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Effects of Aerobic Physical Activity on Student Engagement: Can 20 Minutes of Moderate to Vigorous Physical Activity Affect On-task Classroom Behavior Immediately Following?

A Dissertation Presented

by

BROOKE M. DEWITT

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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University of Massachusetts Amherst
College of Education
School Psychology
Effects of Aerobic Physical Activity on Student Engagement: Can 20 Minutes of Moderate to Vigorous Physical Activity Affect On-task Classroom Behavior Immediately Following?

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ABSTRACT

EFFECTS OF AEROBIC PHYSICAL ACTIVITY ON STUDENT ENGAGEMENT: CAN 20 MINUTES OF MODERATE TO VIGOROUS PHYSICAL ACTIVITY AFFECT ON-TASK CLASSROOM BEHAVIOR IMMEDIATELY FOLLOWING

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Converging evidence suggests moderate to vigorous physical activity (MVPA) has positive effects on cognitive performance. Most specifically bouts of MVPA have been shown to significantly improve cognitive efficiency and response inhibition in children. While these results are consistently observed in laboratory settings, the applications in applied settings remain unclear. This study examined the effects of high intensity exercise, low intensity exercise, and sedentary behavior on response inhibition and classroom on-task behavior following using a repeated measure crossover design. Two one-way ANCOVAs, using number of steps during activity as the covariate, were used to determine if there were any changes to the outcome measures. Results indicate that high intensity activity had a significant effect on successful inhibition of response \( \{F (3, 129) = 3.746, p = 0.013\} \) compared to low intensity and sedentary activity; there were no significant differences in classroom behavior as a result of the activity type \( \{F (3, 147) = 2.544, p = 0.058\} \). These results provide more evidence that 20 min of MVPA has
positive effects on a child’s ability to withhold a behavioral impulse, or respond to a “stop” signal.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xii</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION, BACKGROUND, AND PURPOSE</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Statement of the Problem</td>
<td>10</td>
</tr>
<tr>
<td>1.3 Purpose of Study</td>
<td>11</td>
</tr>
<tr>
<td>2. REVIEW OF THEORETICAL AND EMPIRICAL LITERATURE</td>
<td>14</td>
</tr>
<tr>
<td>2.1 Role of Exercise on Brain Development</td>
<td>14</td>
</tr>
<tr>
<td>2.1.1 Functional changes in the brain associated with exercise</td>
<td>14</td>
</tr>
<tr>
<td>2.1.1.1 Functional changes observed in adults</td>
<td>15</td>
</tr>
<tr>
<td>2.1.1.2 Functional changes observed in children</td>
<td>22</td>
</tr>
<tr>
<td>2.1.2 Structural changes in the brain associated with exercise</td>
<td>27</td>
</tr>
<tr>
<td>2.1.2.1 Structural changes observed in adults</td>
<td>28</td>
</tr>
<tr>
<td>2.1.2.2 Structural changes observed in children</td>
<td>31</td>
</tr>
<tr>
<td>2.1.3 Mechanisms for change</td>
<td>33</td>
</tr>
<tr>
<td>2.1.3.1 Cerebral blood flow</td>
<td>34</td>
</tr>
<tr>
<td>2.1.3.2 Regulation of neurotransmitters</td>
<td>37</td>
</tr>
<tr>
<td>2.1.3.3 Regulation of neurotrophins</td>
<td>39</td>
</tr>
<tr>
<td>2.1.4 Modifying factors</td>
<td>42</td>
</tr>
<tr>
<td>2.2 Role of Exercise in Learning and Schools</td>
<td>43</td>
</tr>
<tr>
<td>2.2.1 Research in schools in the United States</td>
<td>45</td>
</tr>
</tbody>
</table>
2.2.1.1 Program evaluations........................................................................45
2.2.1.2 Randomized controlled studies in schools.................................48

2.2.2 International research in school settings.........................................49

2.2.2.1 Program evaluations........................................................................49
2.2.2.2 Randomized controlled studies in schools.................................51

2.3 Limitations to Research ........................................................................55

3. METHODS ..................................................................................................57

3.1 Design ....................................................................................................57
3.2 Setting ....................................................................................................57
3.3 Participants .............................................................................................58
3.4 Measures ................................................................................................59

3.4.1 Process measure: Accelerometer ....................................................59
3.4.2 Outcome measures ............................................................................60

3.4.2.1 Response inhibition: Go/No-Go ..................................................60
3.4.2.2 Student engagement: BOSS.........................................................61

3.5 Procedure ................................................................................................62

3.5.1 Condition 1: High intensity activity ................................................62
3.5.2 Condition 2: Low intensity non-aerobic activity ...............................63
3.5.3 Condition 3: Sedentary activity.........................................................63

3.6 Data Analysis Plan..................................................................................64

4. RESULTS ..................................................................................................66

4.1 Descriptive Statistics ............................................................................66
4.2 Outlier Removal .....................................................................................67
4.3 Analyses of Underlying Assumptions .................................................67
4.4 Findings ................................................................................................69

5. DISCUSSION .............................................................................................72

5.1 Summary of Findings ............................................................................72
5.2 Limitations and Future Directions ......................................................81
5.3 Implications for Practice .....................................................................86
APPENDICES

A. CONSENT AND RECRUITMENT MATERIALS ..................................................... 88
B. EXAMPLE OF COUNTERBALANCED SCHEDULE ........................................... 91
C. OUTCOME MEASURE TOOL ........................................................................ 92
D. HISTOGRAMS AND PLOTS OF DATA .......................................................... 93
E. INDIVIDUAL STUDENT DATA ......................................................................... 101

REFERENCES ..................................................................................................... 109
LIST OF TABLES

Table | Page
1. Descriptive Statistics for Successful Inhibition (percent of total trials) ............. 70
2. Descriptive Statistics for Off-Task Classroom Behavior (percent of intervals observed) ........................................................................................................... 70
3. Descriptive Statistics for Step Counts ................................................................................................................................. 70
4. Analysis of Co-Variance for Successful Inhibition ......................................................... 71
5. Analysis of Co-Variance for Off-Task Classroom Behavior ....................................... 71
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Histogram and Q-Q plots of Successful Inhibition and Off-Task data</td>
<td>93</td>
</tr>
<tr>
<td>2.</td>
<td>Histogram and Q-Q plots by Activity Level</td>
<td>94</td>
</tr>
<tr>
<td>3.</td>
<td>Outcomes, Activity, and Covariate of Successful Inhibition (No-Go)</td>
<td>98</td>
</tr>
<tr>
<td>4.</td>
<td>Outcomes, Activity, and Covariate of Off-Task Classroom Behavior</td>
<td>100</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION, BACKGROUND, AND PURPOSE

1.1 Introduction

There is a great deal of converging evidence to suggest that physical activity is a critical component of healthy neurological development. Current evidence suggests physical activity, specifically moderate to vigorous physical activity (MVPA), has positive effects on academic achievement, cognitive functioning, and the physiological processes that underlie them. While these relationships are well established in clinical settings, the benefits of physical activity in applied settings are not as recognized. As such, this study looks to extend the applied research of physical activity in public schools by looking at the relationship between physical activity and student engagement.

Research in 7-12-year-old children shows that high-fit children have better performance on response inhibition tasks (Buck, Hillman & Castelli, 2008), math and reading achievement on summative assessments (Castelli, Hillman, Buck & Erwin, 2007), greater hippocampal volume (Chaddock et al., 2010), greater P3 amplitude (Hillman, Castelli, & Buck, 2005; Hillman, Buck, Themanson, Pontifex & Castelli, 2009a; Pontifex et al., 2011), reduced P3 latency (Pontifex et al., 2011), reduced ERN amplitude (Hillman et al., 2009a; Pontifex et al., 2011), faster reaction time (Hillman et al., 2005), and better response accuracy (Hillman et al., 2009a) compared to lower-fit children. Across these findings, higher-fit children maintained task-performance and had greater accuracy in conditions requiring greater mental effort (incongruent or incompatible conditions), leading researchers to conclude that higher-fit children have greater allocation of attentional resources and decreased activation of cognitive
monitoring systems (for a review see Hillman, Kamijo, Scudder, 2011). By contrast, lower-fit children allocate more resources to action monitoring and fewer resources to stimulus engagement (Hillman et al., 2011). Under congruent conditions, this cognitive strategy is effective; however, when stimulus demands increase, lower-fit students have decreased abilities to control cognitive attentional energy, resulting in decreased performance.

These studies, which took place in laboratory settings, determined high fitness through maximal oxygen consumption (VO2max) and OMNI scale for perceived exertion on a treadmill task (Hillman, Pontifex, Raine, Castelli, Hall & Kramer, 2009b) and often used modified Flanker tasks as the outcome measure. This line of research is largely correlational, as higher-fit children likely have different environmental experiences compared to low-fit children, introducing the possibility of other confounding variables contributing to the differences in dependent variables. Regardless, results to date provide emerging evidence that suggests a positive relationship between physical fitness and neurological efficiency.

Specifically, the effects of physical activity on the brain show a strong trend toward physical activity improving response inhibition and reaction time (Best, 2012; Ellemberg & St. Louis Dêschenes, 2010; Hillman et al., 2009b; Tomporowski et al. 2008). While questions still remain about what type of physical activity provokes the most benefits for developing minds, exercise has a greater benefit on more complicated tasks, including interference inhibition (Berwid & Halperin, 2012). The strongest evidence points to exercise promoting positive changes to response inhibition in children (Erikson, Hillman, Kramer, 2015).
Response inhibition is currently defined as encompassing three separate cognitive tasks: interference inhibition, action withholding, and stopping of prepotent motor responses (Barkley, 1997; Sebastin et al., 2013). Self-regulation alters the probability of an individual’s response to an event and the subsequent consequences (Barkley, 1997), with effective self-regulation leading to more successful outcomes. These cognitive tasks interact with one another, making it difficult to parse apart which construct is most benefitted through physical activity.

Response inhibition is one component of executive functioning, and the benefits of exercise and physical activity are not isolated to response inhibition. In addition, acute bouts of physical activity may improve memory recall (Pesce, Crova, Cereatti, Casella, & Belluci, 2009), concentration (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribiero, & Tidow, 2008), arousal (Hillman et al., 2009b), academic performance (Davis et al., 2011), and cognitive measures (Hill, Williams, Aucott, Thomson, Mon-Williams, 2011). Physical activity has been shown to affect both the structure and the function of brains in adults and children, with the most conserved benefits to executive functioning, cerebral communication, memory performance, and protections against cognitive decline.

The type of physical activity may affect the underlying neurological process initiated by the activity, with aerobic activity the most well studied activity. Barenberg, Berse and Dutke (2011) describe three possible physiological pathways for how physical activity provides benefits to executive functions: via cerebral blood flow; neurotrophin release, particularly in the hippocampus; and/or by up-regulation of neurotransmitters, including norepinephrine and dopamine. Barenberg et al. (2011) point out there is
evidence to support all three physiological pathways, and the mechanism linking physical activity and executive functions is not yet fully understood. Hamilton and Rhodes (2015) point out that physical activity and exercise also have positive effects on hormones, may reduce oxidative stress, and alter levels of apoptosis in the brain.

Exercise and physical activity likely promote cascades of reactions and processes (Hamilton & Rhodes, 2015). The responses are primarily due to neurotransmitters and neurotrophins. Dopamine, norepinephrine, and serotonin have been shown to increase following exercise in both rodents and humans (Winter et al., 2007). These neurotransmitters then signal many reactions throughout the brain, leading to changes in focus, attention, behavioral flexibility, and decision-making (Robbins & Arnsten, 2009; Floresco & Magyar, 2006). Additionally, the release of neurotrophins modulates brain plasticity and repair (Barenberg et al., 2011). Evidence from animal studies shows that brain-derived neurotrophic factor (BDNF) is released in the hippocampus following exercise, leading to neurogenesis (for a review see Hamilton & Rhodes, 2015).

Emerging research on the role of physical activity on psychological disorders is promising. Pontifex, Saliba, Raine, Picchietti, and Hillman (2013) found that a single bout of acute 20 min exercise has potential for a “nonpharmacological tool for treatment of childhood ADHD” (p.547), although this hypothesis needs more research to support it (Archer & Kostrzewa, 2012; Berwid & Halperin, 2012). Pontifex et al. (2013) looked at students diagnosed with ADHD and matched controls; both showed greater response accuracy and stimulus-related processing, but students with ADHD also showed enhancements in regulatory processes. Pontifex et al. (2013) observed enhancement of inhibitory control and processing speed in students with ADHD.
In addition, Nicholson, Kehle, Bray, and Heest (2011) observed significant effect sizes on academic engagement for students on the autism spectrum following physical activity. Post (2010) highlights the potential role of BDNF in affective disorders, highlighting that physical activity and exercise play a positive role in offsetting some symptoms of common childhood psychological disorders. It is likely that the positive effects of physical activity across psychopathology are related to its positive effects on executive functions.

Different type of physical activity may trigger different neurological pathways, leading to different neurological changes (Voelcker-Rehage & Niemann, 2013). In addition, the level of engagement may promote differential neurological effects. For example, Fischer (2016) points out that access to a running wheel for rodents improves the enrichment of the environment. Fischer (2016) highlights that enriched environments include physical and “cognitive” exercise, often leading to positive neurological outcomes, including neurogenesis and neurotrophin release. It is likely that a combination of physical activity and cognitive engagement is important for the full beneficial effects of exercise.

There is emerging evidence that the level of cognitive engagement in the physical activity tasks may play an important role in humans as well. Budde et al. (2008) looked at 10 minutes of acute physical activity on the d2 test of attention and a letter cancellation test; the researchers observed significant differences in performance following coordinative exercise compared to a normal sports lesson in adolescents (13-16 years). Both groups had improved measures of performance in concentration with 10 minutes of physical activity, with the coordinative exercise group outperforming the normal sports
lesson group, leading researchers to conclude the type of physical activity matters (Budde et al., 2008). Budde et al. (2008) hypothesize coordinative exercise leads to increased activation of the cerebellum, thus leading to greater changes in tasks of concentration.

Extending this line of research, Pesce et al (2009) looked at the effects of aerobic activity or team games on memory recall in 11-12-year-olds. Both physical activity conditions increased delayed recall on recency items compared to no activity, but the group games also significantly increased immediate recall of both primacy and recency items compared to no activity. The authors conclude the effects of physical activity are different depending on whether recall is immediate or delayed. Additionally, Pesce et al (2009) hypothesized that team games increased cognitive activation and arousal, leading to increases in word retrieval.

Best (2012) further explored the role of cognitive engagement in physical activity on beneficial effects of executive functioning. Using a 2x2 within-subject design, Best (2012) compared tasks of low and high cognitive engagement and low and high physical activity on executive functioning in 6-10-year-olds. While Best (2012) observed significant effects of physical activity, cognitive engagement had no effect on task performance. Physical activity enhanced incongruent reaction time distribution; after a bout of high physical activity, students performed almost as well on incongruent tasks as congruent tasks, whereas after low physical activity, students had longer reaction time for incongruent tasks (Best, 2012). Best (2012) concludes that physical activity reduces the effect of distracting stimuli and allows them to increase efficiency in goal-directed responses.
While there are still unanswered questions about cognitive engagement during physical activity, evidence suggests that physical activity can promote positive changes in academic settings following that activity. Physical activity as an intervention has additionally been observed to improve academic achievement, academic behavior, and cognitive skills and attitudes (Rasberry et al., 2011). In a meta-analysis of research looking at exercise and its effect on academic achievement and cognitive functioning in preadolescent children, Tomporowski, Davis, Miller, and Naglieri (2008) found an overall positive effect and did not discover any published article that found a negative associate between exercise and cognitive performance. Studies either show a positive effect or no significant differences, with a dose-response relationship. Rasberry et al. (2011) reviewed 50 unique studies looking at the effects of physical activity on cognitive skills and attitudes, academic behaviors, and academic achievement and found that 50.5% of the studies reported positive effects, 48% reported no difference, and 1.5% reported negative effects. Confounded here, however, is the variability between studies and study conditions (Voelcker-Rehage & Niemann, 2013) and the different measures of cognitive performance and the physical activity condition used across studies.

