THE EFFECT OF VIGOROUS INTENSITY ACUTE EXERCISE ON EXECUTIVE FUNCTION

by

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A dissertation submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Exercise and Sport Science

The University of Utah

August 2012

The University of Utah Graduate School

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ABSTRACT

The effect of physical activity (PA) and consequent influence on cognition within adult seniors has been widely published. However, there is a paucity of causal research relating PA and cognition to schoolchildren within an authentic setting. Also, little is known about the required intensity and dosage of PA to effect executive function (EF) change, or an optimal time for increased learning posttreatment. The primary aim of this study was to measure the effect of vigorous intensity acute exercise (VIAE) on mathematics test performance in a school setting, with the secondary aims of the study determining the effect of vigorous intensity acute exercise on trails test performance, and to consider whether there is an optimal time for learning post-PA.

Participants included 72 (males *n*=44) 8th graders from an urban middle school. Participants were split into two order groups that received both a single 20-minute bout of PA and a single bout of sedentary activity (SA) over a 2-week period. Four different math tests consisting of 10 previously validated questions were completed 30-minutes and 45-minutes post-PA and SA. Two Trails Making Tests (A and B) were completed 20 and 25 minutes post-PA.

During the PA bout, participants wore heart rate monitors to ensure work rate remained within the vigorous intensity zone as set using the CDC (2011) guidelines. Repeated measures ANOVA showed a significant interaction between treatment and mathematics tests scores $F(1, 68) = 14.420$, $p < 0.001$, $d = .9$, power of .963. Simple main effects for both genders were most significant at 30 minutes post-PA (male, $p = 0.02$, and

females, $p = 0.06$) when compared to the other math tests mean scores at different time points.

Due to order effects and normality violations, one can suggest, with caution, that an acute bout of vigorous intensity PA can help schoolchildren to become better prepared for math test performance. This may influence the amount and timing of PA opportunities throughout the school day. More research in an authentic setting is needed in order to compliment the literature.

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ACKNOWLEDGEMENTS

It all started when I was working as a K-12 cooperating teacher, spending many a humid semester guiding student teacher interns from the PETE program at Florida State University in Tallahassee.

Normally, I was the one asking questions about future plans, teaching philosophy, and commitment. It wasn't too long before my interns suggested that I could be making my own difference, in higher education, as a teacher educator.

A few years later, here lies my dissertation. It has been nothing less than a team effort, for I am not capable of writing this on my own and the people I have to thank are numerous in number. My committee members, to whom I owe the most debt, have been the most instrumental in this research effort. To Dr. Andrea White, 'the brain lady' – thank you. Your knowledge of cognition is unparalleled in the Exercise and Sport Science department. To Dr. Pat Eisenman, so wise in your wealth of experience, especially in how the body responds to exercise. Your help really came to fruition at comps time, a period that forever shaped my dissertation. I realized when I talked to you both how little I knew when before, I actually thought I knew a lot! To Dr. Darla Castelli – the leading researcher in the country in physical activity and cognition in schoolchildren, thank you. You have been hugely influential in this dissertation – you also have a substantial amount of good tunes on your IPOD (apart from Lyle Lovett). Dr. Castelli, many thanks, for the times, especially on the phone, and at AAHPERD, when

you lent a listening ear, and gave a lending hand. Thank you, Dr. James Sibthorp, for jumping in at the last moment when Dr. Williams had to drop out of the committee. Our summer meetings were always fun. I still don't know anything about research design and stats – but you made me laugh.

I would like to thank you, Dr. Barry Schultz, the chair of ESS, for putting your faith in me from the start, and for always having an open door and a 'Schultzism' wisecrack comment ready, never too far away. Dr. Schultz, the man, the legend, the genius.

I would like to extend many thanks to Caleb, Emalee, Leigh, and AJ for your help at the start of this work, and to Alfred Mowdood – a great resource, and an even better friend. Thank you Alfred, for the many breakfasts we shared over the last 4 years, even though you are a Buckeye.

Thank you to all those graduate students I have spent so many laughing hours with in the last 4 years; Brian, Fitni, Skip, Steve, Stephen, Tan Leng, Chad, Charles, Tim, Waller, You Fu, Brian, Ryan, and 'teacher', among many others.

In terms of my time at the University of Utah, I've spent virtually every day with my boss and my mentor, and the chair of my committee, Dr. James Hannon. I could wax rhapsodic about how you've helped me over the last 4 years in preparing me for the future, but the words wouldn't put justice to the truth. I literally owe so much to you, it would take thousands of Starbucks and many trips to Einstein's bagels to come close to saying thank you. Just know that these last 4 years have been the happiest of my working life, because of you, where you have become one of my very closest friends. I know our

paths will inevitably part at some time in the near future, and I am not looking forward to saying goodbye.

To Lynne, Georgia, and Bailey. Know, with every fiber of my body, that I love you. Thank you so much for following me to Salt Lake, and putting up with me throughout the years. There's nothing like my life with you, and there's nothing like you all. I cannot express deeply enough how much I love you.

Finally, most thanks to you, Jesus, my Lord, Savior, and friend. You stirred my spirit, and engineered my circumstances, so that I would end up here in Salt Lake. Thank you for your endless provision, mercy, grace, and love. Without you, I am nothing. Amen.

CHAPTER 1

INTRODUCTION

Background and Statement of the Problem

The No Child Left Behind Act (NCLB), introduced by President George W. Bush in 2001, sought to raise the educational values of American schools through standards-based education reform. The act was geared toward gaining greater accountability for academic results from schools, giving states and communities more freedom, increasing choices to parents, and compelling teachers to use more proven educational methods based on research.

In 1983, the Nation at Risk document suggested that PE and Drivers Education were 'fills' in a secondary curriculum and should therefore be removed. However, Congress (1987) then passed Concurrent Resolution 97, suggesting schools should provide daily Physical Education (PE) for all students from kindergarten through to 12th grade. This resolution was not enforced; even though the government had intended for daily PE to be an integral part of the school curriculum, the demise of the subject from the school day has been initiated by many states. The US congress produced the document 'Goals 2000' (HR 1804, April 1998), which was a predecessor for the NCLB. This document proposed that the United States of America should be leading the world in science and mathematics. Since the inception of the act, the recommendations from

Healthy People 2020 targeting obesity, diabetes, and physical inactivity have been ignored as teachers strive to meet the demands for student academic achievement.

In 2010, the National Association for Sport and Physical Education (NASPE), in partnership with the American Heart Association (AHA), produced their annual report called the 'Shape of the Nation', detailing some alarming statistics. Even though PE has an objective of guiding youngsters to be physically active for a lifetime (Graham, 2010) school districts have not been able to find enough curriculum time for PE to 'help combat the nine million young people' (NASPE, 2006) who are overweight. According to the NASPE/AHA (2010) report, fewer than one- third of children aged 6 to 17 participate in 60 minutes of daily vigorous intensity activity. Inactivity is already an issue for those who are classified as overweight by the age of 8, for they have an 80% chance of becoming obese or overweight when reaching adulthood. Among children aged 6 to 11, 33% are obese, and 17% are overweight. In accordance with CDC cut points, 34% of students aged 12 to 19 are obese (this number having doubled since 1980).

Furthermore, when coupled with the barriers and constraints surrounding PE, the average PE budget in schools across the country equals $764 (per PE department) at the elementary level, to $1370 at the high school level, yet NASPE/AHA estimates that medical costs (to deal with obesity-related illnesses alone) will be $344 billion by the year 2018. The current decline in PE from the curriculum now means only three states--Alabama, Florida, and Louisiana--mandate their elementary schools to provide the NASPE guidelines of 150 minutes per week of PE, for every elementary grade, for the entire school year. Only three states Alabama, Montana and Utah, mandate their middle and junior high schools to provide the NASPE guidelines of 225 minutes per week.

Twenty-seven states require only 1 total credit of PE in high school in order to graduate. Only five states--Illinois, New Mexico, Iowa, Massachusetts, and Vermont--require PE for every grade K-12. Many states that mandate PE do not give any guidelines for instructional time; over half allow exemptions such as marching band or Junior Reserve Officer Training Corps as a substitution for the subject. Since 2008, the only recommendation for school aged children is 60 minutes of PA most days of the week. PA accrued during PE should contribute to these recommendations. Parents, teachers, and students concur that PE should be a daily part of the school curriculum, with 95% of parents being pro-daily PE in a nationwide survey (NASPE/AHA 2010). Seventy-five percent of parents and teachers also agree that PE should not be withdrawn from the curriculum to be replaced by extra academic classes (NASPE/AHA 2010).

This aligns with current research which shows that withdrawing PE time does not increase academic scores, and taking PE class does not compromise academic achievement in any way (Ahamed et al., 2007; Coe et al., 2006; Lindner et al., 1999). This research can be traced back to several prominent studies, such as Dwyer et al. (1983), who compared the reading and math skills of 5^{th} grade students who received more PE curriculum time than other students, yet found that the subject was not detrimental to academic grades. The SPARK study by Sallis et al. (1999) showed no adverse effects of PE time on student achievement over a 2-year period in California. Wilkinson et al. (2003) reported that decreasing PE time did not trigger an increase in academic achievement across 500 schools in Virginia. This research focus (that PE does not negatively affect academics) is continually being validated by recent studies that have produced similar results (Ahamed et al., 2007; Coe et al., 2006).

The trend of reduced time in PE, as indentified by the Shape of the Nation document (2010) is an issue that has sparked controversy on a national level, especially with regard to either remediation of students from the class, or the gradual withdrawal of the subject to make way for further academic study. However, there is a growing body of research that suggests that PE may not hinder learning, but instead be a contributory element in academic achievement.

Evidence

Within the evidence section of this document, the author commonly uses the term 'Executive Function' (EF) as an umbrella term to describe cognitive processes. It should be noted, however, that not all of the studies mentioned used this term specifically. Historically, Spirduzo et al. (1975) conducted seminal research that examined the relationship between cardiovascular fitness and memory, by examining reaction time in accordance with a lifetime of fitness. Kramer et al. (1999) were recognized as one of the first proponents to suggest that the relationship between PA and an increase in Executive Function (EF) was cause and effect. However, an earlier study by Davey et al. (1973) suggested physical exertion affects mental performance by raising arousal levels. These seminal works have led to an abundance of research that has mainly taken a correlational approach which has endeavored to show a positive relationship between the two variables of PA and academic achievement. Many of the studies reported positive relationships between those who were deemed either physically active or successful in fitness tests with test scores, and/or Grade Point Average (GPA). A comprehensive study that reported fitness scores data from the FITNESSGRAM battery of tests was positively correlated with the Texas Assessment of Knowledge and Skills test scores in The Texas

Fitness Study (2010) with 2.4 million high school students. The authors reported that students who were within the FITNESSGRAM healthy fitness zone had higher academic grades.

Trost et al. (2007), in a review article, reported significant positive correlations between PA levels and academic performance in many health surveys from countries ranging from Hong Kong to Australia. Nelson et al. (2006) reported that physically active students were 20% more likely to gain an “A” grade in Math or English in contrast to their sedentary peers. However, it should be noted that the issue of causality and extraneous variables such as socio-economic status make it more complicated to suggest that PA/ fitness levels are directly related to, and could be the cause for, higher academic performance. However, The Physical Activity Across the Curriculum study (PAAC) stated that schools that received a PA intervention showed an increase in academic scores when compared to control schools (Donnelly et al., 2010).

Recently a prominent hypothesis, namely the EF hypothesis, has become the frontrunner in attempting to explain the trigger mechanism between PA and EF. As elements such as planning, organizing, problem solving, and remaining on task (Brown, 2001) are part of EF, it is intuitive to suggest its consequential importance within a classroom learning setting. As learning takes place in the hippocampus, and previous research has indicated PA causes increases in neuro-physiological and chemical processes in the prefrontal cortex, it is salient to suggest that PA can increase certain attributes that may be complementary in a classroom setting.

One area of research that has helped to possibly bridge the gap between PA and EF is research connected with the emergence of trophic factors. A brain protein called

Brain Derived Neurotrophic Factor (BDNF) was discovered by Yves Barde and Hans Thoenen (1983). The function of BDNF is to enable the growth and survival of neurons by promoting communication between brain cells. BDNF was found to be present in the hippocampus of rats in a laboratory experiment at UCLA. The researcher experimented with rats who participated in PA through activity wheels in cages by comparing their brain activity with sedentary rats (Gomez-Pinella et al., 2002). This is significant because the hippocampus is the region of the brain responsible for learning and memory.

The work of Cotman et al. (2002, 2007), among others, has solidified evidence for the acceptance of neural plasticity, and the role of exercise within brain health.
Cotman et al. (2002) suggested that Insulin Growth Factor (IGF) and other growth factors transfer from the muscles during exercise and interact with the brain, and potentate neurotransmitter release. As well as the increase of neurons, the neurotransmitters dopamine, serotonin, and nor-epinephrine engage in the neuroplasticity process. These transmitters affect the ability of the learner by controlling impulsivity, and giving the learner more focus, attention, vigor, and positive self-esteem (an increase in executive function) (Cotman et al., 2002, 2007). The authors stated that acute exercise raises the levels of the serotonin, dopamine, nor-epinephrine, and BDNF. Even though animal science has shown an increase in hippocampus long-term potentiation after acute exercise, there have been few research studies that included controlled interventions involving school-age youth.

However, the effect of exercise on the EF of older adults has been well documented. Colcombe et al. (2003) in a behavioral review of 18 studies from 1966 to 2001, suggested 30 plus minutes per day of exercise produced the most positive results within older adults in terms of EF. Colcombe suggested a mix of both strength training and aerobic exercise produced the most benefit. Colcombe and Kramer, in 2003, also showed that fitness levels in aging adults helps to improve neuroplasticity. Colcombe and Kramer (2004) suggested that cardiovascular fitness helps to reduce deterioration of EF and brain structure. Colcombe et al. (2006) stated that aerobic exercise increased brain volume in aging humans, and that exercise helps to reduce brain tissue loss. Smiley Owen et al. (2008) suggested that aerobic exercise has a beneficial effect on tasks that are produced through the executive control function of the brain. Erickson et al. (2009) determined that aerobic fitness increased hippocampal volume in elderly humans, which in turn has positive effects on memory function.

There is now an increasing body of evidence that is attempting to apply adult paradigms to the issue of EF and exercise with young children. To many researchers, this is a natural continuum of the work of Colcombe and Kramer, in particular, in their work with older adults. It is only logical to suggest that if exercise had a positive effect on cognition with adults, then the statement could also be true with youth. This would have a possible positive effect in the school setting. Hillman et al. (2005) bridged the gap between younger children and older adults with a cross-sectional study design using a Flanker test as the measurement variable. Hillman et al. hypothesized that IQ, task performance, and participation in PA would be linked. The researchers found that PA significantly improved flanker test response time with the older adults, but not so much with younger children. Hillman did suggest that PA was beneficial to general and selective aspects of EF, essentially discovering that there was a 'fitness effect'. Even though Tomporowski et al. (2003) suggested that many long-term chronic interventions do not show an increase in behavior/ EF, there is some evidence that suggests that the effect of acute exercise on EF and behavior is positive.

Within an authentic school setting, Mezzacappa et al. (2004) stated that children who lack cognitive stimulation are linked with poor IQ and school readiness, yet Mahar et al. (2006) found that classroom-based activity programs such as the ‘Energizer’ interventions led to more on-task behavior. Ruibyte et al. (2007) stated that locus of control was connected to academic achievement whereas Budde et al. (2008) showed that PA connected with coordination improves concentration and attention performance. These studies concur with previous research that suggests exercise has a positive effect on mood (Morgan & O’Connor, 1988; Raglin et al., 1997).

Diamond et al. (2007) suggested that EF can be improved in 4 to 5 year olds if exercise were integrated into the school day, and numerous studies have shown that aerobic fitness improves neurocognitive function in children (Hillman et al., 2009; Hillman et al., 2005; Hillman et al., 2003; Tomporowski et al. 2003; Tomporowski et al. 2008). Almost 200 studies have looked at the impact of PA and physical fitness (PF) on EF. Sibley and Etnier (2003) conducted a meta analysis that showed a small but significant relationship between PA and EF in children across 44 studies. However, Sibley and Etnier also published a meta analysis in 2006 that showed there was no linear relationship between aerobic fitness and academic performance. It should be noted that this meta analysis only included 1 study out of 37 that involved school-aged children. Castelli et al. (2011), in the ‘Fitness Improves Thinking’ study, reported that intensity within a bout of PA was influential on cognitive performance and that monitoring heart rate as a measure of intensity was an important indicator of work.

Initial EF research has led to some studies that consider a relationship between acute exercise and academics, especially using math tests as the measurement variable. Gabbard and McNaughten (1993) examined the influence of physical exertion on math tests with 6^{th}-grade students during different times of the school day. Immediately after each period of exertion, a 90-second math test was given to the students. The researchers found that only after 30-40 minutes of acute exercise were there any significant positive differences in scores. Gabbard's original work in 1979 concentrated on the dose of PA prior to a math test. The tests were given shortly after exertion, and again, results were positive. However, Raviv and Low (1990) suggested that time of day affected mathematic performance as opposed to PA. Travlos et al. (2010) reported significance between PA and math processing speed and accuracy in a repeated measures study using an acute bout of PA as the independent variable.

Hillman et al. (2003) extended previous research by showing that cardiovascular activity aided EF in physically fit older adults. Castelli et al. (2007) furthered the research by showing a positive relationship between physical fitness and academic achievement with 3^{rd} and 5^{th} graders in Illinois. The author correlated FITNESSGRAM scores with the Illinois Standards Achievement Test. This cross-sectional research, with some control for socio-economic status, directly relates to a previous study conducted in California by Grissom (2005). Across the 259 schools on which Castelli collected data, no correlation was found between academic achievement and strength and flexibility, but there was a positive relationship between PACER test scores and the state test scores. Hillman et al. (2009) then researched the acute effect of cardiovascular activity on executive control of attention of school children, and assessed them with a school-based academic achievement test. Hillman found that after 20 minutes of submaximal aerobic exercise, there was an improvement in response accuracy on a flanker test, larger P3 amplitude, and better performance on a mathematics test as opposed to results of the same tests performed by a control group who had a resting session prior to testing. Hillman et al. (2008) also suggested the optimal time for learning was 16 minutes after exercise, as opposed to Gabbard's original work where students were tested almost immediately after exercise, rather than letting the heart rate return to normal, thus raising the issue of fatigue and executive function.

Significance

The practical outcomes of a study showing academic learning across time periods could affect PE as we know it today. Issues such as the timing of PE during the school day, and whether PE should be a daily occurrence on the school timetable, could become valid questions. The instructional content and activity time allocation during PE could be deliberated, because there are question marks about what should actually be taught in classes. This research does not suggest that PE should become in essence a health club with students active on gym-based aerobic equipment. However, quality PE lessons that concentrate on appropriate practice, at least 50% MVPA, and opportunities for student learning should be considered as paramount. Coe et al. (2006) suggested that in a regular PE class lasting 50 minutes, only 19 minutes were spent in moderate to vigorous physical activity (MVPA). The implications of suggesting an effect of acute exercise on learning may not just alter the content of PE, but the placement of classes in the school day. This research may also lead to a debate about the usefulness of daily PE as a tool in preparing for academic learning, and help to combat the remediation of students from PE class.

