ABSTRACT

Title of Thesis: THE EFFECTS OF AN ACUTE BOUT OF EXERCISE UPON BEHAVIORAL RESPONSES TO AND NEUROPHYSIOLOGICAL INDICES OF ATTENTION ALLOCATION IN CHILDREN AND ADULTS

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In both child and adult populations, engagement in frequent physical activity results in a myriad of cognitive benefits, including improved executive functioning. However, the relationship between engagement in *acute* bouts of physical activity and cognitive processes, such as attention allocation, are less well understood. **Methods:** This study sought to: 1) Investigate the effects of an acute bout of exercise on behavioral responses; 2) Investigate the effects of an acute bout of exercise on neurophysiological measures; and, 3) Investigate age-related differential effects. EEG was recorded from 32 male participants (n=16 adults, n=16 children 9-11 years of age) who completed a 3-stimulus auditory oddball behavioral task, pre- and post-exercise intervention. **Results:** Contrary to expectations, this study found that, regardless of age, engagement in an acute bout of exercise did not have a significant effect upon some behavioral and all neurophysiological indices of attention, as measured by response accuracy, reaction time percent difference, and P3a and P3b amplitude, respectively. Moreover, the findings indicate no age-related differential effects of acute exercise on these same indices of attention. However, absolute

reaction time results indicate a significant main effect for group ($F(1, 21) = 4.48$, $p<0.05$) in the block immediately following the acute exercise intervention.

Discussion: The relative ease with which both adult and child participants completed the behavioral task indicates that the task may have been simple, rather than executive in nature. Therefore, only some of the behavioral benefits and none of the typical neurophysiological benefits associated with acute exercise bouts were seen in this study, nor were age-related differential effects of acute exercise observed. However, the significant difference in reaction time between intervention and control groups immediately following the intervention, does provide the behavioral results typical of this intervention. Future studies should explore similar acute exercise interventions in combination with a varied behavioral task (e.g., a modified 3-stimulus auditory oddball) that strongly activates the executive functioning network.

THE EFFECTS OF AN ACUTE BOUT OF EXERCISE UPON BEHAVIORAL RESPONSES TO AND NEUROPHYSIOLOGICAL INDICES OF ATTENTION ALLOCATION IN CHILDREN AND ADULTS

By

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Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Master of Arts
2014

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ACKNOWLEDGEMENTS

It is with much appreciation and gratefulness that I acknowledge the following individuals for their numerous contributions to the completion of this thesis:

- Dr. Jane Clark- Before *East of Eden*, “research” was an unknown concept to me. You have challenged me. You have taught me to question. You have taught me to thoroughly learn. You have taught me to fully know. You have led me through this process, and the lessons I have and continue to learn are innumerable. Thank you.
- Dr. Bradley Hatfield- Your value of research, thoughtfulness in problem solving, and support have been unweaning. Your professionalism is admirable. Thank you for your guidance.
- Dr. Marcio Oliveira- From the classroom to serving on this committee, you have never stopped encouraging me to try the unknown. Thank you for your faith.
- Dr. Jeremy Rietschel-Your mind is incredible. I marvel at your thinking. Thank you for your ideas, encouragement, and support. From brainstorming, to troubleshooting, to procedures and analyses, you have been instrumental in all parts of this.
- Yue Du- For your willingness to help with numerous surprise requests for statistical analysis and patience in explaining to me, thank you. Your development as a researcher, and a statistics pro, has been wonderful to see.
- Jennifer Cunningham- Filled with enthusiasm and full of competence through hours of data collection, you were terrific to work with. Thank you for giving of your time.
- Dr. Melissa Pangelinan- Your faithfulness to your lab, generosity of time, dedication to your research, and love of the rigorous process of investigation are exceptional qualities. Thank you for being an incomparable example.

- The Members of the Motor Development Lab- Thank you for your questions, intelligence, and being a wonderful team.
- The Members of the Exercise Science Lab-Thank you for giving of your time in teaching me, answering my many questions, and allowing me to invade your lab.
- Dennis Shingleton- From miles away, your support, through many forms, has never been far. For this, I thank you. You, your values, and your intelligence are exemplary attributes that I hold in the highest esteem.
- Shirley Shingleton- You are a tremendous teacher and a forever student. Thank you for a lifetime of lessons and my passion to learn.
- Maureen Cipriani- Thank you for never telling me that I could not be an astronaut. You are my forever, and greatest, fan. Your belief in me is a constant source of strength.
- Timothy Yee- With a mix of practicality, reality, calm, encouragement, and love, you have provided me with the perfect support for all phases of this process. Your confidence in my abilities overwhelms me. Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

Introduction

Attention is a cognitive construct present in everyday life. From childhood to adulthood, changes in attentional processing abilities, and specifically increases in the efficiency of attentional resource allocation are observable. Attentional resource allocation refers to the allocation of the brain's limited attentional resources to the task or tasks in which an individual is engaged (Wickens, 1991). For adults, efficient allocation of attentional resources happens with ease, but for children efficient allocation is more difficult, suggesting that this cognitive process develops with age (Durston et al., 2002; Rueda et al., 2004).

Unique to this age-related increased efficiency is the protracted development of the neural structures, the frontal lobes, which are implicated in the control of this attentional process (Konrad et al., 2005; Posner & Fan, 2008; Rapoport & Gogtay, 2008). Since the frontal lobes of the brain are highly plastic in nature, indicating the ability to change in neural structure and function in response to life experiences, they are subsequently highly susceptible to changes induced by environmental stimuli (Rapoport & Gogtay, 2008), including participation in physical activity and physical exercise. Children, whose frontal lobes are less developed than the adult population, behaviorally and neurophysiologically show decreased efficiency in allocating attentional resources (Bartgis, Lilly & Thomas, 2003; Durston et al., 2002; Konrad et al., 2005; Määttä, Pääkkönen, Saavalainen, & Partanen, 2005; Rueda et al., 2004). For children, the combined effect of a protracted development and high plasticity lead to the possibility that physical activity and physical exercise may have an impact on the development of the frontal lobes and the processes they control. To explore this relationship, this study proposes an investigation of the effects of an acute bout of exercise upon attentional resource allocation in children and adults through the use of electroencephalography (EEG).

The human brain is limited in attentional resources and relatively fixed in attentional capacity, although this capacity is not uniform for all people and differs with arousal state (Pashler & Johnston, 1998; Posner & Fan, 2008; Wickens, 1991). Since attentional resource allocation follows a protracted development, significant changes, both behaviorally and structurally, can be seen throughout childhood and adolescence (Rueda et al., 2004). Due to the limitations of the human attentional network, efficient allocation of the few available attentional resources is essential for everyday cognitive functioning (Määttä et al., 2005), especially for children whose attentional networks are under-developed as compared to adults. Not only is it challenging for children to focus their attention for long periods of time, it is also difficult for children to accurately process all of the information being presented to them (Määttä et al., 2005).

A potential mediating factor in attentional resource allocation is physical activity and physical exercise. Both physical activity and physical exercise have shown beneficial effects for cognition (Tomporowski, 2003), with this relationship most strongly seen between physical activity and physical exercise and cognitive tasks controlled by the frontal lobes (Bixby et al., 2007; Chodzko-Zaiko & Moore, 1994; Colcombe et al., 2004). To date, research has most commonly focused on the effects of physical activity and physical exercise as positive mediators or preventers of age-related cognitive decline in adult and elderly populations. While physical activity and physical exercise have shown ameliorative effects for age-related cognitive decline in older individuals, similar knowledge pertaining to child populations is less well understood (Tomporowski, 2003). More recently, a shift toward the importance of studying this phenomenon in children has begun. Studies have indicated that even in this young population, participation in physical activity or physical exercise can lead to more efficient cognitive processing (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009a; Hillman, Castelli, & Buck, 2005). Furthermore, additional studies have linked this relationship between participation in physical activity and physical exercise and more efficient cognitive processes directly to academic achievement (Castelli, Hillman, Buck, & Erwin, 2007; Coe, Pivarnik, Womack, Reeves, & Malina, 2006), where positive benefits of physical activity and physical exercise were again observed. However, no studies have investigated the benefits of an acute bout of exercise, specifically upon the maintaining of focal attention in the presence of unannounced, distracting events in children.

To study the relationship between physical activity and physical exercise and cognitive functioning, researchers have frequently relied on event related potentials (ERPs) which are evoked potentials extrapolated from a continuously recoded electroencephalography (EEG) (Pivik et al., 1993). One ERP, the P300 component has frequently been used to investigate the neurophysiological processes underlying attentional resource allocation (Polich, 2007; Ullsperger, Freude, & Erdmann, 2001).

While many studies have indicated the benefits of physical activity and physical exercise for increased cognitive functioning, the mechanisms underlying this relationship are unknown. The most likely mechanism underlying the relationship between an acute bout of exercise and cognition is the upregulation of neurotransmitters. Of the many neurotransmitters that are released following an acute exercise bout, dopamine is one that closely relates to attentional processes (Casey, Durston, & Fossella, 2001). Microdialysis studies (Hattori, Naoi, & Nishino, 1994; Meeusen, Piacentini, & de Meirleir, 2001) have indicated an upregulation of dopamine in the rat striatum after only 20 minutes of exercise. Since increased dopamine levels lead to a greater efficiency of attentional processes, and acute bouts of exercise increase the levels of dopamine, it is likely that this relationship could be a prime candidate for describing the mechanisms underlying the relationship between acute exercise bouts and improved cognitive functioning. While the current study does not measure dopamine changes with exercise, the work on dopamine offers a possible mechanism for how an acute bout of exercise may influence the electrocortical and behavioral measures used in the proposed research.

The purpose of this study is to investigate the effects of an acute bout of exercise upon behavioral responses to and neurophysiological indices of attention in adults and children and to determine any age-related differential effects. This research study has three specific aims: 1) To investigate the effects of an acute bout of exercise upon behavioral responses (indicated by response accuracy and reaction time); 2) To investigate the effects of an acute bout of exercise upon neurophysiological measures (shown by P3a amplitude in response to a novel auditory sound and P3b amplitude to a target sound); and, 3) To investigate any age-related differential effects. It is hypothesized that following the intervention, adult and child participants who engage in the acute exercise bout will demonstrate: (1) improved behavioral responses (indicated by increased response accuracy and decreased reaction time), and (2) improved neurophysiological measures (demonstrated by increased P3a amplitude in response to the novel auditory sound and increased P3b amplitude in response to the target auditory sound) indicative of an increase in spare processing resources and thus improved attentional allocation. Additionally, due to the still developing neural pathways of children, it is hypothesized that age-related differential effects of acute exercise will be visible through these same behavioral and neurophysiological indices of attention, such that children will derive a greater benefit from the exercise bout, as compared to adults.

CHAPTER II

Review of Literature

Introduction

This chapter reviews the literature that provides the empirical and conceptual background to the research proposed in this thesis. The chapter is organized into seven sections. The first section discusses the construct of attention, and has three subsections: The first subsection details the process of attentional resource allocation. The second subsection describes the behavioral development of attentional processes, while the third subsection describes the structural development of these same processes. Both the second and third subsections focus on this development in childhood. The second section depicts the behavioral and structural development of the frontal lobes and how this structure relates to attention, physical activity and physical fitness. Section three highlights neurophysiological measures related to attention. In section four, studies utilizing the aforementioned neurophysiological measures in reference to attentional processes are detailed. The fifth section provides an overview of studies relating physical activity, physical fitness, acute and chronic exercise to cognitive processes in adults and children. Section six provides possible mechanisms underlying the relationship between acute bouts of physical activity and attentional processes. Finally, section seven focuses on the potential "real world" implications of this study, by examining changes seen in academic achievement related to participation in physical activity and physical exercise.

Attention and Attention Processing

Attention is a construct overlying a variety of more specific cognitive processes including selective attention, sustained attention, controlled processing, inhibition, and alerting (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007). Typically, attention involves functions falling into three general categories: 1) achieving and maintaining an alert state; 2) the orienting to sensory events, and 3) controlling one's thoughts and feelings (Posner & Fan, 2008). When individually executed, these attentional functions are simple enough, but when simultaneously executing two of these processes, cognitive functioning becomes much more difficult. When individuals are presented with a task or situation, attentional processing progresses in a sequential manner, where focus first is given to one item, and then another, and then another (Pashler & Johnston, 1998). It is only sometimes that multiple stimuli or events can be processed simultaneously, and this is largely dependent upon the difficulty of a task (Pashler & Johnston, 1998). The more attentionally demanding a task, the more difficult it is to process all information simultaneously (Wickens, 1991). Underlying this increased difficulty in attentional processing is a human brain that is highly limited in both attentional resources and attentional capacity (Pashler & Johnston, 1998; Wickens, 1991). Across individuals, attentional capacity and attentional resources are not uniform and both vary with changes in arousal state and age. In contrast, on an individual basis, and when one is engaged in a given task and remains in a constant mental state, attentional capacity remains fixed and attentional resources do not increase (Wickens, 1991). Therefore, as attentionally-demanding tasks become more challenging (due to added stimuli or distracting events), there is no concurrent increase in attentional capacity or resources, thus making attentional processing more difficult.

Attentional resource allocation. Contrasting the relatively static nature of an individual's attentional capacity and attentional resources is the process of attentional resource allocation. Attentional resource allocation is not fixed and remains flexible in the presence of changing task requirements or processing demands (Strayer & Drews, 2007). Efficient allocation of attentional resources is essential to everyday cognitive processing. Since it is impossible to process all of the constantly provided sensory input, the ability to allocate resources to pertinent stimuli and tasks, while ignoring irrelevant information is key to daily cognitive functioning (Strayer & Drews, 2007). When an individual is engaged in an attentionally-demanding task, a portion of attentional resources are allocated to processing this task, and a reserve of resources remains for processing any other task. With an increase in task difficulty, an individual may allocate more resources to processing a primary task, leaving fewer resources in reserve. On the contrary, if a task is less attentionally-demanding, less attentional resources may be allocated to processing the stimulus, leaving more resources in reserve. In theory, the more difficult a primary task, the less available attentional resources in reserve, and thus the poorer performance on a secondary task. Conversely, the less difficult a primary task, the more available resources in reserve, and a typical performance on the secondary task results (Wickens, 1991).

Making the process of attentional resource allocation less efficient is the presence of distracting events. Even when engaged in a task, if an unusual event is seen or heard, an individual involuntarily orients attention to this event (Polich, 2007). The degree to which this event interrupts focal attention is dependent upon attentional resource allocation and the amount of attentional resources not engaged in the primary task, or those in reserve. The more resources in reserve, the less likely it is that attentional resources will be involuntarily oriented from the primary task to the distracting event. With fewer resources in reserve, an inverse relationship exists, and primary task performance and focal attention are more likely to be affected.

Due to the limitations of individual attentional resources and one's relatively fixed attentional capacity, proper allocation of the available attentional resources is essential for efficient cognitive functioning (Määttä et al., 2005; Strayer & Drews, 2007). Even as individuals effectively allocate attentional resources, depending on the number of attentional resources in reserve, the involuntary orientation of attention can detract from focal attention (Wickens, 1991).

Behavioral and structural development of attentional processes. The ability to efficiently allocate attentional resources develops with age (Posner & Fan, 2008). This change in efficiency is easily visible when comparing the performance of the elderly, adults and children on the same task, such as writing a name while talking on the phone. The process of attentional resource allocation follows a protracted developmental trajectory, which is similar to that of the frontal lobe, a structure implicated in its control (Posner & Fan, 2008). Additionally, brain regions essential to early developmental functions, such as the primary motor cortices, show an earlier refinement than those which underlie complex functions, such as the frontal lobes. Due to this developmental trajectory, significant changes, seen behaviorally and structurally, in the ability to efficiently allocate attentional resources are seen throughout childhood and adolescence and into adulthood (Casey et al., 2001; Rueda et al., 2004).

Behavioral development. For many children maintaining attention for a sustained time is a challenging task, largely because the neural structures that underlie attention are not developed enough to enable the child to do this. With age, the behavioral abilities of differentiating relevant from irrelevant stimuli, attending to relevant stimuli, and inhibiting irrelevant stimuli all show increased efficiency (Määttä et al., 2005). Recently, studies have begun to lay a foundation of the behavioral trajectory associated with attentional development (Bartgis et al., 2003; Durston et al., 2002; Määttä et al., 2005; Rueda et al., 2004). Behaviorally, from 5-7 years of age, large changes are seen in children's attentional development, especially in selective attention (Bartgis et al., 2003). In a study utilizing standard and target auditory tones (similar to an auditory oddball task), children 5, 7, and 9 years of age were asked to respond to the target tone, by button press, only when it was heard in the attended ear. Results indicated that 5 year old children showed no difference in activation of neural networks between attended and non-attended targets, but 7 and 9 year old children showed significantly greater neural activation to the target tones. Although only an age difference of two years, the greater neural activation seen in the older two age groups indicates that in this short time span, children gain a greater ability to allocate attentional resources to a given task, and increase in the ability to process relevant from irrelevant stimuli. In another study looking at the development of various attentional processes in children, Rueda et al. (2004) studied groups of children at four different ages: 6,7,8, and 9 years of age and in a second experiment compared their performance to that of adults. After completing the Attention Network Test (ANT), a test created to analyze the independence of various attentional networks (orienting, alerting, and executive function) a number of findings were identified. Between 6-10 years of age, reaction times and error rates both decreased with age. Additionally, after the age of 7, children showed nearly identical response accuracy across the remaining age groups, indicating that changes in attentional development may be largest before age 7 and then temporarily plateau. Together, the studies of Rueda et al. (2004), and Bartgis et al. (2003) provide behavioral measures indicative of an increased ability to allocate attentional resources through childhood. Furthermore, both studies indicate that by age 7, rapid behavioral changes seen in attention begin to settle to a level which is mainly consistent for the next few years.

Structural development. Development of children's attentional processes is not only reflected behaviorally, but also structurally. Grey matter development follows that of an inverted U (Casey et al., 2001), where increases in matter are seen through childhood and volume reductions typically begin sometime in late adolescence. Although there is no set age or developmental stage at which grey matter begins to decrease, the lowered volume of grey matter may reflect the transition between the immature and mature brain where the refinement of neural connections through synaptic pruning are indicative of more efficient neuronal connections. Interestingly, the grey matter development follows a "back-to-front" development, so parietal structures tend to undergo the process of synaptic pruning first, and the frontal lobes undergo this developmental change last (Casey et al., 2001). Unlike the trajectory for grey matter development, white matter increases linearly throughout childhood, adolescence and potentially into young adulthood. Since increased white matter causes increased myelination, concurrent increases in communication between neurons can be assumed (Casey, Tottenham, & Liston, 2005). Once the synaptic pruning of grey matter begins, the development of grey and white matter becomes complimentary. The resultant structural changes lead to more efficient neuronal processes which underlie cognitive processes, such as attention.

Recently, studies utilizing the neurophysiological measures of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) have combined the behavioral and structural findings. Konrad et al. (2005) combined a modified ANT protocol with fMRI to provide both behavioral and structural results. In the study which compared children 8-12 years of age and adults 20-34 years of age, behaviorally, children were more sensitive to interference, showed lower response accuracy, slower reaction time, and had greater difficulty disengaging from the task, as compared to adults. Structurally, children activated less of the key neural areas associated with the cognitive processes, and over activated other neural areas as compared to adults, potentially indicative of the children's attempt to compensate for their less efficient networks. The behavioral differences (i.e. response time and response accuracy) between the adults and children were mirrored structurally by changes in activation of specific neural networks, which became more refined and efficient with age. Interestingly, in the same brain regions containing greater grey matter, there were also lessened cortical activity for children. This finding indicates that the maturing of the brain (seen in the decreased grey matter) may also be indicative of increased cortical activation in children that begins to mirror that of adults. This study not only establishes a link between the behavioral and structural changes of attentional networks, but also indicates that these networks undergo significant changes across childhood and into adulthood.

Behavioral and Structural Development of the Frontal Lobes

Although many neural regions play a role in directing attentional processes, one neural region, the frontal lobe, is frequently implicated as significantly influencing both the process of attentional resource allocation and executive function (Casey et al., 2001; Posner & Fan, 2008). Similar to attention, executive function is a construct overlying a variety of mental processes. Specifically, executive function refers to conscious, effortful mental processes, including, but not limited to, discrimination tasks, response selection, and inhibitory control (West, 1996). Since attentional resource allocation and executive function are partially controlled by the same neural structures, research on executive functioning has helped to lay the groundwork for studies of attentional resource allocation. It is important to note that each construct represents separate and distinct mental processes, but the similarities in these processes supports the notion that the development of shared neural structures may comparably affect both cognitive processes.

The development of the frontal lobes across the lifespan is unique. The frontal lobes show a protracted development in which full functioning of these lobes is not reached until adulthood. Contrasting the protracted development is the decline of the frontal lobes experienced in late adulthood. While the overall structure and function of the brain decline with age, the frontal lobes show a disproportionally larger, earlier and more drastic decline than any other structure in the brain (West, 1996). Due to this disproportionate decline, research was initially conducted to study the role of physical activity as a mediator of the age-related declines seen in cognitive processes controlled by these lobes. These studies have since provided results which have established a unique link between physical activity and physical exercise and adult cognition.

The frontal lobes of the brain are highly plastic in nature, indicating the ability to change the neural structure and function in response to life experiences and environmental influences. Highly plastic structures are subsequently highly susceptible to changes induced by life experiences (Rapoport & Gogtay, 2008), including participation in physical activity and physical exercise. For children, whose frontal lobes are not fully developed, there is the potential that additional cognitive benefits from physical activity could be acquired during this time. The combined effect of a protracted development and high plasticity leads to the possibility that physical activity and physical exercise may affect the frontal lobes and the processes that they control, such as attention, more strongly than other neural structures that mature earlier in life.

Neurophysiological Measures

In an attempt to identify the neural structures that account for the allocation of attentional resources, researchers have relied on event related potentials (ERPs). ERPs are extrapolated from a continuously recording electroencephalography (EEG) signal. ERPs are unique as they reflect evoked potentials, or voltage changes specifically in response to an external stimulus (Pivik et al., 1993). One component of an ERP is the P300 or P3 component that occurs approximately 300-800 milliseconds after the onset of a stimulus. The P3 component is frequently analyzed in terms of its amplitude and latency, and it is believed to be composed of numerous sub-components which reflect attentional processing (Polich, 2007)**.** Two of the sub-components include P3a and P3b, which reflect the involuntary orienting of attention from focal attention to irrelevant information (Ullsperger et al., 2001) and the activation of neural networks resulting from the updating or revision of the current mental representation (Donchin, 1981), respectively.