Executive functioning is a vital component to student success. Rasberry et al (2011) describe academic behaviors as including on-task behavior, organization, planning, attendance, scheduling, and impulse control. Of these, all but attendance are behaviors typically associated with executive functioning (although one could make an argument that executive functions also play a role in attendance). These behaviors are also commonly referred to as behavioral engagement, student engagement, or academic engagement.
Behavioral engagement focuses on behaviors students display that indicate participation in the learning and school environment (Fredricks, Blumenfeld & Paris, 2004). Behavioral engagement includes following rules, attendance, effort, persistence, concentration, attention to a task, asking questions, and responding to the teacher (Finn, Pannazzo, & Voelkl, 1995; Fredricks et al., 2004; Mahatmya, Lohman, Matjasko, & Farb, 2012). Emotional engagement is generally described as students’ affective reactions to school, including relationships with teachers and peers, interest, and level of boredom (Fredricks et al., 2004). Cognitive engagement is highly related to motivation, self-regulation skills, and flexibility in problem solving (Fredricks et al., 2004).

Shapiro (2011) defines “engaged time” as the time students are actively engaged in academic responding. The time spent actively engaged in the learning process is an important predictor of success (Shapiro, 2011). This concept has become a prevalent way of approaching learning; Gladwell (2008) highlighted this in popular culture when he stated that practice, specifically at least 15,000 hours, is a critical factor in an individual’s success.

Student engagement is a complex, multidimensional construct that is affected by a number of factors, including environmental conditions. These factors include effective instruction and curriculum (Christenson et al., 2008; Howel & Nolet, 2003; Shapiro, 2011). Student motivation and interest also play a role in engagement; if a student is interested in a task, they are more likely to be engaged (Eccles & Wigfield, 2002). Because of this complex nature, it has been difficult to see a clear connection between physical activity and academic engagement; however, there is an emerging trend to
support the hypothesis that physical activity and exercise can have a positive effect on engagement.

The connection between student engagement, particularly time spent on task and responding to teacher direction and instruction, and physical activity presents an exciting link between neuroscience and applied settings. While much of the research on physical activity in children to date has taken place in laboratory or after-school settings, researchers have begun to examine these relationships in applied research in schools. For example, Mahar et al. (2006) examined the effects of Energizers, a classroom-based activity where students take 10-minute activity breaks on the on-task classroom behavior of students following an activity break. Results showed the mean percentage of on-task behavior increased by approximately 8%. This exercise program had a significant effect (p<0.017) on on-task classroom behavior directly following the intervention with a moderate effect size (ES=0.60).

Ma, Mare, and Gurd (2014) replicated the Mahar et al. (2006) study using FUNtervals, a brief bout of high-intensity physical activity and measured classroom on-task behavior following the activity. Results of their study found decreases in passive- (ES= 0.31) and motor- (ES= 0.48) off-task behaviors in 4th grade students; and decreases in passive- (ES= 0.74), motor- (ES= 1.076), and verbal- (ES= 0.45) off-task behaviors in 2nd grade students following the intervention compared to non-activity days. Interestingly, Ma, Mare and Gurd (2014) observed the greatest effect with students with the highest rates of off-task behavior on no-activity days.

Pirrie and Lodewyk (2012) found significant improvements in students’ planning following in-school moderate-to-vigorous physical activity, but did not find changes on
other measures of the Cognitive Assessment System (CAS), including attention. Pirrie and Lodewyk (2012) report that planning, as measured by the CAS, is related to behavioral self-regulation. Pirrie and Lodewyk (2012) observed no significant changes on response inhibition as other studies have; the researchers hypothesize this could be due to the length and intensity of their intervention (30 min with more strenuous activities). These results further highlight the variable nature of this field of research and need for more replication.

1.2 Statement of the Problem

Although it appears clear that physical activity promotes improvements in executive functioning, the type of physical activity required for these changes remains uncertain. Pontifex, Hillman, Fernhall, Thompson and Valentini (2009) compared the effects of 30 min of aerobic exercise and resistance training on reaction time and found a significant difference for only the aerobic exercise condition when compared to seated control. Budde et al. (2008) compared coordinative exercise to a normal sports lesson and observed improved performance on an attentional task following the coordinative exercise group despite no differences in heart rate during both groups. Pesce et al. (2009) observed significant difference in physical activity through group activities compared to circuit training. Finally, Best (2012) explored the relationship between cognitive engagement and physical activity and found that only physical activity, and not cognitive engagement, affected performance on a modified flanker task. These seemingly contradictory results call for more evidence to better understand how cognitive engagement and physical activity promote changes in executive functioning in children.
There is evidence to suggest that physical activity promotes pre-activation of the brain and this pre-activation could be contributing to observed improvements in executive functions following interventions. This hypothesis is further supported by observations from Suzuki et al. (2004) who observed neural activation prior to the initiation of physical activity in adults. Therefore, the question of how cognitive engagement and physical activity are linked remains unclear. Are observed differences a component of the cognitive engagement of the activities or a result of physiological changes associated with aerobic activity, such as BDNF and Dopamine release?

Given these questions, the current study looks to extend Best’s (2012) work examining the role of cognitive engagement and physical activity on executive functions, by comparing three types of cognitively engaging conditions where the physical activity is altered. Specifically, this study looks to extend measures of response inhibition, memory, and attention to look at behaviors linked directly to the classroom through direct observation of student behavior. This study will look at both measures of response inhibition and direct observation of classroom behavior as outcome measures.

1.3 Purpose of Study

This body of research, taken together, suggests that physical activity could be a highly beneficial precursor to student engagement and therefore academic outcomes. For example, Holzschneider, Wolbers, Röder and Hötting (2012) observed positive benefits of exercise when followed with cognitive training or, if applied to children in school, instruction. However, this relationship requires more vigorous empirical evidence of support. There remains a great deal of questions to explore focusing on the relationship between physical activity and classroom engagement. First, the relationship between the
type of activity and observed effects remains unclear. Is it the movement and associated physiological changes that lead to observed changes, or are the changes more associated with cognitive engagement through fun activities? Is there an additive effect of physical activity and cognitive engagement on executive functions and other cognitive processes?

In a review article, Barenberg et al. (2011) found that long-term interventions had effects on all types of executive functions while short-term (single bout) interventions differed in the executive functions they benefitted; for example, a single bout of physical activity may be enough to improve inhibition performance (Barenberg et al., 2011). After reviewing intervention studies, Barenberg et al. (2011) conclude that single-bouts of physical activity, or short-term interventions, are an adequate way of exploring the connections between physical activity and executive functioning.

The preponderance of evidence suggests that moderate-to-vigorous physical activity is needed in order to promote neural changes that subsequently lead to behavioral changes. However, more evidence is needed in order to support the hypothesis that moderate-to-vigorous physical activity is the critical factor as opposed to cognitive engagement or movement in general. This study looks to provide more evidence to this area of research.

The multidimensional nature of student engagement (Fredricks et al., 2004) leads to blurred conceptual distinctions, making measurement challenging. Typical measurement includes surveys and questionnaires, teacher ratings, interviews, and observations (Darr, 2012; Fredricks et al., 2004; Fredricks & McCloskey, 2012). Shapiro (2011) created a tool to directly observe and measure students’ engaged time in naturalistic settings—the Behavioral Observations of Students in Schools (BOSS). This
tool was used by Ma et al. (2014) and Mahar et al. (2006); both Ma et al. (2014) and Mahar et al. observed students for 5 minutes per observation period.

This study looks to extend this body of research by focusing on a specific age not well-studied, including a measure of response inhibition, with a direct measure of classroom behavior. To date, most research looks at students above the age of 7 years. Best (2010) included students who were 6 years of age, but this age group is underrepresented in the current body of research. At the same time, this is an age where response inhibition is a key component to academic success.

This study seeks to answer the question: Does 20 minutes of moderate-to-vigorous physical activity significantly change on-task/off-task classroom behavior in the 30 minutes following the activity for students? In addition, this study seeks to add to the growing body of research looking specifically at different types of activity in order to provide evidence to the question whether exercise needs to meet moderate-to-vigorous levels in order to change on-task/ off-task behavior. In doing so, this study seeks to better understand if any physical activity is more effective at changing on-task/off-task behavior than a sedentary, cognitively engaging activity.

Based on a review of the current body of research, it is hypothesized that 20 minutes of moderate-to-vigorous physical activity will have a significant effect on both response inhibition (as measured by the Go/No-Go task) and student engagement (as measured by the BOSS) compared to a sedentary control condition. It is expected that moderate-to-vigorous levels of activity are needed to create changes in performance. Therefore, students’ on-task and off-task behavior will not change within the sedentary group or the activity group that does not reach moderate-to-vigorous intensity.
CHAPTER 2

REVIEW OF THEORETICAL AND EMPIRICAL LITERATURE

2.1 Role of Exercise in Brain Development

Higher-fit children and adults see improved performance on a variety of cognitive tasks compared to lower-fit individuals (Erikson et al. 2015). Physical activity throughout the lifespan is associated with reduced risk of cognitive decline with aging and the onset of neurodegenerative disease (Hamilton & Rhodes, 2015). Additionally, there are differences in brain structure, connectivity, and effectiveness associated with higher fitness levels (Voelcker-Rehage & Niemann, 2013). Possible mechanisms for these observed changes include changes in blood flow, neurotransmitter levels, and neurotrophin levels (Barenberg et al., 2011; Hamilton & Rhodes, 2015). However, limitations to this field of knowledge still remain despite recent increases in attention. The role of cognitive engagement paired with exercise presents one important limitation that requires more empirical evidence.

2.1.1 Functional changes in the brain associated with exercise.

Across the lifespan, physical activity levels and fitness are associated with better executive functioning and memory. The strongest evidence links fitness and physical activity to better allocation of cognitive activation and energy. Based on the current body of research, response inhibition is the functional process where changes through exercise and physical activity are most consistently promoted.
2.1.1.1 Functional changes observed in adults.

Evidence shows that physical fitness may provide neurological protections against neurodegenerative diseases, including Alzheimer’s disease, dementia, and Parkinson’s disease. In a meta-analysis, Hamer and Chida (2009) identified an inverse risk of developing Alzheimer’s disease and dementia with fitness level. In the studies reviewed, physical activity reduced the relative risk of developing Alzheimer’s disease by 45% and dementia by 28% (Hamer & Chida, 2009). While Hamer and Chida (2009) did not observe a decrease in the onset of Parkinson’s disease through physical activity, David et al. (2015) observed preliminary evidence showing that exercise helps lessen the symptoms of Parkinson’s disease.

How physical fitness and activity levels provide protection may be highly specific, or through general benefits. For example, individuals who carry an allele that increases the risk of developing Alzheimer’s disease show increased benefits from physical activity (Smith, Nielson, Woodard, Seidenberg, & Rao, 2013). In fact, Smith et al. (2013) state that there is evidence that the development of memory decline associated with this specific allele is “exacerbated by physical inactivity” (p. 72). They hypothesize that the neurological benefits of physical activity counteract the negative effects of the genetic marker (Smith et al., 2013). More generally, adults at high risk for developing Alzheimer’s disease due to the development of mild cognitive decline who had high levels of physical activity demonstrated greater activation in left caudate (Smith et al., 2011). This area of the brain is associated with intentional actions and cognitions and may be a factor in the development of Alzheimer’s disease, indicating fitness may provide cognitive protections (Smith et al., 2011) by increasing activity to the region.
In addition to neurodegenerative diseases, the neurological benefits of physical activity likely extend to memory functioning more generally. Recent research has looked into how and why physical activity can provide protections against the effects of aging prior to the development of a neurodegenerative disease. Sofia et al. (2011) investigated the link between physical activity and cognitive decline independent of neurodegenerative disease and found that high levels of physical exercise significantly reduced the risk of cognitive decline. Results of their meta-analysis supported the hypothesis that physical activity level in older adults reduces the risk of cognitive decline with aging (Sofia et al., 2011).

These findings have been supported by research on animal models as well. Early animal models pointed to the hippocampus as an important cognitive structure associated with physical activity (van Praag, Christie, Sejnowski, & Gage, 1999a). Research in mice has shown that exposure to voluntary wheel running and enriched environments that include opportunities to exercise promotes neural growth and differentiation in the hippocampus (van Praag, Kempermann, & Gage, 1999b). This contrasts the fact that the hippocampus shrinks as people age (Erickson et al., 2011; for review see Fjell & Walhovd, 2010). It is a common belief that hippocampal volume increases through physical activity; however, the effects of these volume changes on memory performance are not as clearly established. Research in mice shows wheel running promotes faster reaction and improved consolidation of contextual memories paired with neurogenesis in the hippocampus (Kohman et al., 2012). However, the authors point out the behavioral changes could also be a result of other factors, including neurotrophins and growth factor
levels, enhancement of long-term potentiation, and increased angiogenesis (Kohman et al., 2012).

With humans, early research has found some evidence that physical activity interventions can improve memory. For example, Perrig-Chiello, Perrig, Ehrsam, Staehelin, and Krings (1998) observed that a resistance training intervention with older adults led to significant improvements on memory performance one year later. In another study, Moul, Goldman, and Warren (1995) observed physical activity had a positive effect on information processing, including immediate, auditory, and recent memory. In addition to improvement on common memory tasks, Moul et al (1995) also found enhanced performance on measures of executive functions. In fact, the tasks that required the most attentional capacity showed the greatest improvements with the exercise group, indicating these results may be related to improvements in executive functions in addition to or instead of memory.

More recent research continues to show inconsistent relationships between physical activity and memory. Erickson et al. (2011) observed hippocampal volume changes following year-long walking training in older adults; however, they did not observe corresponding changes in spatial working memory. Ruscheweyh et al. (2011) found that a low-intensity physical activity intervention improved episodic memory. These contradictory results are either due to a cascade of changes promoted by physical activity, making direct results difficult to observe or potentially highlight that the relationships are less direct than currently believed. While physical activity likely provides protections against age-related memory decline, the effects of acute physical activity on healthy adults are less clear. While the hippocampus is a brain area strongly
associated with physical activity levels (Hamilton & Rhodes, 2015), physical activity may not be able to consistently significantly improve memory performance prior to declines in memory performance.

In addition to benefitting memory functioning, physical activity has positive effects on executive functions in older adults. Early research supported the findings in Moul et al. (1995), where exercise interventions could promote positive changes in executive tasks (Kramer et al., 1999). Kramer et al. (1999) found that aerobic activity significantly improved older, sedentary adults’ performance on task switching, reaction time, and distractor interference. Hawkins, Kramer, and Capaldi (1992) showed improved time-sharing performance in older adults with an exercise intervention. Adding more support, Colcombe and Kramer (2003) completed a meta-analysis of the effects of aerobic activity on the cognitive functioning of older, sedentary adults. Their findings support previous results that fitness training significantly improves cognitive performance in older adults, with executive control showing the largest improvements with fitness training.

The meta-analysis completed by Colcombe and Kramer (2003) shaped the next few years of research, as researchers began to focus on the relationship between physical activity and executive functions. Colcombe et al. (2004) showed that physically active older adults demonstrated higher activation in the frontal and parietal regions of the brain and decreased activation in the Anterior Cingulate Cortex (ACC) during a modified Flanker task. Similarly, older adults who were randomly assigned to an aerobic activity group showed increased task-specific neurological responses compared to participants in a non-aerobic control group (Colcombe et al., 2004). Prakash et al. (2011) observed
similar patterns, where higher levels of cardiorespiratory fitness in older adults corresponded with increased activation in the prefrontal and parietal cortices during a Stroop task compared to lower-fit participants. In addition, higher-fit participants demonstrated better task performance (Prakash et al., 2011). In contrast, Liu-Ambrose et al. (2012) observed similar cognitive activation as Prakash et al. (2011), but increased activation did not lead to behavioral changes in task performance.