It is well documented that PA and PE helps combat health issues and behavior problems in schools (CDC, 2010; Hill et al., 1998; Mahar et al., 2005; Pate et al., 1995). It is also suggested that PE aids learning in an authentic setting. Smith and Luonsberry (2009) suggested that academic achievement can be measured in different ways, such as grades, SAT scores, concentration tests, exam scores, and that having PE as part of curriculum time offering 14-26% PA opportunities is beneficial for learning.

Within an authentic setting, Naperville 203, a school district in Illinois, follows a PE 4 Life™ curriculum, which includes heavy doses of aerobic activity weaved into their daily PE classes. These classes precede a student's toughest academic course.

Naperville changed the shape of the school day to incorporate what they believe is an important mechanism in the role of learning, aerobic-based PE. Naperville has infused cardiovascular activity into their curriculum, and in return has shown huge increases in academic scores, but this has not been published in any journals of note due to a lack of controlled research. This is an example of how significant this line of research can be in a practical school-based setting. It must be mentioned, however, that although Naperville uses PE as an integral cog within the school day, they have not published any scientifically rigorous data-driven research to back up their protocols.

There are many gaps in the knowledge relating acute exercise to learning. Questions regarding the 'dose-response' relationship have not been answered – meaning that it is unknown how much PA, and at what intensity it needs to be performed, is required to induce a cognitive change; only Hillman et al. (2009), Brisswalter et al. (2002), and Tomporowski et al. (2003) have recommended dose periods of exercise as to best enable maximal EF – however, these dose periods are all different in terms of time and intensity. There has been a lack of studies where achievement in mathematics has been the dependent variable, which is surprising considering that the literature possibly points toward the order of operations in mathematical computations and problem solving as being the most effected by an increase in EF, and therefore a rationale for a research study. Similarly there is a paucity of research that answers the issue of how long the effects of acute exercise lasts; only Hillman has suggested that the optimal time period for learning is 16 minutes after a period of 20 minutes of submaximal aerobic work (2008), and that the effect may last for 48 minutes postactivity (2003).

To address the experimental design issues of previous research, this study proposes to use a larger sample size than has been utilized in previous studies, and will use mathematics test performance as the primary dependent variable. This study will help to fill in the gaps and extend the knowledge of research by furthering Hillman and Gabbard's research to include time periods of testing after acute exercise, telling us more about the dose response relationship, and increasing the knowledge of work with school-aged children.

Purpose

The primary purpose of this study was to determine how a bout of vigorous intensity acute aerobic exercise impacted an increase in mathematics test performance. The secondary aims of this study were to determine if a bout of vigorous intensity acute exercise caused an increase in trails test performance, and to reflect on an optimal time for learning post-PA. Exploratory questions included considering any gender effects within the data, and to consider dosage and duration of treatment.

This study examined if a bout of PA has beneficial effects on math achievement. The findings of this study may influence the organizational structure of a child's school day. From previous research, one could suggest that there is a relationship between the two; however, this study advanced the existent literature by considering if the relationship has a cause and effect within an authentic setting. The researcher was interested in whether PE had any bearing on academic achievement, by asking if there is a positive effect on learning if the content in PE classes involves at least 20 minutes submaximal aerobic work. Due to research in the last decade, especially by Hillman, one could speculate that there are signs that acute exercise could have an effect on learning. However, it is not known how long that effect lasts or when the optimal time for learning occurs in relation to PA. From previous studies by Gabbard and Hillman, the time used for exercise prior to testing lasted between 20-40 minutes. Due to these gaps in the literature, the researcher proposed to test students in mathematics at differing time periods after a single acute bout of exercise. I anticipated that 30 to 45 minutes postactivity, a student's mathematical test score would increase when compared to a baseline score of a math test taken at an earlier date, as opposed to Gabbard's research (1993) where students were tested almost immediately postactivity. I hypothesized that the scores on tests taken at time periods later after exercise would continue to be above the baseline score, but then decrease back to baseline between 60-90 minutes after the initial bout. I would also expect to find more gain in mean scores of an experimental group compared to baseline testing as opposed to a control group that did not experience any acute exercise prior to testing, but received sedentary 'seat time' instead.

Limitations

The following limitations may affect this study:

1. Participants may not be totally motivated toward repeated measures of math and trails making tests.
2. Participants may not be motivated to exercise.

3. Participants may not follow instructions concerning exercising at submaximal heart rate.

4. Other learning/ extraneous variables may be a partial cause in terms of improved test scores such as socio-economic status, mood, or learning strategies.

Delimitations

The following delimitations were applied to this study:

1. Eighth-grade students at an urban middle school in the southwestern United States will be included.
2. Only those students who are able physically to participate in normal PE lessons will be included.

Assumptions

The following assumptions served as the basis for this study:

1. Participants accurately represented a normal population of middle school males and females.

Aims and Research Hypotheses

Primary Aim and Hypothesis

The primary aim of this study was to examine the effect of vigorous intensity acute exercise on mathematics test performance.

It was hypothesized that students who participated in an acute bout of aerobic exercise prior to testing would have greater gains in math test scores, as opposed to when they were sedentary (and received seat time prior to testing), and consequently would have no gains in their math test scores.

Secondary Aims and Hypotheses

There were two secondary aims in the study. The first was to examine the effect of vigorous intensity acute exercise on comprehensive trails test performance, a surrogate measure of visual attention and processing speed.

It was hypothesized that students who were exposed to an acute bout of aerobic PA prior to testing would have greater gains in trail test scores, as opposed to a sedentary group (who received seat time prior to testing), who would consequently have no significant difference in their results.

The second aim was to determine the time period after PA that is the optimal time for learning. It was hypothesized that the most beneficial time for learning would be after the heart rate has returned to resting. This optimal period was mediated to be between 16 minutes and 60 minutes, with any increase in performance taking place after 60 minutes not being directly related to the bout of exercise, based on the literature published by Hillman et al. (2009).

Exploratory Questions

The following exploratory questions were investigated:

1. Was the relationship between PA and EF moderated by gender?
2. How important was dosage of intensity on math test performance scores?
3. How long (duration) did the effect of acute exercise last on mathematics test performance?

Definition of Terms

For the purpose of this study, the following terms had these meanings:

Academic Achievement

"Academic achievement generally refers to a child's performance in academic areas" (United States Department of Education, http://www.ed.gov/).

Acute Exercise

"A single session of exercise, typically short but can last for 4 hours or more (Dishman et al. 2004, p. 439).

Executive Control

"Acquired skills that can be directly measured" (Royall, 2002, p. 377).

Executive Function

"Executive functions is an umbrella term for functions such as planning, working memory, inhibition, mental flexibility, as well as the initiation and monitoring of action." (Chan, 2008, p. 201).

Moderate Intensity Physical Activity

"On an absolute scale, physical activity that is done at 3.0 to 5.9 the intensity of rest. On a scale relative to an individual's personal capacity, moderate-intensity physical activity is usually a 5 or 6 on a scale of 0 to 10" (Neiman, 2011, p. 6).

Physical Activity

"Bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure" (Darst & Pangrazi, 2009, p. 326).

CHAPTER 2

REVIEW OF LITERATURE

The review of literature tracks the following themes.

To understand the behaviors of the human animal, vigorous bench and wet lab science paradigms need to be translated and applied to human contexts. The PA and EF relationship has been simultaneously researched in both human and nonhuman animals, with the most rigorous experimental designs being found in research conducted using rodents (Greenough et al., 1991; Van Praag et al., 1999).

Paradigms such as the EF hypothesis were established in animal and then applied to adult humans in nonlaboratory settings. Specifically, Kramer applied Greenough's theories to examine PA in relation to reaction time and accuracy of older adults who had experienced cognitive decline due to aging. This translation led to the development of several hypotheses. Around 2002, some scientists began to apply these theories to the developing brain to determine if PA and PF had similarly beneficial effects in children, although within the PE literature, a correlation design was utilized for most studies in trying to determine a connection between PA and academic achievement. Of late, there have been a handful of translational studies that have considered a cause and effect relationship within an authentic setting.

Physical Activity, Academic Achievement, and Executive Function

According to the NASPE Shape of the Nation Report in 2010, only two states in the entire United States legislate for daily PE. Curriculum time for PE has decreased, partly due to the change in direction toward academic performance as laid out in the No Child Left Behind (NCLB) Act in 2001. Other PA opportunities, such as recess, have been reduced, which affects cognitive performance and adjustment to school (Pelligrini et al., 2005).

The effects of the NCLB, through standards-based educational reform, currently drive curriculum design. This essentially has led to the demise of PE, among other noncore subjects from the school day, even though much research (Ahamed et al., 2007; Coe et al., 2006; Lindner et al., 1999; Sallis et al., 1999; Wilkinson et al., 2003) suggest that neither does remediation of PE in favor of extra academic classes increase grades, nor does the place of PE on the curriculum adversely affect academic performance.

This research has achieved little in slowing the cutting back of PE in schools by school districts, and current pedagogy research lines, such as motivation, curriculum models, and PA levels within school children has not helped to advocate for increased PE curriculum time. Principals are under pressure for their students to achieve high levels of academic performance, but it now seems possible that the programs they are cutting back may have legitimate claims on being a plausible answer to the growing problem of academic achievement in the nation’s schools. One could argue that the topic of grades maybe the quickest way of obtaining entry into an administrator’s office when considering the place of PE within the school curriculum.

In the 17 years that Naperville has run a PE4Life curriculum, the district has made strides academically. The school district, in 2001, entered their entire enrollment of middle school students to take part in the Timms test (Trends in International Math and Science Study). Normally this competition is led by countries such as Singapore, Chinese Tapei, and Japan. Five hundred thousand students participate in the test (which takes place every 4 years) across 60 nations across the world. Naperville 201 came in first in the world in science and sixth in math, and to many, the difference maker between Naperville and the rest of the participants was the daily acute bouts of aerobic activity which make up an integral part of the school day. One could legitimately argue that Naperville, a White, affluent area of Illinois, has an advantage in terms of socio-economic status (SES). However, PE4Life™ has been adopted into poor SES areas such as Titusville in Pennsylvania and results in test scores have risen by 17 to 18% above the national average in reading and math. Another pilot study took place in Kansas City where a PE4Life program, of again, daily PE led to a 67% reduction in suspensions. The difference in grades can be associated with the content change in daily PE class and the strategic placement of the subject in the school day. This could be argued as enough pilot evidence to suggest that utilizing a daily aerobic-based PE curriculum model could be advantageous for the entire American education system. It is important to note, however, that the PE4LIFE program has not published any data-driven research within any of the interventions that have taken place.

One scientifically rigorous study, which has attempted to enable the research focus to cross over into mainstream academic classes, was by Donnelly et al. (2010). Fourteen elementary schools participated in an intervention study – called the Physical

Activity Across the Curriculum (PAAC). Ten schools received the intervention, along with 4 control schools that did not. There were 1527 participants (814 in PAAC schools and 713 in control schools). Students were tracked, for 3 years, across 3 grade levels, while participating in 90 minutes of MVPA per week, which was woven into the fabric of academic lessons intermittently dispersed throughout the school day, and delivered by classroom teachers. The primary aim of the study was to attempt to reduce Body Mass Index (BMI) levels of the students (which data showed was only statistically significant at >75 minutes of physical activity per week for a PAAC school when compared to a control group).

The author also noticed an increase in academic grades for PAAC schools. The students were tested in reading, writing, mathematics, and oral skills using the Wechsler Individual Achievement Test-2nd Edition. Donnelly found that academic achievement in the PAAC schools increased when compared to the control schools. Importantly, for this line of research, the study design was a longitudinal and randomized control trial, the concept of the intervention being the comparison of schools that did or did not have a daily PA intervention dispersed throughout the school day (as opposed to previous literature that looked at fitness scores and merely correlated them to grades). In the Donnelly study, all between group differences were significant ($p < 0.01$), allowing the researcher to suggest that the relationship between daily PA and academic achievement needs to be pursued through well-designed and adequately powered studies.

There has been much data published on the correlation between academic achievement and PA. Many of these studies have been based on a longitudinal or cross-sectional approach to the collection of data.

The most common form of correlating data within the activity/ academics relationship is to compare fitness scores with test scores. The first comprehensive study of this kind was investigated by Grissom (2005), who collected data on 884,715 5th, 7th, and 9th grade students in California. The FITNESSGRAM test was mandated by the State Department of Education as a way of assessing fitness levels of students, and the author compared these results to reading and mathematics scores on the Stanford Achievement Test. Grissom found that as overall FITNESSGRAM scores improved, so did mean achievement test scores, and that these scores were significant, and linear in their relationship. Singh et al. (2006) implemented a similar study where academic test scores were aligned with FITNESSGRAM results and similar linear results were found as in the Grissom study. The researchers studied results from 253 elementary schools in California, taking the top 10 and bottom 10 schools in terms of results from the California Standards Test. Singh et al. reported that as FITNESSGRAM scores increased, so did the academic scores of the students. It was also apparent that the low scoring schools had less PE time, and a lack of certified PE teachers when compared to the top scoring schools. Martin et al. (2007) collected data from the nationally recognized President' Challenge Youth Fitness Test. The study linked the Iowa Tests of Basic Skills with fitness scores. The researcher suggested that healthy children learn better. However, even though there was a Pearson coefficient correlation of 0.19 ($p < .05$) showing statistical significance, the correlation data showed that only 3.6% of the variance could be explained by physical fitness, meaning little practical significance. Similar results have been found in research undertaken in different parts of the world. In Australia, Dwyer et al. (2001) found weak but consistent correlations between fitness results and academic achievement in 9000 schoolchildren between the ages of 7-15, whereas Themane et al. (2006) collected data on rural South African school children. The students aged 7-14 years provided the researcher with mixed and inconclusive results; boys who played more games had worse math scores, but girls who took part in outdoor activities had better math scores.

Of late, Eveland-Sayers et al. (2009) suggested that Southern Californian schoolchildren who ran the mile quicker scored higher on math academic achievement tests ($r = -.28$), but Chomtz et al. (2009) stated that reported PA outside of school was more important that PE participation on math scores.

The largest correlation study of all is the Texas Youth Study (2010). This study collected, through a legislated senate bill, a plethora of data that looked at varying fitness variables involved in 2.6 million Texas school children from 3rd through 12th grades. The study stemmed from data on major issues such as the obesity epidemic in children, the lack of PA participation, and the reduction of PE from the curriculum. The primary aim was to consider fitness variables and academic variables, including the Texas Assessment of Knowledge and Skills (TAKS), absenteeism, and negative school incidents. The results showed a stronger Spearman coefficient score of 0.54 for those students who were within the FITNESSGRAM Healthy Fitness Zone (HFZ) for Cardiovascular Fitness and achieved the standards required for the TAKS, as opposed to a moderate Spearman coefficient score of .30 for those students who were within the FITNESSGRAM Healthy Fitness Zone (HFZ) for BMI, and achieved the standards required for the TAKS. These scores were adjusted for SES, minority backgrounds, and school size. The overarching data supported a stronger correlation between fitness scores and academic achievement for middle school grades when compared to other grades, although potentially confounding variables were controlled using a mixed model regression analysis. Those schools that had the highest fitness scores had a better chance of being recognized as an exemplary school in the state, leading to the conclusion that higher fitness scores is an indicator of higher achieving schools. The overall effect of fitness scores on academics was significant, but small (Morrow et al., 2010).

Most of the research has been conducted with school age children although some studies have used college age students. Skibo et al. (2008) conducted a study which compared active to nonactive students (1016 students in total) at two universities in the southwestern United States. The results showed that there was a pronounced impact of cycling and running on academic scores. Skibo reported that it was possible that the exercise level was correlated to graduate and postgraduate education success. Belch et al. (2001) conducted a study of 22,000 freshmen at the college level across 3 years at a college in the southwestern United States. The researchers used an electronic scan system to record visits to the college recreation center by each student, and then correlated these data with the students' grade point average (GPA) scores and school rank. Their data showed that students who regularly used the recreation center had a higher first semester GPA, a higher first year cumulative GPA, and earned more hours in the first year than those students who did not use the recreation center for PA. This study has positive longitudinal data from a highly dense population even though there was a lack of a control group within the research design.

Although there are many limitations one should consider between a possible relationship between exercise and academics, across the body of evidence, many researchers have tried to address causality issues with their work. Bergin et al. (1992)

collected data to look at how leisure activity, motivation, and academic achievement may be linked. The researchers suggested that leisure time activity variables were a predictor of school achievement, but not as strong as the motivation predictor. Both variables (leisure and motivation) were considered weak when comparing the results of future educational goals (attending college) to academic achievement. Other studies, such as the one conducted by Ward et al. (2008), attempted to explain if athletic department budgets and expenditure had any relationship to academic scores at high schools in Arkansas. The results showed that there was no correlation between the two variables, but also, and possibly more importantly that there was no support for the claim that athletic budget reduces student performance. This is an important perspective to remember in light of studies that attempt to show a relationship between PE/ PA – that even if there is not a significant relationship (Frauhiger et al., 2002), there is evidence to suggest that PE/ PA is not detrimental in any way to academic scores (Lindner et al., 1999). In the work done by Ahamed et al. (2007), it was noted that even additional PE classes did not compromise student scores in academic classes. Murray et al. (2007) suggested in a review study that school health programs in general hold promise for improving academic outcomes. Tremblay et al. (2000) grouped together multiple variables of physical activity, self-esteem, and academic achievement. The researchers also took into consideration body mass index as a variable. The cross-sectional study was conducted in Canada, using questionnaires to gain data from 6856 6^{th}-grade students. The data were then correlated with student test scores in reading, math, science, and writing. The results showed that socio-economic status was a significant predictor of physical activity levels ($p < .001$), and that socio-economic status was a relatively strong predictor of academic achievement, with effect sizes 20% of a standard deviation linked with a one standard deviation increase in SES. The authors concluded that increased physical activity levels were linked to increases in self-esteem, lower Body Mass Index (BMI) levels, and a weak relationship with academic achievement.

This study is similar to the longitudinal research by Stevens et al. (2008) who collected data on 22000 families and children attending 1200 schools in the northeastern United States. The authors suggested, again, through data collected via a questionnaire, that outside of school PA was influential on math and reading scores. However, the research also showed that PE and math were the only variables that were not related. It should be stated that from the data collected it was apparent that PE was neither detrimental to, nor did it improve academic scores, and according to the author, the key component within exercise was that of intensity.

Although some researchers have concentrated on a link between activity and academics through data collected with regard to out of school PA, others have looked at the amount of PE curriculum time and correlated those data with grades. Carlson et al. (2008) investigated this relationship in a cross-sectional study within K-5 schoolchildren. The results showed that out of the 5316 students who were surveyed, a correlation was found between females who participated in the highest amounts of PA and math and reading scores. This association was not prevalent with males. The researchers again concluded that curriculum time given to PE had no adverse affect on academics. However, data associated with the achievement variable were not the primary aim on the study. Again, the data could be biased; the largest source of missing information in the data collected was time spent in PE. Tremarche et al. (2007) compared two schools in a research study designed to analyze the means of test scores with the variable of time allocated to PE. Fourth-grade students only were assigned to the sample. The students in school 1 had 28 hours of PE for the school year in 2001, and school 2 had 56 hours of PE. Independent t-tests scores of the Massachusetts Comprehensive Assessment System (MCAS) English and Language Arts, and Math Tests showed a significant difference in English and Language Arts ($p < .001$) in favor of the school that had more curriculum time for PE. There was no significant difference in the math test scores between the two schools.

