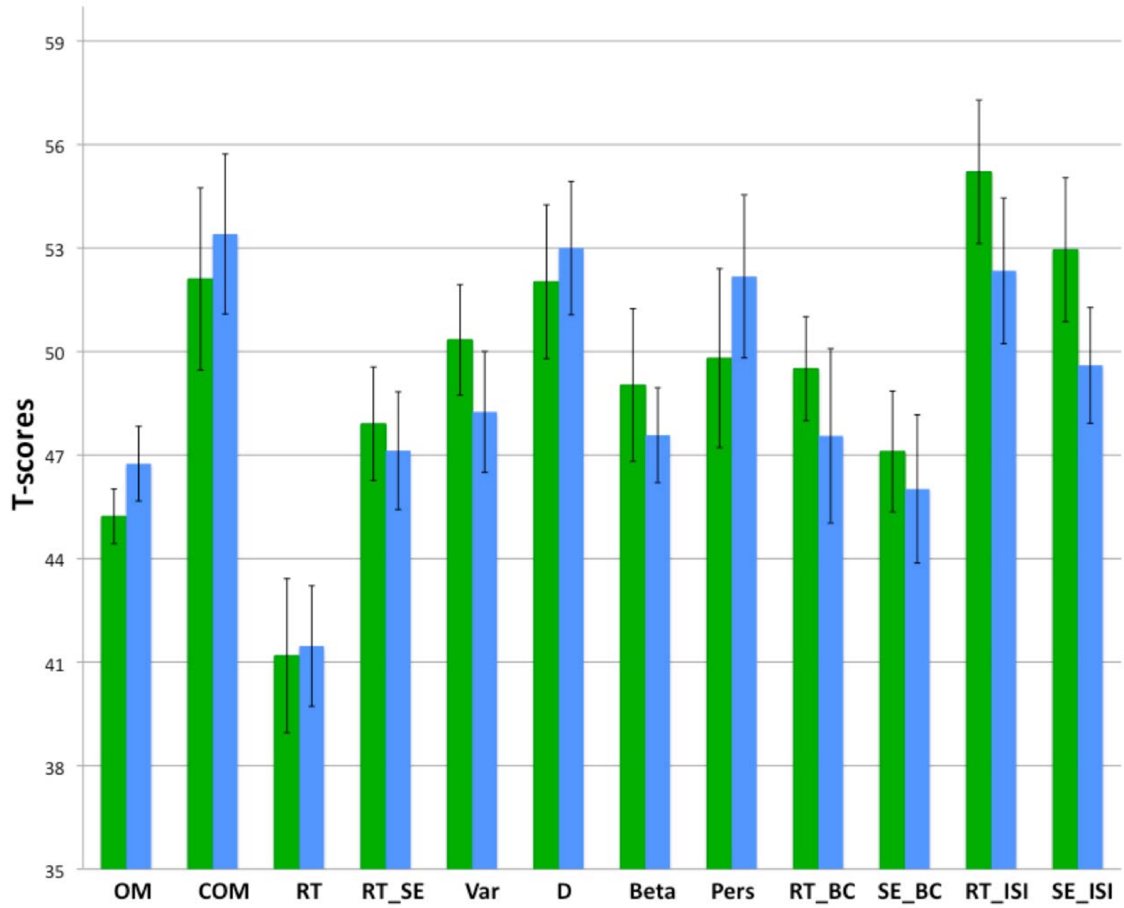

Figure 1. Normalized *T*-scores for CPT II measures following exercise (green) and sedentary (blue) sessions. A *T*-score of 50 represents the normative average. Low scores indicate better performance. OM (omission errors), COM (commission errors, RT (reaction time), RT_SE (standard error of reaction time), Var (variability), D (detectability), Pers (perseverative errors), RT_BC (reaction time by block change), SE_BC (standard error RT by block change), RT_ISI (reaction time by inter-stimulus interval), SE_ISI (RT SE by inter-stimulus interval).