Voelcker-Rehage, Godde, Straudinger (2010) extended this body of research by looking not only at cardiorespiratory fitness, but also motor fitness. Here they found physical fitness was related to executive control while motor fitness was associated with executive control and perceptual speed tasks (Voelcker-Rehage et al., 2010). In contrast to other studies, Voelcker-Rehage, Godde, Straudinger (2011) observed lower prefrontal cortex activation and higher activation in temporal regions during incongruent Flanker tasks in older adults following aerobic exercises. However, the authors point out the pattern matches that of younger adults, concluding that physical fitness may play a role in delaying age-related cognitive declines in executive functioning performance (Voelcker-Rehage et al., 2011). Increased activation is often associated with increased task load (Voelcker-Rehage and Niemann, 2013). They posit less activation may indicate a more “youth-like” brain that requires less compensation, and thus less activation (Voelcker-Rehage et al., 2013, p. 2275). Voelcker-Rehage and Niemann (2013) point out that the observed differences in activation patterns compared to Prakash et al. (2011) and Liu-Ambrose et al. (2012) may be due to sample characteristics and practice over the course of the task.
Although there is some variability in the body of research, higher fitness levels are associated with differential activation patterns in the prefrontal cortex and temporal regions of the brain when asked to perform tasks requiring executive control. Prakash et al. (2011) suggest that cardiovascular fitness could allow prefrontal cortices to respond to task demands by increasing neural recruitment and allowing for the brain to respond to stimuli with greater flexibly. Prakash et al. (2011) hypothesize that there is a greater “reserve” of cognitive resources that higher-fit individuals can access to respond to challenging tasks, particularly tasks that require greater executive control. Higher fitness levels are associated with improved allocation of neural activation and sometimes improved behavioral performance (Gomez-Pinilla & Hillman, 2013). Voelcker-Rehage and Niemann (2013) posit that physical activity and/or fitness may make cognitive resources more available, leading to more effective activation of task-relevant brain regions.

There is evidence in support of neurological changes in older adults, however the role of exercise on brain development in young adults is less well established. Research on young adults generally fails to find significant changes, with some studies using younger adults as a control group (Hillman, Castelli, & Buck, 2005; Voss et al., 2011). Studies have confirmed that performance on outcome tasks changes as a function of time. Early research indicated that young adults shifted attention and processed tasks more efficiently than older adults (Hawkins, 1992), and adults are more effective at executive tasks than children (Hillman et al., 2005).

Smith et al. (2010) completed a meta-analysis that included physical activity intervention studies on participants over the age of 18 years. This meta-analysis updated
the meta-analysis completed by Colcombe and Kramer (2003) and included the entire adult lifespan, not just older adults. Smith et al. (2010) reviewed 29 total studies and discovered aerobic exercise improved attention, processing speed, executive function, and memory, with combined aerobic and strength training interventions showing the larger improvements than aerobic exercise alone. They did not, however, separate studies on older adults from middle-aged adults, reporting that exercise training promotes improvements in the cognitive functioning of healthy older adults (Smith et al., 2010).

There is some preliminary evidence showing that physical activity can have positive effects on young adults. Stroth et al. (2009) found a significant increase in visuospatial memory performance from a running training program in young adults (17-29-year-olds). Pereira et al. (2007) observed improved first-trial learning and a trend toward overall improved learning following an exercise intervention with adults. This improved learning performance was paired with significantly increased cerebral blood volume to the dentate gyrus of the hippocampus (Pereira et al., 2007). The authors hypothesize that measures of cerebral blood volume correlate to neurogenesis through angiogenesis in humans, similarly to the process in mice (Pereira et al., 2007). Meaning, the increased cerebral blood volume observed following an acute activity intervention is the result of neurogenesis in that particular brain region, the hippocampus.

Supporting this, Winter et al. (2007) observed significant changes in catecholamines and BDNF following intense sprints in young adults. These physiological changes also associated with faster learning outcomes; young adults improved their ability to learn by approximately 20% compared to sedentary and low-impact conditions (Winter et al., 2007). Higher levels of BDNF following the activity were associated with
better learning success; dopamine and epinephrine levels were related to better retention of novel vocabulary.

More recent research with young adults observed that spatial training improved participants’ performance on a maze task and that their fitness level was associated with brain activation during the task (Holzschneider et al., 2012). Higher fitness levels were associated with activity in a larger number of brain regions (Holzschneider et al., 2012). However, fitness and/or activity alone were not sufficient to change behavioral performance (Holzschneider et al., 2012). The changes were only observed when paired with a spatial learning exercise (Holzschneider et al., 2012).

Hötting et al. (2012a) randomly assigned adults (40-56 years of age) to either aerobic or stretching/coordinative activity groups. Memory was significantly improved for the cycling and stretching group compared to the sedentary control (Hötting et al., 2012a). The stretching/coordinative group improved on selective attention more so than cycling, but there were no significant changes in executive functioning with the activity (Hötting et al., 2012a). At a 1-year follow up, participants who did not keep up with activity levels lost memory skills (Hötting, Shauenberg, & Röder, 2012b).

2.1.1.2 Functional changes observed in children.

Childhood is a time of neurological growth and development, with circuits developing and pathways pruning. As such, it presents a number of ways physical activity and exercise can produce neurological benefits and improved function. As with adults, the current evidence suggests that physical activity, fitness levels, and acute exercise interventions have positive effects on memory and executive functioning performance.
There is emerging evidence that physical activity can promote memory performance in children. As highlighted previously, the hippocampus is strongly related to physical activity, specifically physical activity can lead to changes in hippocampal volume (Hamilton & Rhodes, 2015). Hippocampal volume in children is associated with relational memory task performance (Chaddock et al. 2010), building on evidence from rodent studies that show structural changes in the hippocampus associated with improved learning and memory in mice (van Praag et al. 1999a).

Supporting this, Pesce, Crova, Cereatti, Casella, and Bellucci (2009) looked at free recall of a 20 item list in 11- and 12-year-olds following aerobic circuit training, team games, and a non-active control. Immediate recall scores in both primacy and recency portions were higher following team games (Pesce et al, 2009). Delayed recall of recency was higher after team games and aerobic circuit training (Pesce et al., 2009). These findings indicate that exercise may facilitate memory storage, but the differential effects suggest cognitive demands of the exercise may be important (Pesce et al., 2009).

While most research on memory looks at recall of learned items, Kamijo et al. (2011) looked at the effects of an afterschool physical activity program on Working Memory in preadolescent children. A 9-month activity intervention improved performance on a working memory tasks compared to a waitlist control group (Kamijo et al., 2011). Similar to findings in adults, the largest increases in performance were observed during trials with greater cognitive demands (Kamijo et al., 2011).

Similar to adults, physically fit children demonstrate more effective executive functioning skills, most specifically response inhibition and reaction time. In an early study, Hillman et al. (2005) compared the reaction time and P3 amplitude of children and
adults. Adults demonstrated faster reaction times, with higher-fit children demonstrating faster reaction time compared to lower-fit children. These behavioral changes were accompanied with differential P3 amplitudes (Hillman et al., 2005). It is believed that P3 amplitudes are related to allocation of attentional resources (Polich & Kok, 1995). The P3a is generally measured on tasks requiring attention and discrimination (Gomez-Pinilla & Hillman, 2013). The P3b component occurs when memory stores in the hippocampus are transferred to the parietal lobe (Gomez-Pinilla & Hillman, 2013). The P3 likely represents attentional resources and working memory in the context of responding to environmental stimuli (Gomez-Pinilla & Hillman, 2013).

Taken together, these findings suggested that fitness is associated with attention and response speed in children (Hillman et al., 2005). These findings were replicated in Hillman et al. (2009a), where higher-fit participants performed better on the incongruent trials of the Flanker task compared to lower-fit preadolescent children. These results were also replicated in an applied setting where an after-school program, FITKids, led to improved inhibition, cognitive flexibility, and changes to the P3 amplitude in 7- to 9-year-old participants (Hillman et al., 2014).

Voss et al. (2011) provided supporting evidence by using a similar methodology but comparing fMRI activation. They also observed that adults performed better on tasks requiring cognitive control and demonstrated a lower response time (Voss et al., 2011). Higher-fit children showed greater accuracy and less interference, providing more evidence of an efficient cognitive response compared to lower-fit children (Voss et al., 2011). Voss et al. (2011) observed that as tasks became more difficult, lower-fit children demonstrated more activation of their neural network, leading the authors to hypothesize
that lower-fit children engage in reactive control and require more cognitive resources as tasks become more challenging. These results were supported by Davis et al. (2011), who observed increased prefrontal activation and reduced parietal activity along with improvements to cognitive control in overweight children following acute exercise.

Chaddock et al. (2012) looked at fMRI activation in high-fit and low-fit 9- and 10-year-old children while completing a modified flanker task and observed that during congruent trials, all children had greater activation in the prefrontal and parietal cortex initially, followed by a reduction in activation later in the task (Chaddock et al. 2012). As the cognitive demands of the task increased through incongruent trials, higher-fit children maintained response accuracy even with this decrease in activity; lower-fit children were less accurate as their activation decreased (Chaddock et al., 2012). This provides more evidence to the hypothesis that physical fitness improves the allocation of neural resources in children (Chaddock et al., 2012). Chaddock-Heyman et al. (2013) showed that a 9-month exercise intervention had positive effects of physical activity on fMRI activation associated with cognitive control, further showing the relationship between neural activation, task performance, and physical activity and fitness.

In addition to randomized control studies, cross-sectional studies provide additional support that fitness levels have a positive relationship to executive function performance. van der Niet et al. (2015) followed 8-12-year-olds in the Netherlands and observed that boys spent more time in MVPA compared to girls. Sedentary time was negatively correlated with performance on the Stroop task. Additionally, the volume of physical activity performed by participants was positively correlated with score and execution time on the Tower of London task; time in MVPA was also positively
correlated with execution time on the Tower of London task. Pindus et al. (2016) used similar methods with 7-9-year-olds in the United States and observed that increased aerobic fitness was positively associated with increased inhibitory control.

Physical fitness may also have positive effects on reaction time performance in children. Ellemburg & St-Louis-Deschênes (2010) observed significant improvements to reaction time in 7- and 10-year-old boys following aerobic activity compared to watching TV. Following aerobic activity, the participants performed a response task an average of 34 milliseconds faster on a simple task and 75 milliseconds faster on choice response (Ellemburg & St-Louis-Deschênes, 2010). However, Hillman et al. (2009a) observed that while fitness level was related to better interference control, it was not significantly related to reaction time in their study.

Additionally, physical activity can affect concentration and attention (Budde et al., 2008). Budde et al. (2008) found that the coordinative exercise showed higher improvements to attention in 13-16-year-olds compared to a normal sports lesson. Evidence so far indicates that exercise promotes “allocation of attentional resources and faster cognitive processing during stimulus encoding” (Hillman et al. 2008, p. 61). Vanhelst et al. (2016) looked at European adolescents and found significant correlations between longer time spent in moderate or MVPA on the d2 test of attention.

There is also evidence to suggest physical activity can affect arousal (Hillman et al., 2009b). Tomporowski, Lambourne, and Okumura (2011) point out early studies looking at the effects of physical activity on children theorized an inverted U-shaped function between arousal and performance that predicts performance will increase with increased arousal up to a point, after which the relationship would decline. Kamijo and
colleagues (2004; 2007) observed similar patterns in arousal looking at adults; medium intensity was the ideal to change P3 amplitude with low and high intensity looking closer to the control group. Winter et al. (2007) observed learning increases in adults following exercise and determined this learning was not likely to be exclusively due to arousal, but that arousal may have played a mediating role. Fitness levels may also have positive effects on over-activation, in that higher-fit individuals are less likely to reach over-activation in both low- and high-demanding tasks (Voelcker-Rehage & Niemann, 2013).

Overall, exercise and physical fitness appear to have many positive effects on brain development in children. Specifically, executive functioning and executive control benefit from regular physical activity. Response inhibition is the most well-studied executive control associated with exercise; however, evidence suggests physical fitness also affects arousal, attention, and reaction time.

2.1.2 Structural changes in the brain associated with exercise.

Structural differences are also observed in cross-sectional studies comparing high-fit individuals to low-fit individuals (for a review see Voelcker-Rehage & Niemann, 2013). In addition, acute and chronic exercise interventions can promote structural changes in the brain across the lifespan. The brain regions that appear to be affected by cardiovascular fitness are also the areas that experience age-related volume loss (Erickson, Leckie, & Weinstein, 2014), including the hippocampus (Fjell & Walhovd, 2010).

Animal models provide the strongest evidence for structural brain changes associated with physical activity and exercise. For example, hippocampal neurons significantly increased in male rats after exercising (Uysal et al. 2005). The type of
exercise appears to matter, with voluntary exercise showing more changes when compared to forced exercise (Arida, Scorza, da Silva, Scorza, & Cavalheiro, 2004). This may be due in part to additional stress placed on the animals when forced to run; mice run intermittently with short bursts on their own, while forced running procedures set a constant rate and speed during the course of the activity (Morgan et al., 2005).

Despite some differences in outcomes, it is generally held that exercise affects brain structure in animals, with high levels of exercise leading to larger brain volumes in specific regions (Hamilton & Rhodes, 2015). The brain region most influenced by exercise is the hippocampus (Hamilton & Rhodes, 2015). In humans, the strongest and most consistent relationships include volume changes of the hippocampus and prefrontal cortex, even given different methodologies and types of activity (Erickson et al., 2014). However, there are interactions that require further exploration, such as age and the role of duration and intensity of activity (Erickson et al., 2014). Additionally, the link between volume changes and cognitive functions needs to be further developed (Erickson et al., 2014).

2.1.2.1 Structural changes observed in adults.

In a meta-analysis of research to date, Erikson et al. (2014) highlights there is consistent evidence to suggest fitness levels promote volume increases in the hippocampus and prefrontal cortices. Voelcker-Rehage & Neumann (2013) also completed a meta-analysis with eight studies finding larger brain volume in the frontal cortex following higher fitness or cardiovascular intervention in older adults (Voelcker-Rehage & Neumann, 2013). In younger adults, fitness was associated with volume of the right anterior insular cortex (Peters et al., 2009).
Weinstein et al. (2012) offered preliminary evidence to show that higher fitness levels were associated with both increased grey matter volume in the prefrontal cortex and better performance on a Stroop task. Erickson et al. (2010) followed aging adults without dementia for 9 years, looking at brain volume and self-reported physical activity. Erickson et al. (2010) found that greater amounts of physical activity were associated with increased gray matter in the prefrontal cortex, anterior cingulate, parietal, cerebellum, and hippocampus. These results are similar to Gordon et al. (2008), were higher fitness levels were associated with observed changes in the temporal, anterior parietal, and inferior frontal areas. These changes were correlated with better behavior on mini-mental status exam and other tests of cognitive functioning (WAIS) (Gordon et al., 2008).

Despite the mostly converging evidence, two of the cross-sectional studies reviewed by Erikson et al. (2014) offered slightly contradictory results. Honea et al. (2009) did not observe differences in gray matter volume in healthy individuals with cardiovascular fitness, only in participants in the early stages of dementia. Adults with mild Alzheimer’s disease did have significantly differential brain volumes in the temporal and parietal cortices associated with cardiovascular fitness. In a second study, Bugg et al. (2012) found changes in hippocampal volume but not in the prefrontal cortex in obese adults.

Hamilton and Rhodes (2015) point out that the hippocampus is the region most affected by exercise. Exercise promotes neurogenesis within the hippocampus, most specifically within the dentate gyrus (Hamilton & Rhodes, 2015; van Praag et al., 1999b). Voelcker-Rehage and Niemann (2013) state “aerobic exercise seems capable of reversing
age related loss of hippocampal volume” (p. 2285). These benefits may not be exclusive to aerobic activity; coordinative exercise also increases hippocampal volume in older adults (Niemann & Voelcker-Rehage, 2014). However, while Erickson et al. (2011) saw similar increases in volume in the hippocampus, hippocampal volume decreased in a toning and stretching control group. These results indicate that aerobic activity can increase hippocampal volume, with questions remaining about the effects of different activity types, including stretching and toning.