Coe et al. (2006) assigned a longitudinal evaluation within 214 6^{th}-grade students in a public school in western Michigan. The students were assigned to four different groups, and given one semester of PE throughout the year. Data were collected on academic achievement, participation in PE via the System for Observing Fitness Instruction Time (SOFIT) instrument, and anthropometrical measurements. The researchers concluded that PE did not have any detrimental effect on grades; however, students who participated in vigorous PA, according to recommended Healthy People 2010 levels, had higher grades ($p< .05$) than unfit students.

In considering the role of PA on brain health within children, we may learn more about early intervention techniques and lifestyle changes, which may offset degenerative disease, but also the place of exercise as a stimulant for learning (Hillman et al., 2009). It would be salient to suggest that the aging population is not the only group who can reap rewards form PA and brain health–the research could not only translate to youth (especially as this target population does not have a fully developed hippocampus) but spill over into a practical school setting.

From a controlled settings perspective, Colcombe and Kramer (who are most recognized for their work with older adults) in their 18 studies meta-analysis in 2003, suggested that EF received the greatest gains after aerobic exercise (*ES* = 0.47). The researchers suggested that EF is mental processing, which involves scheduling, response inhibition, planning, and working memory. In comparison, a meta-analysis of 44 studies by Sibley and Etnier (2003) suggested that elementary and middle-school-aged children had the most to gain in terms of the effect of physical activity (*ES* = 0.40). They showed that math test improvement was at the lower end of their results in effect size (*ES* = 0.20). However, as mentioned previously, the robustness of some of these studies analyzed by the authors should be noted. Only nine were published in peer reviewed journals, due to lack of described methodology. Others, such as Tomporowski and Hillman, have examined the relationship between PA and EF in children through various executive control tasks such as Flanker tests, task switching, and response times. Hillman et al. (2003) suggested that response times after cardiovascular exercise benefited executive control; in 2005, the authors stated that a larger number of neurons were being utilized by high fit children in a response accuracy task after the children had taken part in the FITNESSGRAM test, and in 2009 Hillman examined the positive results of preadolescent children on flanker tests and academic tests after a bout of exercise on treadmills. The author then found similar results for response time again in 2009, in high fit children after completing the PACER test section of the FITNESSGRAM test.

Tomporowski et al. (2001) examined how submaximal aerobic exercise facilitated information processing; he also suggested in 2008 that the results of a bout of 23 minutes of treadmill walking did not positively influence task switching results. Davis and

Tomorowski (2007) assigned 94 overweight children from 7 to 11 years of age to a dosage of exercise treatments. The authors concluded that the high-dose treatment groups had higher posttest scores than both the control and low-dose exercise groups in varying executive control tests. Therefore, questions were raised again relating to the amount of dosage needed to elicit positive effects on the differing types of executive control skills. Tomporowski et al. (2003) also commented on the fact that exercise-induced arousal influences executive control performance but not in the predicted U-shape function. His conclusion in his meta-analysis was that high-intensity exercise led to quicker response times compared to low-intensity or nonexercise. Castelli et al. (2011) suggested that heart rate is an important measure of intensity, and that participation in vigorous activity may have beneficial effects on cognitive performance as opposed to lower intensity work. However, even though heart rate was predicted to be a significant contributor to increased EF, results showed that only those participants who engaged in intensity levels above the target heart rate zone showed an association with EF tasks.

There have only been five studies (which have lacked in scientific rigor) that have attempted to even consider the line of inquiry (within an authentic school setting) that started in animal science and moved then towards aging populations.

To examine the effects of PA on learning in a school setting, Gabbard and Barton (1979) attempted to replicate a laboratory experiment by Davey et al. (1973) by studying 106 2nd-grade boys. One main difference was that Davey had used a cycle ergometer on adults. The researchers arranged for the students to participate in a pretest with no exertion, and then gave the students bouts of 20, 30, 40, and 50 minutes of PA. They then posttested the students 5 minutes after each treatment, administering a 2-minute math test. In total, the students received six tests, which increased in difficulty. A one way ANOVA and Dunnett multiple comparison were used to analyze the computation scores. The results showed that after 50 minutes of PA, the math computation scores were significantly higher than in the other treatments. There was no difference in scores between boys and girls.

In opposition to the main effects of the Gabbard and Barton study, Raviv and Low (1990) suggested that time of day effected learning. The authors divided up 11 and 12 year olds into four groups. Two of the groups took part in a PE lesson, with the other two groups taking part in a science lesson. Both groups had the lessons twice–once in the morning, and once at the end of the school day. The researchers found that performance on a concentration test was significantly better at the end of each lesson, and during the morning as opposed to the afternoon. It is important to state that the authors were not testing mathematical ability, but concentration levels of the students.

As an attempt to better understand the effects of the timing and time of PA in the school day, Gabbard and McNaughten (1993) furthered the research by considering the variables of PA and the time of day that it was administered, to see if there was an effect on mathematical performance. 120 6^{th}- grade boys and girls were selected for the study based on math scores from the most recent standardized test. The dependant variable included a timed mathematical test of addition, subtraction, division, and multiplication. The test was given over 90 seconds, and consisted of 40 problems. The authors admitted that the problems were at the 3^{rd}-grade level. This deliberate notion enabled the students to answer questions, with the idea that none of the students could complete 40 questions in 90 seconds. Consequently the researchers were looking at concentration levels rather than mathematical ability. The 120 students were assigned to four groups, two being control groups and two being treatment. The groups then received testing of different durations, and at different times during the school day. The treatment groups received moderate intensity for 20, 30, and 40 minutes, walked 90 seconds to a classroom, and then took a 90- second math test.

The results showed there was a significant difference between time of day and PA duration. There was no real difference in scores after 20 minutes of exertion, but a significant difference after 30 or 40 minutes of activity. Also, the higher scores took place at 11:50am and 2:20pm as opposed to the 8:30am time slot, which showed no difference between the groups. The researchers argued that 30-40 minutes of activity allowed the students to enter into a ‘relaxation state’, which enabled higher math performance. In conclusion, Gabbard and Mc Naughten’s work suggested that duration of exertion was the most important trigger for any plausible link between activity and mathematical performance.

Travlos et al. (2010) extended the seminal work of Gabbard by using a repeated measures design that considers the effect of PE class on mathematical processing speed and accuracy on simple addition math problems. The students, within PE class participated in a series of four sets of 4-minute runs with a 4-minute walking recovery period in-between each running bout. At the end of the four sets, there was a 6-minute cool down period, after which the students then returned to the classroom. Altogether, there was a 16-minute period after PA before the students participated in the mathematical task. The students were asked to perform, within a 2-minute test, simple addition problems based on a structure of an A4 page with 7 columns with 50 rows of single digit numbers in each. The authors found that during periods one, three, and five, the participants increased both the amount of correct answers, and the speed of their answers when compared to their previous control scores. However, in period six (the last in the school day), the control group scores were higher than the postexercise scores. The authors suggested that motivational variables (based on being in school all day), and central and peripheral fatigue may be the cause of lower scores. It is important to note that the authors did not consider the intensity of the exercise in the study. They only asked the students to self- monitor their heart rate, which they did not attend to in the results in terms of any interactions. There is little attention paid to extraneous variables, such as previous fitness levels, or lunch/ food intake. The authors failed to answer any questions regarding dosage, intensity, and they did not consider the notion of the 16-minute period warm down period, (where the students proceeded to change, go to class, and take a math test). As the recovery time was so large during the class (4 minutes per 4-minute dose of physical activity), the author may have inferred that a single 4-minute aerobic run (i.e. , the last run the students participated in at the end of the treatment) is enough to improve test score. Or is it the culmination of the entire physical activity time? The author does not attend to these important questions within the study that will help to shape the future direction of this line of inquiry.

Physical Activity and Executive Function in Older Adults

The relationship between PA and EF has been well documented and heavily researched. Spirduso et al. (1975) compared data on various simple movement tasks and found that older racket sport athletes and runners performed better than sedentary adults. Not only did the physically active adults outperform older sedentary adults, they also outperformed younger sedentary adults. Although question marks have arisen within the PA/ EF relationship, the essence of ambiguity in some data is beginning to diminish. The extraneous variable of causality is always to be linked with this line of research. The first researchers to suggest a definite cause and effect relationship was Arthur Kramer et al. (1999). He reported aging, fitness, and neurocognitive function processes were not uniform in 124 older adults who participated in an aerobic training program. Some of the reasons for ambiguity in earlier PA/ EF research could be explained by Colcombe and Kramer (2003) in their meta-analysis. They suggested that differences in methodology, theoretical frameworks, and poor choice of executive control skills have muddled the overall results of the data collected. The researchers performed a meta analysis on 18 studies that took place between 1996-2001 and concentrated on two main hypotheses – one of which being that aerobic fitness training has a robust and beneficial influence on the cognition of older adults. The average performance of executive control tasks improved, by a 0.5 standard deviation regardless of the method, technique or task.

Since 2001, other studies have looked at the relationship between activity and EF. Craik et al. (2003) suggested that although EF peaks in the early 20s and declines with age, the decline is partially modulated by health and fitness. Colcombe and Kramer, in an exploratory study in 2003, also collected magnetic resonance scans in adults over the age of 55. Colcombe then confirmed the exploratory data as one of the first empirical links between cardiovascular fitness and the slowing down in decline of brain function. In a similar study of 165 magnetic resonance images, Erickson et al. (2009) showed that higher levels of aerobic fitness were correlated with a larger hippocampus. The researchers took care in controlling for variables of age, gender, and education. The scores for spatial memory performance also correlated with higher fitness levels. Colcombe, Kramer et al. (2004) collected data on 41 older adults, with no mental disabilities, and arranged for the treatment participants to perform, as a cardiovascular group, the Rockport 1-mile walk test. After the test, the adults participated in 17 trials of the Flanker test, all of this while being scanned by a magnetic resonance scanner. The data were then compared to a control group who only took part in stretching and toning treatment. The cardiovascular group had higher levels of attention control (by being able to block out 'interference') and greater activation in several cortical regions, than the stretching and toning only control group. The researchers concluded the effect of PA on executive function is greater than the impact on loss of gray and white matter in areas of the brain such as the frontal and temporal lobes.

There has been some work, of late, that has considered dosage and intensity of activity, and the lasting effects of long duration acute aerobic exercise. Results suggests an increase of arousal between the first and second hour (after 1 hour of acute exercise) but an impairment in processing speed, after 2 hours of exercise (Grego et al., 2004). This research relates to the data collected by Pontifex and Hillman (2007), who showed that reaction time and response accuracy was detrimentally affected <u>during</u> short bouts of acute exercise.

In summary, the findings from the older adult literature suggest that physical fitness, hippocampus volume, and both chronic and acute bouts of PA are beneficial to enhanced cognitive performance.

Mechanism Hypotheses

The PA– brain connection was first discovered in animal science. There is a plethora of research (a search on PubMed involving the words 'physical activity' and 'brain' yielded over 42,000 results). There has been a variety of hypotheses, mainly neurophysiological, that have attempted to explain how physical activity effects executive function in terms of a trigger mechanism; however, this area of research needs further work. These ideas can be separated into four types of hypotheses – speed hypotheses, visuo-spatial hypotheses, controlled hypotheses, and executive function hypotheses.

The speed hypothesis, which was first proposed by Spirduso et al. (1975), and Spirduso and Clifford (1978), suggested that the higher the physical fitness of an individual, the quicker the response time in research participated in by older racket sport and aerobic athletes.

The visuo-spatial hypothesis, which is similar to the game of 'Tetris',™ is connected with perceptual learning, visual storage, and spatial knowledge. This gives the brain the ability to flip or re-arrange a mental image, or to recall a new word written on a chalkboard. This form of spatial memory performance is also correlated with higher fitness levels, and larger hippocampus volume (Erickson et al., 2009).

The controlled hypothesis is connected to the concept that the brain is able to ignore outside 'interferences' and concentrate on the immediate task. This is important in an authentic school setting as the hypothesis is based on inhibition, and subsequent focus. Hillman and Kramer (2002, 2004, 2006) suggested that PA effects event-related brain potentials (ERP) and subsequent P3 amplitude, which may cause changes in executive function. P3 amplitude is connected with a change in electrical voltage in the brain activity, which takes between 300 and 800 milliseconds to attend to, and discriminate, when confronted by a stimulus (Hillman et al., 2005). These findings are similar to results produced by Dustman et al. (1990).

According to Tomporowski et al. (2007), children, until they reach around the age of 20, do not have fully developed frontal lobes (the decision making part of the brain). The brain rewires and recruits other parts of the brain to perform functions, such as the parts involved in learning. Therefore, the brain health reward of PA in children reaches much further than just the hippocampal activity. Hillman et al. suggested that the brain could still be reaping benefits from neurotransmitter production 48 minutes postactivity (2003).

Over the last few years, research has suggested that EF administers (by activating, organizing, integrating, and managing) elements of EF (Smiley Owen et al., 2009). For instance, it is well documented that executive control processes decline over the lifespan, in terms of processing speed, working memory, and short-term memory (Park, Reuter Lorenz, 2009).

The different EF models are considerably greater in number than any other hypotheses that have attempted to explain the PA-EF relationship. There are many different models of EF, such as the problem solving model (Zelazo et al., 1997), Miyake and Friedman's model (2000), cascade of control model (Banich et al., 2009), Lezak's conceptual model (2004), the working memory model (Baddeley et al., 2002), and the self- regulatory model (Barkley et al., 1997). More pertinent, however, are the elements of EF that relate to learning in the classroom. EF, according to Smiley Owen et al. (2009) is the ability to plan, schedule, and give attention to tasks.

Therefore, the EF hypothesis seems to be the most current in attempting to explain the relationship between PA and executive control in the classroom, as many elements of EF seem to be present when understanding how a child learns, and acts within a classroom environment.

Brown (2001) suggested that EF is split into six areas of executive control, each of these effecting academic learning. These six areas are: activation (the ability to plan, prioritize and organize); focus (the ability to focus, sustain, and shift attention to tasks); effort (the ability to regulate alertness, sustain effort, and to process information); emotion (the ability to regulate emotions); memory (the ability to recall facts from short-term memory); and action (the ability to regulate behavior). It is therefore logical to suggest the importance of EF as a precursor to successful learning. St Clair Thompson et al. (2006) suggested therefore that a student who cannot plan, update working memory, and shift mentally is at a disadvantage in the classroom in terms of staying on task. Diamond et al. (2007) suggests that PA can affect EF in children aged as young as 4 to 5 years old, whereas Castelli et al. (2011) reported that EF develops across the entire lifespan of a student, from 3 ½ years old to the early 20s.

As learning takes place in the hippocampus, and with current literature reporting that PA can produce a cascade of neurophysiological and chemical reactions that may alter executive control processes, one can understand how the EF hypothesis may best explain the ‘trigger mechanism’ required to elicit an executive response, especially within a classroom setting. It could be suggested, therefore, that hippocampus volume may be seen as a plausible mediating variable between PA and cognition (Chaddock et al., 2010). The future conceptual direction of EF, according to Best et al. (2010) is a mix of executive control theories that combine task shifting, controlled hypotheses (inhibition), and allocation of working memory.

Understanding the physiology of EF can be somewhat possibly categorized into two areas, that of cerebral blood flow, and trophic factors research.

Cerebral Blood Flow

Another competing hypothesis that may describe the EF/PA relationship is one surrounding cerebral blood flow. As brain function requires oxygen to function efficiently, it is intuitive to think that the presence of more O2 might improve effectiveness (Swain et al., 2003).

Dustman et al. (1994) was already suggesting that not enough is known about the exercise/ EF relationship almost two decades ago, although in 1984, they had suggested that aerobic exercise promoted increased cerebral metabolic activity, therefore reporting a possible mechanism, based on work with older adults. The idea of cerebral blood flow effecting executive function is one that others have reported in their research as a possible trigger mechanism (Ide & Secher 1999), suggesting a larger flow of blood to the brain during exercise and consequent possible growth of smaller blood vessels.

However, according to the Kety–Schmidt technique (1944), cerebral blood flow is constant during exercise. Others, such as Jorgensen Perko, Hanel, Schroeder, and Secher, (1992), suggested that middle cerebral artery mean flow velocity reflects changes in cerebral perfusion during exercise, after getting participants to reach a heart rate of at least 110 beats per minute in a dynamic physical activity. Secher and Quirstorff (2008) reported that lactate and glucose fuel the brain during exercise, therefore compounding a theory that links nutrients with brain function. Their research agrees with previous findings (Chodzko-Zajko et al., 1991) in the work with older adults and declining attentional function.

Trophic Growth Factors

The previous hypotheses have been observable as behavioral responses to stimuli; however, increased brain weight and improved cognitive response in rodents, as a result of aerobic training, suggested that there may be physical function changes to the brain (Greenough et al., 1991).

This concept of 'synaptic plasticity' was first proposed by William James in his '*Principles of Psychology'* book in 1890. Since then, scientists have thought that only certain parts of the brain were 'flexible' and 'plastic', but of late, the work of Cotman et al. (2002, 2007), among others, has solidified evidence for the acceptance of neural plasticity, and the role of exercise within brain health. Cotman argued that exercise facilitates synaptic plasticity (a change in response between two synapses), which is based on Hebbian Theory (Hebb, 1949), where the author suggested that cells that fire together grow new connections, allowing more capacity for communication.

This functional and physical change may be facilitated by the presence a brain protein called Brain Derived Neurotrophic Factor (BDNF). This protein was originally revealed by Yves Barde and Hans Thoenen (1983). The function of BDNF is to enable the growth and survival of neurons by promoting communication between brain cells. Seminal work in animal science by Isaacs and Greenough (1991) has led to work by Andersen et al. (1996), who found that rats who exercised with more complex motor tasks had a larger increase in synaptic growth than rats in an activity wheel group. BDNF protein was found to be present in the hippocampus of rats in a laboratory experiment at UCLA (Gomez-Pinella et al., 2002). The researchers experimented with rats who participated in PA through treadmills in cages by comparing their brain activity with sedentary rats. To the surprise of the researchers, the hippocampus (the area of the brain responsible for learning and memory) illuminated during PA, so much so that the researcher replicated the experiment immediately and found the same results. This research has since been copied by Tong et al. (2006), and Soya et al. (2007), who reported similar data. BDNF was also discovered in the hippocampus of rats after exercise (Russo-Neustadt et al., 2001). Eichenbaum and Howard (1992) suggested that not only did the hippocampus play a critical role in memory function, but that every aspect of the learning experience appeared to be encoded within it. With this in mind, it is important to connect BDNF to the hippocampus. There are many cases which show that BDNF is present in the hippocampus after physical activity (Isaacs et al., 1992; Neeper et al., 1995, 1996; Russo-Neustadt et al., 2001; Zafra et al., 1991).

Cotman et al. (2007) suggests that BNDF, insulin growth factor (IGF), and vascular endothelial-derived growth factor (VEGF) are the major growth factors that transfer from the muscles during exercise and interact with the brain, and potentate neurotransmitter release. Cotman et al. (2002) suggested that these three principal growth factors mediate the effects of exercise on the brain. According to the authors, BDNF enables more growth and longevity of neural connections, through more opportunity for the wiring of cells, and for a longer lifespan through protection via a strengthened myelin sheath. As well as the increase of neurons, the neurotransmitters dopamine, serotonin, and norepinephrine engage in the neuroplasticity process. These transmitters affect the ability of the learner by controlling impulsivity, and giving the learner more focus, attention, vigor, and a positive self-esteem. Russo- Neustadt et al. (2001) suggested that PA could lead to a decrease in neurotrophin deficit when dealing with stress, and Spina et al. (1992) reported that BNDF helps the survival of dopamine neurons when looking at embryonic rats. Sauer et al. (1993) partially disagrees with Spina by suggesting that BDNF does not help dopamine survival, but aids in dopamine function. As it is well known that dopamine aids motivation and attention, whether BDNF helps either the survival or function of the dopamine neuron is a moot point. It has also been recommended by Mamounas et al. (1995) that BDNF promotes the survival and growth of serotonin axons, after his research with rat brains. Serotonin is available in pharmacies in the form of antidepressants; serotonin regulates mood by elevating state. Both serotonin and dopamine are important neurotransmitters that are positively affected by exercise.