Although the P3 component has been investigated and analyzed in many studies, researchers are still puzzled by the specific factors underlying the generation of this component and its sub-components. While the P3a and P3b components are complimentary to attentional processing, both are unique components and differ in many fundamental aspects (Polich, 2007). To elicit a P3a component, a 3-stimulus task (detailed in the following section) is frequently utilized. To elicit a P3b component, an oddball task (detailed in the following section) is typically utilized. Another difference between the P3b and P3a components is their scalp distribution. While the P3a component shows primarily a frontal distribution, the P3b component shows mainly a centro-parietal distribution, with parietal maximal amplitudes. Furthermore, in cognitive tasks involving a primary task and distracting stimuli, the P3a component remains robust, unlike the P3b component which habituates. For this reason, it is believed that P3a is highly indicative of the amount of spare processing resources or the resources not engaged in the primary task; the resources available for the reflexive orientation of attention. Following this theory, greater P3a amplitudes would indicate more spare resources, and more efficient focal attention, since less attentional resources would be needed to complete a primary task. Taken together, the distinct components of P3a and P3b may combine to provide a trajectory of attentional processing.

Attention and ERPs

In an attempt to measure attentional resource allocation, a number of studies have combined the neurophysiological measure of ERPs with auditory oddball tasks. In the typical oddball task, participants are presented with a discrimination or “oddball” task in which two different stimuli, the non-target and target, are presented at varying frequencies, usually 80% to 20%, respectively. These stimuli can be either auditory or visual. Subjects are challenged with the primary task of responding to the infrequent (target) stimulus with the push of a button, and showing no response to the frequent (non-target) stimulus (Allison & Polich, 2008; Johnstone, Barry, Anderson, & Coyle, 1996). In all versions of the auditory oddball task, the automatic detection of the non-frequent tone causes a re-updating of mental representations toward the sound (Polich, 2007). Another version of the oddball paradigm is the 3-stimulus task in which a variety of noises are presented. Like the oddball task, frequent and non-frequent stimuli are presented, but a third stimulus, a non-frequent novel stimulus is also presented. Subjects are again asked to respond by button press, only to the non-frequent stimuli. Studies (Allison & Polich, 2008; Johnstone et al., 1996; Määttä et al., 2005) utilizing variations of the oddball task have provided interesting findings related to attention.

To more directly measure attentional resource allocation, and cognitive workload, Allison and Polich (2008) used a modified auditory oddball task and analyzed P3 amplitude and latency in adults. In their protocol, the frequent stimuli (auditory in this case) were replaced with silence, leaving only the non-frequent cues audible. Subjects were then presented with a primary task of playing a video game. During this time the non-frequent (distractor tone) was audible to the participants. Throughout the study, the difficulty of the video game increased. Results showed that as the primary task increased in difficulty, subjects showed a decreased P3 amplitude and increased P3 latency to the distractor auditory tone, indicating a change in the allocation of resources in the presence of a primary task.

Additionally, Johnstone et al. (1996) conducted a developmental study in children and adolescence 8 to 17 years of age and used a standard auditory oddball task to investigate the changes in amplitude and latency of ERP components across development. With age, the N1 ERP component that represents early sensory identification, and N2 component both decreased linearly in amplitude and latency to standard tones. Additionally, P3 amplitude, in reference to the target tone, increased with age. The decreased amplitude in the N1 and N2 components shows less effort in processing standard stimuli with age, and the increased P3 amplitude indicates that with age greater neuronal networks are available to process the target stimuli.

Määttä et al. (2005) used a 3-stimulus oddball task and ERPs to investigate the development of attention by studying children 9 years of age and adults. In their task, participants were asked to only attend to the standard tones (through button response) on some trials. Similar to Johnstone et al. (1996), children demonstrated a larger N1 than adults to the standard tones. Interestingly, in trials where attention to the tones was required, adults showed increased N2 and P3b components, where children showed only an increased P3b amplitude. The increased N2 amplitude indicated a greater ability of the adults to allocate attentional networks even before the processing of the stimulus, and the lack of this in children shows their inability, and potential under-developed neuronal networks, to complete a similar process.

Taken together, these studies utilizing and combining modified oddball tasks and ERP components indicate the ability of the oddball task to index the ERP components linked to attention, and also indicate that changes in ERP components, potentially mirroring the development of attentional networks, can be seen through the lifespan, with significant changes visible throughout childhood and in comparrison to adults.

Physical Activity, Physical Exercise, and Physical Fitness

Studies focusing on the relationship between physical activity and physical exercise upon general cognitive function in adults have typically shown a positive relationship (Tomporowski, 2003).This relationship is strengthened by studies which focus specifically upon frontal lobe functioning, where unique and even stronger benefits from physical activity participation and cardiovascular fitness have been noted (Bixby et al., 2007; Chodzko-Zaiko & Moore, 1994; Colcombe et al., 2004). The cognitive benefits, measured through behavioral and neurophysiological methods, are not just attributed to one domain of physical activity, but have resulted from a variety of domains including an individual's physical fitness level, participation in physical activity and participation in acute bouts of exercise. Many times, the neurophysiological components have been collected to measure the executive functioning abilities of the individual. Recalling that executive function and attentional resource allocation are separate but comparable constructs with similar underlying structures implicated in their control, inferences based upon the neurophysiological measures of executive function can logically be applied to predict potential changes in attentional resource allocation. While many studies have shown a beneficial relationship between physical activity, physical fitness and acute bouts of exercise upon cognitive function, not all studies have indicated a positive relationship (Etnier, Nowell, Landers, & Sibley, 2006; Tomporowski, Davis, Lambourne, Gregoski, & Tkacz, 2008a).

Overall, this research has been highly focused on adult and elderly populations leaving this same knowledge about child populations less developed (Tomporowski, 2003). In recent years, research with children has become more popular, and findings have contributed to the knowledge about the effects of physical activity and physical exercise upon cognition in the earlier years of life. Even though this research has become more popular, many questions still remain. It is not known why changes in cognition result from exposure to physical activity and physical exercise. Many factors such as exercise type, exercise duration, exercise intensity, involvement in physical activity, involvement in acute physical exercise, and the physical fitness level of the individual, as well as general verses specific cognitive benefits may all differently affect the relationship between physical activity or exercise and observed cognitive changes (Brisswalter, Collardeau, & René, 2002). Due to these many unknown variables, it is imperative to explore the current literature to encompass all of these potential factors.

One of the potential moderators of the relationship between physical activity or physical exercise and resultant cognitive function is the physical fitness level of the individual. A number of studies (Buck, Hillman & Castelli, 2008; Hillman et al., 2009a; Hillman et al., 2005; Hillman, Weiss, Hagberg, & Hatfield, 2002; Pontifex et al., 2010; Pontifex, Scudder, Drollette, & Hillman, 2012) have indicated that the fitness level of the individual plays a significant role in altering cognitive performance.

Typically, older adults show a decreased P3 amplitude compared to younger adults (Hillman et al., 2002), potentially caused by the rapidly declining frontal lobes typically seen in older individuals. In a study of motor planning, Hillman et al. (2002) found that compared to sedentary older adults, the aerobically trained age-matched counterparts showed increased P3 amplitude and shorter P3 latency. The increased P3 amplitude could be indicative that physical activity may increase motor planning efficiency in the physically active individuals by increasing the activated neural networks. Moreover, the increased P3 amplitude seen in the high-fit older adults compared to their less-fit counterparts may mark an older adult attempting to compensate for decreases in cognitive functioning by activating more neural areas, and therefore illustrate a benefit of physical fitness not seen in their less-fit peers. Furthermore, the decreased P3 latency in physically active individuals indicates that these individuals require less time to process any external stimulus.

In another study (Hillman et al., 2005) this time comparing high- and low-fit adults to high- and low- fit children, an oddball task was administered and P3 amplitude and latency were observed. As expected, both the higher-fit adults and children showed a greater P3 amplitude and faster reaction time than their less-fit counterparts. Additionally, the higher fit children showed a greater P3 amplitude than all other groups. Since the neural networks of the adult group are more developed than those of the children, it is likely that it takes less cognitive effort for the adults to complete the same oddball task as compared to the children.

Therefore, the P3 amplitude being greatest in the high-fit children is indicative of their ability to recruit more neural networks to complete a cognitive task more efficiently, an ability which is not seen in their less-fit peers.

Extending upon this study, Pontifex, Hillman, and Polich (2009) investigated the influence of both age and fitness upon the P3a and P3b ERPs in younger (18-22 years of age) and older (61-73 years of age) adults. Subjects completed a VO_2 max fitness test, and then participated in both a visual oddball task and a visual 3-stimulus task. Results indicated that for easier discrimination tasks, higher-fit individuals, regardless of age, demonstrated larger P3b amplitude and shorter reaction time than their less-fit counterparts. For more difficult discrimination tasks, only the higher-fit, younger adults showed a larger P3b component than their less-fit counterparts, indicating that fitness may not protect against the age-related declines in the networks underlying the generation of the P3b component. Furthermore, the P3a component was not affected by fitness in either age group, suggesting that another factor, aside from fitness may underlie this component.

Furthering these findings in children, is a study (Hillman et al., 2009a) comparing high- and low-fit children. The Eriksen-flanker task was used to measure executive functioning and compare the global versus specific effects of fitness upon cognitive function. The higher-fit children again had an increased P3 amplitude, as compared to their less-fit peers, on both congruent and non-congruent trials of the Eriksen-flanker task indicating that in children, the effects of physical fitness may be global.

Building upon the findings of this study, Pontifex et al., (2010) investigated the relationship between children’s (9-11 years of age) fitness level and the ability to flexibly modulate cognitive control. After completing a compatible/incompatible modified version of the Eriksen-flanker task, the N2 and P3 components were analyzed. Lower-fit children demonstrated increased N2 amplitude, decreased P3 amplitude and longer latency for both components as compared to their high-fit counterparts. Results were interpreted to indicate that lower-fit children were more challenged and showed deficits in flexibly allocating cognitive resources during tasks of varying difficulty.

Using a slightly different method than the Eriksen-flanker, Buck et al., (2008) investigated high- and low- fit children (7-12 years of age) and their performance on the Stroop task to again investigate the global versus specific effects of fitness upon cognitive function. Results indicated that, as compared to their less- fit counterparts, the higher- fit children showed increased performance on all conditions of the Stroop task, again indicating global benefits of physical fitness on cognition in preadolescent children.

In an attempt to investigate the relationship between sustained attention, cognitive control and aerobic fitness, Pontifex et al., (2012) again used a modified version of the Eriksen-flanker task, this time to index sustained attention. Pre-adolescent participants (9-11 years of age) were separated by fitness level in to high-fit and low-fit groups and then completed the modified task. Results demonstrated that lower-fit participants exhibited a greater number of errors of omission, and longer sequences of errors of omission, as compared to their higher-fit counterparts, indicating that lower-fit children experience more frequent failures in sustained attention, and that the longer sequences of omission may be indicative of a longer time for the regeneration of attentional resources to the primary task.

Rather than analyzing levels of physical fitness, another study (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004) has used physical activity levels to help investigate the relationship with cognitive function. In a comparison of activity levels (high, moderate, low) of older adults compared to a young control group, the high and moderately active older adults showed a similar P3 topography to the young control group, while the low active adults showed a decreased P3 amplitude at the Cz electrode site, where P3 amplitude typically shows a relative maximum. These findings indicate that with increased levels of physical activity, older adults not only show an activation of neural structures which resembles that of younger adults, but that physical activity may also provide older individuals with the ability to compensate for their age-related cognitive decline by activating more neural networks.

Bringing a unique perspective to this relationship, Booth et al. (2013), longitudinally investigated physical activity levels in adolescents, both males and females, 11-13 years of age. Using accelerometers to track physical activity volume and intensity levels, attention was assessed at 11 and 13 years of age by the Test of Everyday Attention for Children (TEA-Ch) and the Cognitive Drug Research (CDR) system, respectively. In both males and females, a greater volume of physical activity predicted lower performance on the attention assessments. However, when the physical activity was of a higher intensity, it was associated with better performance on the outcome measures, with the association stronger for males as compared to females. While the relationship between the volume of physical activity and lower performance outcomes is not explained in the study, overall results support the relationship between obtaining levels of moderate to vigorous physical activity and improved performance on executive function and attention outcome variables.

Another variable frequently utilized in this investigation is an acute exercise bout. In studies of both adults and children, when comparing acute exercise bouts and cardiovascular fitness (Themanson & Hillman, 2006) and coordinative exercises (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008) with resultant performance on attentionally-demanding tasks, results have been mixed with some studies favoring the acute bout, and others indicating a null effect of the acute bout (Tomporowski et al., 2008a).

In a study of undergraduate students, with an average age of 20.5 years, Hillman, Snook and Jerome (2003) measured ERPs to the Eriksen-flanker task following a 30 minute acute bout of exercise and compared these results to the previously recorded baseline. Results showed that following the bout of exercise, P3 amplitude increased across all conditions within the flanker task, compatible, incompatible and neutral. This increase, seen in all conditions, supports the notion that physical activity increases activation of neural networks. On the other hand, P3 latency decreased with the incompatible task and increased with the neutral task. Even though the latency results were inconclusive, the overall findings indicate that even small bouts of exercise related to increased cognitive functioning.

Building upon the knowledge from the adult population, another study (Hillman et al., 2009b) was conducted to directly measure the effects of an acute bout of exercise upon attentional resource allocation in children. Performance was measured using a flanker task and a general achievement test before and after an acute 20 minute bout of exercise. Results indicated that following this acute bout, children showed an increased P3 amplitude on the flanker task and increased performance on the achievement test, as compared to the control condition in which children rested. While these results show the benefit of an acute bout of exercise on cognitive functioning in children, conclusions drawn from this paper can support executive functioning, but only provide the potential evidence for observing similar results in attentional resource allocation.

Further investigating this relationship in child populations, Drollette and colleagues (Drollette, Shishido, Pontifex, & Hillman, 2012) used a within-subjects counterbalanced design to examine the potential effects of an acute exercise bout on the maintenance of cognitive control, during and immediately after an acute exercise bout of treadmill walking. The child participants (9-11 years of age) completed a modified Eriksen flanker task and a spatial n-back task, before, during and after the acute exercise bout or seated session to investigate the effects of the acute exercise bout on inhibition and working memory, respectively. During the active walking and seated rest, no task performance changes were observed across either task as compared to the baseline condition. However, increased response accuracy for the flanker task was observed following the acute exercise bout, but not after the seated rest. A similar result was not observed for the spatial n-back task. These findings indicate that acute exercise is not detrimental to task performance, and that acute exercise benefits cognitive tasks associated with inhibition, but not working memory.

Extending this research, Scudder and colleagues (Scudder, Drollette, Pontifex & Hillman, 2012) focused their investigation on goal maintenance in adult populations. The within-subjects design had participants engage in a 30 minute acute exercise bout of walking and a non-exercise control session, and both sessions were followed with an AX-continuous performance task, a cognitive performance task that analyzes goal maintenance. During this task, ERPs were recorded. Following the acute exercise bout, individuals exhibited greater response accuracy to target trials, and greater P3 amplitude at midline parietal sites for target and non-target trials. Due to the nature of the cognitive task, results were interpreted to indicate that acute bouts of exercise may enhance goal maintenance processes by enabling individuals to inhibit extraneous neural activity and allocate more attentional resources toward the updating of goal representations.

While these results indicate a positive relationship between acute exercise and cognitive performance, this relationship has been refuted. In a study by Themanson and Hillman (2006), behavioral and neurophysiological responses to the Eriksen-flanker task were measured after a 30 minute bout of acute exercise and after 30 minutes of rest in high and low fit adults. Both behavioral and neurophysiological results indicated that benefits to cognitive processing, specifically action monitoring, resulted from higher cardiorespiratory fitness levels, but had no link to the acute exercise bout (Themanson & Hillman, 2006).

In a study (Budde et al., 2008) of adolescents, 13-16 years of age, children participated in either a 10 minute bout of coordinated exercise or a 10 minute bout of typical physical activity and then completed the d2 test of attention. The coordinated exercises involved activities which required participants to use coordination as well as mental concentration to complete the tasks, such as balancing on a bench and dribbling a basketball simultaneously. Results showed that while students who participated in either type of activity showed increased performance on the attentional test, participation in the coordinated exercises led to a greater improvement on attentional measures than acute exercise bout (Budde, et al., 2008).

Overweight children, 7-11 years of age, participated in a 23 minute acute bout of treadmill walking, in yet another investigation (Tomporowski et al., 2008a). Before and after this bout, children participated in a task-switching paradigm. Results indicated that the acute bout had no effect upon the task performance.

An additional study (Stroth et al., 2009) sought to compare the relationship between physical fitness and an acute exercise bout upon electrophysiological indexes in children. A total of 35 adolescents, 13-14 years of age, participated in a cross-over study design where subjects completed a fitness test on one day, and a combined go/no-go and Eriksen-flanker task both after 20 minutes of exercise and 20 minutes of rest on two subsequent days. During this task, EEG was recorded. Results indicated that while higher fitness levels were related with enhanced task preparation and more efficient executive control (indexed by the CNV and N2 amplitudes, respectively) fitness had no relation to the P3 amplitude. Furthermore, the acute exercise bout had no relation to any of the neurophysiological measures (Stroth et al., 2009). Thus, in light of these findings, the acute exercise bout may have no effect upon attentional resource allocation as this relationship may be mediated by other factors such as cardiorespiratory fitness or coordinative exercises focusing on activating the brain.

Taken together these findings indicate that while physical activity and physical exercise generally show a positive relationship with resultant cognitive performance, results are mixed and many questions remain. Regardless of the age of the population, physical activity, physical fitness, and acute bouts of exercise have all shown differing effects upon resultant cognition. Studies will need to continue to investigate this relationship until a definitive factor emerges as the most influential upon resultant changes in cognition.

Mechanisms

The mechanisms underlying the relationship between an acute bout of physical activity and cognitive processes have yet to be determined. Although a number of potential mechanisms have been proposed, the theory of neurotransmitter upregulation most likely mediates the relationship between acute exercise bouts and attentional resource allocation, specifically in relation to the P3a and P3b ERPs (Polich, 2007).

Dopamine, one of the many neurotransmitters upregulated during exercise, is also a neurotransmitter which plays a significant role in cognitive processing, especially attentional tasks (Polich, 2007). One theory of dopamine's role in attentional processes focuses on the thalomocortical circuits between the cortex, basal ganglia and the thalamus. Within this model, the prefrontal cortex and the basal ganglia work together to inhibit unwanted behaviors and promote a desired response. It has been proposed that the basal ganglia plays a significant role in the inhibition of behaviors, and the frontal cortex, the primary output of the basal ganglia, is responsible for maintaining the neural representations of instructions for appropriate responses. Influencing basal ganglia's and frontal cortex's ability to carry out these given roles is dopamine, where appropriate levels of dopamine are essential to the continual and efficient functioning of this circuit. Imbalances in dopamine levels could impede the direct or indirect pathway of the basal ganglia which could subsequently affect the outcome of its projection to the frontal lobe, which would eventually result in a behavior that is altered from what was initially intended. From a developmental perspective, dopaminergic systems and the ability to suppress inappropriate behaviors or responses follows a parallel developmental trajectory, indicating that in children, increased efficiency in utilizing dopamine may strongly influence the development of inhibitory responses (Casey et al., 2001).

Studies in rat models have indicated that infusions of dopamine agonists into the prefrontal cortex, increasing the uptake of dopamine in these regions, results in increased response accuracy and decreased response latency compared to baseline conditions on the five-choice serial reaction time task (Granon et al., 2000). Furthermore, in humans, the 3-stimulus task was utilized to examine differences in P3a and P3b amplitude in individuals with varying levels of dopaminergic deficits (Poceta, Houser, & Polich, 2006). Topographic amplitude mappings from the unaffected controls (no dopamine deficit), individuals with restless legs syndrome (moderate dopamine deficit) and individuals with Parkinson's disease (significant dopamine deficit) showed significant differences in P3a and P3b amplitude. While the unaffected controls showed robust P3a amplitude to distractor tones over the frontal lobes, this amplitude was decreased in individuals with restless legs syndrome, and practically undetectable in individuals with Parkinson's disease. In reference to the P3b amplitude, controls and individuals with restless legs syndrome had similar amplitudes, while individuals with Parkinson's disease demonstrated smaller P3b amplitudes (Poceta et al., 2006). These findings indicate that dopamine levels affect the attentional processes underlying the P3 component, especially in relation to P3a.

Dopamine levels clearly relate to attentional processes and are also significantly influenced by participation in physical exercise. In order to investigate the relationship between an acute bout of exercise and changes in brain neurochemistry, *in vivo* observation would provide the most telling results. While this method cannot be performed in humans, microdialysis studies (Hattori et al., 1994; Meeusen et al., 2001) performed in rats have produced telling results. The microdialysis technique allows researchers to observe neurotransmitter release in specific brain areas while an animal is participating in an ongoing behavior, for example participating in an acute bout of exercise (Meeusen et al., 2001). In microdialysis studies, after only 20 minutes of an acute exercise bout, upregulations of dopamine in the rat striatum were noted (Hattori et al., 1994). Thus, since greater dopamine levels increase the efficiency of attentional processes, and acute bouts of exercise increase dopamine levels in the basal ganglia, which directly outputs to the frontal lobes, the upregulation of dopamine resulting from the acute bout of exercise may explain subsequent changes in the efficiency of attentional resource allocation. This finding holds significant implications for the potential role of dopamine as the mediating factor between an acute bout of exercise and attentional processing.

Taken together, these various studies indicate the role of dopamine in regulating attentional processes and how this relationship can be affected by acute exercise.

Physical Activity, Physical Exercise, Physical Fitness and Academic Success

Participation in physical activity provides children with the acquisition of numerous social skills including sharing, following rules, and working with groups (Taras, 2005). These acquired skills can be transferred to classroom settings where they foster learning (Tomporowski, Davis, Miller, & Naglieri, 2008b). Additionally, the specific cognitive processes of executive functioning and attentional resource allocation also directly translate to the classroom where efficiency of these processes could help children with effortful thinking and the ability to attend to instructors (Coe et al., 2006).