Although there is strong evidence to support a relationship between physical activity and hippocampal volume, Ruscheweyh et al. (2011) did not observe larger hippocampal volume after 6 months of aerobic or coordinative activity. They did report changes in increased gray matter volume in the prefrontal and cingulate regions (Ruscheweyh et al., 2011). This supports other research showing volume changes in the prefrontal and temporal areas with higher fitness (Colcombe 2004; Colcombe et al., 2006). A stretching and toning control group experienced a slight decrease in volume these brain regions (Colcombe et al., 2006).

In addition to changes in brain volume, there are observed changes in white matter with physical activity. Colcombe et al. (2003) and Colcombe et al. (2006) observed larger or increased volume of anterior white matter in older adults with high levels of cardiovascular fitness. In addition, cardiorespiratory fitness is positively correlated with cerebral white matter integrity (Johnson, Kim, Clasey, Bailey & Gold, 2012) and microstructural integrity (Burzynska et al., 2014; Tian et al., 2014) in older adults. A walking exercise intervention can increase white matter integrity in the prefrontal cortex (Voss et al., 2013).
2.1.2.2 Structural changes observed in children.

If physical activity and fitness levels can help prevent age related volume loss, it is also important to look at the role of fitness on the growth and development of brain areas and volume. Emerging evidence indicates physical activity can have beneficial effects on brain development in the same areas as older adults. There is preliminary evidence to suggest that physical fitness and activity levels are related to increased regional volume (Chaddock et al. 2010a & 2010b), white matter changes (Chaddock-Heyman et al., 2014), and cortical thickness (Chaddock-Heyman et al., 2015).

In one study, lower-fit children were observed to have smaller dorsal striatum, specifically the basal ganglia, and decreased inhibition on a modified Flanker task (Chaddock et al., 2010b). These differences in basal ganglia volume correlated with performance on a Flanker task at 2 time points in a longitudinal study (Chaddock et al., 2012b), indicating these changes in both structure and performance are somewhat conserved, at least in 9- and 10-year-olds. Differences were also observed in the hippocampus, while higher-fit 9- and 10-year-olds had larger bilateral hippocampal volume and better performance on a relational memory task (Chaddock et al., 2010a).

In addition to the observed differences in gray matter in the dorsal striatum and hippocampus (Chaddock et al., 2010a; 2010b), Chaddock-Heyman et al. (2015) also observed decreased gray matter volume in the superior frontal cortex, superior temporal areas, and lateral occipital cortex in higher-fit children compared to lower-fit children. These higher-fit children also demonstrated better performance on an achievement test in math (Chaddock-Heyman, 2015). There were no significant differences in reading or spelling performance. The authors hypothesize that higher levels of fitness help the
cortical-thinning process observed in development during childhood between the ages of 5 and 11 years (Chaddock-Heyman et al., 2015).

Chaddock and colleagues also observed preliminary evidence showing that fitness levels affect white matter in children as well (Chaddock-Heyman et al., 2014). Higher-fit 9- and 10-year-olds had greater white matter fiber tracts compared to their low-fit peers. These findings provide evidence to suggest that fitness and physical activity leads to more tightly bundled white matter fibers in the corpus callosum (Chaddock-Heyman et al., 2014). The authors speculate that this in turn leads to better communication between the hemispheres, and subsequently better cognitive performance (Chaddock-Heyman et al., 2014).

How these structural change affect behavioral performance is still unclear. There is preliminary evidence showing associations between hippocampal volume and a relational memory task (Chaddock et al., 2010a), performance on a modified Flanker task with increased basal ganglia volume (Chaddock et al., 2010b), and better math achievement with decreased volume in the frontal cortex (Chaddock-Heyman et al., 2015), but these results are preliminary. Connecting structural changes to behavioral performance in children represents an area in need of further evidence and support.

The most consistent structural changes associated with physical activity are observed in the hippocampus and prefrontal cortices. These two areas correspond with areas important to memory and executive functions, providing strong evidence that physical activity promotes healthy development and functioning of these areas, and can help protect against age-related declines. The findings to date indicate that physical fitness influences allocation of cognitive resources; higher fitness equates with a more
efficient deployment of activity (Gordon et al., 2008). Both structural and functional changes are observed with both fitness levels and activity interventions; however, the results at this time occasionally point to contradictory results. Researchers hypothesize that these sometimes contradictory results are due to different methodologies or because of the complicated nature of the systems and processes affected (Rooks et al., 2010).

2.1.3 Mechanisms for changes.

At this time, there are three main mechanisms that offer possible explanations for the observed functional and structural changes: increased cerebral blood flow, release of neurotransmitters including dopamine and serotonin, and the release of neurotrophins including BDNF and IGF1 (Barenberg et al., 2011). While Barenberg et al. (2011) hypothesized that most evidence is in favor of dopamine leading to the observed effects of physical activity, it is likely all three mechanisms have positive effects and interact with one another (Hamilton & Rhodes, 2015). In addition, different types of physical activity may promote different mechanisms (Voelcker-Rehage & Niemann, 2013).

Evidence from animal models suggests physical activity training can lead to the growth of new neurons and blood vessels (Voss, Nagamatsu, Liu-Ambrose, and Kramer, 2011) and can increase capillary density in the cerebellum (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990). In addition, physical activity can regulate production of neurochemicals that communicate messages throughout the brain (Voss et al., 2011). Early research with animals showed that physical activity promotes changes in norepinephrine, serotonin, and dopamine levels (Meeusen & De Meirleir, 1995) as well as changes to levels of BDNF gene expression (Neeper, Gomez, Choi & Cotman, 1995). These processes lead to new cell growth in the hippocampus of rodents (van Praag et al,
one of the first important outcomes seen in this body of research (Colcombe & Kramer, 2003).

Current research has started to look at how these different systems may work together. For example, angiogenesis, the formation of blood vessels, is partially controlled by the release of through IGF1 (Lopez-Lopez, LeRoith, & Torres-Aleman, 2004). Angiogenesis in turn leads to changes in cerebral blood flow (Lopez-Lopez et al., 2004), highlighting that both neurotrophin release and changes to blood flow are outcomes of physical activity. Hamilton and Rhodes (2015) point out that these signaling pathways are not well understood, largely due to their complex and interrelated nature.

2.1.3.1 Cerebral blood flow.

Early research on physical activity and cerebral blood flow observed a graded increase of blood flow with exercise (Jorgenson, Perko & Secher, 1992). Swain et al. (2003) observed increased capillary growth and increased blood flow in the cerebral cortex in rodents following exercise on a wheel. Building on the evidence from animal models, Pereira et al. (2007) showed that cerebral blood volume in the hippocampus leads to neurogenesis. The dentate gyrus of the hippocampus saw significantly increased cerebral blood volume following an exercise program, accompanied with improved trial 1 learning on a memory task and a trend toward overall improved learning (Pereira et al., 2007). Burdette et al. (2010) observed resting brain flow in the hippocampus significantly increased in older adults compared to sedentary control; however, a major limitation to this study was a small sample size.

More recent research has looked to understand the relationship between heart rate and oxygenation of blood in the brain. Following aerobic activity, there is an increase in
oxygenated hemoglobin and blood volume (Rooks, Thom, McCully, & Dishamn, 2010), making oxygen more readily available in the brain (Nicastro & Greenfield, 2016). Rooks et al. (2010) completed a systematic review and meta-regression analysis of studies looking at changes in blood flow and oxygenation, showing that there is an overall trend toward increased blood volume and oxygen levels in the brain with increased activity. Cerebral oxygen levels followed a quadratic trend, where levels increased with moderate to hard levels of activity, followed by a sharp decline at very hard levels (Rooks et al., 2010). The increased blood volume and oxygen levels were paired with signals that indicate the increased oxygen is not sufficient for the demand, indicating that at high activity levels the demands of oxygen may be redirected to the muscles (Rooks et al., 2010).

These results are due to a non-linear relationship between cerebral blood volume and physical activity in adults (Timinkul et al., 2008). At the start of exercise, oxygenation slowly increases until the cerebral blood volume threshold is reached, leading to a hyper-oxygenated phase. This happens prior to the lactate threshold. The last phase is a de-saturation phase where oxygenation begins to decline until exercise is terminated (Timinkul et al., 2008). Timinkul et al. (2008) also found a significant relationship between heart rate and oxygenated hemoglobin but these two patterns were not the same, leading researchers to conclude that other variables affect cerebral blood flow.

Another influential study, Suzuki et al. (2004), observed increases in oxygenated hemoglobin in prefrontal and premotor cortexes as human subjects walked or ran on treadmills. Interestingly, Suzuki et al. (2004) observed these changes before subjects
initiated physical activity, indicating this might be an anticipatory reaction. Rooks et al. (2010) completed a meta-analysis and note that of the studies reviewed, there was heterogeneity in the results due to differences in study designs, activity type, and activity intensity (Rooks et al., 2010). The anticipatory effects observed by Suzuki et al. (2004) contribute to the difficulties in comparing results across the studies; the level of cognitive engagement and excitement may affect the results.

Changes to blood volume are considered a bottom-up process, where the body responds first and the brain response is secondary (Nicastro & Greenwood, 2016). Another bottom-up process observed in animals following physical activity is a change in temperature. Changes in temperature trigger reactions from temperature-sensitive neurons, leading to signals that protect the brain from stress (Nicastro & Greenwood, 2016). Specifically, the dorsal raphe nucleus contains temperature-sensitive serotonin-releasing cells that signal other responses in the brain (Nicastro & Greenwood, 2016). This highlights the difficulty in pinpointing the mechanism at work, as temperature changes lead to release of a neurotransmitter.

More recent neuroimaging technology and research indicates that while cerebral blood flow does change in response to exercise, it alone does not adequately explain the positive outcomes of physical activity. Rather, neurotransmitters and neurotrophins released in response to physical activity are more likely the agents of change (Barenberg et al., 2011). Nicastro and Greenwood (2016) point out that this can be either a response to a top-down process, or from a bottom-up process through temperature-sensitive releasing cells. These signals in turn promote important changes observed following exercise and physical activity.
2.1.3.2 Regulation of neurotransmitters.

Physical activity has also been shown to affect the release, inhibition, and uptake of neurotransmitters. Dopamine, norepinephrine, serotonin, and acetylcholine are important neuromodulators in the brain that signal the hippocampus, amygdala, striatum, and prefrontal cortex (Robbins & Arnsten, 2009). There is evidence that each of these neurotransmitters is affected by physical activity; however, the heterogeneity of research outcomes makes it difficult to clearly identify the signaling pathways (Hamilton & Rhodes, 2015; Rooks et al., 2010).

The strongest evidence shows that physical activity can promote the release of catecholamines. Catecholamines, neurotransmitters with a catechol ring and amino group, include epinephrine, norepinephrine, and dopamine. Catecholamines are linked to states of arousal; dopamine and norepinephrine levels are low during lower arousal, moderate during times of focus, and high under stress (Robbins & Arnsten, 2009). Optimal levels of catecholamines lead to focus, attention, and increased memory performance; excessive levels, such as those observed under stress, lead to poorer cognitive performance (Robbins & Arnsten, 2009). Catecholamines are also linked to executive functioning, including inhibition control (Robbins & Arnsten, 2009). Dopamine in particular plays an essential role in working memory, behavioral flexibility, and decision-making (Floresco & Magyar, 2006).

Dopamine and norepinephrine can increase following physical activity. Bailey, Davis, and Ahlborn (1993) observed increases in dopamine levels of rats after 1 hour of physical activity, but fatigue conditions matched resting conditions. Hattori, Naoi and Nishino (1994) also observed dopamine increases in rats following physical activity. In
humans, Winter et al. (2007) observed elevated levels of dopamine, epinephrine, and norepinephrine following sprints. Winter et al. (2007) observed higher levels of absolute dopamine at the beginning of learning tasks that enhanced retention. Increases in norepinephrine were associated with long-term retention of words learned (Winter et al., 2007).

The release of catecholamines in response to exercise and physical activity is cited as one of the central benefits to regular exercise. Hamilton and Rhodes (2015) point out that because of these effects, exercise could potentially restore or repair brain function associated with disorders, including depression, ADHD, Parkinson’s disease, and Huntington’s disease. Exercise can increase neurotransmitter levels, making them more available to the brain (Hamilton & Rhodes, 2015). While this body of research is promising, most of this research is built on animal models, and more research in humans is needed.

Physical activity also affects the release of serotonin, a monoamine that modulates the responses of other neurons. Voluntary wheel running in rodents reduced the activation of serotonergic neurons in reaction to stress, improving the stress response by increasing resistance (Greenwood & Fleshner, 2011). Voluntary wheel running also increased the transporter mRNA that is involved in serotonin reuptake (Greenwood et al., 2005), seen in the dorsal raphe nucleus in the brain stem (Morgan et al., 2015). These changes at the neurotransmitter level are noteworthy due to the effects on the stress response system (Morgan et al., 2015). Exercise may provide neurological protections against stress (Nicastro & Greenwood, 2016). The serotonin released interacts with the
amygdala and hippocampus, affecting limbic and cognitive functions (Morgan et al., 2015).

Neurotransmitters, including dopamine and serotonin, play important roles throughout the brain. The effects of exercise on these systems appear to be generally positive and helpful. The benefits include increased arousal, attention, and responses to stress. Due to the interrelated nature of these transmitters of signals, it is difficult to pinpoint one specific response and different types of activity may affect different transmitters. However, the effects of physical activity and exercise on neurotransmitter-signal pathways are a promising area of research given their important role in brain functioning.

2.1.3.3 Regulation of neurotrophins.

Physical activity also affects the brain through the release of neurotrophins. Neurotrophins - proteins that induce growth, survival, and development of neurons - are vital to vertebrate development and functions (Chao, 2003). The most commonly researched neutrophin factor affected by exercise and physical activity is brain-derived neurotrophic factor (BDNF). However, additional neurotrophins, including IGF1 and VEGF, are also affected by exercise.

Evidence from animal models suggest that physical activity promotes changes in the brain by facilitating allocation of attentional resources by increasing BDNF levels. BDNF is present in the hippocampus, indicating it has a role in memory and learning and has been colloquially labeled the “miracle grow” of neurons (Ratey, 2008). Animal and human research shows BDNF levels are typically depressed in attentional and affective disorders and that physical activity can increase serum levels of BDNF.
BDNF plays a role in attention, focus, impulse control, and the pathology of ADHD (Archer & Kostrzewa, 2012; Berwid & Halperin, 2012). Rats with BDNF knockout display increased locomotor movement (Rios et al. 2001), hyperactivity (Chan, Unger, Byrnes, & Rios, 2006), anxiety (Rios et al., 2001), and hyper-aggression (Chan et al., 2006). This line of research with rodents is connected to research in humans. Levels of BDNF are associated with omission errors on a continuous test in children with ADHD (Shim et al. 2008). In addition, Post (2010) describes decreases in hippocampal BDNF levels with distress threat and in affective episodes like depression.

Neeper, Gomez-Pinilla, Choi & Cotman (1996) observed significant increases of BDNF mRNA in rats after exercise, particularly in the hippocampus. Neurogenesis occurs in the hippocampus in mice with access to running wheels (van Praag et al., 1999b), indicating that the increased BDNF mRNA results in increased cells. Adding to this evidence, studies that block the function of BDNF do not show positive cognitive effects or neurogenesis following exercise in rodents (Vaynmann, Ying, Yin, & Gomez-Pinilla, 2006).