Table 2. Baseline physical activity level and exercise intensity for males and females (means ± SD). * Indicates significant difference from males ($p < .05$)

	Males (N=12)	**Females (N=13)**	**Total**
Age (years)	10 ± .8	10.7 ± 1.4	10.4 ± 1.16
PAQ-C score (1-5)	3.50 ± .53	2.97 ± .57*	3.23 ± .6
Time spent light activity	42.1 ± 20%	34.3 ± 9%	37.8 ± 15.3%
Time spent moderate activity	52 ± 17%	58 ± 11%	55.1 ± 13.8%
Time spent vigorous activity	6 ± 5%	8 ± 5%	7.2 ± 5.9%

analysis[1] to provide a general assessment. However, because the CPT II is often used as a clinical assessment tool, the CI (given as a percentage) indicates whether the participant's results best fit a clinical or nonclinical ADHD population. For approximately 20% of the participants in this study, the CPT II test reported a Confidence Index of 50%, which indicates an inconclusive finding (Conners, 2002). Consequently, the CI has been deemphasized in these results, in lieu of the other 12 performance measures.

Nevertheless, a repeated measures ANOVA found a significant main effect of gender on the overall confidence index ($F(1) = 5.85$; $p = .024$). The average confidence index for females was 69.78% and 55.7% for males. The CPT II program indicates that these CI reflect a 69.8% and 55.7% likelihood of nonclinical ADHD diagnosis for females and males, respectively. As a whole, the CI suggests that females performed better overall on the CPT II than males, regardless of session type.

Discussion

The acute bout of cardiovascular exercise utilized in this study did not result in benefits to selective or sustained attentional processes, as measured by the CPT II, in these participants. However, it is important to emphasize that the exercise bout did not adversely affect attention either. A 20-minute bout of physical activity, similar to what a child might encounter in PE, did not negatively alter any measures of selective attention

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[1] The discriminate function procedures for the CI add and subtract CPT scores to account for the intercorrelations among measures. In some cases, low scores may inflate the index, introducing a conflict with the CPT II T-scores. An adjustment to the index is made when most of a subject's T-scores are high and the index is low, or when most of the T-scores are low and the index is high (more common). In both case, the Confidence Index is adjusted to 50 (the midpoint or inconclusive).

or vigilance in preadolescents. One of the justifications sometimes given for reducing time spent in PE or recess is the notion that such periods of physical activity lead to disruptions in the classroom or otherwise reduce classroom productivity and student focus. These results counter that claim, and it is the first study of its kind to do so specifically with regard to a behavioral measure of attention in this age group.

Furthermore, on average, children spent more than 50% of the exercise session at moderate to vigorous physical activity (MVPA). This meets national recommendations for PE, identified in Healthy People 2010 (U.S. Department of Health and Human Services, 2000). School PE provides an opportunity for regular and structured participation in physical activity. As such, the inclusion of PE in the school curriculum is commonly justified as a significant contribution to children's overall health and fitness (Centers for Disease Control and Prevention, 2006; Zeigler, 1994). Regular recess provides some of these same benefits.

Regularly scheduled physical activity within the school curriculum may not only benefit physical health, but also cognitive health. As discussed further below, numerous studies have found that habitual activity or gains in fitness are correlated to (see Etnier, et al., 1997) or result in (Davis, et al., 2007) executive benefits. It may be that more profound cognitive changes stem from long-term gains in fitness rather transient changes induced by exercise. Providing regularly scheduled opportunities for physical activity during the school day may ultimately result in benefits to academic achievement.

The remainder of this discussion will focus on plausible explanations for why improvements in attention, as predicted, were not observed. A number of factors may have accounted for this. First of all, it may simply be that acute exercise does not induce transient changes in cognition that are sufficient to positively alter attentional processes in children. This is not the first study to lack significant findings with regard to acute exercise and an element of executive functions. It could also be that lower-level processes such as reaction time and stimulus identification are affected by acute CV exercise more so than executive functions, or that executive functions other than attention are primarily targeted. Nevertheless, findings from studies that do suggest significant effects of acute exercise on cognition cannot be overlooked. Methodological elements of this study, such as the choice of the CPT II performance test or the exercise protocol itself may have reduced the effects—if such effects do in fact exist.