It is well documented that the hippocampus reduces in size with age, but that PA can help to minimize this. Cotman et al. suggested in their review paper (2007) that the benefits of PA on brain health are numerous, such as benefits on learning and dealing with depression, neurogenesis (birth of new neurons), and angiogenesis (growth of new capillary blood vessels). They suggested that IGF and BDNF mediate behavorial improvements, and IGF and VEGF supports exercise-induced angiogenesis and neurogenesis. Cotman et al. reported that growth factors, especially IGF-1, ‘orchestrate’ brain responses to exercise. This includes an interactive ‘cascade’ of signaling that reduces peripheral risk factors for cognitive decline such as 'inflammation' which causes neurodegenerative diseases.

Cotman et al. (who originally thought that BDNF was only apparent in the motor regions after PA) now suggests that BDNF lasts for 2 weeks (postexercise) within the brain, after building BDNF production levels by exercising 3 to 4 times a week. Dishman et al. (2004) reported that it took a week for rats (working on activity wheels) to produce BNDF in their hippocampus.

There is little consensus regarding the underlying mechanisms that may facilitate or inhibit cognitive performance. However, it is highly unlikely that there is a single source, but instead a series of interactive effects that are influential. Researchers such as Hillman et al., (2007), and Tomporowski et al. (2003, 2007), who are highly regarded in their field of research, have suggested in their publications that the mechanism that mediates between aerobic exercise and EF is unknown; although there are plausible answers not enough is known about the physiology of exercise to determine a mechanism, and more research is required in the area before they would feel comfortable enough to pass judgment.

However, one can offer some responses to the trigger mechanism question based on previous literature and reports from findings, although, it must be stated, theories connected with younger populations are unsubstantiated. It is possible to draw from animal studies and work with older populations and consider the work of Dustman, Cotman, Erickson, Hillman, Tomporowski, and Kramer and attempt to link their research to the adaptation debate.

Trails Making Tests and Executive Function

The Trails Making Test A (congruent task) and B (incongruent task) are two tests of visual attention and processing speed (Gaudino et al., 1995) that were based on the Army Individual Battery Test from 1944. The Trails Making Tests are more closely associated with executive control elements such as visual/ nonverbal intelligence, than just attention and information processing (Larrabee et al., 1995). Originally, these tests were used to distinguish brain damaged patients from normal control subjects.

Historically, Trails Making Tests have predominantly been used as a measurement instrument as a part of neuropsychological research. Many of these studies have involved the older population as the target group, with research focus concentrating on aging and EF decline. Studies that have used the Trails Making Test as a measurement instrument include the poor performance of Trails Test B being a partial predictor of choice stepping reaction time (Lord et al., 2000); and Trails Making Test performance is a predictor of walking speed in older adults (Ble et al., 2005). However, there are limited studies that have reported an improvement in Trails Making Tests performance, associating executive function with PA, with children as the chosen population. Castelli et al. (2011) reported that the Trails Test B only (an incongruent task where the participant has to elicit inhibitory control) was associated with children who spent time above their target heart rate zone within physical activity during an after school 'Fitness Improves Thinking' intervention.

Review of Literature Summary

Beginning with animal science, there is a plethora of evidence to suggest that PA effects EF. This line of focus has spread to include much work with older populations, where data suggest that PA helps to fend off degenerative disease and signs of aging in the brain. The mechanism for a change in brain function is unknown. However, there has not been a glut of studies using children and youth as the target population. Historically, PA and academic achievement have been linked together via a correlation relationship. However, there is transpiring evidence suggesting the relationship of PA and EF in children and youth (as in the older population) is causal. It is important to therefore consider the possible effect of PA on different elements of EF, and the consequential importance of various types of executive control in enabling school-aged children the ability to plan, schedule, and deal with attention/focus interferences within the classroom.

Some attempts have been made (that have reported different dose response results) within a laboratory attempting to infer causality, with positive results; however, as yet, there are minimal translational studies that have tried to transfer this research into an authentic practical setting; and of the small number of studies that have, many have lacked in scientific rigor.

In order to consider any relationship between acute exercise and EF therefore effecting learning, one must look at previous studies that have taken place in a practical school setting. Unfortunately, due to the lack of studies of note in this line of research, so many questions go unanswered. It is unknown whether acute exercise really enhances learning, although literature does point toward an increase in EF, with control differing by task. There has not been enough research to address the intriguing hypotheses that are attempting to relate acute exercise, EF, and learning together. From previous literature, one can categorically state that even though PE Programs have declined in the last decade, evidence points to the fact that participating in PE does not negatively affect academic performance. The current research study is therefore justified by using a rigorous scientific design to translate laboratory-based studies with an underutilized population within an authentic educational setting.

CHAPTER 3

METHODS

The primary purpose of this study was to examine the effect of an acute bout of aerobic exercise of vigorous intensity on mathematics test performance. The secondary purposes of this study were to examine the effects of an acute bout of aerobic exercise of vigorous intensity on trails test performance, and an optimal time, posttreatment, for learning.

Exploratory questions include gender effects, and how duration and intensity are associated with the relationship between PA and EF. This chapter will describe the participants and setting, instrumentation, methodological procedures, and statistical analysis that were used in this study.

Participants and Setting

Based on the results of an a priori power analysis (results obtained using G Power statistical software), the sample size was set at 80 participants, 40 for each group (allowing for participant drop out - as the original G Power sample size required for both groups was 36 participants). Eighth-grade students enrolled in PE classes from a middle school in the southwestern United States were the intended population for this proposed study. Exclusion criteria included participants who scored 100% on their state tests for math as their data would interfere as potential outliers within the data set (it would be impossible to show an increase in math score if the baseline data were already at 100%). Students were also excluded if they were not able to participate normally within a PE setting due to the study being initiated within the framework of normal PE class. The two PE cohorts were randomly assigned to an order and underwent both treatments in a within subjects counterbalanced design.

The setting for the data collection was a middle school located in an urban city in the southwestern United States. The school has an enrollment of 610 students from 7th and 8th-grades of which 67% are proficient at math for their grade level, according to the 2009-2010 Annual Yearly Progress District Report (SLC K-12 2010). The entire faculty of the school employs licensed teachers, with 52% of them holding an advanced degree. The PE department was led by a teacher with a bachelor's degree in PE and over 20 years' PE teaching experience. There were two other teachers in the department, one of which had a full-time PE schedule, whereas the other taught PE and Health. Both teachers held PE degrees and were licensed teachers. The students had 40-minute PE classes, on alternate days for one semester during the school year, within a curriculum framework which offered the students a variety of activities such as skiing, fitness, dance, and traditional ball games.

Permission to conduct the study was obtained from the University Institutional Review Board, the Salt Lake City School District (see Appendix A), the school administration (see Appendix B), and the teacher prior to the start of this study. The parents provided written informed consent and the students provided written informed assent prior to participation in the study (see Appendices C and D).

Instrumentation

Equipment used in the study included the following: (a) E600 Polar Heart Rate Monitors for physical activity data collection; (b) The DVD--'Dare to Dream, The Story of US Women's Soccer'; (c) Four 10-question math tests taken from the New York State math tests for the equivalent grade level; (d) A physical activity aerobics circuit; and (e) Trails Making Tests A and B.

Heart Rate Monitors

A heart rate monitor uses an electrocardiogram signal that detects the heart beat through a chest strap. A circuit then calculates the interval between heart-beats and stores that data in a heart rate monitor worn on the wrist (Welk et al., 2002). The instrument used to collect physical activity data within this study was the Polar E600 Heart Rate Monitor. Within school settings, Trieber et al. (1989) found high test-retest reliability (.94 to .99) using Polar Heart Rate Monitors. Bar-Or et al. (1996) reported high reliability (.86 to .99) in a similar study. Crouter et al. (2004) suggested that Polar Heart Rate Monitors yield energy expenditure estimates more accurately than pedometers and accelerometers.

For accurate data collection, it is important to properly attach the heart rate monitor and chest strap. The electrodes on the transmitter (chest strap) must be wetted before fitting it around the chest (below the pectoral muscles and across the sternal notch). For best results, the transmitter should be in direct contact with the skin; however, it is possible to wear the transmitter over a t-shirt as long as the area under the electrodes is thoroughly wetted. Finally, the receiver (watch) is placed on the wrist.

The Polar E600 Heart Rate Monitor is designed by Polar specifically for use with school children. Polar suggests the device should be used in PE classes, with the device having a coded heart rate transmission to locate the correct signal, thus reducing the effects of signal interference. The monitor has, within its features, the capability to provide data on time spent within, above, and below the target heart rate zone, the cumulative heart rate and the amount of exercise time. The monitor also collects data on the average heart rate during the within heart rate zone. An audible beep coming from the watch tells the participant when they are above or below the target heart rate zone. The data are downloaded using the Polar PC interface.

The target heart rate zone that was used for the study, to represent vigorous intensity, was taken from the guidelines of the Center for Disease Control (CDC, 2010). The CDC guidelines suggest that vigorous intensity has a target heart rate zone of 70-85% of the age-predicted maximum of the participant. The reason why vigorous intensity was chosen as the proposed level for acute exercise is that it fills in a gap in the literature. Again, as past research is lacking in school-based settings, the researcher was only able to suggest an intensity level that may or may not be prevalent in obtaining data to report a relationship between acute exercise and learning. Data-driven theory on dosage levels, intensity levels, and lasting effect have not been covered in the literature in educational surroundings and so was not used to aid the design within the particular component of the proposed study. However, there are some studies that purport the suggestion of a level of 70-85% of age-predicted maximum heart rate as ‘vigorous’. The US Department of Health and Human Services (DHSS) (2010) suggested that vigorous intensity activity for children and adolescents is any activity where the child ‘breathes rapidly’. This includes the mode of running. The DHSS suggests that brisk walking is ‘moderate to vigorous physical activity’. Consequently, as running is a major component of any PE class, then adopting the heart rate guidelines from the CDC to best represent the ‘vigorous’ intensity of running should be implemented, and therefore validates the reasoning behind setting the target heart rate zone at 70-85%, as it best relates to the mode of ambulation that is more consistent with the study setting. Strong et al. (2005) reviewed 850 articles connected with PA and recommended vigorous intensity aerobic based PA for youth is at 80% maximal heart rate.

Age data were collected from the participants prior to treatment to calculate the Target Heart Rate Zone (THRZ). Using the CDC formula (2010) of subtracting age from 220, the calculations for a 13 year old was, (at 70%) target heart rate zone = 220-13 = 207), 207*.7 = 144.9 beats per minute (bpm). At 85% of maximum heart rate, the calculation would be 207*.85 = 175.95 bpm. Therefore, for a 13-year-old participant in the study, the target heart rate zone was 145 to 176 bpm. The calculation for a 14-year-old was, (at 70%) target heart rate zone = 220-14 = 207. 206*.7 = 144.2 bpm. At 85% of maximum heart rate, the calculation was 206*.85 = 175.1 bpm. Therefore, for a 14-year-old participant in the study, the target heart rate zone was 144 to 175 bpm. The formula of 220-age * .7 and .85 was continually used on anyone younger or older than 13 or 14, which is the normal age range for an 8^{th}-grade student.

<u>DVD</u>

During the sedentary activity, the first 20 minutes of the DVD ‘Dare to Dream – The Story of US Women’s Soccer’ was watched by the participants. The viewed part of the DVD explained how the US National Women’s Soccer team was chosen for the World Cup, with interviews with key players and snippets of game play making up the major part of the content. This video was used because the content relates to a normal sporting activity, which relates to an authentic PE experience within a practical setting.

Aerobic Circuit

The intended purpose of the aerobic circuit was to make certain the participants engaged in vigorous activities The participants underwent a 20-minute aerobic circuit as part of the treatment for the study. The circuit included nine different aerobic stations (see Table 1) that were spread out in a gymnasium at the research site. The participants had practiced performing the aerobic circuit prior to data collection, where they had also become familiar with wearing the heart rate monitors during performance.

The stations were set up previous to the treatment, with each station having a laminated card with the number and name of the exercise to be performed by the participant. The order of the stations to be performed was identical to the order practiced in the familiarization visit prior to data collection.

The students completed a minimum of two full rounds of the circuit. The participants were asked to maintain their heart rate within the target heart rate zone while working at each station for 1 minute, and were given 7 seconds after the 1 minute of aerobic PA to be able to rotate to the next station. Each station was organized so as to be able to attend to 4 participants at one time, and there was a research assistant at each station aiding the participants with encouragement and any help needed. The drills used for each station are described in Table 1.

In order to ensure the participants were working within the THRZ each of the research assistants were instructed to use scripted responses. The participants were constantly asked, by the research assistant 'what is your heart rate'? Depending on the answer, the research assistant responded with the following script (see Table 2).

Math Tests and Trails Making Tests as Measures of Executive Function

There are many models of EF. However, both math tests and Trails Making Tests fall within the element of executive control involving problem solving (Zelazo et al., 1997). Miyake and Friedman et al., (2000) suggested that EF has three domains – inhibition, updating, and task shifting. Essentially, both the math test and Trails Making Tests used in this study directly related to this type of executive control. Utilizing the context of an incongruent task elicits inhibition, asking the students to problem solve elicits updating of working memory, and answering multiple problems involves task shifting.

Math Tests

Four math tests, with 10 questions in each test, were constructed from previous New York State Testing Program (8^{th}-Grade Math) questions, taken from state exams used from 2006-2010. Each of the tests, which are available on the internet at the New York State Testing Program website (www. p12.nysed.gov/osa), are old state tests that were given to 8^{th}-grade students in the State of New York over the last 5 years – the tests are therefore current, and come with technical manuals that verify the multiple choice content with Cronbach's Alpha coefficient scores. The 2006 test had an internal consistency coefficient of $r = 0.87$, with the 2007 test ($r = 0.87$), the 2008 test ($r = 0.83$), and the 2009 test ($r = 0.88$) showing similar results. The type of math questions that were extracted from the exams included (a) number sense and operations, (b) algebra, (c) geometry and (d) measurement, across the four tests. The tests were assembled by a National Board Certified math teacher with a master's degree in mathematics education and over 15 years teaching experience (see Appendix E). The two groups received the math tests in the same order, but took different math tests on the same day of testing to eradicate participants informing the other group of question content. On the first visit, Group 1 (participating in PA) took math test 1 and then math test 2. Group 0 (participating in SA) took math test 3 and math test 4. On the second visit, the Group 1 (participating in SA) took math test 3 and math test 4, and Group 0 (participating in PA) took math test 1 and 2.

Within the original New York State Math Tests, the students were given 45 minutes to answer 27 questions. This gave the student approximately 110 seconds to answer each question. However, in the current study, the participants were allocated 10 questions to answer in 5 minutes, which averaged out at only 30 seconds per question. The validity behind this concept was to consider the idea of a speed test. Brown (1970) suggested that a speed test is a reasonable way to consider response time. A pure speed test, according to Brown, is a test where questions are easy, and can be answered by everyone, given enough time. Speed tests consider response time, not difficulty of question. However, on the other end of the continuum is the power test, which according to Anastasi (1968) has a time limit that will enable everyone to attempt all the questions, which get more difficult and are graded throughout the content. Both tests are designed to prevent perfect scores (as shown by the research site school data, where no participant was excluded from the study, as no one posted a 100% score in their CRT test). Most tests that are assembled are somewhere along the continuum of speed and power, and in this instance helps to validate the shortening of time for answering questions in the test in the current study due to the reported advantages that a dose of acute exercise can give a respondent, according to current literature. Tomporowoski et al. (2003) looked at 45 studies that considered the effects of acute exercise on adult cognitive performance. The author reported that a dose of PA, under certain conditions, can influence response time and accuracy, and facilitate cognitive processes central to focus and problem solving. Tomporowski then suggested that acute exercise provides the respondent with a greater allocation of working memory towards the given task. This theory is compounded by Ellemberg et al. (2010) in his research on information processing in young children. With this in mind, it was legitimate to suggest that decreasing answer time per question in a test (which along the continuum leans more toward a speed test rather than power test) was a valid way to consider if acute exercise triggers an increase in performance in a practical real-world setting such as the school classroom.

Trails Making Test A and B

The Trails Making Test A and B tests (see Appendix G) are two tests of visual attention and processing speed (Gaudino et al., 1995) that were based on the Army Individual Battery Test from 1944. The construct of these neuropsychological tests includes connecting 25 numbers spread out on an A4 piece of paper, in numerical order, as quickly as possible. Test B is exactly the same as Test A except for the inclusion of letters; the participant must alternate between consecutive numbers and letters in order to complete the task. Test B is 56.9 cm longer than test A, so therefore, it takes longer to complete, and there are at least one or more items that are located in the pathway of the trail, making the test more complex. This test is more closely associated with visual/

nonverbal intelligence than just attention and information processing (Larrabee et al., 1995).

The tests are normally used to distinguish brain damaged patients from normal control subjects. Normally, in order to score the tests, the times for the two trails are added together. However, for this research, the researcher will compare the time for each individual test taken within the two different treatments (Gaudino et al., 1995). Test-retest reliability was shown to be at $r = .79$ for test A, and $r = .89$ for test B (Dikmen et al., 1999). In order to eliminate practice effects, the two sets of tests were taken 2 weeks apart

(see Appendix G).

Research Design

This study used a quasi-experimental design, with the statistical methodology being a 2x2x2x2 mixed factor repeated measures cross-over design. PE classes were randomly assigned to two different order groups, and due to the cross-over design, each group experienced each experimental condition.

Data Collection Procedures

Before the start of data collection, parental consent forms and participant assent forms were distributed and collected. Eighth-grade math performance data, based on student's semester grade and state math test scores from the previous year (2010), were collected from the school prior to the study, to eliminate prior math ability as an extraneous variable. Two 8^{th}-grade PE classes were assigned to the study to receive the same treatments, but received those treatments in a different order.

Familiarization and Protocol

There were two visits to the school before data collection in order for the participants to be acclimatized to wearing heart rate monitors during PE lessons. The first visit included conducting the FITNESSGRAM ™ Pacer Test, which is a test of aerobic endurance. The PACER test data were also collected to attend to the confounding variable of previous fitness levels within the study. The second visit oriented the participants with, and practice of, the aerobic circuit. During both visits, the participants were assigned a specific heart rate monitor with a specific identification number written on it. The monitors/chest straps were distributed at the start of class prior to treatment. The participants were instructed to take the chest straps and place them across the sternal notch of their chests in the locker rooms, where research assistants were available to help if needed with proper placement. The participants then returned to the gym, where they picked up the appropriate numbered heart rate watch from a table (the monitors were laid down on specific colored and numbered paper - orange, green, and pink paper that corresponded with a number and colored dot on the front of the chest strap, and on the back of the monitors). The monitors were preprogrammed with age-related THRZ information for the participant. The students were asked to start their monitors (by pressing one button) at the same time, under the instruction of the researcher, and given 1 minute to ensure the technology was working correctly. If the monitor was not working correctly, PE teachers and research assistants were available to help with instrument problems. The researchers ensured that all monitors were working correctly before data collection started. At the end of the treatment, the students were asked to press one button (the stop button), and placed the monitors back on the colored paper on the table, where the research assistants manually downloaded the data-average heart rate, and time spent below, within, and above THRZ. The students returned to the locker room to remove the heart rate straps and then returned those to the table. Orientation of the equipment took place on two occasions prior to data collection.