Berchtold, Chinn, Chou, Kesslak, and Cotman (2005) replicated these findings in a way that better mimics human exercise patterns. Berchtold et al. (2005) observed similar increases in BDNF in rats that exercised on alternating days, concluding that alternating exercise days was as effective at increasing BDNF levels. In addition, Berchtold et al. (2005) found some evidence for an exercise stimulus “memory” in that previously exercising rats who were inactive for 7-14 days had a rapid increase of BDNF when exercise was reinitiated, rather than the slower increase of non-exercising animals.
These models provide valuable evidence to suggest that physical activity can promote neurogenesis in humans as well. Gold et al (2003) discovered that 30 minutes of moderate physical activity induced BDNF production in both adults with multiple sclerosis and healthy controls. Winter et al (2007) observed increases in BDNF following intense physical activity, which was also correlated with improved learning outcomes (memory of novel vocabulary words). The elevated BDNF levels persisted through the learning task, which researchers attributed to better short-term learning successes for participants (Winter et al., 2007). Erickson et al. (2011) associated increased hippocampal volume in older adults to BDNF serum level increases.

However, there is research that shows a different pattern of BDNF release. Ruscheweyh et al. (2011) observed a trend toward increased BDNF with higher activity levels but did not observe significant differences in hippocampal volume for the post-exercise groups. They did, however, observe significantly increased gray matter volume in the prefrontal and cingulate cortex (Ruscheweyh et al., 2011). Coelho et al. (2013) reviewed research between BDNF and exercise and conclude that physical exercise increases concentrations of BDNF, with activities of moderate intensity providing the most effective increase.

Additional neurotrophins, including insulin-like growth factor 1 (IGF-1) and vascular endothelial growth factor (VEGF), are also affected by exercise. In mice, IGF-1 is necessary for adult hippocampal neurogenesis and subsequent spatial learning associated with exercise (Trejo, Llorens-Martin, & Torres-Alemán, 2008), indicating that it also plays an important role in the positive outcomes associated with exercise. Fable et al. (2003) observed similar results that VEGF is also necessary for adult hippocampal
neurogenesis following running in mice. In humans, IGF-1 increases following exercise (Jeon & Ha, 2015). VEGF was significantly elevated in runners following a marathon in the Swiss Alps; the increased neurotrophin levels were observed for 5 days post exercise (Schoberberger et al., 2000). These results provide support that animal models apply to humans as well.

Neurotrophins represent the beginning of a process, including neurogenesis and angiogenesis. It appears that in both animals and humans, multiple neurotrophins are involved with the positive outcomes of exercise. Early evidence showed a strong relationship with BDNF, however more recent research has shown that both IGF-1 and VEGF are also important factors in the positive outcomes of exercise on the brain. It is likely these factors play an important role in the positive effects of exercise as well.

2.1.4 Moderating factors.

Consistent among reviews of this body of research are studies that contradict or provide contrary evidence. Reviewers point out that this is often due to different types of exercise used, different cognitive processes or structures measured, and other possible moderating factors. In addition to type of activity, cognitive engagement, and difference in measures, age and sex play an important role in the interaction between physical activity and neurological development.

As noted in the review, age has a significant role on the effects of exercise on the brain. Much of the research is built on studies looking at cognitive decline with age. More recent research has focused on the developing brain. Hillman et al. (2008) highlighted few studies at that time investigated relationships between exercise and physical activity and brain development; while there has been an increase in interest in
this area, there remains an need for empirical research in this area, particularly in applied settings.

Recent research has indicated that exercise may have differential effects according to sex, but much more research looking at the role of sex is needed. Hamilton and Rhodes (2015) point out that physical activity levels affect salivary levels of estradiol, and exercise and estrogen levels may interact. In applied settings, researchers have observed differential effects of physical activity interventions on adolescent girls (Bunkertorp Käll, Malmgren, Olsson, Linden & Nilsson, 2015; Harveson et al., 2016).

2.2 Role of Exercise in Learning and School

While these findings from laboratory settings are important, understanding how physical activity and exercise affect outcomes in applied settings is also important to focus on. The most consistent effects in children have shown improved response inhibition and cognitive efficiency. However, how this manifests in academic settings is an important question, given that a survey of teachers in Oregon reported 90% think more opportunities for physical activity would improve student concentration (Perera, Frei, Frei, & Bobe, 2015). Of the teachers sampled, 85% answered they were concerned or very concerned about children’s physical activity opportunities, and 71% reported they feel it is very important that children have opportunities to be active (Perera et al., 2015). Additionally, they claimed that the largest barrier to getting more physical activity during the day was competing academic expectations (72%).

These same teachers reported how often elementary school students attend physical education and compared to recommendations by the Center for Disease Control (Perera et al., 2015). In their survey, 92% of schools did not meet these national physical
Forston, James-Burmy, Bleeker, and Beyler (2013) note that opportunities for students to be active at school through recess or physical education are declining. Perera et al. (2015) pointed out that most students in the schools surveyed were not as physically active as the CDC recommends. The declines in physical activity in schools affect students from low-income schools the most (Barros, Silver, & Stein, 2009).

While the research reviewed thus far points out that there is strong evidence to suggest that physical activity can help facilitate learning, especially through components of attention and inhibition, the opportunities in school settings appears to vary greatly (Barros et al., 2009; Beyler, Bleeker, James, Burdumy, & Fortson, 2013; Perera et al., 2015).

As a result, researchers across child development are calling for more research looking at the relationships between physical activity and cognitive development (Hillman et al. 2008). This is an important area of research that has the potential to connect the growing body of neuroscience research to applied, educational practices.

School settings require students to remember information and inhibit motor movement throughout the day. For some students, this is an easy task, while for others this can prove challenging.

The overwhelming evidence points to exercise and physical activity affecting memory and executive functions, promoting positive performance in children and adults. In theory, the benefits to brain development through exercise would also translate to positive performance in school. There is emerging evidence that this is true, with research conducted both in the United States and internationally showing that exercise interventions demonstrate positive effects including improved school behavior (Fortson
et al., 2013), academic performance (Bunkertorp Käll et al., 2015), engagement (Mahar et al., 2008; Ma et al., 2014), and an improved school climate (Fortson et al., 2013).

2.2.1 Research in schools in the United States.

2.2.1.1 Program evaluations.

One of the most successful physical activity programs in the United States is Playworks. Playworks, a program where full-time coaches lead organized play during recess and class time, is designed to increase physical activity and foster social skills in students. Structured recess activities provide active games with a common set of rules that allow students to resolve conflicts that come up during play. Class time games involve teachers leading similar activities. Additionally, the program has older students (typically 4th and 5th grade students) act as role models for younger students during recess. Playworks programs are primarily in schools with high percentages of low-income students.

Between 2010 and 2012, 29 schools participated in a program evaluation on the benefits of Playworks by looking at five outcomes: school climate, conflict resolution and aggression, learning and academic performance, youth development, and student behavior. The program evaluation included 17 treatment and 12 control schools randomly assigned across the United States (Fortson et al., 2013). Overall, this evaluation found a positive effect on student’s use of positive language, perceptions of safety at school, decreased bullying, improved transitions between classrooms and activities, and better student behavior (Beyler et al., 2013).

Implementation of Playworks varied across schools, with schools that had recess in the past showing stronger implementation than schools without recess (Beyler et al.,
2013; Fortson et al., 2013). Schools that began implementing Playworks without a history of recess had difficulty getting students to recess consistently and in a timely manner, making it difficult for coaches to implement the program consistently (Fortson et al., 2013). Across the settings, 4th and 5th grade students at participating schools engaged in significantly higher levels of physical activity during recess compared to students in the control schools (Beyler et al., 2013). Students in Playworks schools were less likely to be sedentary during recess compared to control schools, using a direct observation of recess (Beyler et al., 2013).

Additionally, teachers reported they perceived significantly better behavior during recess and students were reportedly more ready for class after recess (Beyler et al., 2013). However, using direct observation during recess, evaluators did not observe significant differences in student behavior in Playworks schools compared to control schools (Beyler et al., 2013). Beyler et al. (2013) hypothesized improved conflict resolution partly accounted for the change in teacher perceptions; students were better able to resolve conflicts that arose in recess within the context of the Playworks program and conflicts were less likely to enter the classroom after recess. Fortson et al. (2013) also noted that junior coaches intervened and helped resolved conflicts at 71% of schools and in 21% of recess periods observed. Teachers were also more likely to report positive language, feelings of safety, and inclusive behavior among students in schools participating in the Playworks program (Fortson et al., 2013). Direct observation of recess showed that Playworks coaches promoted inclusive behavior in 57% of observed periods (Fortson et al., 2013).
Fortson et al. (2013) noted both teachers and students at Playworks schools reported positive perceptions of the transition from recess to classroom activities. In addition, they reported the transition from recess to classroom learning took less time following the Playworks recess (Fortson et al., 2013). Teachers did not report differences in perceptions of student engagement, homework completion or motivation. There were also no reported differences in reading and math proficiency for 3rd through 5th grade students in the Playworks schools compared to the control schools (Fortson et al., 2013). Academic performance was measured by the percentage of students who met proficient or advanced levels on state achievement tests (Fortson et al., 2013).

Overall, the perceptions of the Playworks program are positive. Teachers reported increased perceptions of inclusive behavior and conflict resolution, with less bullying and exclusionary behavior (Fortson et al., 2013). Teachers also reported improved transitions from recess back to the classroom (Fortson et al., 2013). Playworks is effective at increasing physical activity levels throughout the day, but most specifically during recess (Beyler et al., 2013). Overall, teachers and administrators reported feeling the program was beneficial to the school (Fortson et al., 2013).

In addition to the Playworks program evaluation, Burns, Brusseau, Fu, Myrer, and Hannon (2016) looked at a similar type of intervention, Comprehensive School Physical Activity Program (CSPAP), and the effects on student engagement in 3 elementary schools in the United States. The CSPAP program included a physical activity leader who facilitated increased physical activity opportunities during recess, before and after school, as well as in classrooms. A sub-sample of students in the participating schools were observed prior to the initiation, 6 weeks into the program, and at 12 weeks following the
commencement of the program. Burns et al. (2016) observed increases and improvements in classroom on-task behavior across grade levels. Burns et al. (2016) determined this by calculating a percentage of total classroom on-task behavior, which was then converted into a binary classification of either reaching or not reaching a minimum of at least 80% on-task for the total classroom. Physical activity levels, measured through pedometers, also increased by approximately 600 steps per day.

### 2.2.1.2 Randomized controlled studies in schools.

In addition to large-scale studies like the Playworks program evaluation, studies have looked at individual student time on task and classroom engagement. Howie, Schatz, and Pate (2015) looked at the duration of different physical activity interventions, finding that both 10- and 20-min in-classroom breaks involving running in place and jumping jacks led to significant improvements in math fluency, operational digit recall, and a trail making task compared to 5 min activity breaks and a sedentary control. Researchers observed differential effects, with girls showing the most improvements in math performance (Howie et al., 2015). In addition, students with lower cognitive functioning, lower school engagement, and higher fitness scores showed the most improvements (Howie et al., 2015).

Harveson et al. (2016) used a randomized crossover design to compare different types of exercise on cognition is high school students. In this study, 15-17-year-old students completed an aerobic condition, resistance exercise condition, and a sedentary control. Participants completed a Stroop test and Trail Making task in the 15-40 min following each activity. Harveson et al. (2016) observed increased performance on the Stroop task following both the aerobic and resistance conditions. In addition, participants
displayed improved performance on part A of the trail-making task following aerobic activity. Interestingly, gender had an effect on the tasks; boys outperformed girls on the Stroop Color task following all conditions and on part B of the Trial Making task following resistance and resting conditions (Harveson et al., 2016).

Looking at younger students, Webster, Wadsworth, and Robinson (2015) observed that a 10-min activity break in preschool classrooms led to increased levels of moderate-to-vigorous activity and increase in student’s on-task behavior. In this age group, the students who were most off-task improved the most following the activity break (Webster et al., 2015). This study provides evidence that even in students developing self-regulation skills, exercise reaching MVPA levels can have positive effects on school behavior.

2.2.2 Research in International school settings.

2.2.2.1 Program evaluations.

Schools outside of the United States have also implemented school-wide programming and changes to physical education programming. Bunkertorp Käll et al. (2015) studied the implementation of a play and motion intervention where physical activity doubled with 2 extra weekly physical activity classes in a school in Sweden. Bunkertorp Käll et al. (2015) compared this school to 3 matched control schools. Students in the intervention school had a greater chance of passing the national exam (Bunkertorp Käll et al., 2015). Additionally, teacher and parent reports of behavior revealed fewer conduct problems (Bunkertorp Käll et al., 2015). This was particularly true for girls, who were less likely to be reported as hyperactive by their parents and more likely to pass the national math exam. Bunkertorp Käll et al. (2015) noted that no changes
in hippocampal structure between the intervention students and the control students were observed.

Mullender-Wijnsma et al. (2015a; 2015b) investigated the effects of a classroom-based active lesson, F+V, compared to regular lessons in 6 elementary schools in the Netherlands. The F+V program combines physical activity with academic lessons (Mullender-Wijnsma et al., 2015). During academic lessons, students marched or jogged in place and had to complete specific exercise moves when asked to participate in academic tasks (example given, students had to jump in place for each letter when attempting to spell) (Mullender-Wijnsma et al., 2015).

During the F+V lessons, participants in the 2nd and 3rd grades spent on average 64% of the time in MVPA. There was a grade effect in the effectiveness of the lessons; 3rd grade students performed better on math and reading achievement following F+V; however, 2nd grade students performed significantly worse on math following the F+V lessons (Mullender-Wijnsma et al., 2015a). During the F+V lessons, 2nd grade students spent more time in MVPA, leading Mullender-Wijnsma et al. (2015a) to hypothesize that the task demands of the physical activity lessons interfered with their ability to learn the material.

Following the pilot of the F+V lessons, Mullender-Wijnsma et al. (2015b) looked specifically at how this program would affect students who were socially disadvantaged (based on parental education level). Mullender-Wijnsma et al. (2015b) found that socially disadvantaged children were significantly less on-task compared to children who were not socially disadvantaged prior to the intervention. The intervention program increased time on task for both groups, with no significant differences in the program effects by
advantage level (Mullender-Wijnsma et al., 2015), indicting that exercise had positive effects across parental education level.

2.2.2.2 Randomized controlled studies in school settings.

Randomized control trials in schools in Switzerland have shown that physical activity interventions may positively affect attention and processing speed. Jäger, Schmidt, Conzelmann, and Roebers (2014) investigated 20 min of a cognitively engaging sport sequence on updating, inhibition, shifting, and cortisol levels compared to a sedentary control in 6-8-year-olds. Jäger et al. (2014) compared pre-test levels to immediate post-test, as well as 40 min post cessation of activity. The results from this study support an inverted U release of cortisol, as cortisol levels increased and peaked 20-30 min after the physical activity intervention (Jäger et al., 2014). In addition, Jäger et al. (2014) observed stronger inhibition in the experimental condition at 40 min post activity.

In another study, 45 min of a cognitively demanding physical education lesson, including coordinative exercises, increased attentional performance in 5th grade students compared to a sedentary control (Schmidt, Egger, & Conzelmann, 2015a). Students in the experimental group displayed increased attention and processing speed, with no significant changes in accuracy (Schmidt et al. 2015a). Interestingly, Schmidt et al. (2015a) observed this increased attentional performance not immediately following, but 90 minutes after cessation of activity.

Schmidt, Jäger, Egger, Roebers, and Conzelmann (2015b) also compared 6 weeks of 2 different physical activity programs compared to physical education as usual. Team games, described as “cognitively engaging,” included modified basketball and floor-ball
with signals changing the rules of play, requiring participants to adapt their activity (Schmidt et al., 2015). The second experimental condition, defined as aerobic exercise, consisted of circuits or running tasks that included social interaction with peers (Schmidt et al., 2015). The control condition consisted of the typical national (Swiss) physical education curriculum (Schmidt et al., 2015). Students’ updating, shifting, and inhibition performance following the 6-week interventions were compared to a baseline pretest. The team game condition led to significant changes in shifting performance (Schmidt et al., 2015). Additionally, the two experimental conditions led to improved aerobic fitness compared to traditional physical education lessons (Schmidt et al., 2015).