There are other studies that have found that acute exercise has either minimal positive impact on higher-order cognition or none at all. In Etnier and colleagues' (1997) meta-analysis, acute exercise studies were found to have negligible impact on cognition (effect size = 0.16) but benefited more basic processes such as response speed. Similarly, Barella, Etnier, and Yi-Kai (2010) found no transient effects of acute exercise (20-minutes moderate cycling) on performance of a classic executive function task (Stroop test) in older adults (60-90 years). Performance following exercise improved from the control condition only on the Stroop color test conducted immediately (within 30-90 seconds) after exercise. The color test portion of the Stroop task primarily reflects processing speed, not executive function. Another study on young adults (mean age 22 years) found no effect of acute exercise (40 minutes of moderate paced cycling) on a set switching, executive task (Coles & Tomporowski, 2008). Etnier and colleagues (1997) speculated that cognitive effects might be inconsequential when small, transitory changes are induced via acute exercise, and that the influence of exercise only becomes meaningful when people are habitually active or experience gains in fitness.

In spite of these insignificant findings, numerous methodological elements of this study may have reduced the ability to detect positive effects that have been reported by other labs. The acute CV exercise study by Hillman and colleagues (2003) showed increased P3 amplitude and shorter latency following 30 minutes of activity in young adults. As classically interpreted, these ERP findings suggest that exercise facilitates both the allocation of attentional resource as well as the speed of processing. However, exercise effects on behavioral measures were not significant. These researchers used the Eriksen flankers task, which requires variable amounts of inhibitory control and is thus considered a measure of executive function. It is possible that the behavioral test chosen in this study was also not sensitive enough to detect cognitive changes that may have in fact been induced by exercise. It may be necessary to incorporate neuroelectric indices of cognition, such as ERP, to identify effects of acute exercise. Analysis of ERP offers more temporal precision and isolates processes that occur between stimulus engagement and response selection. Additionally, ERP may be able to assess a more specific cognitive construct (Royall, et al., 2002), whereas some behavioral tasks may demand cognitive functions outside those the task is intended to target. In the future, the incorporation of EEG or magnetoencephalograph (MEG) measures may allow transient effects of exercise on attention to surface.

Despite the advantages of using EEG analysis, the practical significance of behavioral results is perhaps more apparent. If exercise interventions are to be used in an academic setting to enhance focus or performance, then behavioral findings should hold great importance. For this reason, the results of a recently published study by Hillman and colleagues (2009) are essential to this discussion. They recruited preadolescent participants (age 9.5 ± 0.5 years) and found that acute CV activity improved performance on a modified flanker task as well as an academic achievement test. The exercise session consisted of 20 minutes of walking at 60% of estimated maximum heart rate. In addition to these significant behavioral findings, ERP analysis showed a larger P3 amplitude after exercise. Although this study is one of the only reported studies of its kind in children, other researchers have found significant acute exercise-related behavioral effects. Acute exercise has benefited performance on the executive Stroop task for young adults (Ferris, et al., 2006) and on tests of attention and concentration in adolescents (Budde, et al., 2008).

Given the practical importance of these acute exercise studies, further exploration of these behavioral benefits in children is critical. It is possible that characteristics of the CPT II task itself may have contributed to the statistically insignificant behavioral findings of this study. As initially suggested by Chodzko-Zajko (1991), effortful tasks may be most sensitive to the beneficial effects of exercise. Brisswalter and colleagues (2002) further argues that if a cognitive task is not perceived to be challenging and does not demand enough attentional resources, then an exercise effect on cognitive performance is not likely. Many participants in this study reported being bored with the attention test, and this may have adversely affected their performance. Future studies may better determine the specificity of the relationship between acute exercise and cognitive processing by incorporating tasks of varying difficulty.