On the first day of data collection, at 9:00 am in the morning, the researcher met the participants in the gymnasium where the sedentary Group 0 was taken to a quiet area to watch a short video for 20 minutes. The sedentary group watched the video in silence, with no communication with the researchers, teachers, or peers allowed. The PA Group 1 changed, attached the heart rate monitors as practiced in PE class, and took part in 20 minutes of vigorous intensity PA in an aerobics circuit, with an assigned research assistant supervising the participants at each station. The participants worked at each station for 1 minute, and then rotated to the next station within 7 seconds transfer time, where the 1 minute time frame was initiated.

Following the control condition, (after 20 minutes), the participants in sedentary Group 0, in silence, completed the low cognitive functioning Trails Test A, and then at 25 minutes completed the high cognitive functioning Trails Test B. Each student taking the test was individually timed by research assistants with stopwatches. Participants started each test on the command of the research assistant, and the time was recorded on the Trails Making sheet after the participant had completed the test.

After 30 minutes the sedentary group completed a short 5-minute multiple-choice math test (Math Test 1) with 10 questions taken from the New York State Testing Program (8^{th} Grade Math) for 8^{th}- grade students. The test was administered by the lead researcher using a stopwatch, starting and finishing the test on his command. The answers were collected by the research assistants. The students then sat quietly, reading, again after being asked to read in silence, with no communication with the researchers, teachers, or peers allowed, and then had the 10 question multiple-choice math test (Math test 2) process repeated at 45 minutes (with different questions). At this time, the students were dismissed and returned to class.

At the end of the 20-minutes aerobic circuit, the PA Group 1 returned their heart rate monitors to a table at the side of the gymnasium and the data could be downloaded. Data were downloaded after the treatment to confirm that the participants remained within the target heart rate training zone, as described above. The participants got changed as normal after a PE class and returned to a classroom. After 20 minutes postactivity, the participants in the PA group, within a classroom environment, in silence, completed the low cognitive functioning Trails Test A, and then at 25 minutes completed the high cognitive functioning Trails Test B. After 30 minutes, the participants completed a short 5- minute multiple-choice math test (Math Test 3) with 10 questions taken from the New York State Testing Program (8^{th} Grade Math) for 8^{th}-grade students. The students then sat quietly, reading, again after being asked to read in silence, with no communication with the researchers, teachers, or peers allowed, and then had the 10 question multiple-choice math test (Math Test 4) process repeated at 45 minutes postactivity (with different questions). At this time the participants were dismissed and returned to class.

On the second visit, after 2 weeks of time to prevent learning effects, the researcher collected data using the same protocol as the first visit, except with the two groups switching treatments, and answering different questions on the math tests (the PA group from the first visit participated as the SA group, and vice versa; see Table 3).

Data Reduction and Statistical Analysis

The statistical methodology used was based on a 2 x 2 x 2 x 2 mixed factor repeated measures cross-over design. Two PE cohorts were randomly assigned to two different order groups, and due to the cross-over design, each cohort underwent each experimental condition.

Descriptive statistics were used to determine the outcomes of the repeated measure ANOVA data. The outcome variable was math test performance. Planning was made to test for assumptions of normality and homogeneity of variance.

The most important analyses included using a repeated measures ANOVA to interpret the three way interaction of order of treatment group (between subjects) by activity type (within subjects – using heart rate monitor during PA data) by time period (within subjects – using math tests at different time points after activity).

Effect size was set at .25, to align with the meta-analysis effect size by Etnier et al. (1997) relating physical fitness, exercise, and cognitive function. Statistical significance was set at .05 for all statistical tests. It was anticipated that the data would meet all the assumptions required for a Repeated Measures ANOVA statistical method. These tests were all conducted using SPSS version 19.0 (SPSS, Inc., Chicago, IL).

Table 1 – Aerobic Circuit Components

Name of Exercise	Description
Line Jumps	The participants will jump sideways across and back over a line with both feet together.
Ladder Run	Running through an agility ladder/ set of cones, and then run down the side of the ladder/cones to repeat the process.
Hurdles	The participant will hurdle over small 6-12 inch hurdles and then run down the side of the hurdles to repeat the process.
Step Ups	The participant will step up and down on 18 inch high aerobic steps.
High Knees	The participant will lift alternate knees high into the air on the spot.
Shuttle Drills	The participant will sprint to cones and back, 3, 5 and 10 yards away.
Z Pattern Run	The participant will run though a set of cones arranged in a zig zag pattern 5 yards away from each other, and then run down the side of the cones to repeat the process.
Jump Rope	The participant will jump rope on the spot.
Jumping Jacks	The participants will complete jumping jacks on the spot.

(Adapted from Brown and Ferrigno, 2005)

Table 2 – Research Assistant Script

Exercise	Research Assistant Script
Line Jumps	‘You are below your Target Heart Rate Zone. Jump quicker’ ‘You are above your Target Heart Rate Zone. Jump slower’
Ladder Run	‘You are below your Target Heart Rate Zone. Run quicker’ ‘You are above your Target Heart Rate Zone. Run slower’
Step Ups	‘You are below your Target Heart Rate Zone. Step quicker’ ‘You are above your Target Heart Rate Zone. Step slower’
High Knees	‘You are below your Target Heart Rate Zone. High Knees quicker’ ‘You are above your Target Heart Rate Zone. High Knees slower’
Shuttle Drills	‘You are below your Target Heart Rate Zone. Sprint quicker’ ‘You are above your Target Heart Rate Zone. Sprint slower’
Z Pattern Run	‘You are below your Target Heart Rate Zone. Sprint quicker’ ‘You are above your Target Heart Rate Zone. Sprint slower’
Jump Rope	‘You are below your Target Heart Rate Zone. Jump-rope quicker’ You are above your Target Heart Rate Zone. Jump-rope slower’

Table 3 - Data Collection Schedule.

Visit 1	20 mins. Post	25 mins. Post	30 mins. Post	45 mins. Post
20 minutes				
Group 1 PA	Trails Test A	Trails Test B	Math Test 1	Math Test 2
Group 0 Sedentary	Trails Test A	Trails Test B	Math Test 3	Math Test 4
Visit 2	20 mins. Post	25 mins. Post	30 mins. Post	45 mins. Post
20 minutes				
Group 0 PA	Trails Test A	Trails Test B	Math Test 1	Math Test 2
Group 1 Sedentary	Trails Test A	Trails Test B	Math Test 3	Math Test 4

CHAPTER 4

RESULTS

The primary purpose of this study was to consider the effect of a bout of acute vigorous intensity exercise on mathematics test performance. The primary research hypothesis was that mathematics test performance would be positively affected by a prior bout of 20 minutes vigorous intensity exercise, compared to a bout of sedentary activity. The secondary/ exploratory research questions of this study considered an effect of a bout of acute vigorous intensity exercise on Trails Test performance, and if there were to be an effect, how long that effect may last; what type of intensity is needed to help moderate an effect; and, whether there were any notable and significant differences in results of executive function performance between the genders?

Participants

Eighty subjects were originally part of the study; however, 3 were not present during the first data collection visit, and 5 were not present during the second data collection visit. A total of $N = 72$ 8th grade students participated in the study ($n = 36$) in each of two PE classes (after school absences). The participants were aged 14 ($n = 71$), and 15 ($n = 1$). Males totaled ($n = 44$) and females ($n = 28$).

Data Reduction

Data were reviewed by the primary researcher and confirmed by a secondary researcher to assure accuracy of data imputation on a Microsoft excel spreadsheet prior to importation into SPSS. After visual inspection and screening by the lead researcher and two research assistants, the data were found to have no cells left blank, or incorrectly entered, negating the necessity for any data cleaning or use of statistical methodology to amend for error/missing values.

The heart rate monitors were fully functional during the aerobic circuit with research assistants confirming visually and verbally that participants kept within the THRZ. However, data from 20 of the monitors from one of the groups was not able to be downloaded due to participant error in saving the data after the circuit had finished. Consequently, data showing time below, within, and above the THRZ for those participants was not used in the data analysis. The average heart rate of the participants, which is noted in this document, was therefore taken from a sample of the participants.

Assumptions

Some elements of the assumptions of homogeneity of variance and normality of distributions were violated within the data analysis.

Within the math tests, for males, the assumption of Box's test of equality of covariance was met at (p = .531). The assumption was also met within the females at (p = .182). The Levene's test of equality of error variance was met for all four math tests for the males ($p > .05$). However, for the females, the Levene's test of equality of error variance was met for three of the math tests ($p > .05$), but not for the Math Test at 30 minutes post-SA (SEDM30) (p = .035).

In regard to the normality of the distribution, the female participant data were normally distributed, with all four math tests data meeting the assumption at ($p > .05$). However, within the male data, the normality assumption was violated by two of the math tests, at SEDM30 ($p = .013$), and 45 minutes post-SA (SEDM45) ($p = .042$) The Box's test of equality of covariance matrices was violated for males at ($p = 0.002$), and Levene's test of equality of error variance was violated by two out the four Trails Making Tests at Trails Test B, post-PA ($p < 0.001$), and at Trails Test A post-SA at ($p = .030$). The Box's test of equality of covariance matrices was violated for females at ($p = .043$), and Levene's test of equality of error variance was met by all four Trails Making Tests at ($p > 0.05$).

With regard to the normality of the distribution, the male participant data for the Trails Making Tests were not normally distributed, with all four Trails Making Tests data violating the assumption (Trails Test A, post-PA (PATA), at ($p = .001$), Trails Test B post -PA (PATB) at ($p = .013$, Trails Test A post-SA (SEDA) at ($p < .001$), and Trails Test B post-SA (SETB) at ($p = .008$). However, within the female data, the normality assumption was violated by only one out of the four Trails Tests, at PATA ($p = .012$).

In summary, due to assumption violations, the data needed to be interpreted with caution, as other extraneous variables may be partially responsible for differences in variance of scores, homogeneity, and normality statistics.

Descriptive Statistics

The participants were split into two order groups in a counterbalanced design. One group had a bout of 20 minutes PA, and then took Trails Making Test A and B at 20 and 25 minutes posttreatment. Math tests were also administered at 30 and 45 posttreatment. The other group took the same 4 tests after having a bout of SA. Two weeks later, the groups participated in the other treatment, with another set of similar tests.

Descriptive Statistics Math Tests

In terms of math mean scores, descriptive statistics provided data for single and mixed gender for both order groups. In terms of mixed gender by order, the mean scores were fairly linear, with the PA first order group scoring, for the math test taken at 30 minutes post-PA (PAM30; n = 36, M = 5.38, SD = 2.53), the math test taken at 45 minutes post-PA (PAM45; n = 36, M = 4.30, SD = 1.88), SEDM30 (n = 36, M = 3.47, SD = 1.71), and SEDM45 (n = 36, M = 3.63, SD = 1.79).

Males at 30 minutes post-PA (PAM30) had the highest overall mean score for any of the treatments, at (n = 23, M = 6.04, SD = 2.43).

Females achieved lower mean scores for math than the males. At PAM30 (n = 28, M = 5.17, SD = 2.52), at PAM45 (n = 28, M = 3.89, SD = 1.81), at SEDM30 (n = 28, M = 3.42, SD = 2.21), and at SEDM45 (n = 28, M = 3.57, SD = 1.52; see Tables 4 and 5).

Overall, the males in the PA first order group (Group 1) scored between 19-21% higher in mean math scores for PAM30 compared to the other three tests. The males in the SA order group (Group 0) scored between 19-22% more in mean math scores for PAM30 compared to the other three tests.

The females in the PA first order group (Group 1) scored between 11-18% higher in mean math scores for PAM30 compared to the other three tests. The females in the SA order group (Group 0) scored between 17-21% more in mean math scores for PAM30 compared to the other three tests.

Skewness and Kurtosis for Math Tests

One z score for math (out of a total of *N*= 288 tests) was identified as a potential outlier using 2.5 as the cutoff value. The data revealed that none of the skewness or kurtosis statistics across all subgroups was 2.5 times the value of the skewness and kurtosis standard error (no subgroups > 2.5 when dividing the skewness/ kurtosis statistic by the skewness/ kurtosis standard error; see Tables 4 and 5).

Descriptive Statistics Trails Making Tests

Within PATA (congruent task), the overall mean time for all participants was recorded at (N = 72, M = 22.02 sec, SD = 6.86; see Table 6). Within SEDA (congruent task), the overall mean score for males (n = 44, M = 22.54 sec, SD = 5.84) was longer than the mean score for females was at (n = 28, M = 21.21 sec, SD = 4.59).

Within PATB (incongruent task), the overall mean time for all participants was recorded at (N = 72, M =47.82 sec, SD = 13.07; see Table 6). The mean score for males (n = 44, M = 47.15 sec, SD = 14.01) was shorter than the mean score for females (n = 28, M = 48.87 sec, SD = 11.6).

Within SEDB (incongruent task), the overall mean time for all participants (N = 72, M = 52.77 sec, SD = 18.4; see Table 7). The mean score for males was (n = 44, M = 54.87 sec, SD = 18.5) was longer for females (n = 28, M = 49.47 seconds, SD = 18.06; see Table 7).

Skewness and Kurtosis for Trails Making Tests

Seven z scores for trails out of a total of 288 z scores were identified as potential outliers, when using 2.5 as the cutoff value (these cases included 3 at PATA, 2 at SEDA, and 2 at SEDB).

The data revealed that 2 subgroups had a value of > 2.5 or > 3.0 (depending on whether the subgroup had > or < 30 participants) when dividing the skewness statistic by the skewness standard error. The data revealed that 4 subgroups had a value of > 2.5 or > 3.0 when dividing the kurtosis statistic by the kurtosis standard error (depending on whether the subset had > or < 30 participants; see Tables 6 and 7).

Nonparametric Tests

Nonparametric tests were analyzed, due to assumption violations reported in the repeated measures output for the math tests and the Trails Making Tests. For the math tests, the *p* value of ($p = 0.05$) was readjusted using the Bonferroni statistic (.05/number of tests = .0125). Nonparametric tests confirmed statistical significance of the treatment reported at ($p < 0.001$). The test statistic also showed significance for the math test taken at PAM30 when compared to the other 3 tests, at ($p < 0.001$). For the Trail Making Tests, the *p* value of ($p = 0.05$) was readjusted using the Bonferroni statistic (.05/number of tests = .025). The test statistic for Trails Making Test A was not statistically significant at $p > .05$. The Trails Making Test B test statistic was reported, although again not statistically significant, at $p = .034$.

Hypothesis Testing

Main Effects Math Tests

There was a statistically significant interaction for treatment by time at $F(1, 68) = 14.42$, $p < 0.001$ with a large effect size of $d = .9$. Power for this interaction was recorded at .963 (see Table 8). The main effect data for math reported that the interaction of test time scores by sex, and test time scores by order, were not significant ($p > .05$). However, there was an interaction of test time scores by sex by order, significant at $F(1, 68) = 4.756$, $p = .036$, $d = 0.5$, and an interaction of treatment by order at $F(1, 68)$, 5.377, $p = .023$, $d = 0.5$.

Simple Main Effects

An acute bout of PA resulted in higher math test scores at 30 minutes compared to SA before the math test at 30 minutes. There were no differences between the PA and SA groups at 45 minutes on the math test. The math test at 30 minutes was stastically significant at $p < 0.001$ within all three comparisons (see Table 9).

Exploratory Data Analysis Results

Although the interaction of treatment by time by gender was not statistically significant ($p = .719$), further decomposition of the data was analyzed due to gender being part of the exploratory questions in the research design. Total test time scores by treatment were significant at $F(1, 70) = 14.42$, $p = .000$, $d = .8$, and observed power of .96 (see Table 8) although there was a statistically significant time by order interaction reported at $F(1, 68) = 11.084$, $p = .002$, $d = 1.2$ and observed power of .969.

Male data were statistically significant, reported at $F(1,44) = 6.69$, $p = .013$, $d = .8$ and power of .714 (see Table 10). The interaction of test time and treatment for females showed statistical significance at $F(1, 26) = 9.074$, $p = .006$, $d = 1.2$, and power of .826 (see Table 11). The math test taken 30 minutes post-PA was significant at $p < 0.001$ when comparing the math test mean scores with the other three math tests within the male data (see Table 12), and by the female data, with math test at PAM30 being significant within the t test data at $p = .001$ against the math test PAM45, and significant at $p < .001$ when analyzed against the math tests SED30 and SED45, respectively (see Table 13).

In order to possibly help explain order and homogeneity differences between the groups, a covariate analysis was run, aiding the overall direction of the research. The score from the participants Progressive Aerobic Cardiovascular Endurance Run (PACER) from the FITNESSGRAM battery of fitness tests was coded, with the participant either being within or below the healthy fitness zone (HFZ) for aerobic endurance. These data were loaded onto the analysis and run as a covariate, revealing a gender interaction of activity x condition x HFZ significant at $p = .006$. However, when the data were further decomposed, results revealed no significant interaction ($p > .05$) between time x treatment x HFZ covariate for the females, but only for the males, at $p = .014$. Again, order effects were noted for the males at $p < .05$ (see Table 14).

Primary and Secondary Hypotheses Discussion

The primary aim of the study was to determine if a single bout of aerobic exercise increased mathematics test performance. I hypothesized that participants who received a 20-minute bout of vigorous intensity PA prior to testing would have higher mathematics test scores compared to when they were sedentary for 20 minutes prior to a similar math test. A secondary aim of this study was to determine the effect of a single bout of aerobic exercise on an increase in Trails Test performance. I hypothesized those participants who received a 20-minute bout of vigorous intensity PA prior to testing would have quicker Trails Making Test times compared to when they received SA as a treatment prior to similar Trails Making Tests. A further secondary aim was to consider the time period after PA that is optimal for learning. I hypothesized that the most beneficial time for learning would be after the heart rate has returned to resting, that the optimal period for treatment x test time would be between 16 minutes and 60 minutes, with any learning taking place after 60 minutes not being directly related to the bout of exercise, based on the literature published by Hillman et al. (2009) and Davis et al. (2007).

The main analysis revealed a significant test time x treatment interaction. In order to consider this interaction, the mean scores of the four math tests were compared to each other. Simple main effects analysis revealed that math achievement was statistically better at 30 minutes post-PA (PAM30) than PAM45, SED30 and SED45. We observed some differences in test scores between the treatments, but the data had to be treated with vigilance, due to the lack of homogeneity and lack of equal distribution of scores across the two groups. These violations were reported in the results. A plausible explanation for this could be associated with unknown group differences.

The nonparametric analysis (for the secondary aim using Trails Making Tests as the measurement instrument) reported no statistically significant differences in the output. It is plausible to suggest the reason why the Trails Making Tests were not affected by a bout of PA, but the math tests were, is a result of the tasks in the assessments having different cognitive demands. A theme that is constant within this document is the evidence that points toward executive control skills being differentiated by task. It is possible to propose that a bout of PA is more effective towards math tests (problem solving) than that of Trails Making Tests (which for example, calculate attention and processing speed abilities) in an authentic environment. Certainly, school-aged children are more attuned to academic testing, rather than testing executive skills within the classroom. Quite possibly, the students may have needed to reach higher intensity levels to reap any executive function benefits that elicit an decrease in Trails Making Test times, as opposed to the intensity needed to elicit increases in math test scores. In essence, math tests and Trails Making Tests quantify different elements of executive function, and need to be viewed separately as measurement instruments.