Jäger, Schmidt, Conzelmann, and Roebers (2015) furthered this line of research by adding a cognitively engaging sedentary control (card game). This study was similar to the one completed by Best (2012), using a 2 X 2 comparison of cognitive engagement and fitness levels. Here students played a card game, listened to a story, participated in running activities, or participated in brief aerobic games requiring participants to remember rules (Jäger et al., 2015). Each lesson lasted for 20 min and updating, inhibition, and shifting were measured before and immediately following. Jäger et al. (2015) observed no effects based on condition, but when they separated participants into higher-fit versus lower-fit groups, they observed significant changes in updating following both exercise conditions. Additionally, participants with higher academic achievement scores displayed significant changes in updating performance following both exercise conditions compared to sedentary controls and lower-achieving peers.

In the Netherlands, van den Berg et al. (2016) investigated the effects of three different physical activity conditions on 5th and 6th grade classes. Each class participated
in three conditions lasting 12 min each: aerobic exercise, coordination exercise, and strength building exercise (van den Berg et al., 2016). Immediately following these conditions, participants completed the d2 test of attention and a measure of processing speed (letter digit substitution). While the researchers did not observe significant differences in performance on attention or processing speed between the three different types of physical activity, they did observe that participants improved performance on the processing speed task with time, indicating learning effect (van den Berg et al., 2016).

Looking at the timing of attentional benefits from physical activity interventions, Gallotta et al. (2015) investigated immediate and delayed attention in 116 8-11-year-old children in Italy. Children participated in cognitive exertion (curricular lesson), physical exertion (traditional physical education lesson), or a mixed cognitive and physical education (mini-games with changing rules) group. Gallotta et al. (2015) measured attention pre, post, and 50 min post; attention performance was affected by exertion type. Gallotta et al. (2015) also observed improvements in attention immediately after and 50 min following all conditions, indicating a learning effect may have contributed to their results (Gallotta et al., 2015).

Cooper et al. (2016) used a counter-balanced crossover design to investigate the effects of sprint-based exercise on executive functioning. British adolescents (ages 12-13 years old) completed a Stroop, Digit Symbol substitution, and Corsi Block test 30 minutes before, immediately after, and 45 minutes after either running sprints or resting trial. Cooper et al. (2016) observed reaction time on the Stroop was faster 45 min following the sprint condition. Reaction time on the complex Stroop tasks was quicker immediately following the exercise condition, indicating that there may be both an
immediate and long-term relationship between physical activity and reaction time (Cooper et al., 2016).

Spitzer and Furtner (2016) compared 30 min of basketball to 30 min of watching basketball in 13-18-year-old German children in a within-subjects crossover design. Participants completed a Flanker task before and after each condition. Spitzer and Furtner (2016) observed reaction times on incongruent Flanker tasks significantly decreased following the playing condition compared to the watching condition.

Ma, Mare, and Gurd (2016) observed classroom behavior of 7 3rd through 5th grade Canadian classrooms following 4-min high intensity activity breaks, FUNtervals. These breaks occurred in the classroom, led by teachers. In this repeated crossover study, the activity breaks had a relationship with off-task verbal behavior, but did not affect off-task motor or passive behavior (Ma et al., 2016). Children had fewer errors on the d2 test of attention following the activity breaks compared to no activity breaks (Ma et al., 2016).

Wilson, Olds, Lushington, Petkov, and Dollman (2016) investigated the effects of 10 min activity breaks in 5th and 6th grade Australian classes compared to passive lesson breaks. In this crossover design, each activity break condition lasted for 4 weeks, were led by teachers in the classrooms, and based on previous interventions (Take10 and Energizers). In this study, observers looked at on-task behavior 30 min before and 30 min following the different breaks (Wilson et al., 2016). Wilson et al. (2016) did not observe significant differences in on-task classroom behavior with the activity breaks compared to the passive lesson.
Taken together, there is a great deal of evidence that physical activity interventions in schools could be beneficial, but clear conclusions cannot be drawn without more evidence. From this review, the evidence points to at least 10-20 min of time spent performing physical activity (Davis et al., 2011). It is still unclear what type of exercise has the most significant effects, with most evidence pointing to MVPA that is cognitively engaging (Best, 2011). Additionally, the benefits of physical activity may not appear immediately following, but may take up to 40 min for children to experience maximum benefits (Cooper et al., 2016).

2.3 Limitations to the Current Body of Research

In addition to limitations pointed out during the review of the current body of research, there are additional limitations to the current body of research, both the laboratory based research and that conducted in applied settings. Timing remains one of the biggest limitations to this body of research. Research is beginning to answer the question of how long after physical activity can we see cognitive benefits. However, many questions remain, including how long does the exercise need to last and how long after cessation of effects are observed.

Additionally, it can be challenging to disentangle response inhibition from other executive functions. Many tasks that look at response inhibition require participant to hold stimuli directions in their working memory in order to complete tasks. In addition, connecting response inhibition to observable and meaningful behaviors in an applied setting still remains an area in need of more evidence. By having measures of response inhibition, and direct observation of classroom behavior, this study looks to extend
current research and provide more evidence linking response inhibition to student engagement.

The most consistent limitation to this body of research is the lack of empirical support. While researchers have started to explore the relationship between physical activity, exercise, and cognitive processes, this remains an area in need of more empirical support. In particular, the body of literature looking at the benefits of exercise in applied settings, particularly schools in the United States is lacking. This represents an area where more research could help inform ways for schools to better support healthy physical and cognitive development.
CHAPTER 3

METHODS

3.1 Design

This study used a within-subject repeated measure design where each participant experienced three different levels of intervention: 20 min of moderate physical activity, 20 min of non-MVPA physical activity, and 20 min of sedentary social engagement (free play with peers, including board games and Legos). The activities occurred during the students’ P.E. period and alternated throughout 9 days of the study with a counterbalanced order (Appendix B). Each student participated in the three different conditions 3 times each.

At the start of each session, participants were told which group they were participating in that day. Following this, the students returned to their classroom for instructional time. Participants’ academic engagement was recorded through direct observation using a scanning method. Each student was observed for 10 sec, with a momentary time sample for on-task behavior and a partial interval measurement for off-task behavior for a total of 5 min per student. The off-task rate was determined by percentage of interval off-task over the 30 min time period post activity session.

3.2 Setting and Context

This study took place at a public school located in an urban school district in the Mid-Atlantic United States. This school serves approximately 500 students from kindergarten through 5th grade. The school qualifies for Title 1 services with approximately 70% of students qualifying as economically disadvantaged. The school demographics are as followed: 55% African American, 15% Caucasian, 15% multi-
racial, 10% Hispanic, and 5% Asian. Physical Education occurs once a day for grades 1st through 5th, with 30 min of instruction and 15 min of recess time. Based on the P.E. schedule and teachers’ willingness to participate, this study was completed with first grade students. During the course of this study, first grade participated in P.E. daily from 1:10 – 1:55 PM daily. The activities occurred between 1:15 PM and 1:35 PM; the Go / No-Go occurred between 1:40 and 1:50 daily. Students returned to class and classroom observations occurred between 2:05 and 2:45 PM; the start times of the classroom behavior was dependent on classroom transition times between P.E. and classroom activity.

3.3 Participants

Using the program g*power 3, an apriori power analysis was conducted using an ANOVA with within- and between-groups comparisons. Results of that analysis suggested a sample size of 30 for a small effect size and a sample size of 9 for a medium effect size. With an effect size of 0.40 and a $p$ value of 0.05, a sample size of 25 was sufficient to attend to both Type I and II errors a priori (Cohen, 1992). Therefore, this study attempted to recruit 25 participants in order to have sufficient power.

Prior to recruitment of participants, the Institutional Review Board of the Human Research Protection Office at the University of Massachusetts Amherst and the Research Review Committee of the school district approved the study. The primary investigator recruited participants by going into each of three classrooms and presenting a brief overview of the study and requirements. Permission forms were distributed to each student in the classes and participants in the study were selected from the returned permission forms granting consent. Both students and parents were informed that
participation was voluntary. Of the students in the study (n =20), 50% were girls and 50% were boys; the study demographics matched the school demographics. During the course of the study, 1 male moved away after three days (Participant # 6) and another male dropped out after stating he only wanted to do the sedentary activity group (Participant # 9).

3.4 Measures

3.4.1 Process Measure – Accelerometers.

Immediately before the initiation of physical activity, Actigraph GT3X-BT (Actigraph Corp, Pensicola, FL) activity monitors were placed on each student’s non-dominant wrist. After 25 minutes of activity and prior to starting the outcome measures, students removed the accelerometer and returned it to the primary investigator. The same accelerometer was used for each student throughout the study. These activity monitors measure acceleration on 3-axes, and allow for measures of MET rates, steps taken, and physical activity intensity. Data collected from the accelerometers was analyzed using software ActiLife 6 (Actigraph, Pensacola, FL) with an epoch of 15 seconds. Prior to the start of the study, the Actigraph accelerometers were initialized and the information was downloaded after the first three days, after day 4 (prior to a holiday break), after day 6, and after day 9. In order to determine time spent in sedentary, moderate, and vigorous activity levels, the data were converted using 4 and 6 METs (Crouter, Flynn, & Bassett, 2015). Due to the placement on the wrist, a less desirable measure of activity compared to placement on the hip (Trost, McIver, & Pate, 2005), step count provides the best representation of activity.
3.4.2 Outcome Measures.

3.4.2.1 Go / No-Go.

Immediately following the activity groups, participants completed a Go / No-Go task using an iPad (Brainturk, Bodhi Labs). Go/ No-Go tasks are commonly used to research response inhibition as participants are asked to respond to a go stimulus quickly and withhold a response to a no-go stimulus (Chikazoe, 2010). Early research linked Go/ No-Go tasks to the P3 component and the Anterior Cingulate and parietal regions of the brain (Bokura, Yamagucki, & Kobayashi, 2001; Jonkman, Lansbergen, & Stauder, 2003). While the Go / No-Go task is generally considered a measure of response inhibition, it also requires other cognitive factors such as retrieval of the stop stimulus (Verbruggen & Logan, 2008). The Go / No-Go task is commonly used in younger students as it uses fewer trials, requires less stimuli held in the working memory, and is more engaging stimuli compared to other tasks like the Flanker (Howard & Okely, 2015).

Upon finishing their activity period, participants signed into an iPad and were presented with a 2 X 2 grid with three pictures of a sun and one letter (either P or R). During the trial run of the program, participants were provided a demonstration on how to complete the task and were able to practice. Students were directed to tap the P and refrain from tapping the R. On each day of the study students were given the same instructions to complete the task. In addition, signs were posted in the room throughout the study to remind the participants of the rules.

The BrainTurk app stored the data from each day and was available to download by the primary investigator. These data included a number of trials for both the Go and No-Go conditions, as well as the number of times the student tapped the screen. Based on
the number of No-Go trials and number of successful inhibitions, a ratio for each day was created per student indicating the percentage of successful No-Go’s for each day of the study.

3.4.2.2 Behavioral Observation of Students in School (BOSS).

The BOSS is a systematic direct observation system used to assess behaviors related to student engagement, specifically the amount of time students spend time on-task, and off-task behaviors (Shapiro, 2011). The BOSS divides on-task behavior to include active and passive engaged time and divides off-task behavior into three groups: verbal, motor, and passive. Engaged time, either active or passive, is collected using a momentary time sampling approach. Off-task behaviors are recorded using a partial-interval recording system (Shapiro, 2011).

Graduate and undergraduate students were recruited to help with student observations. During the week prior to the start of the intervention the principal investigator trained volunteers on the observation tool. Observers had the opportunity to practice using the observational system, live and in real time the day before the study started (all teachers were at a grade level planning meeting, so the date was used as a trial run). Two classrooms (Classrooms 2 and 3) had the same observer each day of the study. One classroom (Classroom 1) had three observers over the course of the 9-day study. An audio recording was used to cue observers to 10-second recording intervals. Observers followed the same protocol where they observed one student for 10-sec, then moved on to a second student and so on until they had completed a 10-sec observation for each participant. They then started with the first student again and continued this method of observation until each student had been observed for at least 5 min total (Appendix C).
Inter-observer agreement was collected for 5% of observations and was calculated agreements divided by agreements plus disagreements. Based on inter-observer agreement, Observer 2 in classroom 1 overestimated on-task behavior (IOA = 79%). However, the off-task behavior was more consistently observed (IOA= 87%) and was used as the primary outcome. A daily percentage for each student was calculated by dividing the interval off-task by total number of intervals the student was observed.

3.5 Procedures

Prior to the start of the study, each participant was assigned to an order of conditions that were counterbalanced. Immediately before the start of the student’s P.E. time, the primary investigator placed the accelerometer on their non-dominant wrist, and a sticker indicating the activity group. Center 1 was a high intensity aerobic condition, Center 2 was a low intensity activity condition, and Center 3 was the sedentary session.

The students were then instructed to join their group for the day. At the end of 20 min, each participant went to the classroom where the sedentary task occurred and completed the Go / No-Go task on an iPad (lasting approximately 1-2 minutes). As this time was then their recess time, students were allowed to play games on their iPads until the end of their P.E. and recess time. Participants then transitioned back to their classroom for instructional time, where direct observation occurred. Classroom teachers were kept blind to experimental conditions and which activity group students had participated in.

3.5.1 Condition 1: High intensity aerobic activity.

The goal of this condition was to have students engage in 15-20 min of MVPA through group games. Aerobic activity is linked to the most cognitive domains and is the most likely condition to provoke the changes if any of the physiological arousal theories
described by Barenberg et al. (2011) contribute to observed changes in outcome measures. This length of time has been shown to promote neurological changes, although 40 min promoted more changes (Davis et al., 2011). During this condition, students participated in high intensity interval activities where they competed against their peers to complete activity stations intended to reach moderate to vigorous intensity, running between stations. These activities included skater jumps, jumping jacks, and jumping games. This condition was designed to match the children’s activity pattern, where they typically display short bursts of high intensity activity (Bailey et al., 1995).

3.5.2 Condition 2: Low intensity non-aerobic activity.

This condition sought to answer the question: is moderate to vigorous physical activity necessary, or does movement in general promote positive changes? During this condition, participants were not expected to reach MVPA, and as such were not expected to see neurological changes other than arousal or priming (Suzuki et al., 2004). However, participants were active for 20 min. Here participants completed lower intensity games similar to their typical physical education lesson and included activities such as jump rope and low intensity races. In comparison to high intensity aerobic condition, this condition was characterized by more down and wait time between activities, leading to an overall lower intensity activity period.

3.5.3 Condition 3: Sedentary activity.

The goal of this condition was to engage participants’ cognitive engagement via interest, but with no physical activity. Participants were given the choice between playing board games, building Legos, or coloring. This condition served as a control condition. Participants interacted with other peers in this group in sedentary, unstructured activity.
On each day, participants chose each of the activities. This condition most closely matched a sedentary free-play period.

### 3.6 Data Analysis Plan

The results of this study were analyzed using an ANCOVA with the data from the accelerometer serving as the covariate. The outcome measures, Go / No-Go task and BOSS observation were analyzed across condition. This study looked at differences between the three conditions and also within each participant. The data was analyzed for a main effect by group, main effect by outcome measure, and the interaction between the group and the outcome measure.

*Normality of Sampling Distributions.* Prior to analysis with a repeated measures ANCOVA, the sampling distribution was analyzed to determine that it meets this assumption. This was completed using the software program SPSS. In addition, the independence of the outcome measures was tested through tests of sphericity.

*Homogeneity of Regression.* The homogeneity of regression was tested prior to completion of the ANCOVA. If this test fails, Tabachnick and Fidell (2001) offer alternative analysis, most specifically the use of a MANOVA.

*Linearity.* The linear relationship between the covariates and outcome measures was examined using scatterplots for each covariate and outcome measure. These scatter plots were reviewed to see if any curvilinear relationships are suspected; if so the covariate that produces nonlinearity will be eliminated.