More recent studies are also finding that exercise may lead to more generalized cognitive benefits in children, rather than those strictly related to executive function, as exhibited in older populations. For example, the acute exercise bout incorporated into the study on preadolescents by Hillman, Buck, Themanson, Pontifex, and Castelli (2009) led to improved performance on the reading comprehension portion of the Wide Range Achievement Test 3 (WRAT3). Several studies examining CV fitness or more habitual activity levels in children have had similar results. Castelli, Hillman, Buck, and Erwin (2007) indicated that higher aerobic fitness levels are related to better performance on achievement tests of mathematics and reading. Buck, Hillman, and Castelli (2008) also found that high-fit children (7 – 12 years old) performed better on all three Stroop test conditions than their less active counterparts. Regardless of how much executive function was required in the Stroop task, high-fit children performed better. Likewise, Hillman and colleagues (2009) showed that high-fit children performed better across all conditions of a flanker task compared to lower-fit children, regardless of the extent of interference control needed. These findings all suggest that fitness may be associated with more general improvements in cognitive function during development. The same may be true for the effects of acute exercise.

It is also possible that the transient effects of exercise benefit executive functions other than selective and sustained attention. For example, a study on preadolescent children found that a 15-week exercise intervention did not affect performance on a selective attention test, but did enhance performance on an executive task assessing planning and strategy implementation (Davis, et al., 2007). Although this study examined long-term effects of CV exercise, the results suggest that exercise may have selective effects, even within the realm of executive functions. Interestingly, Coles and Tomporowski (2008) reported no acute exercise benefits to executive function (set switching), but did find transitory benefits to long-term memory consolidation. Clearly, it remains to be determined exactly what elements of mental processes benefit most from the transitory and long-term effects of exercise in children.

Aspects of Acute Exercise

Additionally, it is still unclear what aspects of physical exercise are most critical to inducing cognitive benefits. The exact duration, intensity, and even type of acute exercise most likely to result in benefits is still not clear. Tomporowski (2003a) suggests that the intensity and duration of acute exercise may greatly impact its effects on cognition. Researchers have implemented a tremendous range of exercise durations, but results have unfortunately been inconsistent. Colcombe and Kramer's meta-analysis (2003) found that exercise durations less than 30 minutes had no significant effect on cognitive functioning. Following 20 minutes of walking at a moderate pace (60 ± 3% of heart rate reserve), older adults have shown benefits in processing speed, but not Stroop task performance (Barella, et al., 2010). Yet, others have shown mental (Budde, et al., 2008; Caterino & Polak, 1999; Hillman, et al., 2003, 2009; Magnié, et al., 2000) and behavioral (Jarrett, et al., 1998; Mahar, et al., 2006) benefits following exercise durations of just 20 minutes or less.

The duration over which transient physiological changes may affect cognitive processes is also unclear. Heckler and Croce (1992) reported that women's cognitive performance remained heightened when measured immediately, 5 minutes, and 15 minutes following exercise. Another study investigating time course found that acute exercise benefited both response speed as well as inhibitory function for as much as 52 minutes after exercise cessation (Joyce, Graydon, McMorris, & Davranche, 2009). Yet, when Barella and colleagues (2010) investigated the time course of acute bouts of exercise, they found no executive benefits immediately or at any of the 12 time points (increments between 5 – 120 minutes) after exercise. The time-course of transitory exercise effects on cognition clearly warrants further research. The rate of neurotransmitter production and the duration of elevated plasma levels following exercise remain to be determined as well (Tomporowski, 2003b). Assuming that the participants in this study exercised at an appropriate intensity, it is possible that attentional benefits may have been detected during a particular time interval following exercise.