Therefore, results need to be treated with caution due to order effects of the groups, and the violation of assumptions; however, this statistic was rigorous when comparing PAM30 to the mean scores of the other three math tests, and that same *p*-value statistic was reported via nonparametric analysis. It could be suggested, therefore, that the maximal time for an increase in mathematics test performance is at 30 minutes post-PA.

Hillman et al. (2009) had suggested that the optimal time for an increase in EF post- PA was at 16 minutes, possibly lasting to 48 minutes. This research was compounded by Tomporowski and Davis (2005) who suggested 20 minutes as the optimal time for increased EF, after a dose of PA. The data from the current research study suggests that there is a decrease in math scores after 30 minutes post-PA, to 45 minutes post-SA, falling within Hillman's time period.

However, the current research still suggests that the duration of optimal learning may take place between 0 to 44 minutes postactivity, if the content of those tests are incongruent enough to necessitate higher executive function. Scores were not different at 45 minutes post-PA, compared with SA scores. It is difficult to balance optimal time data with any previous research attempted in an authentic setting, as the study design of the research does not compare to the current study. Gabbard and Barton (1979) concentrated on physical activity dosage, in a design that tested school-aged children almost immediately after exertion. Gabbard, along with McNaughten, then replicated the study in 1993. Raviv and Low (1990) studied physical activity and concentration during different times of the day, where research by Travlos et al. (2010) focused on interval training and mathematical processing. However, the research by Travlos did show an increase in math scores at 16 minutes postactivity, although his research did not entail testing the participants at any other time periods posttreatment.

The effect size is not similar to the meta-analysis effect size of d = .20 in Sibley and Etniers work (2003). In the current study, the main effect size of time x treatment was large at d = .8 for males and d = 1.2 for females. However, Sibley and Etnier in their meta analysis reported that mathematics scores were at the lowest end of the measurement scale in terms of how PA may improve areas of EF. Power in the current study is high, but again, this has to be treated with prudence due to other factors, as both gender and order were significant when further analyzing the data. Certainly, there is evidence that suggests children respond differently, in terms of EF after exercise, as opposed to adults. Due to the variability of children, one could suggest there is a more individualistic reaction of physical activity and EF, far less more mechanistic than in adults, where seminal research has reported a decrease in reaction time (Spirduso et al., 1978). Hillman et al. (2005) suggested that these differential effects in EF in children included areas such as accuracy, attention, and reaction speed. This may be due to developmental differences in the prefrontal cortex, where development is based on plasticity, and trajectory of cortical thickness, and development in the growth of the hippocampus within children (Pfulger et al., 1999). Certainly, children have differing and developing EF abilities, and extraneous variables such as engagement in PA leading to diverse cognitive effects from chronic PA may help to explain violations of assumptions due to nonnormality of data distribution. It is reasonable to argue that children are at dissimilar fitness levels and therefore have dissimilar fitness thresholds. There were no data collected within the current study considering the duration of time postactivity, during which the students heart rates stayed elevated.

Exploratory Data Analysis Discussion

Gender Differences

Results indicated no statistically significant interaction of time x treatment x gender, yet due to gender being an exploratory question in the research design, further analysis was warranted. Results revealed, for males only, a time by treatment interaction that was statistically significant, but with order effects. Female data reported no order effects, but with a time by treatment interaction again being statistically significant.

Therefore, it could be argued that the treatment was more effective for females (due to more significant p values) rather than males. It is difficult to assess whether the treatment had more effect because of lower math test ability, or, again, with speculation, that females gained more in terms of improvement due to the fact they were more fit.

Group 0 females, although recipients of a significant interaction between time and treatment, also had the lowest mean score gains within the math tests throughout the study. Alternatively, the treatment may have been effective as the boys were at a higher math level than the girls. It is necessary to consider that the females, as mentioned previously, had lower CRT math scores than the males within the population. However, one needs to consider that the CRT scores were taken from the previous year's results, and consequently were out of date as a real indicator, due to student improvement in math ability over the course of 12 months. The CRT scores can only really be used as a baseline measurement and not as a covariate, especially as the CRT scores and the generated math test questions were from two different states from within the USA. Nevertheless these particular data are confounding; the answer to why there was a gender difference is confusing. It is salient to consider other variables may be effecting the treatment; certainly the females were more aerobically fit than the males, who were, in turn, more math capable than the females. However, as mentioned previously, there was statistical significance and a large effect size within the main and simple main effects results.

Paucity of previous literature within an authentic setting makes for a difficult comparison with the current study. Gabbard and Barton (1979) and McNaughten and Gabbard (1993) reported no differences in gender results in their research regarding an increase in math performance after PA. Raviv and Low (2007) and Travlos et al. (2010) did not include gender as a variable in their research design.

When the math test data were correlated with HFZ as a covariate, the results suggested that fitness levels maybe an important variable to consider as a baseline for improved executive function. The females, already at a higher fitness level, and were not affected by the treatment. There was no record of a Rate of Perceived Exertion (RPE) Scale that took place before/ after any activity. As the fitness data within this current study showed that the females were more aerobically fit than the males, one could suggest that even though both genders were working at a very similar heart rate, the females had to reach a higher threshold in order to receive benefits in EF function. Certainly, during the treatment, the female average heart rate was almost identical to the males. There is a possibility of an increase in EF if the threshold of intensity of exercise for the female participants was increased, perhaps to anaerobic levels as in the Castelli et al. study in 2011. However, this argument then possibly becomes more entwined with the chronic effects of PA, rather than just purely the acute, although it is salient to suggest that the high fit females were not working at a high enough intensity level threshold to elicit EF benefits.

Duration, Dosage, and Intensity

In terms of dosage, Gabbard and Barton (1979), in their study, suggested that there was a significant increase in math test scores only after 50 minutes of PA, although the PA was not regulated in terms of physical output. McNaughten and Gabbard (1993) then suggested an increase in math scores after 20 minutes of PA, but not as significant an increase compared to when participants were involved in 50 minutes of PA. Both of these studies had school-aged children participating in math tests only a few minutes after completion of the PA treatment, and this therefore makes it difficult to compare to the current study due to the variables of fatigue and recovery. However, according to those researchers, there is a positive linear relationship in the amount of PA participated in compared with an increase in math scores. However, as mentioned earlier, both studies were lacking in scientific rigor, as effect size and intensity of PA were not reported in the methodology of the published literature. Essentially, as the current study did not offer different dosages of PA prior to testing, it is not possible to suggest that 20 minutes of vigorous PA is enough to exhibit an increase in cognitive function for all, as intensity of exercise is an important variable too closely related to dosage and individualistic in nature. However, as there was an increase in math scores after a dose of 20 minutes in both Gabbard's 1993 and 1998 study, along with an increase in math scores after a dose of 16 minutes of PA in the Travlos et al. (2010) study, one could suggest that the current treatment of a dose of 20 minutes of PA leading to an increase in math scores is consistent with previous research. As the current study is translational by nature, it is possible to compare results with previous research within a laboratory setting, although it must be stated that one of the true strengths of the current study is that it was held in an authentic location. Hillman et al. (2009) suggested a window of duration for increased cognitive function after a bout of PA from between 16 to 48 minutes within a highly controlled lab- based setting; the current study furthers the research by finding similar results (albeit not at the latter end of Hillman's spectrum) in a clinically controlled design. It is difficult to compare the concept of intensity of acute PA being a moderating variable in improving math test scores in any school-based intervention, as no research, apart from participant measured heart rate in the Travlos et al. study (2010), to date, has been attempted in an authentic educational setting.

The females in this study were more aerobically fit than the males. Quite possibly they were not working at a high enough threshold in order to benefit from the PA. The lower fit males and the lower math achievement females consequently were at a high enough intensity level to achieve higher levels of executive function. In order to increase math scores within the treatment, the intensity level of all the participants was high enough to increase cognition, related to a particular set of tests (Tomporowski et al., 2007).

Indeed, Hillman et al. (2005) reported high fit children had more P3 amplitude than both low fit children and low and high fit adults. However, adults had faster P3 latency than high fit children who had faster P3 latency than low fit children. This information poses questions on the differing implications of PA on EF in children, as there seems to be dissimilar individualistic responses in executive function components such as attention, working memory, and response speed. Research suggests that this relationship is not linear, and is multifactorial. This seems likely, as mentioned previously, related to diverse rates of prefrontal cortex development and hippocampal growth within children.

There are no real data (apart from Castelli et al., 2011) linking intensity levels of PA with EF benefits within children in an authentic setting. In that particular study, the researcher found a relationship between an increase in cognitive tests and time spent above the target heart rate zone, which was set at a vigorous intensity level (55-80% max heart rate). Therefore, heart rate was not a predictor of EF benefits, but time spent above 80% of the participants maximum heart rate was (this would be at the anaerobic level). However, this intervention measured the chronic effects (the intervention was over a 10-month period) of PA on EF with tests such as the K-BIT, Stroop Test, and the Trails

Making Tests, which are more intellectual tests by nature as opposed to being stringently academic and authentic for schoolchildren.

Certainly, not enough is known, within the literature, regarding recommended levels of intensity, dosage, and duration of PA and its consequent effects on EF within children, especially in an authentic setting.

Table 4

Math Tests Postphysical Activity Descriptive Statistics

Source	Sex	Order	N	Mean	SD	SEM	Var	Skew St	Skew SE	Kurt	Kurt SE
PAM30	male	.00	23	6.04	2.44	.51	5.95	-.67	.48	-.71	.93
		1.00	21	6.19	2.06	.45	4.26	.13	.50	-1.04	.97
		Total	44	6.11	2.24	.34	5.03	-.39	.36	-.73	.7
	female	.00	13	4.23	2.35	.652	5.5	.492	.62	-.19	1.19
		1.00	15	6.0	2.45	.63	6.00	-.370	.580	-.33	1.12
		Total	28	5.18	2.52	.477	6.37	.036	.44	-.85	. 86
	total	.00	36	5.39	2.53	.42	6.4	-.220	.39	-1.18	.77
		1.00	36	6.11	2.2	.367	4.84	-.15	.39	-.62	.77
		Total	72	5.75	2.39	.28	5.68	-.25	.283	-.86	.56
PAM45	Male	.00	23	4.83	1.95	.41	3.79	-.54	.48	-.50	.94
		1.00	21	4.29	1.85	.40	3.41	-.20	.5	.4	.97
		Total	44	4.57	1.90	.27	3.6	-.35	.36	-.35	.7
	female	.00	13	3.38	2.02	.56	4.09	.88	.62	1.03	1.19
		1.00	15	4.33	1.54	.399	2.38	.56	.58	1.18	1.12
		Total	28	3.89	1.81	.34	3.28	.45	.44	.36	.86
	total	.00	36	4.3	2.07	.34	4.27	-.07	.39	-.92	.77
		1.00	36	4.3	1.7	.28	2.9	.005	.39	.48	.77
		Total	72	4.3	1.89	.22	3.53	-.04	.28	-.44	.55

.00 = SA first in treatment order
1.00=PA first in treatment order

Table 5

Math Tests Postsedentary Activity Descriptive Statistics

Source	Sex	Order	N	Mean	SD	SEM	VAR	Skew	Skew SE	Kurt	Kurt SE
SED30	male	.00	23	4.04	1.66	.35	2.78	.12	.48	1.57	.94
		1.00	21	5.4	1.96	.43	3.86	.29	.5	-1.38	.97
		Total	44	4.7	1.92	.29	3.7	.34	.36	-.05	.7
	female	.00	13	2.46	1.33	.369	1.76	-.03	.62	.19	1.19
		1.00	15	4.27	2.52	.65	6.35	.33	.58	-.68	1.12
		Total	28	3.43	2.22	.42	4.92	.82	.44	.38	.86
	mixed	.00	36	3.47	1.72	.29	2.94	.25	.39	.77	.77
		1.00	36	4.94	2.25	.38	5.08	.09	.39	-.82	.77
		Total	72	4.21	2.12	.25	4.5	.36	.28	-.25	.56
SED45	male	.00	23	3.91	1.95	.41	3.81	-.03	.48	-.66	.94
		1.00	21	4.81	1.83	.4	3.36	.09	.5	-.13	.97
		Total	44	4.34	1.93	.29	3.72	-.02	.36	-.41	.7
	female	.00	13	3.15	1.41	.39	1.97	.11	.62	.13	1.19
		1.00	15	3.93	1.58	.41	2.49	0.00	.58	.01	1.12
		Total	28	3.57	1.53	.29	2.33	.12	.44	-.15	.86
	mixed	.00	36	3.64	1.79	.30	3.21	.17	.39	-.46	.77
		1.00	36	4.44	1.76	.29	3.11	.16	.39	-.1	.77
		Total	72	4.04	1.81	.21	3.28	.14	.28	-.32	.56

.00 = SA first in treatment order
1.00=PA first in treatment order

Table 6

Descriptive Statistics for the Trails Making Test A, Postphysical and Sedentary Activity

	Sex	Order	N	M	SD	SEM	Var	Skew	Skew SE	Kurt	Kurt SE
PATA	male	.00	23	20.68	7.54	1.57	56.87	1.91	.48*	3.22	.94^
		1.00	21	24.07	4.27	.93	18.22	.88	.5	3.68	.97^
		Total	44	22.3	6.36	.96	40.5	1.28	.36	2.09	.7
	female	.00	13	20.76	5.06	1.4	25.61	.44	.62	-.13	1.19
		1.00	15	25.28	9.02	2.38	81.29	.94	.58	.75	1.12
		Total	28	23.18	7.67	1.45	58.8	1.22	.44	1.94	.86
	total	.00	36	20.71	6.67	1.11	44.52	1.73	.39	3.19	.77
		1.00	36	24.57	6.58	1.1	43.29	1.22	.39	2.74	.77
		Total	72	22.64	6.86	.81	47.07	1.26	.28	1.97	.56
SEDA	male	.00	23	23.81	7.01	1.46	49.09	1.19	.48	.37	.94
		1.00	21	21.17	3.96	.86	15.71	.59	.5	.04	.97
		Total	44	22.55	5.85	.88	34.2	1.42	.36	1.79	.7
	female	.00	13	22.24	5.35	1.48	28.66	.36	.62	-8.28	1.19
		1.00	15	20.32	3.78	.97	14.27	.06	.58	-1.27	1.12
		Total	28	21.21	4.59	.868	21.09	.47	.44	-.4	.86
	total	.00	36	23.24	6.42	1.07	41.26	1.09	.39	.57	.77
		1.00	36	20.81	3.86	.64	14.86	.39	.39	-.36	.77
		Total	72	22.03	5.4	.64	29.16	1.26	.28	1.78	.56

*a. * skewness stat/ skewness SEM value>2.5/ 3.0*
b. ^ kurtosis stat/ kurtosis SEM value>2.5/ 3.0
c. .00 = SA first in treatment order
d. 1.00=PA first in treatment order
e. PATA = Trails Test A, Post PA
f. SEDA = Trails Test A, Post SA

Table 7

Descriptive Statistics for the Trails Making Test B, Postphysical and Sedentary Activity

	Sex	Order	N	Mean	SD	SEM	Var	Skew	Skew SE	Kurt	Kurt SE
PATB	Male	.00	23	46.86	17.48	3.65	305.65	.58	.48	-1.21	.94
		1.00	21	47.47	9.26	2.02	85.8	1.09	.5	.87	.97
		Total	44	47.15	14.01	2.11	196.38	.65	.36	-.48	.7
	female	.00	13	46.98	11.95	3.31	142.73	.4	.62	-1.21	1.19
		1.00	15	50.51	11.48	2.96	131.84	-.24	.58	-.16	1.12
		Total	28	48.87	11.62	2.19	135.03	.04	.44	-.94	.86
	Total	.00	36	46.9	15.53	2.59	241.06	.55	.39	-.99	.77
		1.00	36	48.74	10.2	1.7	104.09	.42	.39	-.18	.77
		Total	72	47.82	13.08	1.54	170.99	.45	.28	-.66	.56
SEDB	Male	.00	23	58.83	21.66	4.52	469.24	.99	.48	.63	.94
		1.00	21	50.53	13.51	2.95	182.4	.17	.5	-.93	.97
		Total	44	54.87	18.51	2.79	342.5	1.09	.36*	1.52	.7
	female	.00	13	55.23	12.64	3.5	159.68	.19	.62	-1.02	1.19
		1.00	15	44.49	20.86	5.39	435.2	1.15	.58	4.64	1.12^
		Total	28	49.48	18.07	3.41	326.43	.50	.44	2.67	.86
	Total	.00	36	57.53	18.78	3.13	352.78	1.06	.39	1.29	.77
		1.00	36	48.01	16.95	2.83	287.45	.6	.39	2.74	.77^
		Total	72	52.77	18.4	2.17	338.58	.84	.28	1.83	.56

*a. * skewness stat/ skewness SEM value>2.5/3.0*
b. ^ kurtosis stat/ kurtosis SEM value>2.0/3.0
c. 00 = SA first in treatment order
d. 1.00=PA first in treatment order
e. PATB = Trails Test B, post PA
f. SEDB = Trails Test B, post SA

Table 8

Interaction of Math Tests by Treatment, Mixed Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Power
Between-Subject Effects							
Sex							
Order	64.42		64.42	6.51	.013	.087	.71
Sex x Order	55.08		55.08	5.57	.021	.076	.64
	12.41		12.41	1.26	.266	.018	.2
Within-Subject Effects							
Test Time	56.53		56.53	30.79	.000	.31	1.0
Test Time x Sex	1.03	1	1.03	.56	.457	.008	.11
Test Time x Order	6.88	1	6.88	3.75	.057	.052	.48
Test Time x Sex x Order	8.4	1	8.4	4.58	.036	.063	.56
Test Time Error	124.84	68	1.84				
Treatment	38.67	1	38.67	21.37	.000	.239	.99
Treatment x Sex	3.14	1	3.14	1.74	.192	.025	.25
Treatment x Order	9.73	1	9.73	5.38	.023	.073	.63
Treatment x Sex x Order	.48	1	.48	.26	.609	.004	.08
Treatment Error	123.04	68	1.8				
Test Time x Treatment	29.30	1	29.30	14.42	.000	.175	.96
Test Time x Treatment x Sex	.26	1	.26	.13	.719	.002	.06
Test Time x Treatment x Order	4.32E-	1	4.32E-	.000	.996	.000	.05
Test Time x Treatment x Sex x Order	.17	1	.17	.09	.771	.001	.06
Error	138.17	68	2.03				

Computed using alpha = .05

Table 9

Comparison of Math Test Scores at Different Time Points by Mixed Gender

	Paired Differences							
	Mean	SD	SEM	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
Source				Lower	Upper			
PAM30 -PAM45	1.44	2.03	.24	.97	1.92	6.05	71	.000
PAM30 - SED30	1.54	2.16	.25	1.04	2.05	6.07	71	.000
PAM30 - SED45	1.71	1.95	.23	1.25	2.17	7.42	71	.000
PAM45 - SED30	.097	2.02	.24	-.378	.57	.41	71	.685
PAM45 - SED45	.26	1.83	.216	-.167	.69	1.22	71	.225
SED30 - SED45	.167	1.9	.22	-.28	.613	.75	71	.459