Coe et al. (2006) studied the effects of an intervention of daily physical education classes upon academic performance in 6th grade students. Students were randomly assigned to two groups that had physical education classes either the first or second semester of the school year, and were in the classroom for the other semester. In addition to the physical education class, typical physical activity using the 3 Day Physical Activity Recall (3DPAR) was measured. Grades from four core curriculum classes and from standardized tests were used to measure academic achievement. Results indicated that the presence of physical education classes had no effect upon increased academic achievement, but results also showed that the presence of physical education classes did not decrease academic achievement, either. Furthermore, children whose recollected physical activity from the 3DPAR placed them in a category of "vigorous" exercising, tended to have higher grades and standardized test scores than the less vigorously active classmates. This finding indicates that the 55-minute physical education class, of which only 19 minutes was actual physical activity, may not be enough time or intensity to result in a significant change in improving academic achievement.

Further investigating the relationship between physical education and cognitive performance and academic achievement, Ardoy et al. (2014) conducted a four-month study in which 67 adolescents (12-14 years of age) were assigned to a control and two experimental groups, such that the control group participated in two physical education classes a week, the first experimental group participated in four physical education classes per week, and the second experimental group participated in four, high-intensity physical education classes per week. Prior to the intervention, students completed a baseline cognitive test (the Spanish Overall and Factorial Intelligence Test) that assessed non-verbal and verbal ability, abstract reasoning, spatial ability, verbal reasoning and numeric ability. Additionally, student's academic achievement, assessed via grades in core courses, were recorded pre-intervention. Following the four-month intervention, all variables assessed in the Spanish Overall and Factorial Intelligence Test, with the exception of verbal reasoning, increased significantly more in the high-intensity experimental group as compared to the control group. Additionally, greater increases were seen in the academic achievement of the high-intensity experimental group, as compared to the control group.

Another study of academic achievement studied third- and fifth- grade students. Castelli et al. (2007) found that increased levels of physical fitness were related to greater academic achievement. After administering the Fitnessgram, a battery of tests including measures of aerobic fitness and muscle capacity, the children's fitness results were compared with their results on the Illinois State Assessment Test (ISAT). The higher- fit children had a greater correlation with higher standardized test scores compared to the lower scores of their less-fit counterpart.

In an attempt to not take away from "classroom time," but still integrate physical activity into the day, Katz et al., (2010) developed the Activity Bursts in the Classroom (ABC) Fitness Program. Implemented in elementary schools, 1214 students in second through fourth grade were assigned to either the control or intervention groups. The intervention classrooms were led by teachers who had been trained in the practices of the ABC Fitness Program. Through their training, teachers were instructed on four various methods of implementing physical activity into their daily lessons. Teachers were encouraged to use the ABCs whenever the class seemed distracted or bored. After implementation of only one school year, results indicated significant increases in abdominal strength and decreased dependence on medicine for asthma and attention deficit hyperactivity disorder. While results for academic achievement and attitudes toward physical activity were not changed, both were trending in a positive direction and were predicted to become significant with the continuation of the program (Katz et al., 2010).

Another study (Davis et al., 2011) sought to investigate a potential dose-response relationship between exercise and executive functioning and academic achievement in overweight children. A total of 171 sedentary children, 7-11 years of age, were assigned to one of three groups: control (no-exercise), low-dose exercise (20 minutes per day), and high-dose exercise (40 minutes per day). After a 3-month intervention, results indicated a dose-response relationship for executive function and math achievement as measured by the Cognitive Assessment System (specifically planning) and the Woodcock-Johnson Test of Achievement III (specifically math), respectively. Therefore, the greater amount of physical activity, the greater the cognitive benefits were seen.

Building upon the research in which increased P3 amplitudes (as a result of physical fitness, physical activity levels, and acute exercise bouts) and academic achievement are seen together, Hillman et al. (2012) investigated if neuro-electric indices of attention and inhibition could serve as a biomarker of academic achievement in preadolescent children. After administering the Wide Range Achievement Test, the P3 component was assessed during participation in a Go/NoGo task. Analyses indicated that P3 amplitude during the Go task had a significant relationship with reading achievement, P3 amplitude during the NoGo task had a significant relationship with arithmetic achievement, and no relationship was observed for spelling. Taken together these findings support that P3 amplitude may serve as a unique biomarker for academic achievement in specific school subjects.

While some mixed results have been found (Tomporowski et al., 2008b), the overall conclusion is that participation in physical activity does not negatively impact children's academic success (Taras, 2005; Tomporowski et al., 2008b).

Overview of Review of Literature

In recent years, research investigating the relationship between physical activity, physical exercise and physical fitness upon general cognitive function has become more robust in both adult and child populations. While a unanimous consensus has not been reached, overall studies indicate a generally positive relationship between these components (Taras, 2005; Tomporowski et al., 2008b). Results indicate that an especially strong relationship exists physical activity, physical exercise and cognitive functions of the frontal lobes (Bixby et al., 2007; Chodzko-Zaiko & Moore, 1994; Colcombe et al., 2004), such as executive functioning. To index this relationship with neurophysiological measures, researchers rely on the event related potentials (ERPs) of P3a and P3b (Polich, 2007). To elicit these ERPs, behavioral tasks, such as visual and auditory oddball tasks (Allison & Polich, 2008; Johnstone et al., 1996) are utilized.

However, while this line of research is now established, many questions remain. Specifically, it is unknown how acute bouts of exercise affect attentional resource allocation, a cognitive process related to, but differing from, executive functioning (Wickens, 1991). Furthermore, attention allocation is a cognitive process that develops, both structurally and behaviorally (Casey et al., 2001; Rueda et al., 2004) with age. With limited research conducted to explore the role of age in this relationship, it is unknown how child and adults populations may differ.

By furthering research in the area of physical activity, physical exercise, physical fitness and cognitive function great potential exists to extend the findings to real world settings, such as schools, where demonstrated benefits of physical exercise upon attention, could enhance the learning process for students, teachers, and schools, alike.

CHAPTER III

Methods

Participants

Thirty-two male participants, sixteen children (9 to 11 years of age), and sixteen adults (19 to 24 years of age) with no known neurological or motor disorders were recruited from the greater Baltimore-Washington D.C. Metro Area. In an effort to reduce group heterogeneity, only male subjects were recruited for the present investigation. Initially split by age into adult and child groups, each group was then randomly assigned to the control or intervention group. All adult participants and parents/guardians of child participants signed informed consent forms (Appendix A and Appendix B), and child participants signed informed assent forms (Appendix C and Appendix D). All procedures were approved by the Institutional Review Board at the University of Maryland, College Park. For their participation in the study, each participant received 35 dollars after completion of both days of testing, and child participants received a toy prize in addition to the monetary compensation.

Exclusionary Criteria

Participants meeting any of the following criteria were excluded from the study: 1) children with a score below the 25^{th} percentile on the Movement Assessment Battery for Children II (MABCII) (Appendix E) which is indicative of a potential motor skill deficit; and, 2) adults or children with reported diagnosed learning disabilities, attention deficit disorder, or any other neurological disorder, pervasive developmental disorder, mental disability, and/or neuromuscular disorder, or general health problem as measured by the Pediatric Health Questionnaire (for children) (Appendix F), or the General Health Questionnaire (for adults) (Appendix G).

Measures for Children

Pubertal stages questionnaire. To assess the current pubertal stages of the child participants, the parent/guardian of the child participant was asked to complete the Tanner stages (Tanner, 1962) (Appendix H) upon arrival for testing. This questionnaire uses gender-specific pictures representing different developmental stages to help respondents make accurate self-assessments. A developmental level of 1 or 2 on the scale classifies as pre-pubescent. Since it may have been difficult or uncomfortable for the younger children to properly give this self-assessment, parents completed the survey for their child, regardless of the child's age. Of note, this questionnaire was administered so that the data could be used for later possible post-hoc analysis.

Physical activity assessment. To assess the physical activity levels of the participants, each child, guided by the researcher, completed the 3-Day Physical Activity Recall (3DPAR) (Bouchard et al., 1983) (Appendix I). In this recall, children are given a chart, which divides the day into 30-minute intervals, and a guide that provides all of the potential activities in which the child may have participated. If the child participated in more than one activity during a given 30-minute interval, they were advised to choose the activity which took up the majority of that time block. The questionnaire also asks children to indicate the intensity at which they performed the activity, where they performed it and with whom. These activities were then converted to metabolic equivalent (MET) values. The 3DPAR has high test-retest reliability with an intraclass correlation coefficient of 0.97 (Argiropoulou, Michalopoulou, Aggeloussis & Avgerinos, 2004). Additionally, the 3DPAR has shown moderate concurrent validity with the MTI/CSA accelerometer with a correlation coefficient of 0.63 (Argiropoulou et al., 2004). Of note, this assessment was administered so that the data could be used for later possible post-hoc analysis.

Attention assessment. Children completed the d2 test of attention (Brickenkamp & Zillmer, 2002) (Appendix J), to provide researchers with a baseline measure of the child's attention. The d2 test consists of 14 rows with 47 characters per line. These characters are the letter d or p, with a total of one to four dashes above and below each letter. Children were asked to scan each line and cross out only the characters containing the letter d with two dashes. The overall performance score acquired from the d2 test has a very high internal consistency with a Cronbach's α of 0.96 among children 7-12 years of age (Cullbertson & Zillmer, 1998). Additionally, the overall performance score of the d2 test has demonstrated concurrent validity with the Tower of London executive functioning assessment ($r = -0.44$) (Cullbertson & Zillmer, 1998). Of note, this assessment was administered so that the data could be used for later possible post-hoc analysis.

Motor skillfulness assessment. The MABC-2 (Henderson & Sugden, 2007) (Appendix E) was administered to all child participants as an indicator of motor skillfulness or motor skill deficits. Subjects completed tasks falling within the requirements of the second or third age band for the battery. The tasks (8 total) are split into three categories: manual dexterity; aiming and catching; and, balance. Within the domain of manual dexterity, children were challenged with tasks such as placing pegs and a drawing trail. For the aiming and catching assessment, some activities included children catching with two hands or throwing a ball at the wall. Finally, to assess the balancing abilities of each child, participants completed tasks such as a board balance, walking heel to toe forward, and hopping on mats. Specific instructions and a practice session were given immediately preceding each activity.

Upon completion of these activities, performance scores recorded through the battery were tallied and compared to the standardized percentiles of the test. If the participant's score fell at or below the 25th percentile, the child was excluded from the study. The MABC-II has strong test-retest reliability with a correlation coefficient of 0.80 (Chow, Chan, Chan, & Lau, 2002). Additionally, the total score values on the overall assessment correlate well with the categories of manual dexterity ($r = 0.76$), aiming and catching ($r = 0.65$), and balance ($r = 0.73$) (Henderson & Sugden, 2007).

Fitness testing. Participants' fitness levels were assessed using a maximal oxygen uptake (VO_2max) treadmill test (Hill & Lupton, 1923; Whaley, Brubaker, & Otto, 2006). Children were first familiarized with the treadmill and all equipment that they would be wearing during the task. After children indicated the ability to walk on the treadmill with ease, they then continued into the process of running on the treadmill. Once at a comfortable running pace, the child warmed up for a few minutes. Following this, the subject was then fitted with a mouthpiece breathing valve and a nose clip. Time was taken to ensure that the children were comfortable with each piece of equipment that was placed on them and that they were able to still run with ease. Children were also briefed in hand-signals to enhance communication with researchers. The VO_2max test consisted of a graded exercise test following the modified Balke treadmill protocol (Balke & Ware, 1959) that consists of two-minute stages. Following this protocol, researchers worked with participants to help them select a speed that required a little more effort than a casual run. Once warmed-up and comfortable with the equipment, participants then began the fitness testing. Throughout all stages of the test, the speed of the treadmill (previously chosen by the participant and researcher) remained constant, but the incline that began at 0% for the first stage and subsequently increased by 2% every two minutes until the subject could not continue. Heart rate (recorded by a Polar™ heart rate monitor) was recorded every 30 seconds throughout the test duration. If heart rate reached above 95% of age-predicted maximum (208 - 0.7 x age), or if the heart rate began to decrease, the testing was immediately terminated. Upon conclusion of the test, children were instructed regarding the use of the OMNI rating of perceived exertion (RPE) scale (Robertson et al., 2001) (Appendix K), and asked to assess their exertion at the very end of the test. Criteria for establishing the achievement of a maximal effort required the attainment of at least 2 of the following criteria: 1) heart rate approaching 95% of age-predicted maximum (208 - 0.7 x age); 2) respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) >1.0; 3) ≤250 mL/min change in VO_2 in the final 60 seconds of the test; 4) RPE≥ 8 (Whaley et al., 2006). Throughout the fitness testing, subjects were closely monitored by the researchers who continually looked for signs of extreme fatigue, the need to catch the subject if they became unstable, or the need to stop the study due to these or any other indicators (irregularly high heart rate) of risk to the subject.

Electroencephalography (EEG). EEG set-up consisted of first placing an electrode cap upon the participant's head. Skin sensors were then placed above and below the child's eye in order to record eye blinks, and placed on his or her mastoids to serve as a references for the recordings. These areas were lightly rubbed with alcohol in order to remove any extra oil or skin cells on the surface. Using a blunt end needle and plastic tube, the participant's scalp was lightly rubbed at the skin site corresponding to each electrode site on the cap. The purpose of this step was to gently move the hair away from the sensors and allow contact between the skin and the electrodes. Researchers ensured that the skin was not broken. Food

& Drug Administration (FDA) approved non-toxic conducting gel was then applied to each sensor to enable continuous connection between each sensor and the skin of the scalp.

EEG activity was recorded from 19 electrode sites along the scalp (F_z, C_z, P_z, F_P1/2, F7/3/4/8, T5/3/4/6, C3/4, P3/4, O1/2), in accord with the 10-20 system (Jasper, 1958) using an Electro-Cap International Electro-Cap (Electro-Cap International, Eaton, OH). Recordings were referenced to averaged mastoids (M1, M2), with FP_z serving as the ground electrode, and impedances were kept below 10kΩ. Additional electrodes were placed above and below the left eye to monitor electro-oculographic (EOG) activity. EEG was sampled at a rate of 1000 Hz, and amplified 500 times using Neuroscan Synamps1 amplifiers using the Scan™ software (version 4.3, Herndon, Virginia, USA). Offline processing is detailed in the data processing section, below.

Attentional task. The attentional task consisted of an auditory 3-stimulus task (Escera, Alho, Winkler, & Näätänen, 1998; Knight, 1984). Stimuli were generated by the Neuroscan Stim software running on a Dell computer. To elicit the ERPs, 76% standard (1500Hz) tones, 12% target (1000Hz) tones and 12% novel sounds were presented. Tone duration was 84ms for the standard and target tones, and 100ms for the novel sounds, with an instantaneous rise and fall time. The non-frequent novel stimuli consisted of various sounds such as a barking dog, a chirping bird, or a coughing person. All of the noises were presented at 75dB, and were delivered to the ears by headphones. Subjects were given a practice block to help discriminate the standard from the target tones. During this block, only standard and target tones were presented. In the actual task, a total of 500 stimuli with 60 novel sounds were presented across 3 test blocks, lasting around 5 minutes each, with a rest period in between. Throughout this time, the subject was instructed in the primary task of pressing a button, as quickly as possible, in response to only the target tones. Additionally, the subject was instructed to stare at the visual cue in the center of the screen. EEG was recorded throughout this 15-minute task.

Resting period. Children assigned to the control group sat with the researcher for 20 minutes and engaged in minimal conversation.

Acute exercise bout. Children assigned to the intervention group participated in the acute exercise bout. The acute exercise bout occurred on a treadmill and lasted for 20 minutes. The results from the VO_2 max test were plugged into the following equation, VO_2= (0.2 x S) + (0.9 x S x G) + 3.5 (Whaley et al., 2006), to determine the treadmill speed needed to elicit an exercise intensity equivalent to 70% of each subject's VO_2 max. Once this speed was reached, it maintained for the duration of 20-minute acute bout. The participant's heart rate was recorded by a Polar™ heart rate monitor. Throughout the fitness testing, subjects were closely monitored by the researchers who continually looked for signs of extreme fatigue, the need to catch the subject if they became unstable, or the need to stop the study due to these or any other indicators (irregularly high heart rate) of risk to the subject.

Measures for Adults

Measures for testing adults were exactly the same as those for the children, but with only the following minor adjustments. Adults did not complete the pubertal stages questionnaire or the MABC II. The pubertal stages questionnaire (Tanner Stages), motor skillfulness assessments (MABCII), and physical activity level questionnaire (3DPAR), were not created to be used as assessments for adults. For the adults, the Tanner Stages assessment (used to indicate if a child has reached puberty) was not necessary as it was assumed that participants older than 18 years had developed beyond puberty. Additionally, the MABCII, can only be used to test children up to the age of 16, so it was not appropriate to administer this to adults. Furthermore, the 3DPAR, is only valid and reliable in assessing children's physical activity levels. Therefore, the 7-day physical activity recall (7DPAR) (Sallis, Haskell, & Wood, 1985) (Appendix L), created to assess physical activity levels in adults, was used with the adult participants. Finally, different criteria were used to indicate the achievement of maximal effort during the fitness test. The details of these modifications are explained below.

Physical activity assessment. The 7DPAR (Sallis et al., 1985) is an interviewer administered physical activity recall. In this recall, adults are given a chart which divides the past seven days into three sections, morning, afternoon and evening. Adults are asked to recall only activities requiring at least a moderate effort. Through directed questions and probing techniques initiated by the researcher, the participant recalls their physical activity participation for the past week. Each activity is marked as moderate, hard, or very hard, as directed by the recall's guidelines, and decided upon by the participant. The questionnaire also takes into account weekend days, sleep hours, and comparison of the past week's activity levels to the past three months. These activities were converted into daily kilocalorie expenditures (kcal/day). The 7DPAR has a strong test-retest reliability with a correlation coefficient of 0.78 (Sallis, Patterson, Buono, & Nader, 1988). Furthermore, the validity of the 7DPAR demonstrates good concurrent validity when correlated with VO_2max (r= 0.33) and body fat (r= -0.50), respectively (Blair et al., 1985). Of note, this assessment was administered so that the data could be used for later possible post-hoc analysis.

Fitness testing. The only differences in the fitness testing between adults and children is the criteria used to indicate when VO_2max was met, and the RPE scale. Rather than the OMNI scale, adults used the Borg 15 point scale (Borg, 1982) (Appendix M). For adults, criteria for establishing the achievement of a maximal effort requires the attainment of at least 2 of the following criteria: 1) heart rate approaching 85% of age-predicted maximum (220-age); 2) respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$)>1.1; 3) ≤250 mL/min change in VO_2 in the final 60 seconds of the test; 4) RPE≥ 18 (Howley, Bassett, & Welch, 1995).

Procedures

Each participant was tested over two consecutive days, with day one of testing lasting an hour for adults and an hour and a half for children, and day two lasting two hours for both adults and children. Prior to the first day of testing, the health questionnaires were completed by self-report for the adults, and completed by parents for the children and returned to the tester. This questionnaire served as the first level of screening for participants. If a participant did not illustrate typical neurological development or possessed a health condition which could have made the fitness components of the procedure increasingly risky, the participant or the parent was thanked for their interest, asked to not participate in the study, and was directed to alternative participation opportunities. Additionally, subjects were asked not to exercise on the first day of the visit and to avoid intense activity on the days of both testing sessions.

The experimental protocol was divided across two days according to the following table:

Protocol by Day for Children:

Day 1 (approximately 1.5hr) Group I and Group II	**Day 2 (approximately 2 hr) Group I**	**Day 2 (approximately 2 hr) Group II**
1. d2 Attention Test (10 min)	1. EEG Set Up (30 min)	1. EEG Set Up (30min)
2. PA Questionnaire (20min)	2. 3-Stimulus Task (20 min)	2. 3-Stimulus Task (20min)
3. MABC II (30 min)	3. Resting Period (20 min)	3. Acute Exercise Bout (20min)
4. VO_2 Max Test (20 min)	4. 3-Stimulus Task (20 min)	4. 3-Stimulus Task (20min)

Protocol by Day for Adults:

Day 1 (approximately 1 hr) Group I and Group II	**Day 2 (approximately 2 hr) Group I**	**Day 2 (approximately 2 hr) Group II**
1. d2 Attention Test (10 min)	1. EEG Set Up (30 min)	1. EEG Set Up (30 min)
2. PA Questionnaire (20 min)	2. 3-Stimulus Task (20 min)	2. 3-Stimulus Task (20 min)
3. VO_2 Max Test (20 min)	3. Resting Period (20 min)	3. Acute Exercise Bout (20 min)
	4. 3-Stimulus Task (20 min)	4. 3-Stimulus Task (20 min)

Day 1:

The procedures for day one were the same for both the control and the intervention group.

Upon entering the lab for the first day of testing, informed consent and assent were obtained from the parent/guardians and children, respectively. Participants were then introduced and familiarized with the protocol for both the exercise testing and EEG recording. Along with signing the consent form, the parent/guardian was asked to complete the Tanner Stages for their child.

After obtaining the consent or assent form, the actual testing began. Participants began the study by responding to the physical activity recall. Then they completed the d2 test of attention. Following this, only child participants completed the MABC II testing. Then, all participants completed the fitness testing. Once maximal effort was met during the fitness test, participants were helped to cool down and were offered water to drink.

Day 2:

Day 2 procedures differed for the control and intervention group.

Control group. Upon entering the lab, EEG set-up began. These set-up procedures were explained in detail so that participants felt comfortable with the process. Next, participants began the 3-stimulus auditory oddball task. EEG was recorded throughout this 15-minute task. Once this task was completed, participants (remaining in the EEG cap to prevent movement of electrodes) then sat restfully with the researcher, having some conversation. Ranging from 10 to 15 minutes after this 20 minute period of rest concluded, the participant then completed the 3-stimulus task for the second time. Impedances were checked for a second time following the resting period. Before and after each of the auditory 3-stimulus tasks, EEG was recorded for one minute in both the eyes-opened and eyes-closed condition.

Treatment group. The protocol for the treatment group mirrored that of the control group with the only difference being found during the intervention period. Upon entering the lab, the participant was prepared for the cognitive task by undergoing the EEG set-up protocol (detailed above). Following this set-up, the participant completed the 3-stimulus task. Once this task was completed, the participant (remaining in the EEG cap to prevent movement of electrodes) engaged in the 20-minute acute bout of exercise.