With regard to exercise intensity, much of our current knowledge stems from measures of cognitive performance taken during exercise. During activity, the degree of central nervous system arousal seems to be closely linked with exercise intensity as well as the rate of catecholamine elevation (Brisswalter, et al., 2002). There appears to be a range of exercise intensity, reflected in an inverted "U" shape, which elicits optimal function. Up to a point, greater energy expenditure demands attention is diverted away from cognitive control and towards controlling movements (Brisswalter, et al., 2002). Less is known about the influence of exercise intensity when the cognitive task occurs following exercise. Furthermore, like other acute exercise studies (Hillman, et al., 2003; Magnié, et al., 2000), CPT II testing did not begin in this study until participant heart rate was within 10% of baseline levels. This step was taken to minimize purely arousal effects of the central nervous system on attentional focus.

Only a few studies have examined cognitive performance following various intensities of exercise. The results from Ferris and colleagues (2006) are of particular interest as they used a younger population (25.4 ± 1 years) as well as a test of executive function, the Stroop test. Participant performance on the Stroop color-word test benefited from a 30-minute ride on a cycle ergometer only when cycling 10% above ventilatory threshold. No effects were seen when cycling at 20% below threshold. Furthermore, serum BDNF measures increased from baseline following the efforts above ventilatory threshold, but not below.

Other studies suggest that cognitive benefits may not be limited to cardiovascular exercise, and may also stem from coordinated activity or strength training. Budde and colleagues (2008) found that 10 minutes of coordinated physical exercise improved adolescent performance on a test of attention and concentration (d2-test). Participants progressed along a series of stations, each of which emphasized bilateral coordinated movements. They reasoned that highly coordinated movement might increase activation of prefrontal regions, because of studies showing high connectivity between the cerebellum and frontal lobe.

More recent evidence suggests that cognitive benefits may be derived from exercise as a result of the interrelationship between motor structures and cognition. Specifically, fMRI data indicates that the cerebellum, an area traditionally associated with motor control and coordination, is also active during executive tasks (Bellebaum & Daum, 2007). Learning complex movement sequences may simultaneously stimulate both the cerebellum and prefrontal cortex (Serrien, Ivry, & Swinnen, 2007). Although the present study incorporated some balance and agility movements, cardiovascular activity was emphasized. In the future, it may prove valuable to investigate the effects of highly coordinated activities, such as martial arts or dance, on attention in this same population. It may also be beneficial to investigate the effects of strength training on executive function. In their meta-analysis, Colcombe and Kramer (2003) found that combined aerobic and strength training (effect size = 0.59) produced better cognitive functioning than aerobic exercise alone (effect size = 0.41).

Furthermore, no correlations were revealed between exercise intensity, as measured by the accelerometers, and the CPT II performance measures. Although the Actigraph accelerometer has been shown to be a valid indicator of energy expenditure and activity levels in youth (Janz, 1994; Puyau, et al., 2002; Treuth, et al., 2004), correlations between activity counts and heart-rate monitoring or direct observation have been highest for walking and running on treadmills. Correlations have not been as strong for free-living conditions (Leenders, Sherman, Nagaraja, & Kien, 2001; McMurray, et al., 2004).

ActiGraph thresholds, or cut points for light, moderate, and vigorous activity are also a point of concern. Although the activity count thresholds implemented here were based on established criteria in youth age 6-16 years old (Puyau, et al., 2002), they are ultimately arbitrary units. Reilly and colleagues (2006) recommend that age-specific cut-points be established, as it is unlikely that broad cut-points will account for the changing relation between accelerometer counts and energy expenditure during growth. Interindividual variability in activity counts may also be high for various activities (Ekelund, Aman, & Westerterp, 2003). Given the variety of physical movements incorporated in the aerobic circuit of this study, it is possible that the ActiGraph did not accurately capture exercise intensity for this 4-year age range of children.

Influence of Gender

As predicted, gender was not a moderating factor in the relationship between acute exercise and performance on the CPT II test. The acute exercise bout appeared to affect males and females equally, despite the reportedly higher baseline physical activity scores for males. However, according to the confidence index, females did perform significantly better overall on the attention test than boys, regardless of session type. While the confidence index was reported to be inconclusive for many of the participants, results imply that females have better inhibitory control than males at this age.