*Handling of Outliers.* First, the outcome data was analyzed for univariate outliers. If however there are multivariate outliers when looking at the covariates, Tabachnick and
Fidell (2001) refer to Mahalanobis distance as the preferred method for determining multivariate outliers. This can be performed using the computer software SPSS.
CHAPTER 4
RESULTS

The purpose of this study was to determine if 20 min of moderate to vigorous physical activity can improve on-task / off-task behavior by improving response inhibition. Physical activity was measured through Actigraph accelerometers placed on the non-dominant wrist and converted to time spent in MVPA and step counts using 4 and 6 METs and an epoch length of 15 sec. Outcome measures for response inhibition and on-task / off-task classroom behavior were collected after students participated in a high-intensity interval activity, a lower intensity P.E. activity, or a sedentary free-play period.

It was hypothesized that students would demonstrate improved response inhibition and less off-task behaviors following the high intensity activity period. It was hypothesized that there would be a trend where the lower intensity activity group would show improvements to response inhibition and off-task behaviors compared to the sedentary activity and the higher intensity activity group showing greater improvements than the medium intensity group. It was hypothesized that changes in response inhibition would co-occur with changes to off-task classroom behavior.

The study utilized a randomized repeated measures design with each student participating in each of the activity conditions over the course up to three times each. Analysis of Covariance (ANCOVA) was used with step count as the covariate to test for statistically significant differences in performance on a Go / No-Go task and Off-Task classroom behavior.
4.1 Descriptive Statistics

Tables 1 and 2 provide descriptive statistics for the dependent variables that were analyzed to assess differences in students’ response inhibition and off-task behavior. Table 3 includes descriptive statistics for the outputs of the process measure, the acclerometry data.

4.2 Outlier Removal

Prior to analysis, a multivariate outlier analysis revealed one outlier at a significance level of 0.009. A box-plot of the off-task data for this participant indicated that the student had two incidences of over 70% off-task behavior. As a result, the data from this participant was removed from all subsequent analyses.

4.3 Analyses of Underlying Assumptions

The successful inhibition and off-task behavior data were examined in relation to the assumptions of ANCOVA, including normality, homogeneity of variance, the linear relationship between the dependent variable and the covariate for each level, and homogeneity of regression slopes.

The skewness of the Successful Inhibition data before the outliers were removed was -0.365; following the removal of the outliers the skewness was -0.363. These fall within the +/-1 range, indicating the outcome was approximately normal. The kurtosis of the Successful Inhibition data before the outliers were removed was -0.511; without the outliers, it was -0.634. This falls within the +/-1 range for normality indicating the outcome is approximately normal. Examination of the histogram and Normal Q-Q plots (Figure 1, Appendix D) indicates the data were within the limits of acceptable distribution.
The skewness of the Off-task data before the outliers were removed was 0.904; following the removal of the outliers the skewness was 0.826. These fall within the +/-1 range, indicating the outcome was approximately normal. The kurtosis of the Off-task data before the outliers were removed was 0.337; without the outliers, it was 0.310. This falls within the +/-1 range for normality indicating the outcome is approximately normal. Examination of the histogram and Normal Q-Q plots (Figure 1, Appendix D) indicates the data were within the limits of acceptable distribution.

The Shapiro-Wilk value for the Successful Inhibition data before the outliers were removed was 0.006; after the removal of outliers the Shapiro-Wilk value was 0.007. The Shapiro-Wilk for Off-task data before the outliers were removed was 0.000; after the removal of outliers the Shapiro-Wilk was still 0.000. The Shapiro-Wilk represents a highly conservative test of normalcy; therefore for both data sets the skewness and kurtosis values were divided by the standard error to provide a less conservative analysis. For Successful Inhibition, the skewness value is 1.769 (-0.363/0.210) and the kurtosis value is 1.520 (-0.634/0.417). For Off-Task, the skewness value is 4.193 (0.826/0.197) and the kurtosis value is 0.7908 (0.310/0.392). Using this less conservative analysis indicates both data sets fall within acceptable skewness for an analysis of variance calculation. The Levene statistics for Successful Inhibition was 0.165 and for Off-Task was 0.438, indicating there was homogeneity of variance in both data sets. In testing the homogeneity of regression assumption, the relationship between the covariate and the Successful Inhibition dependent variable was significant (alpha = 0.05), F (3, 129) = 3.746, p = 0.013). The relationship between the covariate and the Off-task dependent variable was not significant (alpha = 0.05), F (3, 147) = 2.544, p = 0.058). These results
indicate that significant findings with regard to Successful inhibition should be viewed with caution.

4.4 Findings

Subsequent to the evaluation of parametric assumptions, two separate 1-tail ANCOVAs were conducted to evaluate whether significant differences were observed in Successful Inhibition and Off-Task behavior following physical activity. A 1-tail analysis was considered appropriate as the a priori hypotheses were directional in nature. The 1-tail approach places the rejection region of the ANCOVA all on one side of the distribution and increases power of the analysis. In each case, the independent variable, activity level, included three levels: High-Intensity Physical Activity, Low Intensity Physical Activity, and Sedentary Free-play. The covariate was the step count of the participant during the activity period.

Results of the ANCOVA for Successful Inhibition indicated a significant main effect for group (F (2, 129) = 5.620; p. = 0.005; see Table 4). Follow-up between group post-hoc analysis indicated that the high intensity group outperformed the low intensity physically active and sedentary groups. Results of the ANCOVA for Off-Task Classroom Behavior yielded non-significant main effects (F (2,147) = 0.745; p. = 0.477; see Table 5).
### Table 1. Descriptive Statistics for Successful Inhibition (percent of total trials)

<table>
<thead>
<tr>
<th></th>
<th>Complete Data Set</th>
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<th>Outliers Removed</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
</tr>
<tr>
<td>High Intensity Activity Group</td>
<td>48</td>
<td>67.461</td>
<td>24.003</td>
<td>45</td>
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<tr>
<td>Low Intensity Activity Group</td>
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<tr>
<td>Sedentary Group</td>
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<td>61.209</td>
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<tr>
<td>Total</td>
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<td>23.097</td>
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</table>

### Table 2. Descriptive Statistics for Off-Task Classroom Behavior (percent of intervals observed)

<table>
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<tr>
<td></td>
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<td>Min</td>
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<tr>
<td>High Intensity Activity Group</td>
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<td>20.138</td>
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<tr>
<td>Low Intensity Activity Group</td>
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<td>26.980</td>
<td>18.345</td>
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<tr>
<td>Sedentary Group</td>
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<tr>
<td>Total</td>
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### Table 3. Descriptive Statistics for Step Counts

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<td></td>
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<td>High Intensity Activity Group</td>
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<tr>
<td>Low Intensity Activity Group</td>
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<td>182.267</td>
<td>53</td>
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<tr>
<td>Sedentary Group</td>
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<td>481.519</td>
<td>93.388</td>
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<tr>
<td>Total</td>
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<td>945.600</td>
<td>366.360</td>
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Table 4. Analysis of Co-Variance for Successful Inhibition

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step Count</td>
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<td>4940.423</td>
<td>10.232</td>
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<td>.073</td>
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<tr>
<td>Activity Level</td>
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<td>2713.611</td>
<td>5.620</td>
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<td>.080</td>
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<tr>
<td>Error</td>
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<td>129</td>
<td>482.853</td>
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<tr>
<td>Total</td>
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<td>133</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 5. Analysis of Co-Variance for Off-Task Classroom Behavior

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>η²</th>
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</thead>
<tbody>
<tr>
<td>Step Count</td>
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<td>1472.073</td>
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<td>.025</td>
<td>.034</td>
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<td>Activity Level</td>
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<td>213.866</td>
<td>0.745</td>
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<td>.010</td>
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<tr>
<td>Error</td>
<td>42210.020</td>
<td>147</td>
<td>287.143</td>
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<tr>
<td>Total</td>
<td>44667.529</td>
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CHAPTER 5
DISCUSSION

5.1 Summary of Findings

In children, physical activity and high levels of fitness appear to improve the allocation of attentional resources and increases cognitive efficiency (Hillman et al., 2011). Emerging evidence indicates that even acute doses of MVPA can lead to significant improvements in cognitive processing (Barenburg et al., 2011); however, applications of these changes in real-life settings, such as schools, remain unclear. The purpose of this study was to explore the effects of 20 minutes of moderate-to-vigorous physical activity, compared to lower-intensity physical activity and sedentary activity.

This study used a within subjects, counterbalanced design with first grade students from an urban elementary school in the South East United States. Over the course of nine days, students participated in specially designed activities during the students’ physical education class time, with participants wearing an Actigraph accelerometer measuring the amount of movement and steps. Participants spent 20 min completing high-intensity intervals, low-intensity typical physical education activities, or sitting and playing board games. Following each of the activities, participants completed a Go / No-Go task on an iPad and their classroom behavior was observed for approximately 30 min following the activity (5 min per student). Data collected included number of steps, the percent of successful inhibition (Correct No-Go trials/total No-Go trials), and off-task percent (total intervals off-task/total intervals observed).

Results of two separate one-way ANCOVAs indicated a significant main effect on successful inhibition for No-Go trials, but not for classroom off-task behavior.
Following the high intensity activity period, students were more likely to inhibit their response on the No-Go signal \((F = 5.62, p = 0.005)\) compared to physical activity as usual and sedentary activity. The effect size of 0.080 indicates a small-to-medium effect. Students were no more likely to be more engaged and less off-task following 20 min of activity, either moderate-to-vigorous or low intensity \((F = 0.745, p = 0.477)\).

Research question one asked if 20 min of MVPA could significantly improve successful inhibition of a behavioral response (response inhibition) compared to lower intensity physical activity and a sedentary control. The hypothesis of this study, that 20 min of MVPA would have a significant effect on participant’s response inhibition (as measured by the Go/No-Go task), was based on previous research and converging evidence showing that acute bouts of physical activity can significantly improve inhibition and executive functions. Consistent with previous findings, the current study provides further evidence that bouts of MVPA can improve behavioral response control compared to low-intensity physical activity and sedentary activity.

Previous research indicates that fitness levels are associated with better performance on inhibition, shifting, or responding to incongruent stimuli (Buck et al., 2008; Chaddock et al., 2012 Hillman et al., 2009b; Voss et al., 2012). Research has shown strong correlations between higher fitness levels in children and behavioral and cognitive inhibition. Higher-fit children demonstrate different neural patterns and energy activation compared to lower-fit peers. Specifically, greater fitness levels are associated with improved cognitive efficiency and cognitive strategies to approach tasks (Voss et al., 2012).
For example, Chaddock et al. (2012) observed that during incongruent trials, higher-fit participants initially had increased prefrontal and parietal recruitment; however as the task continued the cognitive activation reduced while task performance and accuracy remained intact. In contrast, lower-fit participants demonstrated consistent recruitment and activation throughout the incongruent trials and their performance declined over time. Because of these results, the authors suggested that higher levels of fitness are associated with better activation of neural processes and better response to task demands (Chaddock et al., 2012).

Hillman et al. (2009b) observed larger P3 amplitudes in higher-fit children compared to their lower-fit peers, along with fewer errors and reduced conflict during response selection. These results replicated the findings of Hillman et al. (2005) and were further replicated by Pontifex et al. (2011), where higher fitness was correlated with greater modulation of P3 amplitude and smaller error-related negativity (Pontifex et al., 2011). Pontifex, Scudder, Drollette and Hillman (2012) observed lower-fit children made more errors of omission and sequential orders of omission compared to higher-fit peers, indicating possible waning attention or cognitive fatigue.

Voss et al. (2011a) identified that higher-fit participants had less activation in the neural network associated with cognitive control on incongruent trials of a modified Flanker task compared to lower-fit peers. These changes were associated with greater accuracy, leading Voss et al. (2011a) to hypothesize that the cognitive response was more efficient. Higher-fit children’s brains are primed or ready to respond using less neural resources, while lower-fit children use reactive cognitive control processes (Voss et al., 2011a).
While these results are encouraging, there are criticisms to this line of research, including the possibility of selection bias. Each of these studies identified students by fitness levels, introducing the possibility that there are other factors that underlie the differences in performance. In addition, there is variability in the results, methods, and measures. Moreover, age and global cognitive functioning are also associated with better performance on Stroop tasks (Buck et al., 2008), indicating global cognitive performance and development may play a role in the allocation of cognitive resources. For example, Ellemberg and St-Louis-Deshênes (2010) observed that 10-year-olds demonstrated better cognitive flexibility and inhibition compared to 7-year-olds.

Fitness behaviors are also associated with executive functions and cognitive performance. In these studies, participants record their movement using an accelerometer for a week and complete outcome measures including measures of executive function. In the Netherlands, more time spent in sedentary behavior was related to worse inhibition performance and volume of physical activity was associated with better planning and execution of the Tower of London task (van der Niet et al., 2015). Longer time spent in MVPA or moderate PA was associated with improved attention performance in European adolescents (Vanhelst et al, 2016). Lastly, significant associations between aerobic fitness and inhibitory control were observed in American children, but time in MVPA during the study was not significantly associated with cognitive functions or academic achievement (Pindus et al., 2016).

Other lines of research suggest that physical activity interventions can improve cognitive performance. Davis et al. (2011) observed increased bilateral prefrontal cortex activity and reduced bilateral posterior parietal cortex activity following a 13-week
physical activity intervention in overweight participants. Participants demonstrated significantly improved planning following the intervention, with a dose response where 40 min (high dose) of physical activity increased planning performance more than 20 min (low dose) of physical activity. Both physical activity groups demonstrated improved planning compared to a non-activity control.

Looking specifically at attention, Budde et al. (2008) observed that 10 min of coordinative exercises improved performance on a test of attention compared to baseline performance. The coordinative exercise group improved their attentional performance more than a traditional physical education lesson while the heart rate levels for the two groups were similar (Budde et al., 2008). Gallotta et al. (2014) used similar methods, comparing a classroom lesson, physical exertion group, and mixed cognitive and physical exertion group. Participants in the physically active groups demonstrated higher working speeds and improved concentration scores immediately following and 50 min post cessation of activity (Gallotta et al., 2014).

Several studies have examined the relationship between physical activity and executive functions including shifting, updating, and planning. MVPA significantly improved planning in 4th grade students, but did not affect attention or simultaneous/successive processing (Pirrie & Lodewyk, 2012). In another study, 20 min of a sport sequence significantly improved inhibition compared to a sedentary control group, with the intervention affects leveling out 40 min post activity (Jäger et al., 2014).

In Schmidt et al (2015a), shifting improved following team games but not following aerobic exercise or a sedentary control. In contrast, Jäger et al. (2015) examined different activity types on updating, inhibiting, and shifting and observed no
significant main effects. Jäger et al. (2015) separated the participants by fitness level and academic performance. When looking at participants with higher fitness levels or higher academic achievement, physical activity did significantly improve updating performance for these groups.

Physical activity in school settings can also improve children’s performance on Flanker and Stroop tasks, similar to studies completed in laboratory settings. Cooper et al. (2016) observed that response times on simple Stroop tasks improved 45 min after exercise while response time to complex Stoop problems improved immediately following exercise. Reaction time on incongruent Flanker stimuli significantly decreased after playing basketball compared to watching basketball on TV (Spitzer & Furtner, 2016). These results are similar to those observed by Best (2012), where physical activity improved response speed and success at resolving interference stimuli on a modified Flanker task (Best, 2012). In contrast, sedentary and cognitively engaging activities did not have similar effects on response speed and accuracy.

While the results of this study support the previous research regarding research question one, the results diverge from the current body of research regarding question two. Research question two looked to extend the findings of question one to meaningful classroom behavior and applications to applied settings. This study looked to extend the current body of research by looking at whether 20 min of MVPA could significantly decrease off-task classroom behavior. The hypothesis of this study was that 20 min of MVPA would significantly improve classroom behavior and engagement. This research question is less well researched, with previous studies finding both significant main effects (Ma et al., 2014; Mahar et al., 2006; Mullender-Wijnsma et al., 2015a; Mullender-
In one of the earlier studies looking at the effects of physical activity in schools on classroom engagement, Mahar et al. (2006) observed that students participating in a classroom based activity program (Energizers) demonstrated improved on-task behavior by approximately 8% with a moderate effect size (ES = 0.60). Ma et al. (2014) also observed that a classroom activity program (FUNtervals) reduced passive and motor off-task behaviors in 4th grade students and passive, verbal, and motor off-task behaviors in 2nd grade students. Students with highest rates of off-task behavior on no-activity days showed the greatest improvements following the activity breaks (Ma et al., 2014).