Ranging from 10 to 15 minutes after cessation of the exercise bout, the participant then completed the 3-stimulus task for the second time. Impedances were again checked following the acute exercise bout. Before and after each of the 3-stimulus auditory oddball tasks, EEG was recorded for one minute in both the eyes-opened and eyes-closed condition.

Data Processing

The continuous data were processed offline. Data were filtered using a zero phase shift 20 Hz (24dB/octave) low-pass filter. Epochs were created by extracting -100 to 900ms around the stimuli, and baseline corrected using the 100ms pre-stimulus interval. Sweeps with voltages exceeding ±100 µV were considered artifact and thus excluded from additional processing. ERP averages were then derived by averaging the remaining epochs for each stimulus category.

A number of steps were taken to identify the average amplitudes of the components of interest. First, the temporal windows, from which the average amplitude for each of the ERP components were determined, were identified by a grand average in which the EEG signal was collapsed across all subjects and time and separated by eliciting tone/sound (target, standard, novel) . For each ERP component, the eliciting tone and the corresponding midline site (Fz, Cz, Pz), where the peak amplitude was to be expected, was noted. Then, the latency around the peak amplitude (at the previously selected midline site) was identified, and a window around the peak amplitude was determined. These temporal windows were then projected on the scalp to confirm the windows corresponding to each component exhibited a topographical distribution consistent with existent descriptions in the literature. Finally, average amplitudes were computed for each potential component of interest. Specifically, the P3a component was defined as the most positive-going peaks (to the rare non-target stimuli), occurring within 320-360 ms and 240- 280 ms for children and adults, respectively. The P3b component was defined as the most positive-going peaks (to the target stimuli) occurring within 560-640 ms and 490-570 ms for children and adults, respectively. Figure 1, below, depicts these grand average ERPs to each specific tone/sound and collapsed across subject and time. The average amplitude of each ERP is marked in red. Corresponding to each grand average is the topoplot which indicates the source densities across the scalp and helps confirm the temporal windows identified for each component.

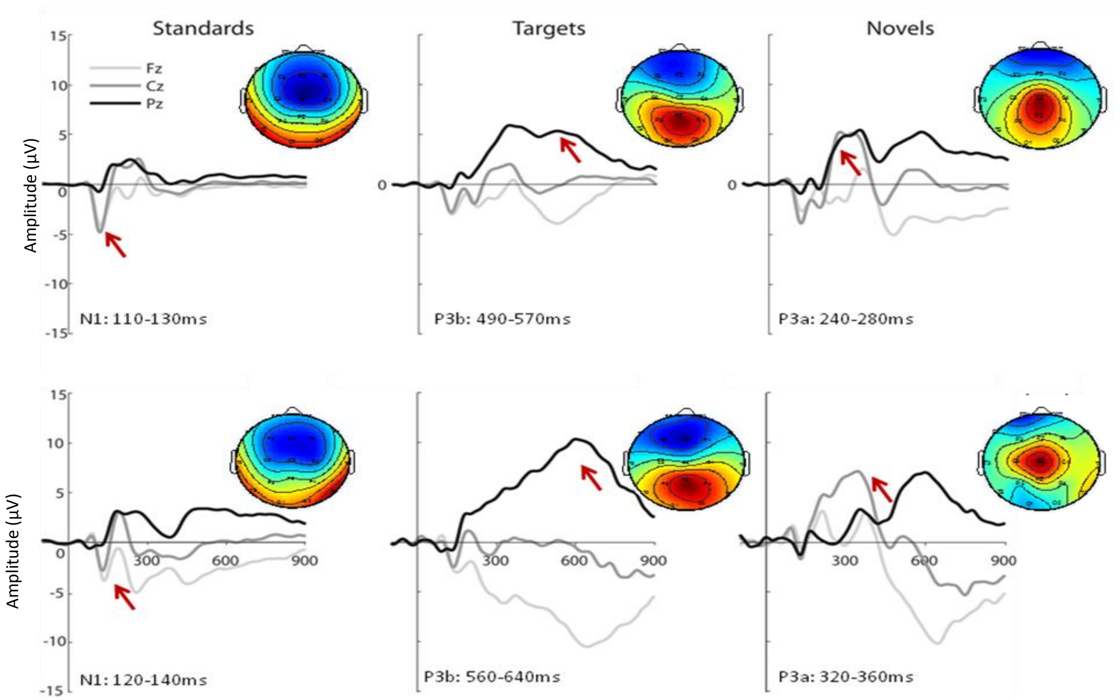


Figure 1. Grand Average ERPs and Corresponding Topoplots.
The top row depicts the adult participants. The bottom row depicts the child participants. Each line corresponds to a different midline electrode site (Fz, Cz, Pz).

Statistical Analyses

Behavioral measures. In order to analyze behavioral changes, reaction times (RT) were separated into three blocks. For each of these blocks, reaction time percent differences (RT_{DIFF}) were calculated as follows: RT_{DIFF} = (post-intervention RT (by block) - pre-intervention RT average)/pre-intervention RT average) X 100.

Reaction time percent differences (RT_{DIFF}) were analyzed by a 2 (age) X 2 (group) X 3 (block) two-way ANOVA with repeated measures on the last factor. The two levels of the age factor were: (1) children; and, (2) adults. The two group levels were: (1) the control group; and, (2) the treatment group (participants in the acute exercise bout). The three blocks were: (1) the first 20 RT differences post-intervention; (2) the middle 20 RT differences post-intervention; and, (3) the final 20 RT differences post-intervention.

Additionally, only block 1 reaction times were subjected to an additional analysis: a 2 (age) X 2 (group) ANCOVA with average reaction time (pre intervention) as the covariate.

For all statistical analyses, the level of significance was set to $p < 0.05$.

Neurophysiological measures. P3a amplitudes at Fz were subjected to a 2 (age) X 2 (group) ANCOVA with pre-intervention P3a amplitude as the covariate. The two age levels were: (1) children; and, (2) adults. The two groups were: (1) the control group; and, (2) the treatment group (participants in the acute exercise bout).

P3b amplitudes at Pz were subjected to the same analysis only with pre-intervention P3b amplitude as the covariate.

Post-hoc analyses were conducted using independent samples t-tests. For all statistical analyses, the level of significance was set to $p < 0.05$.

CHAPTER IV

Results

Behavioral Analyses

Response accuracy. There were no significant differences in response accuracy between the children and adults. Prior to the intervention, adults demonstrated 99% response accuracy, and post-intervention demonstrated 98% response accuracy. Children demonstrated 98% response accuracy prior to the intervention and 99% response accuracy post-intervention.

Reaction time percent difference (RT_{DIFF}) analysis. The repeated measures ANOVA for RT_{DIFF} indicated a marginally significant main effect for group ($F(1,22)=3.94$, $p=0.06$), and a significant effect for block ($F(2,44)=7.81$, $p < 0.01$), and age by block interaction ($F(2,44)=4.24$, $p < 0.05$), in which block 1, block 2, and block 3 are defined by first 20 RT_{DIFF} post-intervention, second 20 RT_{DIFF} post-intervention, and third 20 RT_{DIFF} post-intervention, respectively. Post-hoc analyses with Bonferroni correction revealed that adults and children differed significantly in RT_{DIFF} at block 3 ($p< 0.01$) (see Figure 2.), and that RT_{DIFF} is different between the control and exercise group ($p=.06$) (see Figure 3.).

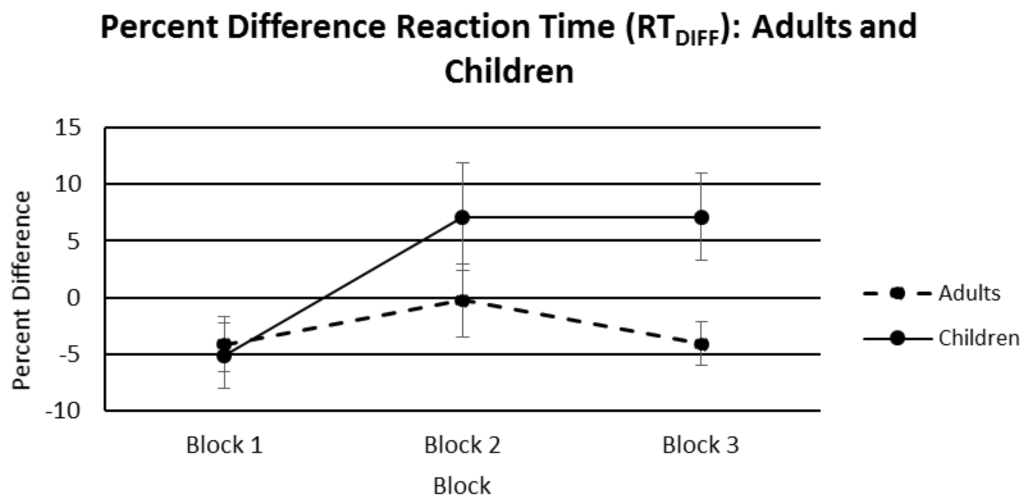


Figure 2. Reaction Time Percent Difference (RT_{DIFF}) of Adults and Children at Block 1, Block 2, and Block 3. (Error bars=standard error.)

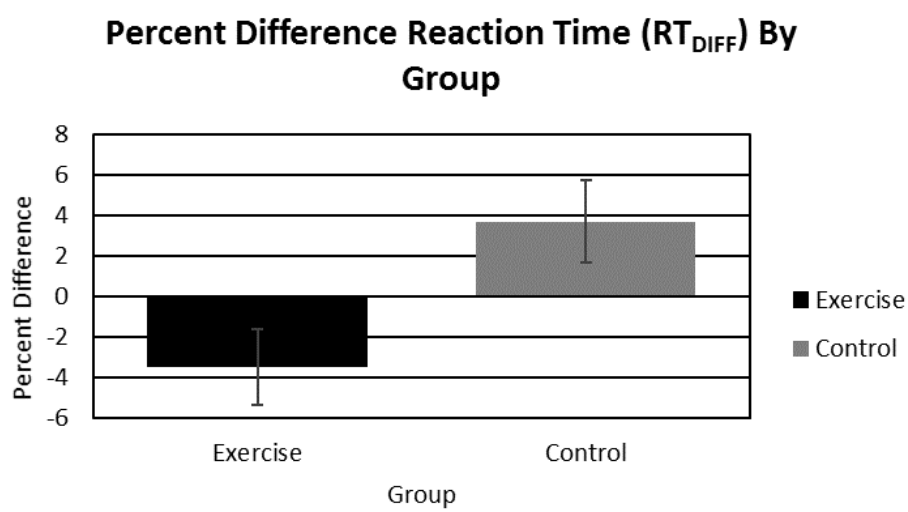


Figure 3. Reaction Time Percent Difference (RT_{DIFF}) by Group. (Error bars=standard error.)

To futher explore the group difference, a 2 (age) X 2 (group) ANCOVA with average reaction time (pre intervention) as the covariate was employed. Results indicate a significant main effect for group ($F(1, 21) = 4.48$, $p < 0.05$) (see Figure 4.).

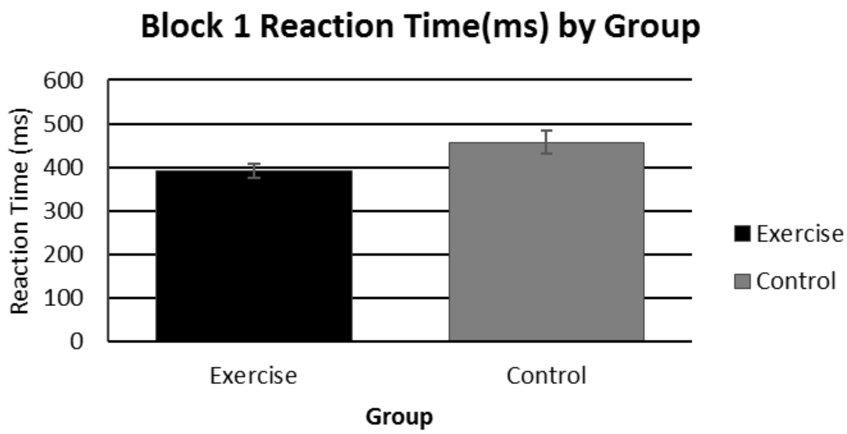


Figure 4. Reaction Time in Block 1 by Group. (Error bars=standard error.)

ERP Analyses

Neither the ANCOVA with pre-intervention P3a amplitude as the covariate, nor the ANCOVA with pre-intervention P3b amplitude as the covariate indicated main effects or interactions for age or group for ERP measures P3a at Fz nor P3b at Pz. However, the ANCOVA for P3b was nearing a significant effect for group ($F(1, 23) = 3.1$, $p = .09$). The lack of significance in P3b amplitude at Pz for children and adults is detailed below in Figure 5. The lack of significance in P3a amplitude at Fz for children and adults is detailed below in Figure 6.

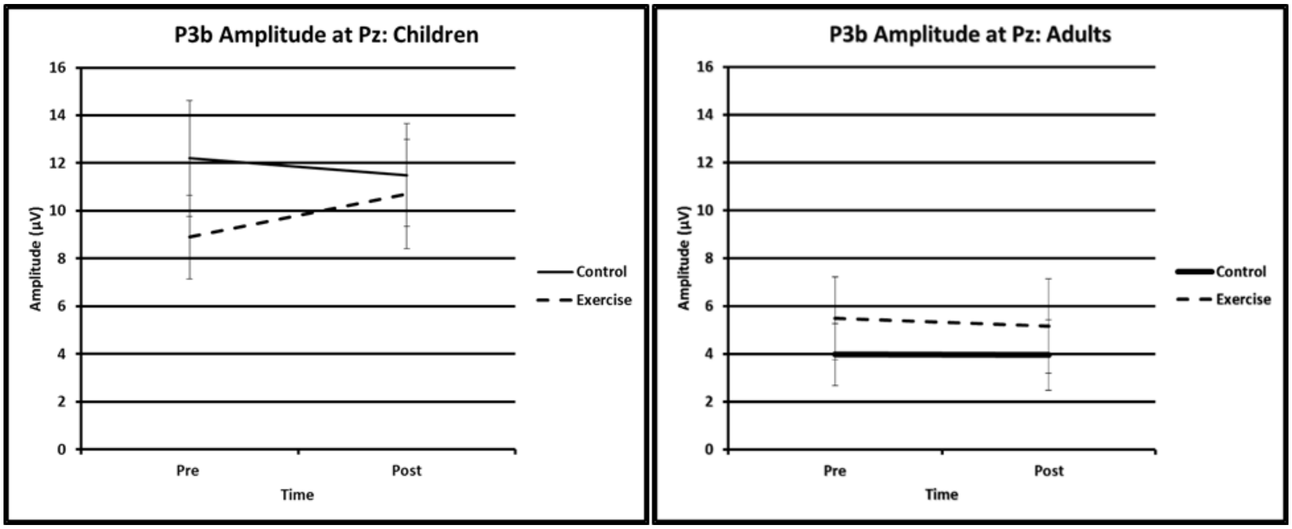


Figure 5. Mean P3b Amplitude at Pz, Pre- and Post- Intervention for the Control and Exercise Group. Children-Left, and Adults-Right. (Error bars=standard error.)

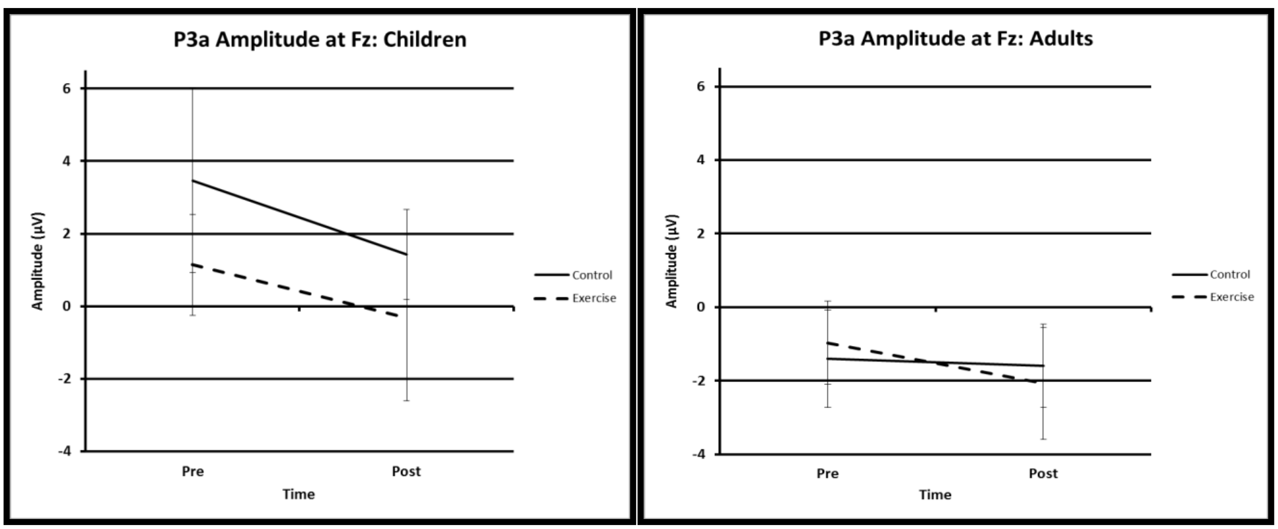


Figure 6. Mean P3a Amplitude at Fz, Pre- and Post- Intervention for the Control and Exercise Group. Children-Left, and Adults-Right (Error bars=standard error.)

CHAPTER V

Discussion

The purpose of this study was to investigate the effects of an acute bout of exercise upon behavioral responses and neurophysiological indices of attention in children and adults, and to determine any age-related differential effects. Specifically, the study investigated children's and adult's ability to attend to a primary behavioral task (button press to target tones) in the presence of distracting stimuli (unexpected sounds) following participation in a brief bout of moderate exercise. Previous research has identified both behavioral (response time and response accuracy) and neurophysiological (ERPs) indices that demonstrate positive responses to engagement in acute exercise bouts (Hillman et al., 2003; Hillman et al., 2009b; Drollette et al., 2012; Scudder et al., 2012).

For both adults and children, behavioral data indicate increased response accuracy following engagement in acute exercise bouts (Drollette et al., 2012 and Scudder et al., 2012). Additionally, neurophysiological data indicate increased P3a and P3b amplitude following engagement in acute exercise bouts (Hillman et al., 2003; Hillman et al., 2009b; Drollette et al., 2012; Scudder et al., 2012). Furthermore, developmental evidence indicates that due to the plasticity of the child's brain (Rapoport & Gogtay, 2008), children may more readily demonstrate benefits of acute exercise bouts as compared to adults. In contrast to the previous research, this study found only some of the behavioral benefits (as measured by response accuracy, reaction time percent difference) and none of the typical neurophysiological benefits (as measured by P3a and P3b amplitude) associated with engagement in acute exercise bouts. Additionally, no age-related differential effects of acute exercise were observed.

It was hypothesized that following the physical activity intervention, adult and child participants who engaged in the acute exercise bout would demonstrate: (1) improved behavioral responses (indicated by increased response accuracy and decreased reaction time), and (2) improved neurophysiological measures (demonstrated by increased P3a amplitude in response to the novel auditory sound and increased P3b amplitude in response to the target auditory sound) indicative of an increase in spare processing resources and thus improved attentional allocation. Additionally, due to the still developing neural pathways of children, it was hypothesized that age-related differential effects of acute exercise would be visible through these same behavioral and neurophysiological indices of attention, such that children would derive a greater benefit from the exercise bout, as compared to adults.

Following an acute exercise bout, do adults and/or children demonstrate improved behavioral responses?

Similar to previous studies where engagement in acute exercise bouts result in improved response accuracy for adults and children (Drollette et al., 2012 and Scudder et al., 2012), and where individuals exposed to more physical activity demonstrate decreased reaction times (Hillman et al., 2005 and Pontifex, Hillman, and Polich, 2009), it was expected that similar benefits would be observed in this study. However, mixed results were observed.

In terms of response accuracy, the exercise intervention had no significant effect on behavioral response in adults, as a response accuracy greater than 98 % was maintained pre-intervention and post-intervention.

In terms of RT_{DIFF}, post intervention, a marginally significant main effect for group, and a significant effect for block and age by block interaction were observed. Adults do demonstrate improved behavioral responses as compared to children, as seen in the significant difference in performance in block 3.

In terms of absolute reaction time in block 1, both adults and children in the exercise group respond with significantly faster reaction times than the adults and children in the control group.

Are these behavioral responses indicative of an age-related differential effect of an acute exercise bout?

With both adults and children maintaining a response accuracy great than 98% pre-intervention and post-intervention, results do not support an age-related differential effect of an acute exercise bout upon response accuracy in a 3-stimulus auditory oddball task.

As indicated by RT_{DIFF}, adults do demonstrate improved behavioral responses as compared to children, as seen by the significant difference in performance in block 3. However, this may not be attributable to acute exercise. Throughout blocks 2 and 3, children's RT_{DIFF} increases greatly. This increase is indicative of slowing reaction time. This slowing could be due to fatigue, rather than the exercise intervention, so the difference between adult and child performance in this block may not be indicative of an age-related differential effect of an acute exercise bout.

To explore this relationship without the potential factor of fatigue, when just looking at absolute reaction time in block 1, both adults and children in the exercise group respond with significantly faster reaction times than the adults and children in the control group.

Therefore, results do not support an age-related differential effect of an acute exercise bout upon RT_{DIFF}, or absolute reaction time, but they do suggest a group effect of the acute exercise bout upon absolute reaction time.

Following an acute exercise bout, do adults and/or children demonstrate improved neurophysiological responses?

Similar to previous studies where neurophysiological data indicate increased P3a and P3b amplitude following engagement in acute exercise bouts for adults and children(Hillman et al., 2003; Hillman et al., 2009b; Drollette et al., 2012; Scudder et al., 2012), it was expected that similar benefits would be observed in this study. However, similar results were not observed.

For children, there is a non-significant increase in P3b amplitude post-exercise for the intervention groups, an increase that is not visible for the control groups. For P3a amplitude, there is very little change in P3a amplitude post-intervention, but for children and adults, although non-significant, P3a amplitude does decrease. Taken together, the neurophysiological responses to an acute bout of exercise are non-significant for both adults and children across intervention groups.

Are these neurophysiological responses indicative of an age-related differential effect of an acute exercise bout?