As mentioned, baseline physical activity levels were significantly different for males and females. Males' PAQ-C scores indicated they were more physically active than females. According to the hypothesized results regarding benefits of baseline physical activity levels, it would then be expected that males would benefit more so from the acute exercise than females. Because acute exercise had little impact on CPT II performance for both genders, these findings imply that differences in baseline physical activity may not moderate the relationship between exercise and attention. Similarly, Magnié and colleagues (2000) found that aerobic fitness level had no influence on the relationship between acute exercise and cognition. However, self-report instruments, such as the PAQ-C used in this study, are limited in their ability to accurately depict activity levels. Boys have also been known to report higher activity levels than girls (McMurray, et al., 2004). Alternative or additional methods should be considered in the future to obtain a more comprehensive measure of baseline activity levels.

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

Conclusions

The findings from this study show that a 20-minute bout of physical activity does not adversely affect selective and sustained attentional processes, as measured by the CPT II test, in preadolescent children. Because children in this study exercised at the national recommended level of 50% MVPA, these results support the notion that physical activity may be incorporated into the school day without it having a negative impact on student attention in the classroom. By regularly integrating MVPA into the school curriculum, children may not only achieve gains in physical fitness, but also gains in cognitive health, associated with increased habitual exercise in children.

Because other recent studies have found cognitive benefits following acute exercise, identifying the specific parameters of exercise that may be responsible for these temporary changes warrants additional research. Findings would have direct application to structuring and promoting educational environments conducive to optimal learning.

Future Directions

In the future, it may be advantageous to examine certain populations, which might exhibit disproportional benefits from exercise. Tantillo and colleagues (2002) targeted the effects of acute exercise on the dopamine system among children (8 - 12 years old) diagnosed with Attention Deficit Hyperactivity disorder (ADHD). Following a brief bout of treadmill walking at 65-75% VO^2 max, children exhibited faster acoustic startle eye blink responses (ASERs). Because the ASER is sensitive to dopamine agonists, Tantillo and colleagues concluded that acute exercise might have efficacy in treating ADHD symptoms. Interestingly, no effects were seen for the control children who did not have ADHD. In this study, noteworthy results surfaced with the male diagnosed with ADHD. Although nearly all of this individual's CPT II measures were outliers, the exercise session improved several measures of performance. For example, omission errors declined from 119 to 63 errors, response times became more consistent, and vigilance scores markedly improved. Based on these findings, it is possible that acute exercise interventions would be most beneficial to populations with attention disorders.

Acute exercise also appears to benefit behavior, particularly in children who may have behavioral disorders. Studies conducted with these populations contradict anecdotal claim that PE and recess overly excite children and disrupt classroom performance. For example, a decline in class disruptions has been reported after 15 and 30 minutes of jogging, and improved classroom behavior has been observed after a mere 10 minutes of jogging (see Tomporowski, 2003b). Mahar and colleagues (2006) found that 10-minute class interventions that incorporated physical activities increased on-task behavior for students who were least focused during class. Moreover, a study on healthy fourth graders found children more on task and less fidgety on days they had a 15 - 20 minute recess than on nonrecess days (Jarrett, et al., 1998). Some researchers support the notion of an exercise-induced relaxation state where concentration is enhanced. Evidence that short bouts of exercise improve mood, and reduce anxiety, depression, and cortisol levels is well supported in the adult population (see Tomporowski, 2003b). Children are likely to benefit in a similar fashion.

Participants in this study lived in a rather physically active suburb, and it can be seen from the CPT II *T*-scores that this was a relatively high-performing group of children. It is plausible that participants reached a threshold whereby their habitually active lifestyles limit the transient cognitive benefits of acute exercise. Recruiting from a more diverse population, comprised of a range of activities levels, would serve to address this. It would also be advantageous to recruit from school districts with a wider range of baseline achievement scores. It may be that children from underachieving districts benefit more so from intermittent CV activity.