Computed using Alpha=.05

Table 10

Significant Interaction of Math Tests by Treatments, Male Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Power
Test Time	27.25	1	27.25	15.39	.000	.268	.969
Test Time x Order	19.64	1	19.64	11.08	.002	.209	.902
Test Time Error	74.41	42	1.77				
Treatment	41.17	1	41.17	22.26	.000	.346	.996
Treatment Error	77.61	42	1.85				
Test Time x Treatment	15.45	1	15.45	6.69	.013	.137	.714
Error	97.03	42	2.31				

Computed using Alpha=.05

Table 11

Significant Interaction of Math Tests by Treatments, Female Gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Power
Test Time	29.75	1	29.75	15.34	.001	.371	15.34	.965
Treatment	8.08	1	8.08	4.62	.041	.151	4.62	.544
Treatment Error	45.42	26	1.75					
Test Time x Treatment	14.36	1	14.36	9.07	.006	.259	9.07	.826
Error	41.14	26	1.58					

Computed using Alpha=.05

Table 12

Comparison of Math Test Scores at Different Time Points, by Male

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	SD	SEM	Lower	Upper	t	df	Sig. (2-tailed)
PAM30 - PAM45	1.55	2.13	.32	.9	2.19	4.81	43	.000
PAM30 - SED30	1.41	2.22	.33	.73	2.08	4.2	43	.000
PAM30 - SED45	1.77	2.04	.31	1.15	2.39	5.75	43	.000
PAM45 - SED30	-.14	1.99	.3	-.74	.47	-.45	43	.653
PAM45 - SED45	.23	1.99	.3	-.377	.83	.76	43	.452
SED30 - SED45	.36	1.94	.29	-.23	.95	1.24	43	.221

Computed using Alpha=.05

Table 13

Comparison of Math Test Scores at Different Time Points, by Female

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	SD	SEM	Lower	Upper	t	df	Sig. (2-tailed)
PAM30 - PAM45	1.29	1.88	.36	.56	2.02	3.61	27	.001
PAM30 - SED30	1.75	2.07	.39	.95	2.55	4.48	27	.000
PAM30 - SED45	1.61	1.83	.35	.90	2.32	4.64	27	.000
PAM45 - SED30	.46	2.05	.39	-.33	1.26	1.20	27	.240
PAM45 - SED45	.32	1.59	.3	-.29	.94	1.07	27	.294
SED30 - SED45	-.143	1.82	.34	-.85	.56	-.42	27	.681

Computed using Alpha=.05

Table 14

Significance of the Healthy Fitness Zone as a Covariate in Math Test Performance

source sex	In HFZ	Out HRZ	Significance
Mixed	n=49	n=23	
Test Time x Treatment			.006
Test Time x Treatment x HFZ			.046
Treatment x Order			.002
Male	n=24	n=20	
Test Time x Treatment			.001
Test Time x Treatment x HFZ			.014
Treatment x Order			.001
Female	n=25	n=3	
Test Time x Treatment			.023
Test Time x Treatment x HFZ			n/s
Treatment x Order			n/s

Computed using Alpha=.05

CHAPTER 5

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Conclusion

The data showed an acute effect of PA on EF via a math test as the measurement instrument, which is consistent with the literature within an authentic environment (Gabbard & Barton, 1979; Gabbard & McNaughten, 1993; Travlos et al., 2010). However, unlike previous literature (that alluded to a spectrum of time) this effect was only noted at a test time of 30 minutes post-PA. The results of this translational study also align with controlled setting findings, which suggest EF benefits from bouts of PA (Hillman et al., 2008, 2009). These results, due to violations of normality and homogeneity assumptions, should be guarded with reservation. There were also order x treatment interactions. However, the significance of the treatment on mathematics test performance was at $p < 0.001$ for both order groups, irrelevant of gender, and compounded by a nonparametric analysis.

The mean scores differences were between 11-22% higher after the treatment at 30 minutes post-PA compared to any of the other tests. Attempting to align an optimal time for learning post-PA is difficult, due to a lack of studies that have proffered a legitimate and definitive answer. The spectrum of time seems to be somewhere between 16 to 60 minutes (Hillman et al., 2003, 2008), including studies with different durations of PA with different intensity levels. Therefore, this study is within the parameters of past research. Again, however, results differ from one study to the next, and as the PA/ EF relationship is so individualistic, it is impossible as of now to state an optimal time for learning, but more suitably, a timeframe. Data did show that there is no significance between bouts of PA/SA post-45 minutes, yet this still concurs with the literature that suggests having PE on the curriculum does not hinder learning, and perhaps, within certain parameters, may enhance it. In summary, within this particular study, the results suggest a significant main effect of 20 minutes of vigorous aerobic PA on EF skills, using math tests as the measurement instrument, within a time period lasting up to 45 minutes posttreatment.

Therefore, there may be an acute effect of PA on EF; but it is likely to be aided by other variables which are chronic by nature. Past literature made it difficult to find a relative effect size for the overall power of the study, (d =.025 was chosen based on a previous meta-analysis looking at children, cognition, and fitness). However, that meta-analysis surveyed a majority of publications that had not taken place in the school environment. Both these factors, along with extraneous chronic variables, group differences, and dissimilar EF reactions to PA within the participants may, have caused assumption violations, and may or may not hide the true significance of this research. However, as physical fitness levels may be one of these variables causing an increase in EF, one can still see the importance of PA both in and outside of school. As children are at different stages in their prefrontal cortex development (Shaw et al., 2006), and hippocampal growth (Pfluger, et al., 1999), one should expect variance in the ways children react cognitively to exercise. Children do not cognitively respond uniformly to PA as adults do, mechanistically, in terms of reaction time (Spirduso et al., 1978), according to the literature. There are more extraneous factors that may or may not affect children in terms of increases in executive function after PA, and so more individualistic results should be expected by researchers. It is also difficult to discount the element of motivation as a factor within the treatment. However, with the possibility of the suggested increase in executive function raising attention and focus after PA (Cotman et al., 2007), one could suggest that a lack of motivation due to a lack of focus and arousal within the sedentary tests became a factor in the reported lower math and trails scores. Certainly, it is well documented that physical activity aids inhibitory control in children (Hillman et al., 2003). However, not enough is known about a possible trigger mechanism that causes an increase in EF, which is more likely to be a cascade of factors rather than a singular event (Cotman et al., 2007). 'Cascade of factors' may also be a useful term in describing the holistic and individual way in which many variables, of which acute PA may be included, come together to elicit an increase in executive control skills, that are beneficial in an authentic environment. However, in opposition to previous meta-analysis research, the effect size of the treatment for both genders, when exposed to PA, is large, and significant. Of course, one most also consider extraneous factors, although the positive news is that many of these extraneous factors, such as fitness and adiposity levels, BMI, engagement, and heart rate, are all affected by PA.

It is also possible that the instruments used in the study were not sensitive enough to measure change. Why the primary aim using math tests was significant, yet the secondary aim using Trails Making Tests was not significant is maybe due to the participants not reaching the intensity levels of PA needed to elicit an increase in specific executive skills particular to each type of test. Executive control skills are relative to the task used, and quite possibly the PA task, the intensity levels, the Trails Making Test, and the executive control skills needed to be successful in the Trails Making Tests did not align properly. Very few interventions, especially ones with scientific rigor, have been attempted within an authentic school setting, and therefore, it was difficult to make parallel the data with reasoned previous literature.

After an a priori effect size calculation, the minimum number of participants in the study was set at N=72, and as the final number of participants (after some school children missed one of the data collection visits) was at N=72 it was decided to keep all data. Therefore, for instance, any element of confusion on the tests, which may have led to outliers in the data, were kept in the study. Outliers can lead to a false impression of the overall effectiveness of a treatment, but were not utilized in the analysis of this study. However, the number of outliers/ skewness and kurtosis factors in the study was low (1 outlier for the math test means scores, 7 outliers among the Trails Making Test times, and 6 factors in total for skewness and kurtosis). One of the strengths of this study design is that it was set in an authentic setting. It would be relevant to suggest that a wider distribution of means should be expected from a varied population, and that this would be typical, expected, and realistic of any test taken in a school.

The relationship between PA and EF was moderated by gender. There were gender differences reported within the study related to previous mathematics ability and fitness levels. The data did reveal overall significance, with a large effect size for both genders. The results suggests the more fit and able at math you are, the more math gains you may make from the treatment – as the females with the lower math scores made less gains than the males with the higher math scores/ females with higher math scores and were more fit. However, the treatment does work for students of all academic backgrounds because both order groups and genders made significant gains in math scores at 30 minutes post-PA compared to test scores at 45 minutes post-PA and after both tests taken after sedentary activity. As the boys were less fit, one could suggest that the treatment had more of an effect than for the females who were more fit, again implying other variables were part of a valuable treatment.

In terms of the Trails Making Tests moderated by gender, there were faster mean times recorded by 2 subsets of participant's - males that were low fit, and females with lower CRT scores. The only group that did not improve their time after PA was the group of high fit, high CRT score females. As there was no record of rate of perceived exertion during activity, it is not known if the treatment was not effective for these particular females because they were not working as intensely as the males even though their heart-rates were at an almost identical level. However, as mentioned previously, there are many reasons why this particular group of participants may not have been affected by the treatment, such as individual responses to PA, not reaching their threshold to initiate an effect on EF, and other unknown extraneous variables.

In order to further decompose gender as a moderating variable, it would have been useful to consider the differing math ability between the participants. It was not possible to use math ability as a covariate in the study as CRT scores were a year old, and the test questions and CRT scores were from different states from within the USA.

Questions that may aid further research include considering differing types and levels of fitness between the genders, the gender culture of PE, and how this may affect

PA levels. It is not so much that there were gender differences in the study; rather, there were fitness and math ability differences that were confounded by gender.

Dosage was not really measured in this study, as the dosage was the same for each participant who only received one bout of PA, that of 20 minutes. Further research is necessary to account for the different dosages that may affect EF skills, although this figure is likely to be individualistic by nature. The lasting duration of the positive effect of PA on EF did fall within the parameters of the current literature, although again, it is impossible to pinpoint the optimal time due to individual constraints. Intensity levels, again, will differ from participant to participant, although the results from the current study did report that the participants were working at a vigorous level. There is not enough data on gender differences, intensity, dosage, and duration within the literature linking the treatment of children in an authentic setting to help expand on this topic.

In summary, one can suggest, from the current study, that the results indicate how important PA can be in the potential of the development of the student in K-12 education. This current study (although it has stated limitations in terms of assumption violations) is an attempt to move away from literature that is, by nature, chronic, and of a correlation design. Although over 200 studies have been written about PA and cognition, this focus of research is relatively young, and has only developed mainly over the last 15 years. Most of the research has been highly controlled laboratory-based experiments not using school-aged children as the chosen population. Neither has the research been authentic in setting, treatment, and in instruments used for data collection. This study is an attempt to add to, and compliment, the most current field research completed by Donnelly et al. (2010) and Castelli et al. (2011) that takes place in a school setting.

As physical educators, we are currently affected by the demise of our subject from the curriculum in spite of recent research that shows that PE does not hinder academic achievement. We can see how PE can be an integral part of the school day, with models in place across the country showing significant increase in learning, when PA is fostered in a holistic health models approach to school structure. It is salient to suggest that we all experience an intuitive ‘feel’ on how PA affects us. If we connected this intuition to models of PE being integrated with academics across the country, with past research that states PE/ PA is not harmful to academics, to the lack of existent literature in authentic school environment, and the growing body of literature that suggests that PA effects EF, one can see the relevance of a study such as this. Indeed, much literature does not unite the ideals of principals and policy makers with the reality of PE. This current study aims to directly challenge the concept of remediating PE from the curriculum, by stating, albeit from a guarded position, that PE can be a positive variable in assisting grades and on task behavior.

This research should be considered as adding to, and agreeing with, the existent literature that suggests that physical activity breaks, especially within a coordinated PA model, may be beneficial to the sedentary world of K-12 education.

Recommendations

1. More research needs to be undertaken in an authentic setting - with scientific rigor.
2. Sensitive authentic instruments need to be adopted to measure the effectiveness of the treatment, especially as there are different elements of executive control skills, and these skills are differentiated by task.

3. Larger populations need to be involved in a study so as to consider outliers within data; some students may just be confused with a test, for some unknown reason, or be unmotivated to participate in some of the treatments.
4. More research is needed to fill in the gaps in the literature about intensity of PA leading to an increase in executive function. As some of the heart rate monitors did not offer downloadable data, it was not possible to consider the role of intensity within this study.
5. Baseline measurements, such as resting heart rate or RPE, should be collected prior to data collection to ascertain the variance explained by previous fitness levels.
6. It is difficult to answer too many questions in a single research study such as this. It would be easier to attempt to fill in gaps in the literature by separating dosage intensity levels, duration, and optimal time. A single-minded approach toward research design is needed to answer these questions. Dosage, intensity, and duration need to initially be treated separately.
7. A mixed methods design, one that tracks qualitative and quantitative data may be a relevant model for future research. A student may be more open to learning throughout the school day if PA is molded into the structure of education. A qualitative questionnaire or survey that tracks how a person feels toward learning after an acute bout of PA could be used as a viable instrument for recording data.
8. The type of exercise that is best related to an increase in executive function is relatively unknown – more studies need to be designed to look at modalities.

9. More research needs to be conducted, that attempts to consider other variables (that may help to increase executive control skills) in an acute setting.
10. More research is required to best understand the different ways in which children react cognitively to PA.
11. In a future study, parallel forms software needs to be utilized to aid reliability within each individual question, on any assembled math tests.
12. In a future design, math tests should be crossed (it would have been more helpful, in terms of strength of the intervention, to compare the mean scores of the same math test after a bout of PA with one group, and after a bout of SA with a different group – this should be viewed as a limitation in the study).
13. Further studies should consider if comprehensive PE programs with vigorous bouts of PA may help academically across a variety of subjects.

APPENDIX A

IRB PERMISSION FORM FROM SALT LAKE CITY SCHOOL DISTRICT

SALT LAKE CITY
SCHOOL DISTRICT
Your Best Choice

January 26, 2011

DAVID PHILLIPS
201 HPER North
Department of Exercise and Sport Science
University of Utah
SLC, UT 84112

Dear David,

Salt Lake City School District is committed to the advancement of educational research, and we receive and consider many requests for research every year. All requests are reviewed to see if they fit with the goals we have defined for the district, and we are very cautious about taking instructional time from our teachers and our students.

We have reviewed your recent application for external research titled*: The Effect of Acute Exercise on Mathematics Performance?* The review committee could see the value of the focus of your research request and the information that would be gained from such research. While the committee has decided to approve your project for research in Salt Lake City School District, be reminded that Clayton Middle school will be the only site approved.

SLCSD is very interested in the findings of this research and possible implications. Please be aware that it is your responsibility to share your findings with our Assessment and Evaluation Department upon completion of your project. This approval letter grants you permission to conduct research from January 2011 until August 1, 2011. Should you require additional time, you will need to submit an update and reapplication.

Sincerely,

Dr. Jo Ellen Shaeffer

Dr. Jo Ellen Shaeffer

JO ELLEN SHAEFFER
Director
Assessment and Evaluation

joellen.shaeffer@slc.k12.ut.us

p 801.578.8222
f 801.578.8681

Salt Lake City School District
440 East 100 South
Salt Lake City, UT 84111

www.slcschools.org

APPENDIX B

IRB PERMISSION FORM FROM CLAYTON MIDDLE SCHOOL

Clayton Middle School

Building on the Past… Leading in the Present… Preparing for the Future!

1470 S 1900 East
Salt Lake City, Utah 84108
801-481-48102

Linda Richins
Principal

Jared Wright
Assistant Principal

December 21, 2010

To Whom it May Concern:

Re: David Phillips Data Collection / IRB School Concent

We allow David Phillips (University of Utah) to conduct his data collection at Clayton Middle School, so long as permission is granted by the Salt Lake City School District.

Sincerely,

Linda Richins, Principal

APPENDIX C

PARENTAL PERMISSION FORMS

THE UNIVERSITY OF UTAH

DEPARTMENT OF EXERCISE & SPORT SCIENCE

MARCH 2011

BACKGROUND
Your child is being asked to take part in a research study within normal physical education class. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you will allow your child to take part in this study. The purpose of this study is to collect data with normal physical education class in order to greater understand the uses and benefits of physical education and to see if an acute bout of physical activity effects learning. It is important that you do not mention to your child that the purpose of the study is to see if there is a effect on math tests after physical activity, as knowledge of the purpose of the study may affect the student responses in the tests and effect the study results. Please do not disclose the purpose of the study, but you may tell your child that they will be taking part in a research study, that they will be participating in regular activities they would participate in normal physical education lessons.

STUDY PROCEDURE
It will take your child 2 physical education classes to complete this study. Data will be collected during one of these two classes via heart rate monitors, while the students participate in an aerobic circuit (such as running in place, step ups, and skipping), and short five minute math tests.

RISKS
The risks of this study are minimal. These risks are not anymore than they would experience in a physical education class, with lesson content and format being no different than students would receive during normal lessons.

BENEFITS
We cannot promise any direct benefit to your child for taking part in this study. However, possible benefits include learning about their physical activity levels will help with information in developing a greater understanding of the uses and benefits of a physical education curriculum.

CONFIDENTIALITY
Your child's data will be kept confidential. Data and records will be stored in a locked filing cabinet or on a password protected computer located in the researcher's work space. Only the researcher and members of this study team will have access to this information. Results of the study may be published, but no names or identifying information will be included in the publication. Teachers will not have access to test results.

PERSON TO CONTACT
If you have questions, complaints or concerns about this study, you can contact David Phillips at 801-581-3836. If you feel your child has been harmed as a result of participation, please call David Phillips at 801-581-3836 who may be reached during 10:00 am – 4:00 pm Monday-Friday, or by email at david.phillips@hsc.utah.edu.

Institutional Review Board: Contact the Institutional Review Board (IRB) if you have questions regarding your child's rights as a research participant. Also, contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Utah IRB may be reached by phone at (801) 581-3655 or by e-mail at irb@hsc.utah.edu.

Research Participant Advocate: You may also contact the Research Participant Advocate (RPA) by phone at (801) 581-3803 or by email at participant.advocate@hsc.utah.edu.

VOLUNTARY PARTICIPATION
It is up to you to decide whether to allow your child to take part in this study. Refusal to allow your child to participate or the decision to withdraw your child from this research will involve no penalty or loss of benefits to which your child is otherwise entitled. This will not affect your or your child's relationship with the investigator. Your child will still be able to participate in the structured physical fitness tests even if he/she chooses not to be in the study. Refusal to allow the child to participate or the choice to withdraw the child will have no effect on the child's relationship/academic standing with the school.

COSTS AND COMPENSATION TO PARTICIPANTS
Your child will not receive any compensation for being in this study. There will be no costs to the child or their parents.

..

CONSENT
By signing this consent form, I confirm I have read the information in this parental permission form and have had the opportunity to ask questions. I will be given a signed copy of this parental permission form. I voluntarily agree to allow my child to take part in this study.

____
Child's Name

____
Parent/Guardian's Name

__________________________ _____________
Parent/Guardian's Signature Date

____
Relationship to Child

____
Name of Researcher or Staff

__________________________ _____________
Signature of Researcher or Staff

APPENDIX D

ASSENT FORMS

Assent to Participate in a Research Study

We are from the department of Exercise and Sport Science at the University of Utah.. We would like to ask if you would be in a research study. A research study is a way to find out new information about something.
This is the way we try to find out how to improve the physical education curriculum
We are asking you to be in this research study because we want to learn more about how to improve physical education classes. We want you to be in this study because we want to collect data in a real world school environment.