Mullender-Wijnsma et al. (2015b) observed an activity intervention improved on-task behavior in participants with similar effect sizes as observed by Mahar et al. (2006): 0.60 at the midway point of the intervention and 0.59 at end of the intervention. Webster et al. (2015) observed that 10 min activity breaks lead to significantly improved on-task behavior in preschoolers with most off-task students improving by as much as 30% points.

In contrast to these studies, Wilson et al. (2016) compared an active lesson to a passive lesson and observed that neither significantly affected sustained attention or on-task behavior. The results of this current study are most similar to the findings of Wilson et al. (2016), where MVPA did not significantly improve on-task classroom behavior. There are two possible explanations for these findings. First, it is possible that limitations in the study and the execution of the study did not reveal an effect that is present.
Additionally, it is possible that previous studies incorrectly identified an effect that is not present.

It is likely that the lack of experimenter control in the classroom following the activity led to a failure to reject the null hypothesis. While participating in the study, the teachers were asked to continue instructions as usual. The typical activity for the classrooms was a read-aloud story followed by an independent writing activity connected to the book. However there were days where the classroom activity was different due to other factors, such as need to complete assessments or other changes to the daily schedule. Even small changes, for example having a story read aloud by a person versus an animated showing of a book, created variations within the classroom environment, leading to greater variability in the classroom observation data. While this decision was made to ensure recruitment of participating teachers and minimal disruption to the instruction, the lack of experimental control over the classroom environment is a major limitation.

Because of variability in the classroom environment, student engagement with the activity at hand played an important role in the on-task and off-task behaviors of the participants. Students who were engaged in preferred classroom activities, regardless of the type of physical activity they participated in, were more likely to be on task. Greater control over the classroom environment would be needed in order to decrease the effects of activity interest and reduce the chance of competing factors leading to error and failure to reject the null hypothesis.

Additionally, the direct observation tool may have lacked sensitivity to pick up changes in classroom behavior. It was noted by an observer that the degree to which a
student was off-task may have changed, but the differences were not picked up by the
direct observation tool. For example, it was noted that one student’s level of off-task
behavior changed as a function of the activity he participated in, but based on the coding
system of the observation tool he remained off-task. Following the sedentary activity, the
student was often out of his seat and required frequent redirections. In contrast, following
the high-intensity activity period, the student remained seated but engaged in fidgeting at
his seat. These changes were likely meaningful to the teacher, as the changes in behavior
required significantly less teacher direction. An improvement would have been to survey
teacher’s perceptions following instruction to get a better sense if they noticed changes in
students’ behaviors. Additionally, the observation tool may be better suited to older
students.

Another explanation for the results of this study diverging from the current body
of research is the population of the participants. This study took place in a Title 1 school,
where the majority of students live in poverty. While Mullender-Wijnsma et al. (2015b)
looked at socially disadvantaged students in the Netherlands, the effects of social class
and poverty on the positive benefits of physical activity and exercise on cognitive
functioning is not well studied. Mullender-Wijnsma et al. (2015) identify that students
identified as socially disadvantage were less likely to be on-task compared to socially
advantaged peers; in their population, physical activity did improve off-task behavior in
both groups of participants.

While less likely, it is also possible that previous studies identified an effect of
physical activity on on-task/off-task behavior when in fact the results were due to
regression to the mean. Of the studies that found significant results, two of the three
noted the most significant change in students who were the most off-task during control observations (Ma et al., 2014; Wilson et al., 2016). In addition, some studies have relied on separating the population of the study by fitness level, cognitive functioning, or academic achievement in order to obtain significant findings (Jäger et al., 2015). Continued research is needed to further explore the relationship between bouts of physical activity and classroom engagement in order to better understand these findings and in order to understand additionally underlying factors that may play a role in the effects.

5.2 Limitations and Future Directions

The largest limitation and threat to internal validity to this study is instrumentation. Agreement between observers was not as high as preferred. This highlights a need for better and more comprehensive training for the observers. Replication of this study with stronger inter-observer agreement, particularly for on-task behaviors, would be needed in order to improve upon this study. This would also allow for more detailed analysis of the classroom observations. For example, Ma et al. (2014) observed brief bouts of high-intensity activity decreased motor, passive, and verbal off-task behaviors differentially. Ma et al. (2014) noted there were also differences in the changes to off-task behaviors based on grade (2nd grade and 4th grade). With improved observations, these differences could be looked at with validity.

There were also measurement errors due to the placement of the accelerometers. The Actigraph accelerometers were placed on the wrist; a better location would have been the hip. The hip is considered the most effective placement for valid and reliable measures for the Actigraph (Crouter et al., 2015). This would have improved the
calculations of activity level using the acclerometry data. Crouter et al. (2015) highlight that measurement using the wrist placement in children has large individual errors. Replication of this study using a hip placement would provide better information on the level of activity for each participant and provide a better estimate of time spent in MVPA.

Another major limitation to this study is the effect of testing. Participants completed the same task each day and could have improved their performance as a function of learning, confounding the results for research question one. In one study, the participants improved performance on outcome measures over time, indicating a testing effect (Gallotta et al., 2015). This study used a counterbalanced-crossover design in an attempt to reduce this threat to validity, but it remains an important limitation. The counterbalanced design also provided protections against sequencing as a threat to validity.

It is also possible there was some diffusion of treatment. Participants completed the Go/No-Go task in the same room by classroom. Therefore, students participating in different activity groups completed the outcome task next to each other. Additionally, participants in different levels of activity then interacted in the classroom. For example, a participant in the high-activity treatment condition was at times paired with a participant in the sedentary-activity treatment condition in the classroom, leading to the potential of diffusion of treatment across both outcome measures.

This study was designed to occur over a brief period of time in an attempt to protect against maturation and historical events. This study took place during a three-week period of time that included a break in the school routine due to the Thanksgiving holiday. This timing could have introduced the chance of an event occurring at home that
was unaccounted for, creating the possibility of an historical event threatening the study’s validity. However, the short duration of the study makes it unlikely that any significant maturation occurred.

Using a within-subject method, this study intended to protect against selection bias. However, the participants selected were a balance of students typically off task and those that are not typically off-task. This was intended to create intervention groups that could be more easily managed, but may have introduced a selection bias. In addition, the participating school is a Title 1 school; this may have also introduced a selection bias based on the school environment and population of students.

One limitation based on the selection of participants is the age studied. This particular age group is also challenging at times to elicit compliance. For example, one student (Student 9) refused to continue participating in the physical activity groups. This is an age group where students tend to struggle more to follow directions, especially in less structured times, which likely affected both the study conditions and the classroom observation period. This limitation likely led to variability that may have accounted for the non-significant findings for off-task behavior.

Attrition occurred during the study, likely affecting the statistical power and subsequent analysis. On the first day of the study, one student reported to the primary investigator that she had physical activity limitations and was removed from the study prior to the initiation. Additionally, one student moved out of the area after three days of the study, and one student refused to participate in the physical activity conditions following day four of the study. This highlights a limitation and possible area of further research.
Student interest has recently come out as an important variable in looking at the effects of physical activity on the following cognitive performance. Student 9’s preference to only participate in the sedentary activities highlights that interest and motivation may play a role in the interaction of physical activity and benefits. In exploring cognitive engagement, physical activity, and cognitive and behavioral outcomes, it may also be important to consider individual preference and interest. This represents an area that as research continues to focus on cognitive engagement may emerge as an important moderating factor.

Lastly, there are some limitations to this study due to statistical conclusion validity. Due to attrition, the study ended up with fewer participants than initially intended, possibly leading to low power. In addition, the data initially did not meet the assumptions necessary for a parametric analysis and an outlier participant had to be removed.

There are also limitations to this study regarding the external validity. As mentioned before, this study took place in an urban school in the United States. This is a particular population and the results may not translate to other populations and population validity. Much of this research base is based on international studies, most taking place in Europe and Canada, making comparisons to American children and students more challenging. It is possible that different socio-cultural factors, both at home and school affect the ability to apply these findings to other populations.

More research is needed looking at differences by groups in order to improve population validity of these results. For example, Davis et al. (2011) point out that performance on the Cognitive Assessment System can vary by sex and race. There is
emerging evidence to suggest that there is an interaction between sex and positive effects of physical activity; however, this requires more research in order to better understand the relationship. In addition, few studies have looked specifically at the interaction between race, socio-economic status, and other socio-cultural factors and physical activity.

Another limitation to this current study is the possibility of reactive effects of experimentation. Participants were aware that they were participating in a research study and while they were blind to the specific outcome variables, they were aware of the classroom observer following. It is likely that some of the participants changed their behavior, even slightly, due to the effects of experimentation. This is a difficult limitation to address given the direct observation of behavior. One improvement would be to videotape the classroom to minimize the observation effect.

One major area that needs more empirical evidence is the question of timing. How long following the cessation of activity are behavioral responses seen? Most research to date looks at outcomes in the hour following cessation of activity. However, Schmidt et al. (2015b) observed increased attentional performance not immediately following activity, but 90 minutes after. In contrast Jäger et al. (2014) observed positive effects to attention following exercise leveled out at 40 min post activity. Given the underlying pathways, the timing of the effects continues to present a challenge to researchers and requires more specific evidence regarding. Are improvements to cognitive processes immediate, or do they require time for the release of neurotransmitters and other factors in order to be observed? This is an important area of study that requires more empirical evidence to better understand in order to better observe the effects of physical activity.
5.3 Implications for Practice

This presents an area of exciting opportunity for future research. Given the possible positive benefits of exercise and specific, targeted physical activity programs in children’s neurological and academic development, this is an area in need of strong empirically sound research. In particular, more research looking at the connection between response inhibition and meaningful outcomes like academic behaviors including student engagement is also needed.

Exercise and acute bouts of physical activity, most specifically MVPA, have clear benefits to cognitive processes and structures. These benefits are likely triggered by a cascade of responses, including increased cerebral blood flow, neurotransmitters including dopamine and serotonin that go on to increase focus, attention, and behavioral flexibility, and the release of neurotrophin growth factors that prime the brain for the building of new neuronal connections. The results of this study provide more evidence that short bouts of physical activity can improve response inhibition in students as young as six years of age. This study adds to the growing body of literature highlighting the importance of both acute and chronic exercise and physical activity during childhood. In particular, 20 min of MVPA can have significant and positive effects on a child’s ability to withhold a behavioral impulse, or respond to a “stop” signal.

The implications of this in applied settings, such as schools, remains an important issue. It is clear that participation in exercise and physical activity promotes healthy cognitive functioning. It is therefore important to consider ways that educators, child psychologists, and parents can support physical activity and regular exercise in everyday life for developing children.
This study took place in a school district where physical education occurs daily for students. In fact, students participate in physical education for a minimum of 30 minutes (P.E. block is 50 min and includes a 15 min recess break). In contrast, many schools in the United States do not have daily physical education. The participants in this study have the benefit of regular, daily physical education. This study, along with the evidence reviewed throughout, highlight the importance of regular participation in exercise.

While this study failed to see significant changes to classroom behavior, there are also implications for the classroom setting. Many teachers report anecdotally that students need to move more often and that movement can improve focus and attention. In this study, participants demonstrated significantly improved response inhibition, but the link to applied settings remains ambiguous. However, improvements to response inhibition are likely important for academic success. Moderate to vigorous physical activity presents an interesting and exciting opportunity for those working with children given the body of research to date.
APPENDIX A

CONSENT AND RECRUITMENT MATERIALS

Are you interested in science?
Do you want to participate in a research study?

Who: Anyone in _______________’s class can sign up!

What: This science study looks at physical activity (i.e. the games you do in P.E.)
and how it can help you learn better.

When: 2 weeks in P.E. This group will rotate between playing board games and
different physical activity groups. Before P.E. ends you will play a game on the
computer/iPad.

How: In order to participate, we need you parent’s permission. If you sign up,
you may decide to stop participating at any time without needing to give a reason.

After the experiment is over, more details of the study and the results will be
shared with you along with some small prizes.

Please contact Ms. DeWitt if you have any questions. This is part of a research
experiment through the University of Massachusetts, Amherst.
Dear Parent(s),

Ms. Dewitt, our School Psychologist, is looking for student participants for a research project. We would love for your child to participate in it! Enclosed you will find a more detailed description. This study is looking at physical activity and its effect on classroom behavior following PE. If you agree, your child will participate in a special PE group where they will play sports games, have drill practice, or play a board game. This research study will take place during 9 days of school (dates: ____________). This will not interfere with their classroom learning. At any point of time, you can contact me with any questions or concerns. Also at any point of time, you can decide you no longer want your child to participate.

Student name: __________________________

Teacher name: __________________________

______As a parent/legal guardian, I DO give my consent and permission for my child to participate.

______As a parent/legal guardian, I DO NOT give my consent and permission for my child to participate.

Sincerely,
Brooke M DeWitt
Brooke.dewitt@vbschools.com
(757) 263-2723
Dear Parents/Guardians,

My name is Brooke M DeWitt and I am a graduate student in the school psychology program at the University of Massachusetts Amherst. This fall, I am planning on conducting a research study with students at Elementary School. The research looks at exercise and how it can benefit students in classrooms. PE teaching assistants will lead students in structures games before school and then students will take a brief assessment on reaction times. The assessment is similar to games found on tablets and smartphones. In addition, trained graduate students will observe students in their classrooms following the activities.

Your child’s teacher has agreed to have his or her class participate in this project. If completing the research is upsetting to your child in any way, he/she can stop participating at any time. I will not be recording personal student information and all data will be coded to protect student identities throughout the project.

Your child’s participation and your assistance in this project will help to inform current research on the benefits of physical activity on learning. If you are interested in looking at the reaction time assessment, I am happy to provide you with more information. If you have further questions about this project, please contact me at bdewitt@educ.umass.edu or my advisor, Dr. John Hintze at hintze@educ.umass.edu. If you have any questions concerning your rights as a research subject, you may contact the University of Massachusetts’ Human Research Protection Office at (413) 545-3428.

Thank you for helping me to move forward with my research project.

Sincerely,

Brooke M DeWitt, M.Ed
## APPENDIX B

**EXAMPLE OF COUNTERBALANCED SCHEDULE**

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### APPENDIX C

**OUTCOME MEASURE TOOL**

Behavioral Observation of Students in Schools

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APPENDIX D
HISTOGRAMS AND PLOTS OF DATA

Figure 1. Histogram and Q-Q plots of Successful Inhibition and Off-Task data

Successful Inhibition (No-Go)

Off-Task Classroom Behavior
Figure 2. Histogram and Q-Q plots by Activity Level

Successful Inhibition (No-Go)
Off-Task Classroom Behavior

Histogram
for Activity Level: High Activity

Histogram
for Activity Level: Medium Activity

Normal Q-Q Plot of Off-Task Percentage
for Activity Level: High Activity

Normal Q-Q Plot of Off-Task Percentage
for Activity Level: Medium Activity
Figure 3. Outcomes, Activity, and Covariate of Successful Inhibition (No-Go)
Figure 4 Outcomes, Activity, and Covariate of Off-Task Classroom Behavior
Percent Intervals Off-Task

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Legend:
- Low Intensity Activity
- High Intensity Activity
- Sedentary Activity
APPENDIX E

INDIVIDUAL STUDENT DATA

Percent of Intervals Off-Task
Student 1

Percent of Successful No-Go
Student 1

Percent of Intervals Off-Task
Student 2

Percent of Successful No-Go
Student 2

Percent of Intervals Off-Task
Student 3

Percent of Successful No-Go
Student 3
Percent of Intervals Off-Task
Student 13

Percent of Successful No-Go
Student 13

Percent of Intervals Off-Task
Student 14

Percent of Successful No-Go
Student 14

Percent of Intervals Off-Task
Student 15

Percent of Successful No-Go
Student 15
REFERENCES


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