Lastly, a weakness of this study is that physical activity outside of the protocol was not properly controlled. Several children reported attending various athletic camps (soccer, lacrosse, etc.) earlier in the day that testing occurred. A few other participants used modes of transportation, such as biking or walking, to travel to the University for testing. Given that the time course of acute exercise effects is not well characterized, physical activity earlier in the day may have interfered with the testing protocol and performance on the CPT II test.

APPENDIX A

PHYSICAL ACTIVITY QUESTIONNAIRE FOR CHILDREN

Physical Activity Questionnaire (Elementary School)

Name:________________________ Age:__________

Sex: M______ F______ Grade:__________

Teacher:______________________

We are trying to find out about your level of physical activity from ***the last 7 days*** (in the last week). This includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

1. There are no right and wrong answers — this is not a test.
2. Please answer all the questions as honestly and accurately as you can — this is very important.

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1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Mark only one circle per row.)

	No	1-2	3-4	5-6	7 times or more
Skipping	❍	❍	❍	❍	❍
Rowing/canoeing	❍	❍	❍	❍	❍
In-line skating	❍	❍	❍	❍	❍
Tag	❍	❍	❍	❍	❍
Walking for exercise	❍	❍	❍	❍	❍
Bicycling	❍	❍	❍	❍	❍
Jogging or running	❍	❍	❍	❍	❍
Aerobics	❍	❍	❍	❍	❍
Swimming	❍	❍	❍	❍	❍
Baseball, softball	❍	❍	❍	❍	❍
Dance	❍	❍	❍	❍	❍
Football	❍	❍	❍	❍	❍
Badminton	❍	❍	❍	❍	❍
Skateboarding	❍	❍	❍	❍	❍
Soccer	❍	❍	❍	❍	❍
Street hockey	❍	❍	❍	❍	❍
Volleyball	❍	❍	❍	❍	❍
Floor hockey	❍	❍	❍	❍	❍
Basketball	❍	❍	❍	❍	❍
Ice skating	❍	❍	❍	❍	❍
Cross-country skiing	❍	❍	❍	❍	❍
Ice hockey/ringette	❍	❍	❍	❍	❍
Other:					
______________________	❍	❍	❍	❍	❍
______________________	❍	❍	❍	❍	❍

2. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? (Check one only.)

I don't do PE .... ❍
Hardly ever .... ❍
Sometimes .... ❍
Quite often .... ❍
Always .... ❍

3. In the last 7 days, what did you do most of the time *at recess*? (Check one only.)

Sat down (talking, reading, doing schoolwork)...... ❍
Stood around or walked around .... ❍
Ran or played a little bit .... ❍
Ran around and played quite a bit .... ❍
Ran and played hard most of the time .... ❍

4. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? (Check one only.)

Sat down (talking, reading, doing schoolwork)....... ❍
Stood around or walked around .... ❍
Ran or played a little bit .... ❍
Ran around and played quite a bit .... ❍
Ran and played hard most of the time .... ❍

5. In the last 7 days, on how many days *right after school*, did you do sports, dance, or play games in which you were very active? (Check one only.)

None .... ❍
1 time last week .... ❍
2 or 3 times last week .... ❍
4 times last week .... ❍
5 times last week .... ❍

6. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Check one only.)

None .... ❍
1 time last week .... ❍
2 or 3 times last week .... ❍
4 or 5 last week .... ❍
6 or 7 times last week .... ❍

7. *On the last weekend*, how many times did you do sports, dance, or play games in which you were very active? (Check one only.)

None .... ❍
1 time .... ❍
2 — 3 times .... ❍
4 — 5 times .... ❍
6 or more times .... ❍

8. Which *one* of the following describes you best for the last 7 days? Read *all five* statements before deciding on the *one* answer that describes you.