While the changes in P3a and P3b amplitude were non-significant, there were visible trends. Adults and children displayed similar, non-significant trends in P3a amplitude such that post-intervention, the amplitude decreased for adults and children. Therefore, results do support a non-significant age-related differential effect of an acute exercise bout upon P3a amplitude.

Taken together, what does this investigation indicate in regards to the effects of an acute bout of exercise upon attention allocation in adults and children? And, what do these results indicate in regard to age-related differential effects?

The 3-stimulus auditory oddball task is a basic behavioral task. Its simplicity is highlighted by the near perfect response accuracy pre- and post- intervention by both adults and children. The relative ease with which both adult and child participants were able to complete the behavioral task could explain why there were no significant neurophysiological changes. The task may have been so simple that the theoretical "executive" component of the task was never activated, thus the significant changes in ERPs, typically induced by engagement in an acute exercise bout, were not visible. However, the significant difference in reaction time between groups immediately following the intervention (in block 1), does provide the behavioral results typically associated with acute exercise, such that the exercise group demonstrated enhanced behavioral performance as compared to the control group.

While significant neurophysiological changes were not obtained, there were trends, in children and. For children and adults, P3a amplitude decreased, non-significantly post-intervention. This decreased amplitude is potentially indicative of another factor that could have affected results: mental fatigue. A decreased P3a amplitude indicates fewer attentional resources in reserve, and more attentional resources in use, or in this case, more resources needed to complete the task. When coupled with the children's behavioral data of slowing reaction time post-intervention, the decreased P3a amplitude indicates that if children are using more spare processing resources to produce a slower reaction time to a basic task that has not increased in difficulty, another factor, such as mental fatigue, must be mediating the results or making the basic task more challenging.

Further supporting this hypothesis is the adult data. Unlike children, the adults do not show a trend of non-significant decreased P3a across both groups. This could be accounted for by the adults having more developed neural and attentional networks, thus being less susceptible to mental fatigue, and thus being able to complete the task without having to utilize spare processing resources.

Taken together, the results indicate that regardless of age, engagement in an acute bout of exercise minimally affects behavioral or neurophysiological indices of attention as measured by RT_{DIFF} and P3a and P3b amplitude, respectively. However, absolute reaction time results immediately following the intervention indicate a significant effect of acute exercise. Due in large part to the behavioral task employed, its inability to activate executive networks, and the potential role of mental fatigue, the typical neurophysiological benefits associated with acute exercise bouts were not seen in this study for adults or children. Furthermore, no significant age-related differential effects of acute exercise were detected.

Summary and Conclusions

Although some trends were visible, significant results indicate that regardless of age, engagement in an acute bout of exercise minimally affects neurophysiological and some behavioral indices of attention, but significantly affects reaction time immediately following intervention. Largely due to the behavioral task employed, only some of the behavioral benefits and none of the typical neurophysiological benefits associated with acute exercise bouts were not seen in this study, nor were age-related differential effects of acute exercise observed.

CHAPTER VI

Limitations and Future Directions

This study has a number of limitations, in particular, with regard to the child participant's engagement in the exercise testing, the behavioral task itself, and time of observation post-intervention.

While the VO_2max testing protocol can be explained to children, the concept of reaching maximal exertion was a complicated one for some children to understand. Thus, while some subjects had reported they had reached their "max," the physiological data indicated otherwise. Future studies should pursue other measures of children's fitness levels such as Fitnessgram, a fitness tool that measures not only aerobic capacity, but also muscular strength, muscular endurance, flexibility, and body composition. Fitnessgram is recommended for use for individuals in kindergarten through college. While the measure of aerobic capacity within Fitnessgram, the Progressive Aerobic Cardiovascular Endurance Run (PACER), is recommended for individuals in third grade and above, as compared to a VO_2max test, the PACER is easier for young children to complete. Additionally, in the 2012 Institute of Medicine (IOM) Report, "Fitness Measures and Health Outcomes in Youth," (released after the initiation of this study), the IOM recommended progressive shuttle runs (such as the PACER) as the ideal measure of aerobic capacity for youths.

Although findings from this study did not support previous neurophysiological research, the extant literature is based on a relatively small amount of studies in which consistency amongst behavioral tasks, age group, exercise intervention, duration, and type is not present (Hillman, Kamijo, & Scudder, 2011). For example, using the 3-stimulus auditory oddball task to indicate effects of an acute exercise bout upon cognition has not been employed in studies such as the current one. Other behavioral tasks, such as a basic oddball, Eriksen-flanker, and 3-stimulus visual oddball all activate the executive functioning network. However, the 3-stimulus auditory oddball task is attractive as it activates the executive functioning network and includes a distractor tone which results in a P3a amplitude that does not habituate. This study was novel in pairing a 3-stimulus auditory oddball paradigm with an acute exercise intervention. While novel, this pairing may have prevented the neurophysiological results typically associated with acute exercise interventions from being seen. Other behavioral tasks, such as the visual oddball and Eriksen-flanker, are more likely to tap executive function and may better capture the neurophysiological effects of an acute exercise bout. Future studies should explore the same acute exercise intervention with a modified 3-stimulus auditory oddball task or a different, more executive, behavioral task. For example, presenting the common and target tones at a more similar frequency could increase the difficulty of the behavioral task. Additionally, presenting tones in shorter time blocks could prevent mental fatigue.

In addition to differing the behavioral task, there is also opportunity to begin observation post-intervention even closer to exercise cessation. With significant group effects seen immediately post-intervention in this study, researchers could begin the behavioral task before participants have reached their resting heart rate, or within 5 minutes of exercise cessation. Additionally, there is no consensus on the type, intensity, duration, or frequency of physical activity that elicits the greatest neurophysiological benefit in children (Chaddock, Pontifex, Hillman, & Kramer, 2011). With the great potential for physical activity to benefit academic achievement, identifying which of these factors most benefits children would be valuable. To do this, the duration (e.g., longer or shorter than 20 minutes), type (e.g., bikeriding, rather than running), and intensity (e.g., more or less intense than 70%) of the acute exercise bout employed in this study could be varied.

Taken together, these modifications could lead to uncovering the unknown intricacies underlying the relationship between acute exercise and attention allocation in children and adults.

Appendix A. Adult Consent Form

CONSENT FORM

Project Title	The Effects of An Acute Bout of Exercise on Cortical Dynamics and Attention in Children
Why is this research being done?	This research project is being conducted by Kristin Cipriani at the Department of Kinesiology, University of Maryland, College Park. We are inviting you to participate in this research project because you are over 18 years of age. The purpose of the research is to investigate the affects of an acute bout of exercise upon cognitive function, specifically attention.
What will I be asked to do?	The procedures involve two days of testing with a duration of around 90 minutes per day. The study will be conducted in the Kinesiology Department of the School of Public Health at the University of Maryland, College Park. **Day 1:**First,you will complete a physical activity recall, in which you will be asked to detail your participation in physical activity over the past seven days. Then, to measure your baseline attention level (a general measure of your attention span), you will complete a task in whichyou visually scan a document for a specific character. Following this, your fitness level will be measured through a moderately intense fitness (VO_2max) test performed on a treadmill. You will be instructed regarding the use of the Borg rating of perceived exertion (RPE) scale, to help you express feelings of fatigue.This scale includes numbers which are paired with various levels of fatigue.. By indicating a number that corresponds with the fatigue level, you will be able to indicate to researchers how tired you feel. After this, you will be fitted to a mouthpiece breathing valve and a nose clip. Time will be taken to be sure that you are comfortable with this set-up. The fitness test consists of a graded exercise test in which you walk on a treadmill that increases in speed and incline in 2 minute increments. These increases will continue until you reach a near maximal effort (heart rate = ~200 beats per minute) or until volitional exhaustion (the point where youvoluntarily indicates that you aretoo tired to continue). This protocol may be modified on an individual basis to ensure that fitness testing time does not exceed 15 minutes. All researchers are CPR certified, and every effort will be made to ensure your safety. Total day 1 testing time will be around 90 minutes **Day 2:** Upon entering the lab, you will be fitted with a special electrode cap (similar to a swim cap) placed on your head. The purpose of the cap is to record electrical brain activity from 12 locations along the scalp. In addition skin sensors will be placed above and below your left eye in order to record eye blinks, and placed on your ear lobes to serve as a references for the recordings. These areas will be lightly rubbed with alcohol in order to remove any extra oil or skin cells on the surface, and the ear lobes will be rubbed with Nuprep gel. Your skin will be lightly rubbed with the blunt end of a wooden Q-tip at the skin site

	corresponding to each electrode site on the cap. The purpose of this step is to gently move the hair away from the sensors and allow contact between the skin and the electrodes. Researchers will ensure that the skin is not broken. Using a blunt end needle and plastic tube, Food & Drug Administration (FDA) approved non-toxic conducting gel will be applied to each sensor to enable continuous connection between each sensor and the skin of the scalp. Again, the skin will not be broken. These set-up procedures will take approximately 15 minutes and each step will be explained so that you feel comfortable with the process. Next,you will begin the cognitive task. Headphones will first be placed over your ears. During this task, youwill hear three different types of noises: including tones and sounds (all presented at an audible, but not harmful level). While listening to the noises, you will be asked to press a button in response to only the non-frequent tones. This task will last for approximately 15 minutes and EEG will be recorded throughout. Once this task is completed, you (remaining in the EEG cap to prevent movement of electrodes) will then participate in one of two activities for 20 minutes; 1)a restful session of sitting 2) a bout of exercise on the treadmill. In the bout of exercise, your heart rate will be recorded by a heart rate monitor. You will exercise at 60% of your VO_2max (maximum oxygen consumption, a value recorded from the fitness testing) for the duration of the bout. In both conditions your efforts will be encouraged by the researcher. Exactly 5 minutes after this 20 minute period is completed, you will then complete the 3-stimulus task for the second time. Total day 2 testing time will be around 90 minutes. After the conclusion of both days of testing, monetary compensation of $35 will be given.
Project Title	The Effects of An Acute Bout of Exercise on Cortical Dynamics and Attention in Children
What about confidentiality?	We will do our best to keep your personal information confidential. To help protect your confidentiality, the following standards will be met. All information collected in the study is strictly confidential. The data you provide will be grouped with data others provide for reporting and presentation. Your name will not be included on the surveys and other collected data. A code will be placed on the survey and other collected data, and through the use of an identification key, the researcher will be able to link your survey and collected data to your identity. Only the researcher will have access to the identification key. Data collected from excluded participants will not be used and will be subsequently shredded immediately. Data will be stored in a locked file cabinet and/or on password protected computers in a secured university laboratory facility. Only the investigators and their collaborators will have access to this locked file. All those with access to the data are NIH certified in the procedures for protecting

	participants in scientific experiments. If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law. All data will be destroyed after 10 years.
What are the risks of this research?	There may be some risks to you from participating in this research study. As a result of participation in this study, and specifically wearing the electrode cap to measure brain activity, participants may experience some slight sensation and irritation of the skin as the scalp is lightly rubbed at the electrode sites. Participants may experience a modest degree of fatigue from the concentration required during the performance on the 3-stimulus task. Additionally, there are always risks associated with exercise testing in any age group. Due to the maximal effort required with a high intensity exercise, these may include lightheadedness, syncope, nausea, muscle soreness, chest discomfort, and dry mouth and throat due to the breathing valve used for gas collection. In rare cases heart attacks and death may occur. The risks associated with this study are no greater than those present during high-exertion play and intense sports training, and will provide the most accurate measure of fitness. Aside from these, there are no other known risks and no long-term effects associated with participation in this study.
What are the benefits of this research?	The experiment is not designed to help you specifically, but it may have substantial impact on understanding how attentional processes respond to an acute exercise bout.
Do I have to be in this research? May I stop participating at any time?	Your participation is this research is completely voluntary. You may choose to not take part at all. If you decide that your will not participate in this study or if you stop participating at any time, you will not be penalized. You will be given a signed copy of this permission form and the investigators will provide you with your individual results from this study. Investigators will guide you through the results and be willing to answer any of your questions. Subjects who only attend the first day of testing will receive no compensation.
Is any medical treatment available if I am injured?	The University of Maryland does not provide any medical, hospitalization or other insurance for participants in this research study, nor will the University of Maryland provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.
What if I have questions?	This research is being conducted by Dr. Jane Clark, department of Kinesiology, and Dr. Bradley Hatfield at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Dr. Jane Clark at: Department of Kinesiology, 2305 HHP Bldg University of Maryland, College Park, MD 20742 (301)-405-2495

	If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) irb@deans.umd.edu; (telephone) 301-405-0678 This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.
Statement of Age of Subject and Consent	Your signature indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been fully answered; and you freely and voluntarily chose to participate in the research study described above

Signature and Date	**NAME OF SUBJECT**	
	SIGNATURE OF SUBJECT'S PARENT/GUARDIAN (IF MINOR):	
	DATE	

CONSENT FORM

Project Title	The Effects of An Acute Bout of Exercise on Cortical Dynamics and Attention in Children
Why is this research being done?	This research project is being conducted by Kristin Cipriani at the Department of Kinesiology, University of Maryland, College Park. We are inviting you to participate in this research project because you are over 18 years of age and are the parent or legal guardian of 7- to 12-year-old child. We are inviting your child to participate in our study. The purpose of the research is to investigate the affects of an acute bout of exercise upon cognitive function, specifically attention, in children.
What will I be asked to do?	The procedures involve two days of testing with a duration of around 90 minutes per day. The study will be conducted in the Kinesiology Department of the School of Public Health at the University of Maryland, College Park. **Day 1:** Prior to testing, you will complete a pubertal stages survey (a survey indicating the level of pubertal development) for your child if they are under 10 years of age. If your child is 10 years of age or older, they will personally complete the survey. Next, your child will complete a physical activity recall, in which they will detail their participation in physical activity over the past three days. Then, to measure your child's baseline attention level (a general measure of your child's attention span), your child will complete a task in which they visually scan a document for a specific character. Next, your child will participate in a variety of tasks in three domains, manual dexterity, aiming and catching, and balance, to show their motor skill. A score on these tasks that is lower than the 20^{th} percentile will result in exclusion from the study. Following this, your child's fitness level will be measured through a moderately intense fitness (VO_2max) test performed on a treadmill. Your child first will be instructed regarding the use of the OMNI rating of perceived exertion (RPE) scale, to help your child express feeling of fatigue. This scale includes cartoon pictures of children who are at various levels of fatigue. By indicating a number that corresponds with the fatigue level, your child will be able to indicate to researchers how tired he or she feels. After this, your child will be fitted to a mouthpiece breathing valve and a nose clip. Time will be taken to be sure that your child if comfortable with this set-up. The fitness test consists of a graded exercise test in which your child walks on a treadmill that increases in speed and incline in 3 minute increments. These increases will continue until your child reaches a near maximal effort (heart rate = ~200 beats per minute) or until volitional exhaustion (the point where your child voluntarily indicates that he or she is too tired to continue). This protocol may be modified on an individual basis to ensure that fitness testing time does not exceed 15 minutes. All researchers are CPR certified, and every effort will be made to ensure your child's safety.

	Total day 1 testing time will be around 90 minutes **Day 2:** Upon entering the lab, your child will be fitted with a special electrode cap (similar to a swim cap) placed on his or her head. The purpose of the cap is to record electrical brain activity from 12 locations along the scalp. In addition skin sensors will be placed above and below his or her left eye in order to record eye blinks, and placed on his or her ear lobes to serve as a references for the recordings. These areas will be lightly rubbed with alcohol in order to remove any extra oil or skin cells on the surface, and the ear lobes will be rubbed with Nuprep gel. Your child's skin will be lightly rubbed with the blunt end of a wooden Q-tip at the skin site corresponding to each electrode site on the cap. The purpose of this step is to gently move the hair away from the sensors and allow contact between the skin and the electrodes. Researchers will ensure that the skin is not broken. Using a blunt end needle and plastic tube, Food & Drug Administration (FDA) approved non-toxic conducting gel will be applied to each sensor to enable continuous connection between each sensor and the skin of the scalp. Again, the skin will not be broken. These set-up procedures will take approximately 15 minutes and each step will be explained so that you and your child feel comfortable with the process. Next, your child will begin the cognitive task. Headphones will first be placed over your child's ears. During this task, children will hear three different types of noises: including tones and sounds (all presented at an audible, but not harmful level). While listening to the noises, you child will be asked to press a button in response to only the non-frequent tones. This task will last for approximately 15 minutes and EEG will be recorded throughout. Once this task is completed, your child (remaining in the EEG cap to prevent movement of electrodes) will then participate in one of two activities for 20 minutes; 1)a restful child's yoga video; 2) a bout of exercise on the treadmill. In the bout of exercise, your child's heart rate will be recorded by a heart rate monitor. He or she will exercise at 60% of their VO_2max (maximum oxygen consumption, a value recorded from the fitness testing) for the duration of the bout. In both conditions your child's efforts will be encouraged by the researcher. Exactly 5 minutes after this 20 minute period is completed, your child will then complete the 3-stimulus task for the second time. Total day 2 testing time will be around 90 minutes. Parents are not required to be present for testing, but are welcome to wait in a designated waiting area while the testing occurs. After the conclusion of both days of testing, monetary compensation of $35 will be given.
Project Title	The Effects of An Acute Bout of Exercise on Cortical Dynamics and Attention in Children

What about confidentiality?	We will do our best to keep your child's personal information confidential. To help protect your confidentiality, the following standards will be met. All information collected in the study is strictly confidential. The data your child provides will be grouped with data others provide for reporting and presentation. Your child's name will not be included on the surveys and other collected data. A code will be placed on the survey and other collected data, and through the use of an identification key, the researcher will be able to link your child's survey and collected data to their identity. Only the researcher will have access to the identification key. Data collected from excluded participants will not be used and will be subsequently shredded immediately. Data will be stored in a locked file cabinet and/or on password protected computers in a secured university laboratory facility. Only the investigators and their collaborators will have access to this locked file. All those with access to the data are NIH certified in the procedures for protecting participants in scientific experiments. If we write a report or article about this research project, your identity will be protected to the maximum extent possible. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law. All data will be destroyed after 10 years.
What are the risks of this research?	There may be some risks to your child from participating in this research study. As result of participation in this study, and specifically wearing the electrode cap to measure brain activity, participants may experience some slight sensation and irritation of the skin as the scalp is lightly rubbed at the electrode sites. Participants may experience a modest degree of fatigue from the concentration required during the performance on the 3-stimulus task. Additionally, there are always risks associated with exercise testing in any age group. Due to the maximal effort required with a high intensity exercise, these may include lightheadedness, syncope, nausea, muscle soreness, chest discomfort, and dry mouth and throat due to the breathing valve used for gas collection. In rare cases heart attacks and death may occur. The risks associated with this study are no greater than those present during high-exertion play and intense sports training, and will provide the most accurate measure of fitness for children. Aside from these, there are no other known risks and no long-term effects associated with participation in this study.
What are the benefits of this research?	The experiment is not designed to help your child specifically, but it may have substantial impact on understanding how attentional processes respond to an acute exercise bout.
Do I have to be in this research? May I stop participating at any time?	Your child's participation is this research is completely voluntary. You may choose for your child to not take part at all. If you decide that your child will not participate in this study or if your child stops participating at any time, you will not be penalized. You will be given a signed copy of this permission form and the investigators will provide you with your child's individual results from this study. Investigators will guide

	parents through the results and be willing to answer any of the parent's questions. If your child's score on the MABC falls below the 20th percentile, or if they have reached puberty, as indicated by the pubertal assessment, they will be asked to no longer participate in the study. Subjects who are excluded based on aforementioned criteria will be paid 5 dollars, and invited to participate in an alternative study. Subjects who only attend the first day of testing will receive no compensation.
Is any medical treatment available if I am injured?	The University of Maryland does not provide any medical, hospitalization or other insurance for participants in this research study, nor will the University of Maryland provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.
What if I have questions?	This research is being conducted by Dr. Jane Clark, department of Kinesiology, and Dr. Bradley Hatfield at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Dr. Jane Clark at: Department of Kinesiology, 2305 HHP Bldg University of Maryland, College Park, MD 20742 (301)-405-2495 If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742; (e-mail) irb@deans.umd.edu; (telephone) 301-405-0678 This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.
Statement of Age of Subject and Consent	Your signature indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been fully answered; and you freely and voluntarily chose to permit the participation of your child in the research study described above

Signature and Date	**NAME OF SUBJECT**	
	SIGNATURE OF SUBJECT'S PARENT/GUARDIAN (IF MINOR):	
	DATE	

Appendix C. Child Assent Form (Children 10 and Older)

ASSENT FORM – For Children 10 years old and older
University of Maryland, Cognitive-Motor Behavior Laboratory

This study examines the relationship between physical exercise and attention. On the first day of testing, you will fill out a two forms. One form will be about your level of development, and the other will ask you to remember what activities you participated in over the past few days. Then you will participate in a few activities where you will draw, catch and balance. Then you will be asked to exercise on a treadmill until you feel exhausted. When on the treadmill, you will have a large mouthpiece in your mouth and also a nose clip on your nose. This may make breathing a little more difficult, but it helps us to monitor how your breathing changes. All of these activities will take about 90 minutes. On the second day of testing, you will be asked to wear a cap with sensors that will measure your brain signals. You will also wear sensors that measure how your eyes move. It will take about 15 minutes to put the cap and sensors on. You will then be asked to sit and listen to different noises for about 15 minutes. During this time, you will press a button only when you hear a specific tone. Then for the next 20 minutes you will either watch a yoga video, or exercise on the treadmill (with less effort than the last time). After this, you will listen to the noises again. When you finish this, you will be given monetary compensation.

You do not have to be in the study if you do not want to. You can always ask to stop for any reason. You may feel bored, tired, or your head may feel sore while listening to the noises. Also, when exercising, you may feel dizzy, your muscles may hurt, and your stomach may ache. If this happens tell the person with you and you can take a break or end the task. Also, you can always ask questions.

↑ Yes, I know what I will have to do in this study and would like to take part.