If you decide to be in this research study and your parent or guardian agrees, this is what will look like.

We will come into visit with you twice in Physical Education Class. **One of the classes will involve you participating in an aerobics circuit (doing things such as running on the spot, doing step ups on a single bleacher step, dribbling a basketball between cones and doing shuttle runs).**
We will ask you to take part in these lessons as you normally would in regular classes. We will look at your physical activity levels, using heart rate monitors to collect data. You will be in the study for two classes

There is a chance that during this research study you could feel afraid, uncomfortable, or hurt. We will try to help you feel better if this happens. You can stop at any time if you want to. However, you will be at minimal risk – we will only ask you to participate in activities which would be considered normal within physical education classes.

We do not know for sure if being in this research study will help you. It is possible that we could learn something to help other people with physical education lesson content some day.

Only the researchers will be able to see the information about you from this research study. **We will keep your answers and the information we write down about you**

locked up or on a password-protected computer so no one but us can see them.

It is okay to ask questions. If you don't understand something, you can ask us. We want you to ask questions now and anytime you think of them. If you have a question later that you didn't think of now, you can call David Phillips at 801-581-3836 or ask us the next time we see you.

You do not have to be in this study if you don't want to. Being in this study is up to you. No one will be upset if you don't want to do it. Even if you say yes now, you can change your mind later and tell us you want to stop. You can take your time to decide. You can talk to your parent or guardian before you decide.
We will also ask your parent or guardian to give their permission for you to be in this study. But even if your parent or guardian say "yes" you can still decide not to be in the research study.

I was able to ask questions about this study. Signing my name at the bottom means that I agree to be in this study. My parent or guardian and I will be given a copy of this form after I have signed it.

____
Printed Name

____ ______________________
Sign your name on this line Date

____
Printed Name of Person Obtaining Assent

____ ______________________
Signature of Person Obtaining Assent Date

The following should be completed by the study member conducting the assent process if the participant agrees to be in the study. Initial the appropriate selection:

__________ The participant is capable of reading the assent form and has signed above as documentation of assent to take part in this study.

__________ The participant is not capable of reading the assent form, but the information was verbally explained to him/her. The participant signed above as documentation of assent to take part in this study.

APPENDIX E

MATH TESTS

Math test 1

1. Jerome surveyed 643 skateboarders and found that 209 of them preferred wood skateboards to plastic or aluminum skateboards. Based on the number of people surveyed, what is the **most reasonable estimation** of the percent of skateboarders who preferred wood skateboards?

A 10%
B 30%
C 40%
D 50%

2. Simplify the expression below.
$(3x^3 + 2x^2 - 5x) + (-8x^3 + 3x)$
A $-11x^3 + 2x^2 - 2x$
B $11x^3 - 2x^2 + 8x$
C $-5x^3 + 2x^2 - 2x$
D $5x^3 - 2x^2 - 8x$

3. The scale on a road map is shown below.
SCALE1 cm = 75 miles

Sam measures the distance on the map between Rockland and Newbury as
5 centimeters. What is the actual distance, in miles, between Rockland and Newbury?

A 15
B 80
C 375
D 575

4. Multiply the expression below.

$-3x(x - 4)$

A $-3x^2 - 4$

B $-3x^2 - 7$
C $-3x^2 - 12x$
D $-3x^2 + 12x$

5. Which situation is **best** represented by the expression $2c - 5$?
A Alicia walked 2 miles fewer than 5 times the number of miles, *c*, Courtney walked.
B Alicia walked 5 miles fewer than 2 times the number of miles, *c*, Courtney walked.
C Alicia walked 2 more than 5 times the number of miles, *c*, Courtney walked.
D Alicia walked 5 more than 2 times the number of miles, *c*, Courtney walked.

6. Omar wants to solve the equation 3 *x* _ 2 _ 10. Which steps could Omar follow to find the solution?

A Add 2 to both sides. Then divide both sides by 3.
B Divide both sides by 3. Then add 2 to both sides.
C Subtract 2 from both sides. Then divide both sides by 3.
D Multiply both sides by 3. Then subtract 2 from both sides

7. What is the sum of $(3 + 3)^2$ and 2^3?

A 18
B 20
C 26
D 44

8. Simplify the expression below.

$10y^2 - 15y^2$

A -5
B 5
C $-5y^2$
D $-5y^4$

9. Simplify the expression below.
$4k^2 + 5k - 3 + 5k^2 + 2$
A $4k^2 + 10k - 1$
B $9k^2 + 5k - 1$
C $9k^2 + 7k - 3$
D $14k^2 + 5k - 1$

10. What verbal expression is the same as the algebraic expression below?
$8 - 3x$

A three times a number minus eight

B three minus eight times a number
C eight times a number minus three
D eight minus three times a number

Math test 2

1. Sarah earned a 4% commission on all of her sales in March. Her total sales were $80,000 in March. How much money did she earn from commissions?

A $320
B $3,200
C $32,000
D $320,000

2. Simplify the expression below.

$\frac{24x^2y}{6xy^3}$

A $18\,x^3y^4$

B $4\,xy^2$

C $\frac{4x}{y^2}$

D $\frac{18x^2}{y^2}$

3. The scale on a map of Audrey's home state indicates that 1 centimeter is equivalent to 30 miles. On this map, the distance between Davenport and Vansburg is 12 centimeters. What is the actual distance between Davenport and Vansburg?

A 90 miles
B 180 miles
C 360 miles
D 720 miles

4. What is the product of the expression below?

$(a - 3b)(2a + 2b)$

A $2a^2 - 4ab - 6b^2$
B $2a^2 + 4ab - 6b^2$
C $2a - 4ab - 6b$
D $2a + 4ab + 6b$

5. Janine's dog weighs three pounds less than twice the weight of Wanda's dog, *d*.

Which expression represents the weight of Janine's dog?

A $2 + d - 3$
B $3 + d - 2$
C $2d - 3$
D $3 - 2d$

6. What value of x makes the equation below true?

$$\frac{x + 3}{2} = 8$$

A 1
B 5
C 13
D 19

7. A pair of sandals is on sale for 20% off the original price. If the original price is $16.00, what is the sale price?

A $3.20
B $12.00
C $12.80
D $19.20

8. What is $3m^3 + 6m^2$ divided by $3m$?
A $m^2 + 6m^2$
B $m^2 + 2m$
C $3m^2 + 6m$
D $m^3 + 2m^2$

9. Which situation is **best** represented by the expression $4h + 2$?
A Kepa spends 4 hours babysitting and 2 hours traveling.
B Kepa spends 4 hours babysitting and receives $2 in travel expenses.
C Kepa will be paid $4 for babysitting and spends 2 hours traveling.
D Kepa will be paid $4 for every hour of babysitting plus $2 for travel costs.

10. What is the sum of $(3 + 3)^2$ and 2^3 ?
A 18
B 20
C 26
D 44

Math test 3

1. Jessica went shopping for a new watch. She found a watch that was originally priced at $50 on sale for $40. By what percent had the watch been marked down?

A 10%
B 20%
C 25%
D 40%

2. Simplify the expression below.

$(3x^2 - 2x - 1) + (-2x^2 + 4)$
A $x^2 + 3$
B $5x^2 + 3$
C $x^2 - 2x + 3$
D $5x^2 - 2x + 3$

3. The distance between two cities on a map is 2 inches. The map was drawn using the scale shown below.
1 inch = 344 miles
What is the actual distance, in miles, between the two cities?
a. 86
b. 344
c. 688
d. 1,032

4. What is the product of the expression below?
$(2x - 5)(2x - 3)$
A $4x^2 + 16x + 15$
B $4x^2 - 16x - 15$
C $4x^2 + 16x - 15$
D $4x^2 - 16x + 15$

5. The sum of a number and its square is less than or equal to negative three. Which inequality represents this relationship?
A $n(n2) \leq -3$
G $n(n2) \leq 3$
H $n + n2 \leq 3$
J $n + n2 -3$

6. Find the value of x in the equation below.

$3(x + 2) = x$

A - 3
B -1
C 2
D 3

7. Anneke and her parents had dinner at their favorite restaurant. The dinner bill was $50.00, and her parents tipped their server 20% of the bill. How much money did Anneke's parents leave as a tip?

A $1.00
B $10.00
C $20.00
D $25.00

8. Simplify the expression below.

$3xy\ (9xy + 14x)$

A $27xy + 42x$

B $9xy + 42x^2y$

C $27x^2y^2 + 14x$

D $27x^2y^2 + 42x^2y$

9. In order to purchase a new CD player, Rosa must save **at least** $85.00. What inequality represents the amount of money, *m* , Rosa must save?

A $m \leq 85.00$
B $m < 85.00$
C $m \geq 85.00$
D $m > 85.00$

10. Which verbal expression is the same as $\frac{n}{2} + 6$?

A two more than half of six
B six more than half of a number
C the sum of a number and two plus six
D six more than the product of a number and two

Math test 4

1. The cost of Cynthia's dinner is $15.20. She leaves a tip that is 15% of the cost of the dinner. What is the **best** estimate for the amount of the tip?

A $1.00
B $2.00
C $3.00
D $4.00

2. Simplify the expression below.
$(3a^2 + 5a - 11) - (11a^2 + 2a - 12)$
A $-8a^2 + 3a + 1$
B $-8a^2 + 7a - 23$
C $14a^2 + 7a + 1$
D $14a^2 + 3a - 23$

3. What is the product of $(6a^2 b^3 c^4)$ and $(3a^3 b^4 c)$?

A $9a^5 b^7 c^4$
B $9a^5 b^7 c^5$
C $18a^5 b^7 c^5$
D $18a^5 b^7 c^4$

4. Bruce needs 30 five-foot pieces of rope for a school project. The hardware store sells rope by the yard. How many yards of rope will Bruce need to purchase?

A 10
B 30
C 50
D 75

5. Carol wants to earn at least $150.00 for her charity while running a race. She will earn $20.00 for participating plus $7.00 for each mile she runs. If *m* represents the number of miles she runs, which inequality represents the money Carol wants to earn?

A $7m + 20$ _ 150
B $7m + 20$ _ 150
C $20m + 7$ _ 150
D $20m + 7$ _ 150

6. Solve the equation below for *x.*
$9(x - 5) = 4x - 5$
a. 8
b. 10
c. - 8
d. -10

7. A 20-ounce bag of popcorn costs \$2.80. If the unit price stays the same, how much does a 35-ounce bag of popcorn cost?

A \$3.60
B \$4.00
C \$4.50
D \$4.90

8. Simplify the expression below.

$$\frac{12x^2y^3}{3xy}$$

A $4xy^2$

B $4x^2y^2$

C $\frac{4}{xy^2}$

D $\frac{4x}{y^2}$

9. The table below shows a relationship between *x* and *y*.

x	2	5	6	9
y	6	9	10	13

Which equation shows the relationship between *x* and *y* ?
A $y = 3x$
B $x = 3y$
C $y = x + 4$
D $x = y + 4$

10. Sarah went on a one-day bus tour from Las Vegas to the Grand Canyon. The cost of the bus ticket was \$80. She also paid 15% of the cost of the ticket as a tip to the bus driver. What was the amount of the tip that Sarah paid the bus driver?

A. \$5
B \$12
C. \$15
D. \$19

APPENDIX F

MATH TEST ANSWER KEY

Math test 1

1	B
2	C
3	C
4	D
5	B
6	A
7	D
8	C
9	B
10	D

Math test 2

1	B
2	C
3	C
4	A
5	C
6	C
7	C
8	B
9	D
10	D

Math 3

1	B
2	C
3	C
4	D
5	D
6	A
7	B
8	D

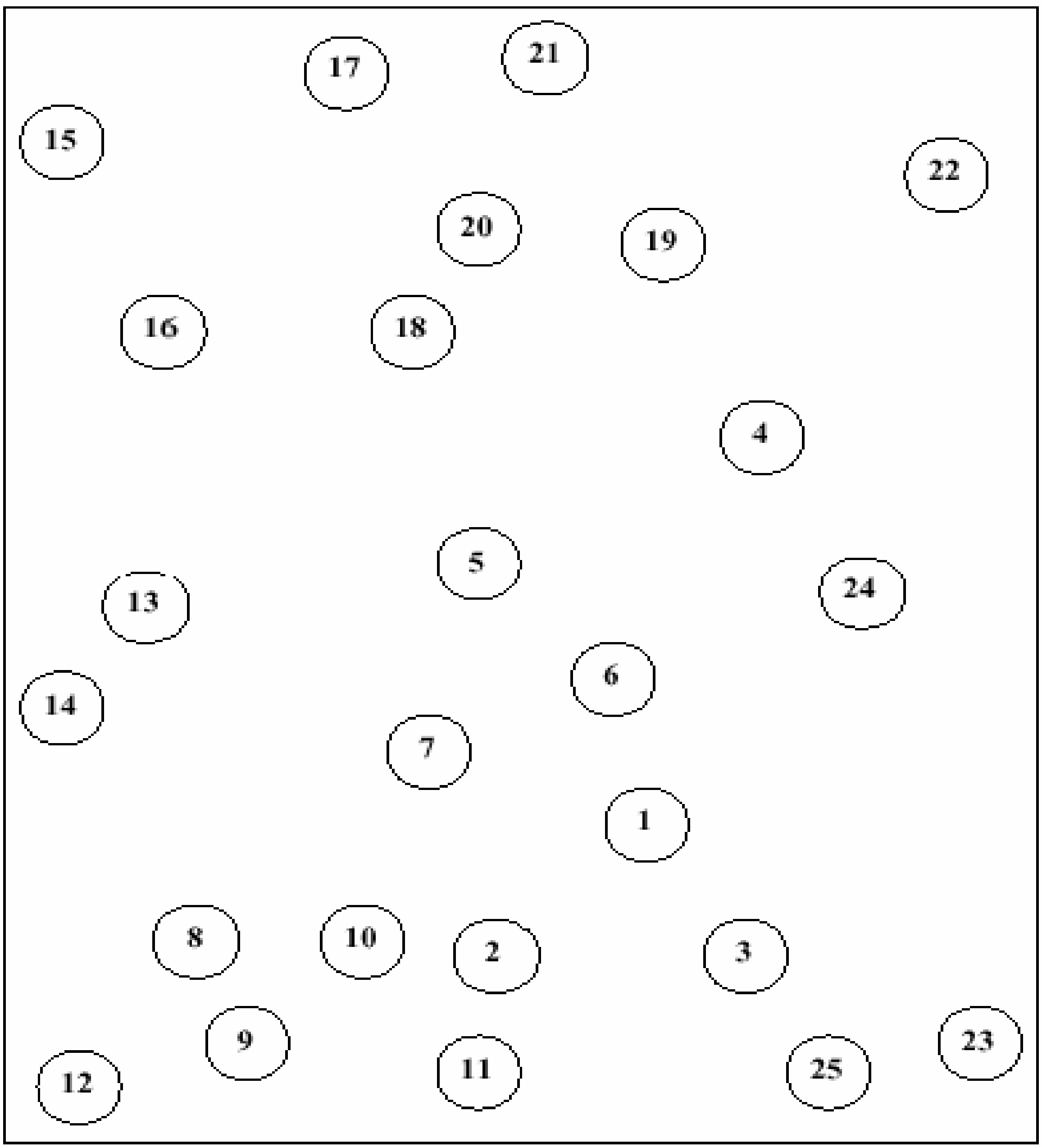
9	C
10	B

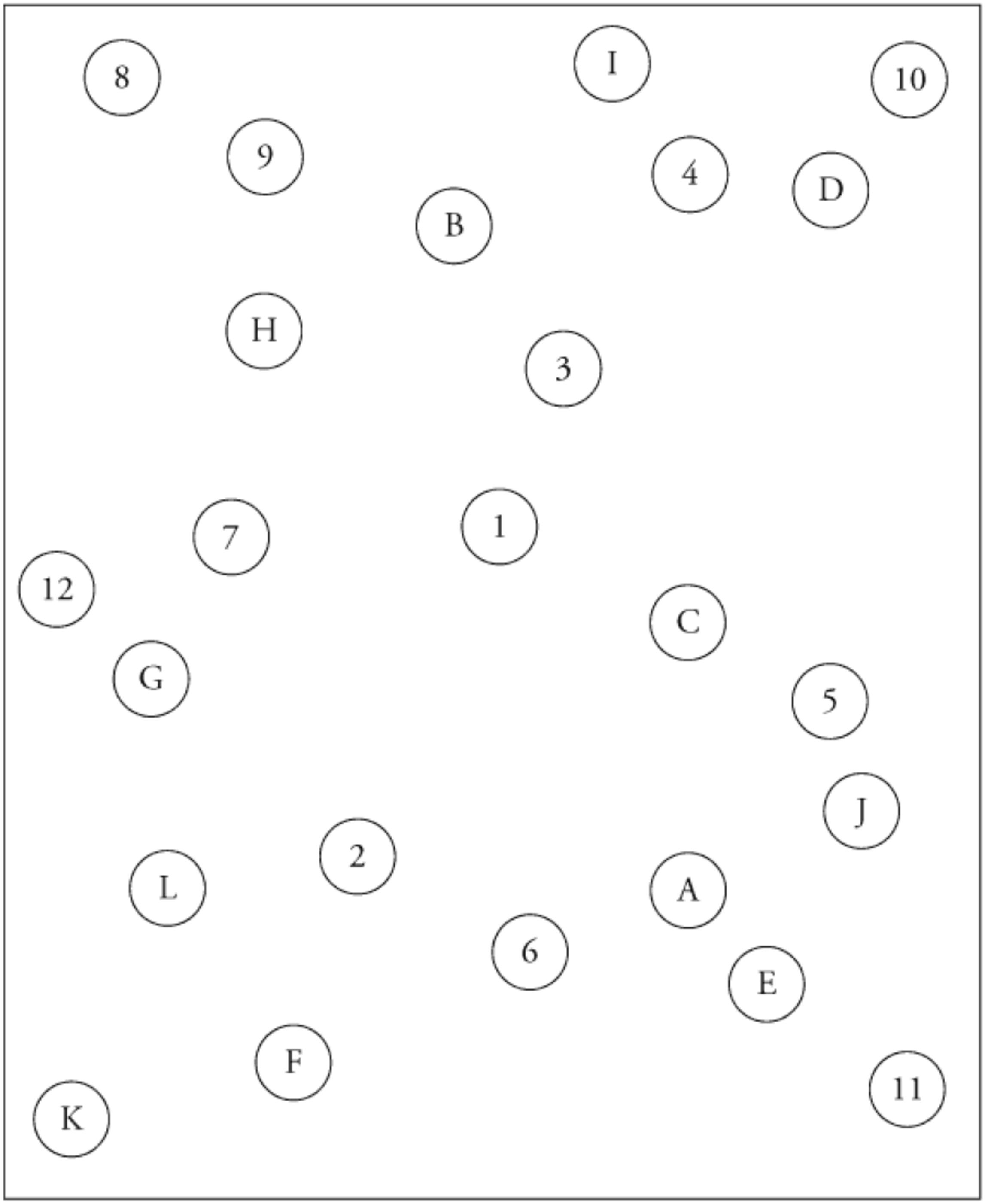
Math test 4

1	B
2	A
3	C
4	C
5	B
6	A
7	D
8	A
9	C
10	B

APPENDIX G

COMPREHENSIVE TRAILS MAKING TESTS

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