A. All or most of my free time was spent doing things that involve little physical effort .... ❍

B. I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics) .... ❍

C. I often (3 — 4 times last week) did physical things in my free time .... ❍

D. I quite often (5 — 6 times last week) did physical things in my free time .... ❍

E. I very often (7 or more times last week) did physical things in my free time .... ❍

9. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	None	Little bit	Medium	Often	Very often
Monday	❍	❍	❍	❍	❍
Tuesday	❍	❍	❍	❍	❍
Wednesday	❍	❍	❍	❍	❍
Thursday	❍	❍	❍	❍	❍
Friday	❍	❍	❍	❍	❍
Saturday	❍	❍	❍	❍	❍
Sunday	❍	❍	❍	❍	❍

10. Were you sick last week, or did anything prevent you from doing your normal physical activities? (Check one.)

Yes .... ❍
No .... ❍

If Yes, what prevented you? ________________________________

APPENDIX B

GLOSSARY OF CPT II MEASURES

1. Confidence Index: provides a probabilistic assessment regarding clinical ADHD or nonclinical classification. As reported, higher values indicate better performance and a closer match to a nonclinical profile. Values are determined via the CPT II program's discriminant function analysis.

2. Omissions: omission errors occur when the subject fails to respond to target letters (letters other than X).

3. Commissions: commission errors are made when responses are given to non-targets (i.e., Xs).

4. Hit Reaction Time (RT): the average speed of correct responses for the entire test

5. Standard Error (SE): Overall hit RT SE is a measure of response speed consistency. The higher the SE, the more inconsistency in response speed.

6. Variability: Variability of standard error measures "within respondent" variability. It measures the amount of variability the individual shows with RT in separate segments of the test, in relation to his or her own overall SE. The higher the variability of SE, the greater the inconsistency in response speed.

7. Detectability (d'): a measure of the difference between the signal (non-X) and noise (X) distributions. d' provides a measure of an individual's discriminative power. Typically, the greater the difference between the signal and noise distributions, the greater the ability to distinguish and detect X and non-X stimuli.

8. Beta (*B*) or Response Style Indicator: Beta (*B*) represents an individual's response tendency. Some individuals are cautious and choose not to respond very often. Conceptually, such individuals want to make sure they are correct when they give a response. Higher values of Beta reflect this response style. The emphasis is on avoiding commission errors. Other individuals respond more freely to make sure they respond to most or all targets, and they tend to be less concerned about mistakenly responding to a non-target. Lower values of Beta are produced by this response style.

9. Perseverations: Any reaction time that is less than 100 ms is classified as a perseverative error. Given normal physiological constraints of response time, perseverations are usually either slow responses to a preceding stimuli, a random response, an anticipatory response, or a response repeated without consideration of the stimuli or task requirements.

10. Hit Reaction Time by Block (Hit RT Block Change): Hit RT Block Change measures change in reaction time across the duration of the test. High values of Hit RT Block Change indicate a substantial slowing in reaction times. Low values indicate that responses got quicker as the test progressed.

11. Standard Error by Block (Hit SE Block Change): Standard Error by Block detects changes in response consistency over the duration of the test. High values of Hit SE Block Change indicate a substantial loss of consistency as the test progressed. Low values on this measure indicate sustained or improved response consistency.

12. Reaction Time by Inter-Stimulus Interval (Hit RT ISI change): This measure examines change in average reaction times at the different Inter-Stimulus Intervals (i.e., when the letters are presented at 1, 2, or 4 sec. intervals).

13. Standard Error by Inter-Stimulus Interval (Hit SE ISI change): This measure examines change in the standard error of reaction times at the different Inter-Stimulus Intervals (i.e., when the letters are presented at 1, 2, or 4 sec. intervals).

APPENDIX C

AEROBIC CIRCUIT DESIGN

Station #1: jump rope (20 times)

Station #2: dribble soccer ball in and out of cones

Station #3: beanbag toss (5 tosses)

#4 —Run or shuffle down the length of the gym—

Station #5: balance beam

Station #6: agility ladder drills

Station #7: step-ups onto box

Station #8: balance disc (hold 30 seconds)

#9 —Run back down the length of the gym—

Note: Participants moved in a clockwise fashion around the perimeter of the gym. After the halfway point (10 minutes), participants were told to reverse and travel in a counterclockwise fashion. With the exception of a water break at 10 minutes, participants were continuously moving.

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