____

Name of Child

Appendix D. Child Assent Form (Children Under 10)

ASSENT SCRIPT – For Children under 10 years
University of Maryland, Cognitive-Motor Behavior Laboratory

This study looks at physical exercise and attention. On the first day of testing, you will fill out a form about activities that you have recently done. Then we will play games where you draw, catch, and balance. Then you will have to work very hard and walk on a treadmill until you are really tired. When you are on the treadmill, you will have a plastic mouthpiece in your mouth, and a nose clip on your nose. Even though you will still breathe regularly, the mouthpiece and nose clip may make it a little more difficult. All of these activities will take about 90 minutes. On the second day of testing, you will wear a cap on your head. The cap will measure what your brain is doing. You will also wear sensors that record when you move your eyes. It will take 15 minutes to put the cap and sensors on your head. Then you will listen to noises and sometimes press a button. Then you will either have a relaxing activity or walk on the treadmill. Then you will listen to noises again. These activities will also take about 90 minutes.

You do not have to be in the study. If you feel uncomfortable and want to take a break or stop just tell someone. You can ask questions if you do not know what to do.

Do you still want to be in the study? (Check the box that you agree with)

Yes, I still want to be in the study ☐

No, I do not want to be in the study ☐

Movement Assessment Battery for Children – 2

Test Record Form Age Band 3 (11-16 years)

Name: ______ Gender: M / F

Home address: ______

School: ______ Class/year/grade: ______

Assessed by: ______

Referral source: ______

Preferred (writing) hand: ______

	Year	Month	Day
Date tested			
Date of birth			
Chronological age			

Movement ABC-2
Checklist completed? Y / N

Item Scores and Equivalent Standard Scores

Item code	Name of item	Raw score (best attempt)	Item Standard Score
MD 1*	Turning Pegs preferred hand		
	Turning Pegs non-pref hand		
MD 2	Triangle with Nuts and Bolts		
MD 3	Drawing Trail 3		
A&C 1	Catching with one Hand – best hand		
	Catching with one Hand – other hand		
A&C 2	Throwing at Wall Target		
Bal 1*	Two-Board Balance		
Bal 2	Walking Toe-to-Heel Backwards		
Bal 3	Zig-Zag Hopping best Leg		
	Zig-Zag Hopping other Leg		

Total Test Score Sum of 8 item **standard** scores:	

*For Turning Pegs, Catching with One Hand and Zig Zag Hopping, look up standard score for each limb, add these and divide by 2. If the result is above 10, round up; if below 10, round down.

Three Component Scores[†]

Manual Dexterity^ MD 1 + MD 2 + MD 3

Component score	Standard Score	Percentile

Aiming & Catching^ A&C 1 + A&C 2

Component score	Standard Score	Percentile

Balance^ Bal 1 + Bal 2 + Bal 3

Component score	Standard Score	Percentile

^In each case sum the item standard scores.

Total Test Score	Standard Score	Percentile Rank

†For confidence intervals, see Examiner's Manual p139 (Chapter 7)

Manual Dexterity 1: TURNING PEGS

Record: Preferred hand: R / L (should be same as for Drawing Trail); Time taken (secs); **F** for failure; **R** for refusal; **I** if inappropriate (note reasons below)

Preferred hand		Only administer a second trial if the first trial takes longer than the time stated below:							Non-preferred hand		Only administer a second trial if the first trial takes longer than the time stated below:						
Trial 1			11:0-11:11	12:0-12:11	13:0-13:11	14:0-14:11	15:0-15:11	16:0-16:11	Trial 1			11:0-11:11	12:0-12:11	13:0-13:11	14:0-14:11	15:0-15:11	16:0-16:11
Trial 2			25 secs	22 secs	22 secs	22 secs	22 secs	22 secs	Trial 2			31 secs	26 secs	26 secs	26 secs	26 secs	26 secs

Qualitative observations

Posture/body control

- Sitting posture is poor ☐
- Holds head too close to task ☐
- Holds head at an odd angle ☐
- Does not look while manipulating pegs ☐
- Does not use pincer grip to pick up pegs ☐
- Exaggerates finger movements in releasing pegs ☐
- Does not use the supporting hand to hold board steady ☐
- Does extremely poorly with one hand (asymmetry striking) ☐
- Changes hands or uses both hands during a trial ☐
- Hand movements are jerky ☐
- Moves constantly/fidgets ☐

Adjustment to task requirements

- Misaligns pegs with respect to holes ☐
- Uses excessive force when inserting pegs ☐
- Is exceptionally slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other ______________________

Comments: ______________________

Manual Dexterity 2: TRIANGLE WITH NUTS AND BOLTS

Record: Time taken (secs); **F** for failure; **R** for refusal; **I** if inappropriate (note reasons below)

No. of seconds		Only administer a second trial if the first trial takes longer than the time stated below:						
Trial 1			11:0-11:11	12:0-12:11	13:0-13:11	14:0-14:11	15:0-15:11	16:0-16:11
Trial 2			55 secs	48 secs	48 secs	48 secs	48 secs	48 secs

Qualitative observations

Posture/body control

- Sitting posture is poor ☐
- Holds materials too close to face ☐
- Holds head at an odd angle ☐
- Does not look at hole while inserting bolt ☐
- Does not use pincer grip to hold nuts and bolts ☐
- Finds it difficult to hold bolt with one hand and screw nut on with the other ☐
- Changes hands during a trial ☐
- Hand movements are jerky ☐
- Moves constantly/fidgets ☐

Adjustment to task requirements

- Sometimes misses hole with tip of bolt ☐
- Gets muddled in the construction sequence ☐
- Is exceptionally slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other ______________________

Comments: ______________________

Manual Dexterity 3: DRAWING TRAIL 3

Note: Bic Atlantis pen to be used

Record: Hand used: R/L/Both; No. of errors; **F** for failure; **R** for refusal; **I** if inappropriate (note reasons below)
Number of errors should be counted after testing using scoring criteria provided in Appendix A of the Manual.

	No. of errors
Trial 1	
Trial 2	

Do not administer a second trial If the child completes the first trial perfectly (i.e. no errors).

Qualitative observations

Posture/body control

Sitting posture is poor ☐
Holds head too near paper ☐
Holds head at an odd angle ☐
Does not look at trail ☐
Holds pen with an odd/immature grip ☐
Holds pen too far from point ☐
Holds pen too close to point ☐
Does not hold paper still ☐
Changes hands during a trial ☐
Moves constantly/fidgets ☐

Adjustment to task requirements

Progresses in short jerky movements ☐
Uses excessive force, presses very hard on paper ☐
Is exceptionally slow ☐
Goes too fast for accuracy ☐
Other ______

Comments: ______

Aiming & Catching 1: CATCHING WITH ONE HAND

Record: Number of correctly executed catches; **R** for refusal; **I** if inappropriate (note reasons below)

Right Hand Practice: ☐☐☐☐☐ 10 Trials: ☐☐☐☐☐☐☐☐☐☐ Total: ______

Left Hand Practice: ☐☐☐☐☐ 10 Trials: ☐☐☐☐☐☐☐☐☐☐ Total: ______

Qualitative observations

Posture/body control

Standing posture is poor ☐
Does not follow trajectory of ball with eyes ☐
Turns away or closes eyes as ball approaches ☐
Holds hand out flat with fingers stiff as the ball rebounds ☐
Hands and arms held wide apart, fingers extended ☐
Arm and hand do not 'give' to meet impact of ball ☐
Fingers close too early or too late ☐
Does extremely poorly with one hand (asymmetry striking) ☐
Movements lack fluency ☐

Adjustment to task requirements

Does not adjust body position for catching ☐
Does not adjust position of feet as necessary ☐
Judges force of throw poorly (too much or too little) ☐
Does not adjust to height of rebound ☐
Does not adjust to direction of rebound ☐
Does not adjust to force of rebound ☐
Other ______

Comments: ______

Aiming & Catching 2: THROWING AT WALL TARGET

Record: Hand used: R / L / Both; Number of successful hits; **R** for refusal; **I** if inappropriate (note reasons below)

Practice: ☐☐☐☐☐ 10 Trials: ☐☐☐☐☐☐☐☐☐☐ Total:__________

Qualitative observations

Posture/body control

- Balance while throwing is poor .... ☐
- Does not keep eyes on target .... ☐
- Does not follow through with the throwing arm .... ☐
- Releases ball too early or too late .... ☐
- Changes hands from trial to trial .... ☐
- Movements lack fluency .... ☐

Adjustment to task requirements

- Errors are consistently to one side of the target (asymmetry striking) .... ☐
- Control of direction is variable .... ☐
- Judges force of throw poorly (too much or too little) ...... ☐
- Control of force is variable .... ☐
- **Other** ______________________________

Comments: ____

Balance 1: TWO-BOARD BALANCE

Record: Time balanced (secs); **R** for refusal; **I** if inappropriate (note reasons below)

	No. of seconds
Trial 1	
Trial 2	

Do not administer a second trial if the child maintains balance for 30 seconds

Qualitative observations

Posture/body control

- Body appears rigid/tense .... ☐
- Body appears limp/floppy .... ☐
- Sways wildly to try to maintain balance .... ☐
- Does not hold head and eyes steady .... ☐
- Makes no or few compensatory arm movements to help maintain balance .... ☐
- Exaggerated movements of arms and trunk disrupt balance . ☐
- Cannot hold feet in a straight line .... ☐
- **Other** ______________________________

Comments: ____

Balance 2: WALKING TOE-TO-HEEL BACKWARDS

Record: Number of correct consecutive steps from the beginning of the line; Whether entire line was walked successfully; **R** for refusal; **I** if inappropriate (note reasons below)

	No. of steps	Entire line?
Trial 1		YES / NO
Trial 2		YES / NO

Do not administer a second trial if the child completes 15 steps OR completes the whole line in fewer than 15 correctly executed steps

Qualitative observations

Posture/body control

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Sways wildly to try to maintain balance ☐
- Does not look behind to check position on track ☐
- Does not compensate with arms to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐
- Is very wobbly when placing feet on line ☐

Adjustments to task requirements

- Goes too fast for accuracy ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐

Other ______

Comments: ______

Balance 3: ZIG-ZAG HOPPING

Record: Number of correct consecutive hops (maximum of 5); **R** for refusal; **I** if inappropriate (note reasons below)

		No. of hops			No. of hops
Right Leg	Trial 1		Left Leg	Trial 1	
	Trial 2			Trial 2	

Do not administer a second trial if the child completes 5 perfect hops on the first trial

Qualitative observations

Posture/body control

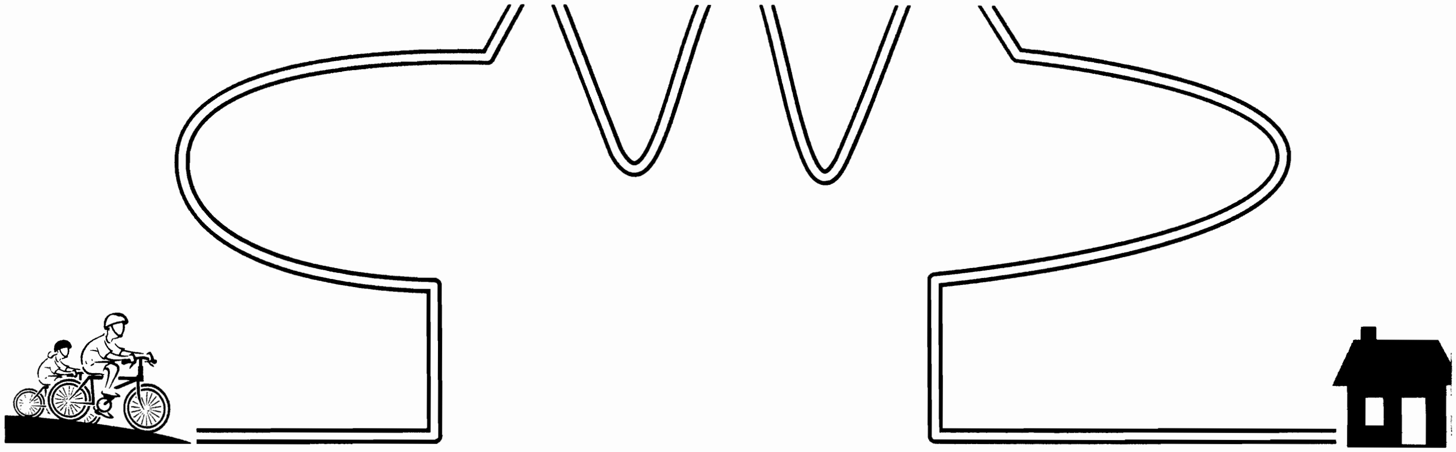
- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Non-supporting leg held up in front of body ☐
- Hops with stiff legs/on flat feet ☐
- Lacks springiness/no push-off from feet ☐
- Arm movements are exaggerated ☐
- Does not use arms to assist hop ☐
- Stumbles on landing ☐
- Does extremely poorly with one leg (asymmetry striking) ☐

Adjustments to task requirements

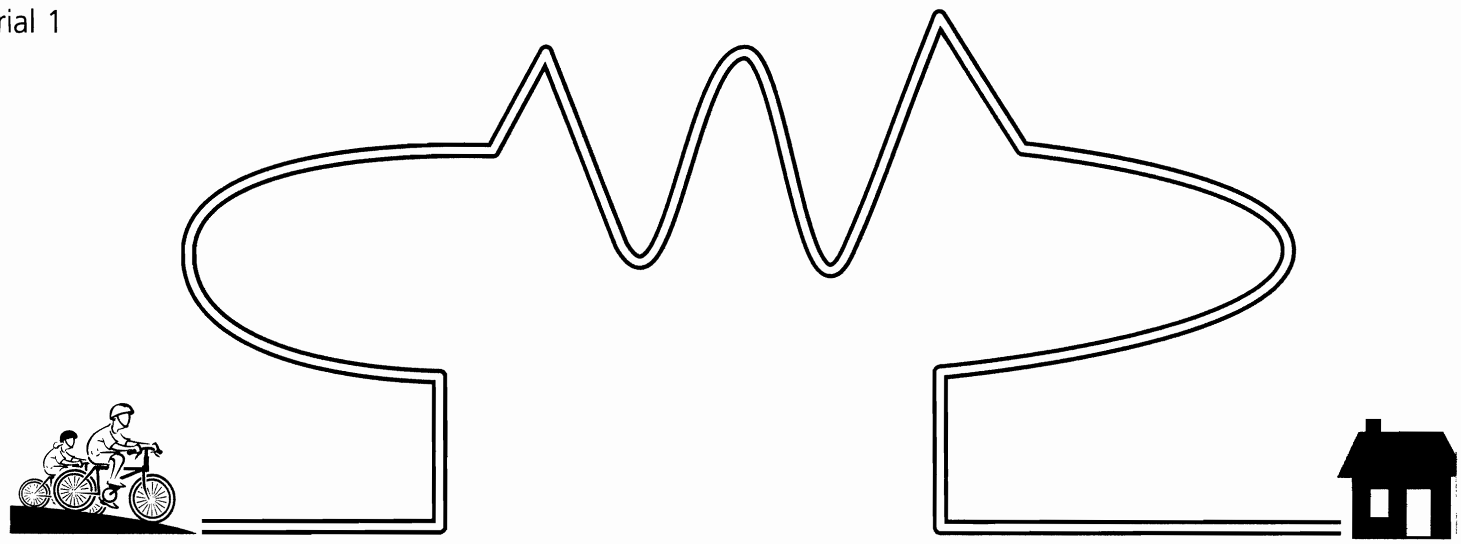
- Goes too fast for accuracy ☐
- Does not combine upward and forward movements effectively ☐
- Uses too much effort ☐
- Movements are jerky ☐

Other ______

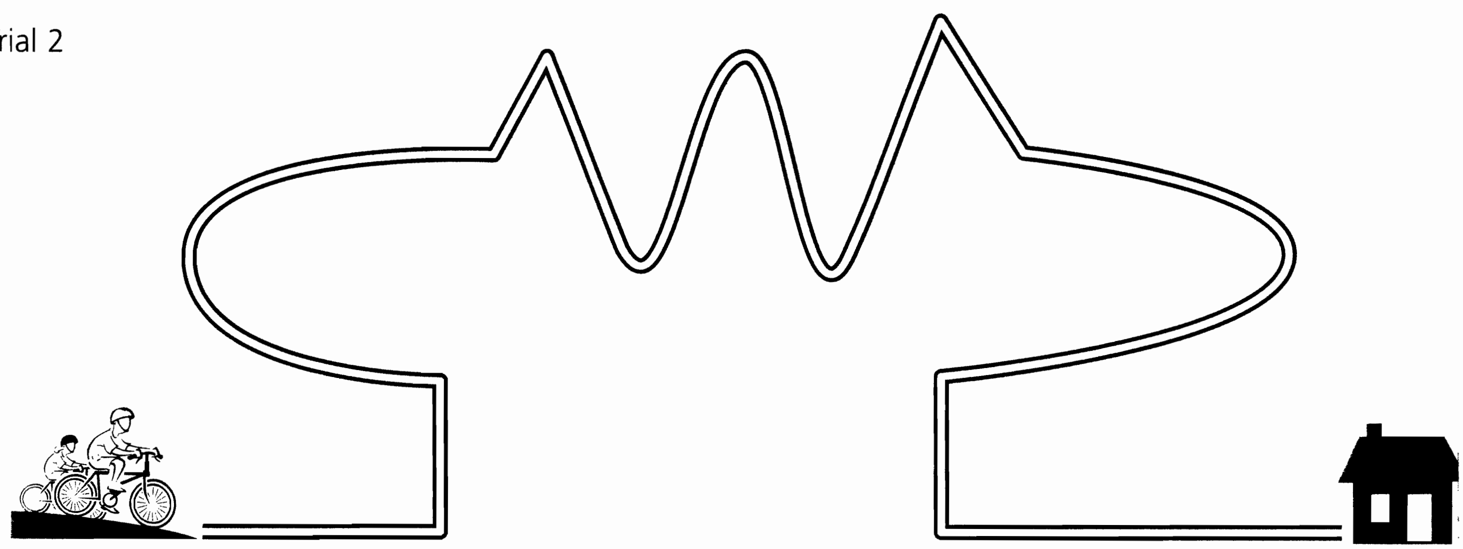
Comments: ______



Trial 1



Trial 2



Appendix F. Pediatric Health Questionnaire

Pediatric Health Questionnaire

Child's Name____
Sex___________ Age___________ Date of Birth___________

Past Medical History

Please list any prior major illnesses and/or injuries:

General Health:

1. Does your child have or has your child ever had any major physical illness, injury or disability? If yes, please explain:

2. Does your child take any medications? If yes, please explain.

3. Does your child have a hearing impairment?

4. Does your child have?

   a) Restrictions to physical activity

   b) Cardiovascular disease (heart defect, heart murmurs, high blood pressure, etc.)

   c) Pulmonary disease (asthma, etc.)

   d) Skeletal or muscle disorders

If you answered YES to any item above, please explain.

Hospitalization/Surgery/Injury:

5. Except at birth, has your child been hospitalized? Yes__ No__
   If yes, list age(s) and reason:

6. Has your child ever had surgery? Yes__ No__
   If yes, list age(s) and reason:

7. Has your child ever had a head injury involving unconsciousness? Yes__ No__
   If yes, how long?

8. Has your child had any illness that caused a permanent decrease in memory or cognition? Yes__ No__
   If yes, please explain:

9. Has your child had any illness that caused a permanent decrease in motor ability (including speech)? Yes__ No__
   If yes, please explain:

Review of Neurological Health

10. Does your child have or has your child ever had seizure disorder? Yes__ No__
    If yes, please explain:

11. Does your child have or has your child ever had developmental delay? Yes__ No_
    If yes, please explain:

12. Does your child have or has your child ever had speech delay? Yes__ No__
    If yes, please explain:

13. Does your child have or has your child ever had diagnosed learning disabilities?
    Yes__ No__ If yes, please explain:

The above information was obtained by the researcher through a phone interview.

I am in agreement with the accuracy of the health history listed above.

Printed Name of Parent or Guardian ______________________________

Signature of Parent or Guardian __________________________

Date_______________

Appendix G. General Health Questionnaire

Health Questionnaire

Name____
Sex___________ Age___________ Date of Birth___________

Past Medical History

Please list any prior major illnesses and/or injuries:

General Health:

1. Do you have or have you ever had any major physical illness, injury or disability? If yes, please explain:

2. Do you take any medications? If yes, please explain.

3. Do you have any hearing impairments? If yes, please explain.

4. Do you have?

   a) Restrictions to physical activity

   b) Cardiovascular disease (heart defect, heart murmurs, high blood pressure, etc.)

   c) Pulmonary disease (asthma, etc.)

   d) Skeletal or muscle disorders

If you answered YES to any item above, please explain.

Hospitalization/Surgery/Injury:

5. Except at birth, have you been hospitalized? Yes__ No__
   If yes, list age(s) and reason:

6. Have you ever had surgery? Yes__ No__
   If yes, list age(s) and reason:

7. Have you ever had a head injury involving unconsciousness? Yes__ No__
   If yes, how long?

8. Have you ever had any illness that caused a permanent decrease in memory or cognition? Yes__ No__
   If yes, please explain:

9. Have you had any illness that caused a permanent decrease in motor ability (including speech)? Yes__ No__
   If yes, please explain:

Review of Neurological Health

10. Do you have or have you ever had seizure disorder? Yes__ No__
    If yes, please explain:

11. Do you have or have you ever had developmental delay? Yes__ No_
    If yes, please explain:

12. Do you have or have you ever had speech delay? Yes__ No__
    If yes, please explain:

13. Do you have or have you ever had diagnosed learning disabilities? Yes__ No__
    If yes, please explain:

14. Have you ever had a diagnosed attentional disorder (ADD, ADHD)? Yes__ No__
    If yes, please explain:

The above information was obtained by the researcher through a phone interview.

I am in agreement with the accuracy of the health history listed above.

Printed Name of Participant ______________________________

Signature of Participant __________________________

Date________________

Appendix H. Tanner Stages

Tanner Stages: Male

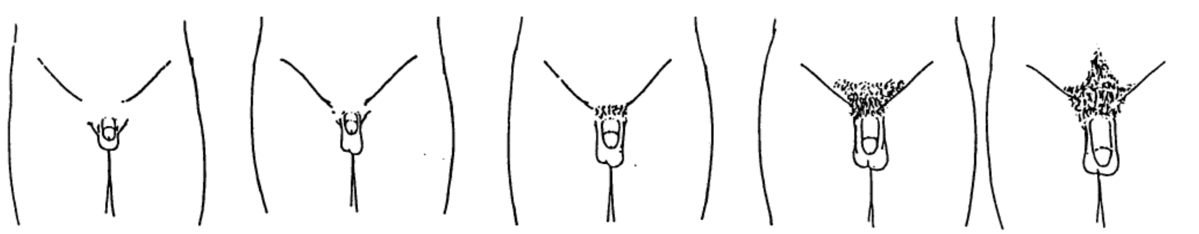
As a child continues to grow over the next few years, their body will go through several changes. These changes happen at different ages for different children, and you may have already observed some of these changes. Sometimes it is important to know how a person is growing without having a doctor examine them. It can be hard for a person to describe themselves or others in words, so doctors have drawings of stages that all children go through. There are 5 drawings of pubic hair growth which are attached for you to observe.

Using the attached set of drawings, we want to know your current stage of growth. All you need to do is pick the drawing that you most closely resemble. Put a check-mark above the drawing that best describes your stage, or your child's stage (if form is being completed by a parent) of hair development.

.

The drawings on this page show five different stages in pubic hair development. As boys grow into adulthood, they usually pass through each of these stages. Please look at each drawing and read the description under it. Then choose the drawing that is closest to your son's current stage of pubic hair development and mark it with an X. In choosing which picture to mark, try to focus only on the amount of pubic hair, not the size and shape of the genitals. If you feel you don't know enough about your son's current development to answer, just put an X in the space at the bottom of the page marked *Don't Know*.

STAGE I ________ **STAGE II** ________ **STAGE III** ________ **STAGE IV** ________ **STAGE V** ________



No pubic hair.	There is a little long, downy, fairly light hair that may be straight or slightly curled. Most of the hair is at the base of the penis.	The hair is darker, coarser, and curlier than in Stage II. It has spread out and thinly covers a larger area.	The hair is as dark, curly, and coarse as in an adult man, but it covers a smaller area. It has not spread to the inner thighs.	The mature adult stage. The hair is dark, coarse, and curly. It covers the same area as in an adult man, extending to the inner thighs.

Don't Know _______

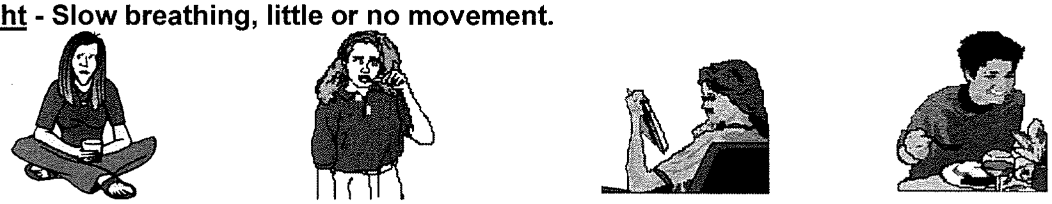
3DPAR Instructions and Intensity Scale

Instructions: The purpose of this questionnaire is to approximate the amount of physical activity that you perform. The name of each day that you will describe is in the top left-hand corner of each Activity Time Sheet.

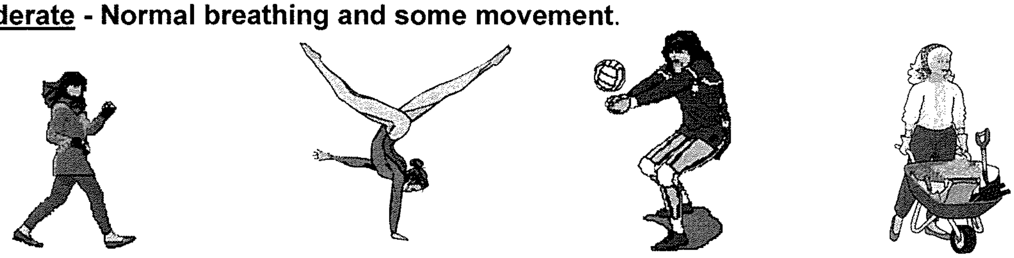
1. For **each** time period, write in the activity number that corresponds to the **main** activity you actually performed during that particular time period. If you did more than one activity during the 30 minutes, record the activity that you did for **most** of the time. The activity numbers are found on the **Coding Instructions Sheet**. Note that the first eighteen (18) activities are shaded.
2. If the activity is shaded on the **Coding Instructions Sheet** then you do not need to fill out any of the remaining columns and you should go to the next time period. Otherwise, proceed with 3-5 below.
3. For activities 19-71, rate how physically **hard** each activity was. Place a "✓" in the timetable to indicate one of the four intensity levels for each non-shaded activity.
4. Indicate **where** you performed each non-shaded activity by writing in the corresponding number found on the **Coding Instructions Sheet**.
5. Finally, write the corresponding number for **with whom** you performed the non-shaded activity.

Intensity Scale:

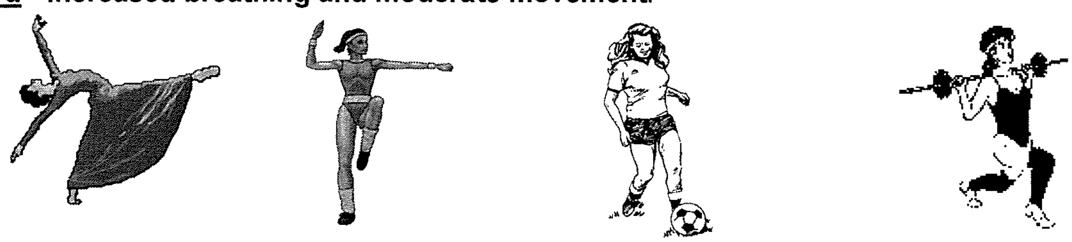
• **Light - Slow breathing, little or no movement.**



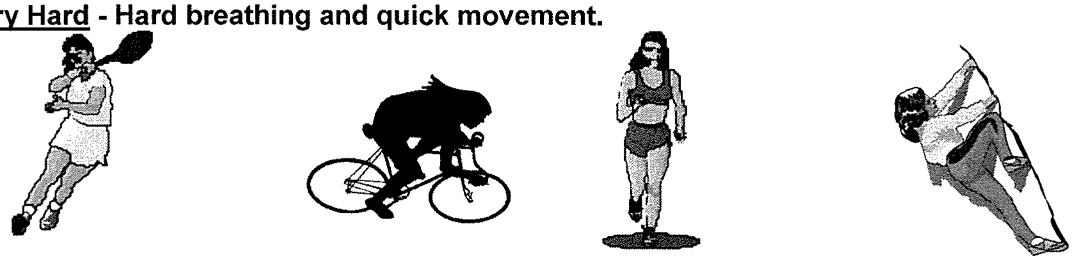
• **Moderate - Normal breathing and some movement.**



• **Hard - Increased breathing and moderate movement.**



• **Very Hard - Hard breathing and quick movement.**



Sample Activity Time Sheet

The table below shows the correct way to fill out the activity time sheets. Note that only **one** intensity level is checked for each physical activity.

	Activity Number	Light	Moderate	Hard	Very Hard	Where	With Whom
6:00-6:30	16						
6:30-7:00	15						
7:00-7:30	14						
7:30-8:00	23		√			2	1
8:00-8:30	18						
8:30-9:00	18						
9:00-9:30	21			√		2	3
9:30-10:00	21			√		2	3
10:00-10:30	18						
10:30-11:00	18						
11:00-11:30	18						
11:30-12:00	1						

Coding Instructions Sheet

'Activity' Numbers:

EATING
1. Eating a meal
2. Snacking

AFTER SCHOOL/SPARE TIME/HOBBIES
3. Church
4. Hanging around
5. Homework
6. Listening to music
7. Music lesson/playing instrument
8. Playing video games/surfing internet
9. Reading
10. Shopping
11. Talking on phone
12. Watching TV or movie

SLEEP/BATHING
13. Getting dressed
14. Getting ready (hair, make-up, etc.)
15. Showering/bathing
16. Sleeping

SCHOOL
17. Lunch/free time/study hall
18. Sitting in class
19. Club, student activity
20. Marching band/flag line
21. P.E. Class

TRANSPORTATION
22. Riding in a car/bus
23. Travel by walking
24. Travel by bicycling

WORK
25. Working (e.g., part-time job, child care)
26. Doing house chores (e.g., vacuuming, dusting, washing dishes, animal care, etc.)
27. Yard Work (e.g., mowing, raking)

PHYSICAL ACTIVITIES
28. Aerobics, jazzercise, water aerobics, taebo
29. Basketball
30. Bicycling, mountain biking
31. Bowling
32. Broomball
33. Calisthenics / Exercises (push-ups, sit-ups, jumping jacks)
34. Cheerleading, drill team
35. Dance (at home, at a class, in school, at a party, at a place of worship)
36. Exercise machine (cycle, treadmill, stair master, rowing machine)
37. Football
38. Frisbee
39. Golf / Mini-golf
40. Gymnastics / Tumbling
41. Hiking
42. Hockey (ice, field, street, or floor)
43. Horseback riding
44. Jumping rope
45. Kick boxing
46. Lacrosse
47. Martial arts (karate, judo, boxing, tai kwan do, tai chi)
48. Playground games (tether ball, four square, dodge ball, kick ball)
49. Playing catch
50. Playing with younger children
51. Roller blading, ice skating, roller skating
52. Riding scooters
53. Running / Jogging
54. Skiing (downhill, cross country, or water)
55. Skateboarding
56. Sledding, tobogganing, bobsledding
57. Snowboarding
58. Soccer
59. Softball/baseball
60. Surfing (body or board) / Skimboarding
61. Swimming (laps)
62. Swimming (play, pool games – Marco Polo, water volleyball, snorkeling)
63. Tennis, racquetball, badminton, paddleball
64. Trampolining
65. Track & field
66. Volleyball
67. Walking for exercise
68. Weightlifting
69. Wrestling
70. Yoga, stretching
71. Other

'Where' Numbers:

1 – HOME / NEIGHBORHOOD (yours or a friend's)
2 – SCHOOL (including gym and grounds)
3 – COMMUNITY FACILITY (for example: Park, Playground, Rec Center, Church, Dance Studio, Field or Gym)
4 – OTHER OUTDOOR PUBLIC AREA (for example: Beach, River, Levee, Ski Area, Camping Area)
5 – OTHER (for example: Mall, Doctor's Office, Movies)

'With Whom' Numbers:

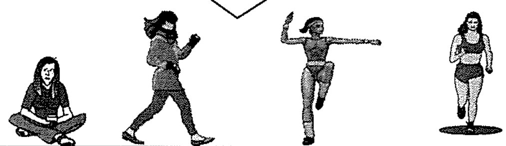
0 – BY YOURSELF
1 – WITH 1 OTHER PERSON
2 – WITH SEVERAL PEOPLE (but NOT an organized program, class or team)
3 – WITH AN ORGANIZED PROGRAM, CLASS or TEAM

Day: ____________

Write 'Activity' numbers in this column.

Put a "✓" to rate the intensity of each activity.

Write numbers for 'Where' and 'With Whom' in these columns.



	Activity Number	Light	Moderate	Hard	Very Hard	Where	With Whom
6:00-6:30							
6:30-7:00							
7:00-7:30							
7:30-8:00							
8:00-8:30							
8:30-9:00							
9:00-9:30							
9:30-10:00							
10:00-10:30							
10:30-11:00							
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6:00-6:30							
6:30-7:00							
7:00-7:30							
7:30-8:00							
8:00-8:30							
8:30-9:00							
9:00-9:30							
9:30-10:00							
10:00-10:30							
10:30-11:00							
11:00-11:30							
11:30-12:00							

d2 Test of Attention

Rolf Brickenkamp & Eric A. Zillmer

Name: ______________________________

Age: ______ Sex: ☐ male ☐ female

Handedness: ☐ L ☐ R

Years of education: ______________________

Occupation: ___________________________

Examiner: __________________ Date: _________

Example:

	''		'
	d	d	d
		''	'

Practice line:

''	''	'		''		''	'		'		''		'	'	''		''	''			'
d	p	d	d	d	d	p	d	d	p	d	d	d	d	p	p	d	d	d	p	d	d
		'	'		''		''	''	'	'		''	''	''		''	''		''	'	'
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

	Raw Score	Percentage	Percentile Rank	Standard Score
TN (total number)				
Omissions: E1				
Commissions: E2				
E (errors)				
TN-E (total-errors)				
CP(concentration performance)				
FR (fluctuation rate)				

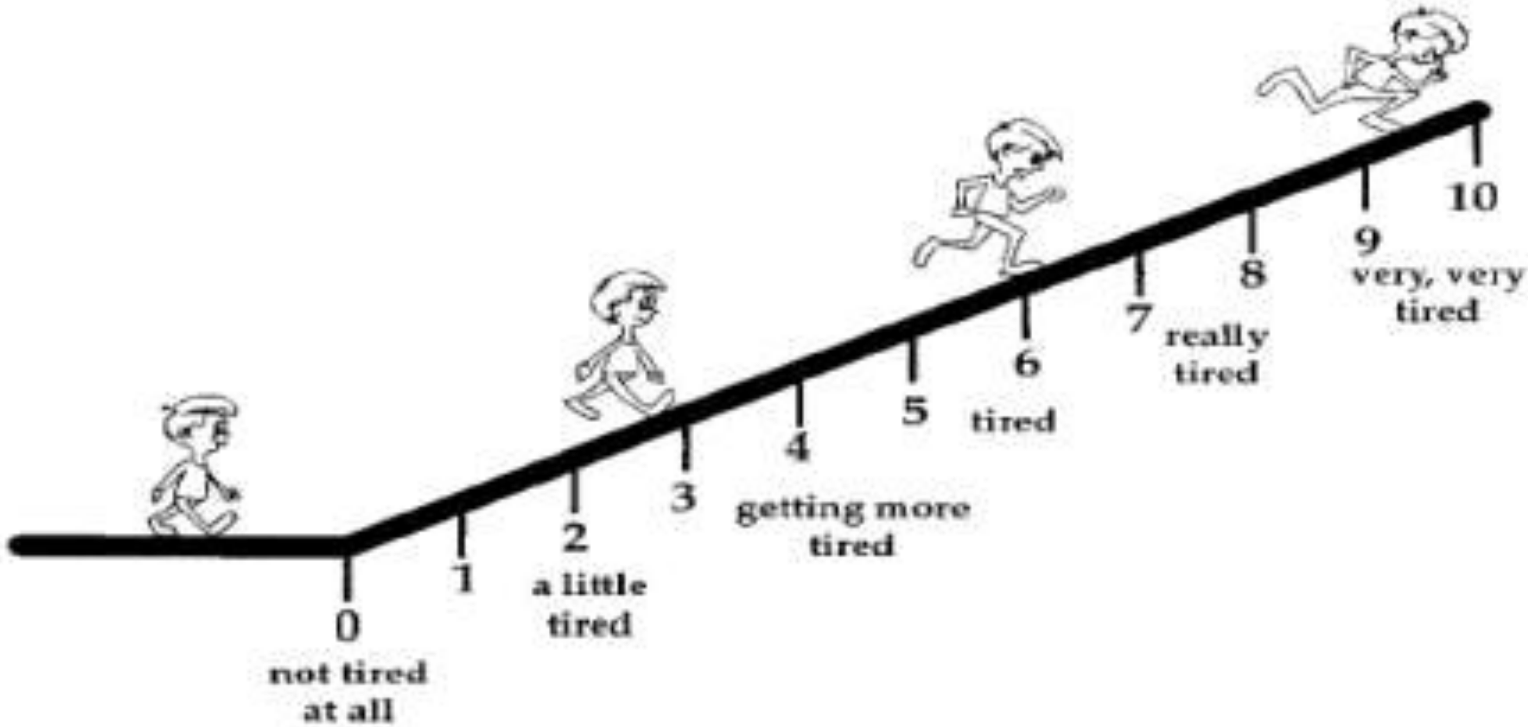
S-Syndrome: ☐

Order number #01 013 22

Appendix J. D2 Attention Assessment

```
        " " "     ' '   "   " " ' ' "     '   " '   ' "   ' ' " " '   " "   '   ' " "   '       "
 1  d d p d d d p p d p d d d d d p d p d d d p p d d d d d d d p d p d d p p d d d d p p d p d d p
    " '   '   " " ' ' "   "   ' ' ' " " "   '     " ' " "   '   "   "     " ' " "     " ' " " "

    " " ' "     " ' " " ' '     "   '   '       " '     " "   "   "     ' ' " ' "   '   " "   ' "
 2  p d p p d d d d p d p d d d p d d p d p d p d d p d p d d d d p d p d p d p d d d d p d p d d
            " ' " '   "   " " "   "   " ' " " '   ' " '   ' "   '   " " ' '       " ' "     " '

    " '   " "   "   '   "   '   " ' " " ' " " ' '   ' '     "     " " " ' " " " '     " '   " " '
 3  d d d d p p d p d p p p d d p d p d p d d p d p d d p d p p d d d d p d d p d p d d d d d p d
    "   "     "   ' ' '   " ' "   '       '     ' " " ' ' "   " '   "   ' '     ' " "   ' '     '

        " " "     ' '   "   " " ' ' "     '   " '   ' "   ' ' " " '   " "   '   ' " "   '       "
 4  d d p d d d p p d p d d d d d p d p d d d p p d d d d d d d p d p d d p p d d d d p p d p d d p
    " '   '   " " ' ' "   "   ' ' ' " " "   '     " ' " "   '   "   "     " ' " "     " ' " " "

    " " ' "     " ' " " ' '     "   '   '       " '     " "   "   "     ' ' " ' "   '   " "   ' "
 5  p d p p d d d d p d p d d d p d d p d p d p d d p d p d d d d p d p d p d p d d d d p d p d d
            " ' " '   "   " " "   "   " ' " " '   ' " '   ' "   '   " " ' '       " ' "     " '

    " '   " "   "   '   "   '   " ' " " ' " " ' '   ' '     "     " " " ' " " " '     " '   " " '
 6  d d d d p p d p d p p p d d p d p d p d d p d p d d p d p p d d d d p d d p d p d d d d d p d
    "   "     "   ' ' '   " ' "   '       '     ' " " ' ' "   " '   "   ' '     ' " "   ' '     '

        " " "     ' '   "   " " ' ' "     '   " '   ' "   ' ' " " '   " "   '   ' " "   '       "
 7  d d p d d d p p d p d d d d d p d p d d d p p d d d d d d d p d p d d p p d d d d p p d p d d p
    " '   '   " " ' ' "   "   ' ' ' " " "   '     " ' " "   '   "   "     " ' " "     " ' " " "

    " " ' "     " ' " " ' '     "   '   '       " '     " "   "   "     ' ' " ' "   '   " "   ' "
 8  p d p p d d d d p d p d d d p d d p d p d p d d p d p d d d d p d p d p d p d d d d p d p d d
            " ' " '   "   " " "   "   " ' " " '   ' " '   ' "   '   " " ' '       " ' "     " '

    " '   " "   "   '   "   '   " ' " " ' " " ' '   ' '     "     " " " ' " " " '     " '   " " '
 9  d d d d p p d p d p p p d d p d p d p d d p d p d d p d p p d d d d p d d p d p d d d d d p d
    "   "     "   ' ' '   " ' "   '       '     ' " " ' ' "   " '   "   ' '     ' " "   ' '     '

        " " "     ' '   "   " " ' ' "     '   " '   ' "   ' ' " " '   " "   '   ' " "   '       "
10  d d p d d d p p d p d d d d d p d p d d d p p d d d d d d d p d p d d p p d d d d p p d p d d p
    " '   '   " " ' ' "   "   ' ' ' " " "   '     " ' " "   '   "   "     " ' " "     " ' " " "

    " " ' "     " ' " " ' '     "   '   '       " '     " "   "   "     ' ' " ' "   '   " "   ' "
11  p d p p d d d d p d p d d d p d d p d p d p d d p d p d d d d p d p d p d p d d d d p d p d d
            " ' " '   "   " " "   "   " ' " " '   ' " '   ' "   '   " " ' '       " ' "     " '

    " '   " "   "   '   "   '   " ' " " ' " " ' '   ' '     "     " " " ' " " " '     " '   " " '
12  d d d d p p d p d p p p d d p d p d p d d p d p d d p d p p d d d d p d d p d p d d d d d p d
    "   "     "   ' ' '   " ' "   '       '     ' " " ' ' "   " '   "   ' '     ' " "   ' '     '

        " " "     ' '   "   " " ' ' "     '   " '   ' "   ' ' " " '   " "   '   ' " "   '       "
13  d d p d d d p p d p d d d d d p d p d d d p p d d d d d d d p d p d d p p d d d d p p d p d d p
    " '   '   " " ' ' "   "   ' ' ' " " "   '     " ' " "   '   "   "     " ' " "     " ' " " "

    " " ' "     " ' " " ' '     "   '   '       " '     " "   "   "     ' ' " ' "   '   " "   ' "
14  p d p p d d d d p d p d d d p d d p d p d p d d p d p d d d d p d p d p d p d d d d p d p d d
            " ' " '   "   " " "   "   " ' " " '   ' " '   ' "   '   " " ' '       " ' "     " '
```

TN	E_1	E_2	CP


0
not tired
at all
1
2
a little
tired
3
4
getting more
tired
5
6
tired
7
really
tired
8
9
very, very
tired
10

Vol. 29, No. 6 Supplement Official Journal of the American College of Sports Medicine **S91**

The Seven-Day Recall

PAR#: 1 2 3 4 5 6 7 Participant________________________________

Interviewer________________Today is__________________ Today's Date_____

1. Were you employed in the last seven days? **0. No** (Skip to **Q#4**) 1. **Yes**
2. How many days of the last seven did you work? ____ days
3. How many total hours did you work in the last seven days? ____ hours last week
4. What two days do you consider your weekend days? ________ ________ (mark days below with a squiggle)

WORKSHEET **DAYS**

	SLEEP	**1 __**	**2 __**	**3 __**	**4 __**	**5 __**	**6 __**	**7 __**
MORNING	**Moderate**							
	Hard							
	Very Hard							
AFTERNOON	**Moderate**							
	Hard							
	Very Hard							
EVENING	**Moderate**							
	Hard							
	Very Hard							
Total Min Per Day	**Strength:** **Flexibility:**	_____	_____	_____	_____	_____	_____	_____

4a. Compared to your physical activity over the past three months, was last week's physical activity more, less or about the same?
1. More
2. Less
3. About the same

Worksheet Key:	**Rounding:** 10-22 min.=.25	1:08-1:22 hr/min.=1.25
An asterisk (*) denotes a work-related activity.	23-37 min.=.50	
A squiggly line through a column (day) denotes a weekend day.	38-52 min.=.75	
	53-1:07 hr/min. =1.0	

INTERVIEWER:

Please answer questions below and note any comments on interview.

5. Were there any problems with the 7-Day PAR interview? 0. No
   1. Yes (If yes, please explain.)

   Explain any problems you had with this interview:

   ____

   ____

   ____

   ____

6. Do you think this was a valid 7-Day PAR interview? 0. No
   1. Yes

7. Please list below any activities reported by the subject which you don't know how to classify.

   ____

   ____

   ____

   ____

8. Please provide any other comments you may have in the space below.

   ____

   ____

   ____

   ____

INSTRUCTIONS

Comprehensive instructions are included below in the Project GRAD Manual, courtesy of Dr. James F. Sallis.

Project GRAD Seven-Day Physical Activity Recall Interviewer's Manual

Contributors
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James Sallis, and Karen Calfas
San Diego State University
San Diego, CA

HISTORICAL BACKGROUND

The Seven-Day Physical Activity Recall (PAR) interview was originally developed for use in the Stanford Five-City Project in the early 1980s (11). Because it is a general-purpose measure of physical activity that has been evaluated many times over the years, it is widely used in epidemiologic, clinical, and behavior change studies.

The methodology has evolved a great deal over the years, because of accumulated experience, changing needs of studies, and changing concepts of physical activity and health. That process of evolution continues. In the Stanford

The Borg Scale

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Appendix N. Data for Child Participants

Subject ID	Group	Reaction Time Pre-Intervention (ms)	Reaction Time Post-Intervention (ms)	P3a Amplitude (Fz) Pre Intervention (µV)	P3a Amplitude (Fz) Post Intervention(µV)	P3b Amplitude (Pz) Pre Intervention(µV)	P3b Amplitude (Pz) Post Intervention (µV)	VO2max(ml/min/kg)	D2 (Percentile)	3DPAR (Average Daily METs)	MABC (Percentile)
C01	0	363.2	368.9	0.2	-1.7	13.9	7.6	46.4	94.5	49.2	63
C02	1	400.7	356.3	2.6	4.8	15.7	14.7	44.9	99.9	73.0	75
C03	1	460.9	493.0	-6.0	-6.4	11.6	12.0	47.1	90.3	77.5	63
C05	1	556.5	640.2	1.1	-9.3	8.3	19.3	44.9	50.0	57.0	63
C06	0	733.3	732.5	12.4	5.9	10.0	11.9	43.3	81.6	80.0	63
C07	0	673.7	759.1	-2.6	2.4	12.4	10.7	43.9	75.8	71.5	37
C08	1	644.3	640.8	1.8	-3.7	5.1	5.1	50.6	46.0	58.5	25
C10	0	598.1	587.6	9.2	2.6	12.0	9.2	41.6	69.2	73.0	37
C11	1	424.7	350.0	6.4	5.5	5.3	9.2	NA	86.4	54.7	NA
C13	1	471.5	518.2	1.1	4.5	4.7	3.9	47.0	NA	119.2	50
C14	1	421.1	394.9	1.1	2.4	12.1	16.3	41.0	99.2	73.8	75
C15	0	410.6	529.3	3.9	-2.5	3.3	4.0	41.6	98.2	65.6	25
C16	0	385.1	372.5	-2.3	1.9	21.7	20.7	NA	84.1	82.0	63

*Group: 0-Rest, 1-Exercise

*Reaction Time: The reaction times listed above represent the average reaction time by subject across the pre-and post-intervention sessions to only the target auditory tones.

Appendix O. Data for Adult Participants

Subject ID	Group	Reaction Time Pre-Intervention (ms)	Reaction Time Post-Intervention (ms)	P3a Amplitude (Fz) Pre Intervention (µV)	P3a Amplitude (Fz) Post Intervention(µV)	P3b Amplitude (Pz) Pre Intervention(µV)	P3b Amplitude (Pz) Post Intervention (µV)	VO2max(ml/min/kg)	D2 (Percentile)	7DPAR (kcal/day)
A01	1	346.7	313.1	-1.8	-3.9	11.2	14.0	52.5	98.2	678
A04	1	299.1	288.6	-0.3	-5.0	6.6	7.2	51.3	88.5	906
A06	0	300.1	284.1	-0.3	1.6	5.1	10.3	43.4	NA	996
A08	0	385.1	434.9	-2.5	-0.2	1.1	1.5	46.0	99.8	1452
A09	1	289.9	282.8	0.1	-0.2	9.2	0.5	51.5	NA	1072
A10	0	538.2	595.0	2.0	-3.2	10.7	6.5	54.4	NA	1284
A11	1	414.6	397.6	-5.9	-6.6	3.8	1.6	60.1	99.9	795
A12	1	389.4	352.2	0.6	-0.1	-1.5	1.1	62.2	98.2	1509
A13	0	341.3	328.5	-5.2	-4.6	2.6	-0.3	54.1	75.8	1032
A14	0	472.3	440.6	-2.5	-4.4	3.2	4.4	60.4	97.1	879
A15	0	376.6	346.2	-5.4	-3.2	2.0	1.3	47.9	98.9	1048
A17	0	402.1	431.9	3.9	2.8	3.1	4.0	56.2	99.7	617
A18	1	427.0	373.3	2.0	3.3	3.6	6.6	53.4	97.1	1171

*Group: 0-Rest, 1-Exercise

*Reaction Time: The reaction times listed above represent the average reaction time by subject across the pre-and post-intervention sessions to only the target auditory tones.

Reaction Time Percent Difference (RT_{DIFF}) Across Blocks in Adults

Subject ID	Group	(RT_{DIFF}) Block 1	(RT_{DIFF}) Block 2	(RT_{DIFF}) Block 3
A01	1	-8.23	-7.95	-12.86
A04	1	2.48	-11.75	-1.53
A06	0	-9.01	-2.87	-4.58
A08	0	3.37	21.70	10.63
A09	1	-12.15	6.22	-1.66
A10	0	7.90	21.68	2.05
A11	1	-2.25	-3.26	-6.77
A12	1	-11.28	-10.06	-7.29
A13	0	-8.35	4.17	-7.07
A14	0	-10.47	0.71	-10.44
A15	0	-3.50	-8.90	-11.79
A17	0	14.17	2.53	4.87
A18	1	-16.12	-15.29	-6.26

*__Group:__ 0-Rest, 1-Exercise, A: Adults

***Blocks:** Block 1, Block 2 and Block 3 are defined as the first 20 reaction times (to target auditory tone) post-intervention, the second 20 reactions time (to target auditory tone) post-intervention, and the final 20 reaction times (to target auditory tone) post-intervention, respectively.

***RT_{DIFF}** = (post-intervention RT (by block) - pre-intervention RT average)/pre-intervention RT average) X 100.

Reaction Time Percent Difference (RT_{DIFF}) Across Blocks in Children

Subject ID	Group	(RT_{DIFF}) Block 1	(RT_{DIFF}) Block 2	(RT_{DIFF}) Block 3
C01	0	-9.28	11.39	2.59
C02	1	-18.47	-9.01	-5.78
C03	1	-1.34	13.55	8.72
C05	1	-4.27	26.75	23.09
C06	0	-13.68	-1.02	15.49
C07	0	10.97	16.92	10.11
C08	1	-13.96	3.33	9.11
C10	0	-8.12	-0.43	4.82
C11	1	-13.89	-17.01	-21.91
C13	1	-4.02	7.11	27.82
C14	1	-9.82	-1.34	-7.61
C15	0	16.77	48.62	22.56
C16	0	2.64	-6.27	3.63

***Group:** 0-Rest, 1-Exercise, C: Child

***Blocks:** Block 1, Block 2 and Block 3 are defined as the first 20 reaction times (to target auditory tone) post-intervention, the second 20 reactions time (to target auditory tone) post-intervention, and the final 20 reaction times (to target auditory tone) post-intervention, respectively.

***RT_{DIFF}** = (post-intervention RT (by block) - pre-intervention RT average)/pre-intervention RT average) X 100.

References

Abernethy, B., Maxwell, J. P., Masters, R.S.W., van der Kamp, J., & Jackson, R. C. (2007). Attentional processes in skill learning and expert performance. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed.) (pp. 245-263). Hoboken, NJ: Wiley.

Allison, B. Z., & Polich, J. (2008). Workload assessment of computer gaming using a single-stimulus event-related potential paradigm. *Biological Psychology, 77,* 277-283.

Argiropoulou, E.C., Michalopoulou, M., Aggeloussis, N., & Avgerinos, A. (2004). Validity and reliability of physical activity measures in Greek high school age children. *Journal of Sports Science and Medicine, 3,* 147-159.

Ardoy, D. N., Fernández-Rodríguez, J. M., Jiménez-Pavón, D., Castillo, R., Ruiz, J. R. & Ortega, F. B. (2014). A Physical education trial improves adolescents' cognitive performance and academic achievement: The EDUFIT study. *Scandinavian Journal of Medicine & Science in Sports, 24,* 52-61.

Balke, B., Ware, R.W. (1959). An experimental study of physical fitness of air force personnel. *U.S. Armed Forces Medical Journal, 10*, 675-688.

Bartgis, J., Lilly, A.R., & Thomas, D.G. (2003). Event-related potential and behavioral measures of attention in 5-,7-, and 9-year-olds. *The Journal of General Psychology, 130,* 311-335.

Bixby, W.R., Spalding, T.W., Haufler, A.J., Deeny, S.P., Mahlow, P.T., Zimmerman, J.B., & Hatfield, B.D. (2007). The unique relation of physical activity to executive function in older men and women. *Medicine and Science in Sports and Exercise, 39,* 1408-1416.

Blair, S.N., Haskell, W.L., Ho, P., Paffenbarger, R.S., Vranizan, K.M., Farquhar, J.W., & Wood, P.D. (1985). Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. *American Journal of Epidemiology, 122*, 794-804.

Booth, J.N., Tomporowski, P.D., Boyle, J.M., Ness, A.R., Joinson, C., Leary, S.D., & Reilly, J.J. (2013). Associations between executive attention and objectively measured physical activity in adolescence: Findings from ALSPAC, a UK cohort. *Mental Health and Physical Activity, 6,* 212-219.

Borg, GA. (1982). Psychophysical basis of perceived exertion. *Medicine and Science in Sports and Exercise, 14,* 377-381.

Bouchard, C., Tremblay, A., Leblanc, C., Lortie, G., Savard, R., & Theriault, G. (1983). A method to assess energy expenditure in children and adults. *American Journal of Clinical Nutrition, 37*, 461-467.

Brickenkamp, R., & Zillmer, E. (2002). *D2 test of attention.* Cambridge, MA: Hogrefe and Huber.

Brisswalter, J., Collardeau, M., & René, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine*, *32,* 555-566.

Buck, S.M., Hillman, C.H., & Castelli, D.M. (2008). The relation of aerobic fitness to stroop task performance in preadolescent children. *Medicine and Science in Sports and Exercise*, *40*, 166-172.

Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*, 219-223.

Casey, B. J., Durston, S., & Fossella, J. A. (2001). Evidence for a mechanistic model of cognitive control. *Clinical Neuroscience Research, 1*, 267-282.

Casey, B.J., Tottenham, N., Liston, C., & Durston, S. (2005). Imaging the developing brain: What have we learned about cognitive development? *TRENDS in Cognitive Science, 9,* 103-110.

Castelli, D.M., Hillman, C.H., Buck, S.M., & Erwin, H.E. (2007). Physical fitness and academic achievement in third- and fifth- grade students. *Journal of Sport and Exercise Psychology, 29*, 239-252.

Chaddock, L., Pontifex, M.B., Hillman, C.H., & Kramer, A.F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neurophysiological Society, 17,* 1-11.

Chodzko-Zaiko, W.J., & Moore, K.A. (1994). Physical fitness in cognitive function and aging. *Exercise and Sports Sciences Review*, *22*, 195-220.

Chow, S., Chan, L.L., Chan, C.P.S., & Lau, C.H.Y. (2002). Reliability of the experimental version of the movement-abc. *British Journal of Therapy and Rehab, 9,* 404-407.

Coe, D.P., Pivarnik, J.M., Womack, C.J., Reeves, M.J., & Malina, R.M. (2006). Effect of physical education and activity levels on academic achievement in children. *Medicine and Science in Sports and Exercise, 38,* 1515-1519.

Colcombe, S.J., Kramer, A.F., Erickson, K.I., Scalf, P., McAuley, E., Cohen, N.J.,…Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity and aging. *Proceedings of the National Academy of Science, 101,* 3316-3321.

Cullbertson, W.C., & Zillmer, E.A. (1998). The tower of london drexel univeristy: A standardized approach to assessing executive functioning in children. *Archives of*

Clinical Neuropsychology, 3, 285-302.

Davis, C.L., Tomporowski, P.D., McDowell, J.E., Austin, B.P., Miller, P.H., Yana, N.E.,…Naglieri, J.A. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Healthy Psychology, 30,* 91-98.

Donchin, E. (1981). Surprise!… Surprise?. *Psychophysiology*, *18*, 493–513.

Drollette, E.S., Shishido, T., Potifex, M.B., & Hillman, C.H. (2012). Maintenance of cognitive control during and after walking in preadolescent children. *Medicine and Science in Sports and Exercise, 44,* 2017-2024.

Durston, S., Thomas, K. M., Yang, Y., Uluğ, A. M., Zimmerman, R. D., & Casey, B. J. (2002). A neural basis for the development of inhibitory control. *Developmental Science,5*, 9-16.

Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of involuntary attention to acourstic novelty and change. *Journal of Cognitive Neuroscience, 10,* 590-604.

Etnier, J.L., Nowell, P.M., Landers, D.M., & Sibley, B.A. (2006) A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52,* 119-130.

Granon, S., Passetti, F., Thomas, K.L., Dalley, J.W., Everitt, B.J., & Robbins, T.W. (2000). Enhanced and impaired attentional performance after infusion of D1 dopaminergic receptor agents into rat prefrontal cortex. *Journal of Neuroscience, 20,* 1208-1215.

Hattori, S., Naoi, M., & Nishino, H. (1994). Striatal dopamine turnover during treadmill running in the rat: Relation to the speed of running. *Brain Research Bulletin, 35,* 41-

49.

Henderson, S.E., & Sugden, D.A. (2007). *Movement assesment battery for children* (2nd ed.). London: The Psychological Corporation.

Hill, A.V., & Lupton, H. (1924). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly Journal of Medicine, 16,* 135-171.

Hillman, C.H., Belopolsky, A.V., Snook, E.M., Kramer, A.F., & McAuley, E. (2004). Physical activity and executive control: Implications for increased cognitive health during older adulthood. *Research Quarterly for Exercise and Sport, 75,* 176-185.

Hillman, C.H., Buck, S.M., Themanson, J.R., Pontifex, M.B., & Castelli, D.M. (2009a). Aerobic fitness and cognitive development: Event-related brain potential and task performance indices of executive control in preadolescent children. *Developmental Psychology, 45,* 114-129.

Hillman, C.H., Castelli, D.M., & Buck, S.M. (2005). Aerobic fitness and neurocognitive function in healthy preadolescent children. *Medicine and Science in Sports and Exercise, 37,* 1967-1974.

Hillman, C.H., Kamijo, K., & Scudder, M. (2011). A review of chronic and acute physical activity participation on neyroelectruc measure of brain health and cognition during childhood. *Preventative Medicine, 52, S21-S28.*

Hillman, C.H., Ponitfex, M.B., Motl, R.W., O'Leary, K.C., Johnson, C.R., Scudder, M.R., … Castelli, D.M. (2012). From ERPs to academics. *Developmental Cognitive Nueroscience, 2S,* S90-S98.

Hillman, C.H., Pontifex, M.B., Raine, L.B., Castelli, D.M., Hall, E.E., & Kramer, A.F. (2009b). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*, 1044-1054.

Hillman, C.H., Snook, E.M., & Jerome, G.J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology, 48*, 307-314.

Hillman, C.H., Weiss, E.P., Hagberg, J.A., & Hatfield, B.D. (2002). The relationship of age and cardiovascular fitness to cognitive and motor processes. *Psychophysiology, 39*, 303-312.

Howley, E.T., Bassett, D.R., & Welch, H.G. (1995). Criteria for maximal oxygen uptake: Review and commentary. *Medicine and Science in Sports and Exercise, 27,* 1292-1301.

Jasper, H.H. (1958). The ten-twenty electrode system of the international federation. *Clinical Neurophysiology*, *10*, 370-375.

Johnstone, S.J., Barry, R.J, Anderson, J.W., & Coyle, S.F. (1996). Age-related changes in child and adolescent morphology, amplitude and latency to stanard and target stimuli in an auditory oddball task. *International Journal of Psychophysiology*, *24,* 223-238.

Katz, D.L., Cushman, D., Reynolds, J., Njike, V., Treu, J.A., Walker, J., …Katz, C. (2010). Putting physical activity where it fits in the school day: Preliminary results of the ABC (activity bursts in the classroom) for fitness program. *Preventing Chronic Disease*, *7,* 1-10.

Knight, R.T. (1984). Decreased response to novel stimuli after prefrontal lesions in man. *Electroencephalography and Clinical Neurophysiology*, *59,* 9-20.

Konrad, K., Neufang, S., Thiel, C. M., Specht, K., Hanisch, C., Fan, J., … Fink, G.R. (2005).

Development of attentional networks: An fMRI study with children and adults. *NeuroImage, 28*, 429-439.

Määttä, S., Pääkkönen, A., Saavalainen, P., & Partanen, J. (2005). Selective attention event-related potential effects from auditory novel stimuli in children and adults. *Clinical Neurophysiology, 116*, 129-141.

Meeusen, R., Piacentini, M. F., & de Meirleir, K. (2001). Brain microdialysis in exercise research. *Sports Medicine, 31*, 965-983.

Pashler, H., & Johnston, J.C. (1998). Attentional limitations in dual-task performance. In H. Pashler (Ed.), *Attention* (pp. 155-189). East Sussex, UK: Psychology Press.

Pivik, R. T., Broughton, R. J., Coppola, R., Davidson, R. J., Fox, N., & Nuwer, M. R. (1993). Guidelines for quantitative electroencephalography in research contexts. *Psychophysiology, 30*, 547.

Poceta, S.J., Houser, M., & Polich, J. (2006). Event-related potentials in restless legs syndrome and Parkinson's diease. *Sleep, 28,* A274.

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*, 2128-2148.

Pontifex, M.B. Hillman, C.H., & Polich, J. (2009). Age, physical fitness, and attention: P3a and P3b. *Psychophysiology, 46*, 379-387.

Pontifex, M.B., Raine, L.B., Johnson, C.R., Chaddock, L., Voss, M.W., Cohen, N.J., …Hillman, C.H. (2010). Cardiorespiratory fitness and the flexible modluation of cognitive control in preadolescent children. *Journal of Cognitive Neuroscience, 6,* 1332-1345.

Pontifex, M.B., Scudder, M.R., Drollette, E.S., & Hillman, C.H. (2012). Fit and vigilant: The relationship between poorer aerobic fitness and failure in sustained attention during preadolescence. *Nueropsychology*, *26,* 407-413.

Posner, M.I., & Fan, J. (2008). Attention as an organ system. In J.R. Pomerantz (Ed.) *Topics in Integrative Neuroscience: From Cells to Cognition* (pp. 31-61). Cambridge, UK: Cambridge.

Rapoport, J. L., & Gogtay, N. (2008). Brain neuroplasticity in healthy, hyperactive and psychotic children: Insights from neuroimaging. *Neuropsychopharmacology, 33*, 181-197.

Robertson, R.J., Goss, F.L., Boer, N., Gallagher, J.D., Thompkins, T., Bufalino, K.,…Williams, A. (2001). OMNI scale percieved exertion at ventilatory breakpoint in children: Response normalized. *Medicine and Science in Sports and Exercise*, *33,* 1946-1952.

Rueda, M.R., Fan, J., McCandliss, B.D., Halparin, J.D., Gruber, D.B., Lercari, L.P., & Posner, M.I. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*, 1029-1040.

Sallis, J.F., Haskell, W.L., & Wood, P.D. (1985). Physical activity assessment methodology in the five city project. *American Journal of Epidemiology*, *121*, 91-106.

Sallis, J.F., Patterson, T.L., Buono, M.J., & Nader, P.R. (1988). Relation of cardiovascular fitness and physical activity to cardiovascular disease risk factors in children and adults. *American Journal of Epidemiology*, *127*, 933-941.

Scudder, M.R., Drollette, E.S., Pontifex, M.B., & Hillman, C.H. (2012). Neuroelectric indices of goal maintenance following a single bout of physical activity. *Biological Psychology*, *59,* 528-531.

Strayer, D.L., & Drews, F.A. (2007). What is attention and why is it important? In F. Durso (Ed.), *Handbook of Applied Cognition* (2nd ed.) (pp. 29-54). Hoboken, NJ: Wiley.

Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114-124.

Tanner, J.M. (1962). *Growth at adolescence* (2nd ed.). Oxford: Blackwell.

Taras, H. (2005). Physical activity and student performance at school. *Journal of School Health, 75*, 214-218.

Themanson, J.R., & Hillman, C.H. (2006). Cardiorespiratory fitness and acute aerobic exercise effects on neuroelectric and behavioral measures of action monitoring. *Neuroscience, 141*, 757-767.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112*, 297-324.

Tomporowski, P.D., Davis, C.L., Lambourne, K., Gregoski, M., & Tkacz, J. (2008a). Task switching in overweight children: Effects of acute exercise and age. *Journal of Sport and Exercise Psychology, 30,* 497-511.

Tomporowski, P.D., Davis, C.L., Miller, P.H., & Naglieri, J.A. (2008b). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*, 111-131.

Ullsperger, P., Freude, G., & Erdmann, U. (2001). Auditory probe sensitivity to mental workload changes- an event-related potential study. *International Journal of Psychophysiology, 40*, 201-209.

West, R.L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, *120*, 272-292.

Whaley, M.H., Brubaker, P.H., & Otto, R.M. (Eds.). 2006. *ACSM's guidelines for exercise testing and prescription* (7th ed.). Baltimore, MD: Lippincott.

Wickens, C.D. (1991). Processing resources in attention. In D.L. Damos (Ed.), *Multiple Task Performance* (pp. 3-34). Bristol, PA: Taylor.