ACUTE EXERCISE AND ACADEMIC ACHIEVEMENT IN YOUTH

by

Andrew Harveson

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

December 2015

The University of Utah Graduate School

STATEMENT OF DISSERTATION APPROVAL

The dissertation of **Andrew Harveson**

has been approved by the following supervisory committee members:

James Hannon	, Chair	**8-25-2015** Date Approved
Timothy Brusseau	, Member	**9-8-2015** Date Approved
Leslie Podlog	, Member	**9-8-2015** Date Approved
Lynne Durrant	, Member	Date Approved
Charilaos Papadopoulos	, Member	**9-8-2015** Date Approved

and by **Janet Shaw**, Chair of

the Department of **Exercise and Sport Science**

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

The purpose of this study was to determine differences in mathematics performance and cognition between acute bouts of resistance exercise, aerobic exercise, and a nonexercise control in 5th-, 8th-, and 10th-grade students. Aerobic exercise has consistently shown small, positive changes in youth cognition and academic achievement. However, no research exists documenting the effects of resistance exercise on similar outcomes in youth. This study utilized a randomized crossover design. Participants performed 30 minutes of aerobic exercise, resistance exercise, and nonexercise in a randomized order, separated by 7 days each. Immediately following each exercise intervention, participants were assessed using separate 10-question math tests created from the New York state standardized mathematics exams. Additionally, cognition was assessed in 8th- and 10th-graders after each exercise intervention using the Stroop Test (Victoria version). Data were analyzed using repeated measures ANOVA. Results indicated that for both 5th- and 8th-grade students, math performance increased significantly following resistance exercise over the nonexercise control. Practically significant increases were seen in math performance following aerobic exercise in 5th-, 8th-, and 10th-graders, and following resistance exercise in 10th-graders as compared to the nonexercise control. Amongst 8th-graders, significant differences were found in Stroop test performance following both aerobic and resistance exercise as compared to the nonexercise control. Tenth-grade students performed significantly better on the Stroop

Dot and Color test following aerobic exercise, and better on the Stroop Dot test following resistance exercise as compared to the nonexercise control. Findings from this study are novel in that they mark the first instance of resistance exercise demonstrating increases in academic achievement and cognition in youth. Importantly, it appears that both resistance and aerobic exercise exhibit similarly positive effects on academic outcomes in three different youth age groups. Findings could influence the use of acute resistance exercise as an alternative or complement to aerobic activity for educators aiming to increase pupils' physical activity and academic performance concurrently.

TABLE OF CONTENTS

LIST OF FIGURES

Figures

CHAPTER 1

INTRODUCTION

Physical activity (PA) has been found to play an important role in the health of young people, influencing factors such as cardiovascular health, anxiety, and body composition (Strong et al., 2005). However, statistics on the amount of PA being achieved by today's youth reveal an alarming trend. Less than one-third of children between the ages of 6 and 17 meet the 60 minutes of daily moderate to vigorous PA that is recommended (NASPE, 2010). Such a severe lack of PA in today's youth poses serious health problems for our nation, with estimated medical costs of obesity-related disease being in the hundreds of billions of dollars by the year 2018 (NASPE, 2010). Despite youth PA levels being so low, school physical education (PE) programs are often reduced or cut in favor of a greater focus on academic subject matter. This trend is often cited as having begun with the No Child Left Behind Act, established in 2001 by George W. Bush. This act was intended to jump start the American education system, centralizing its focus on a standards-based approach with the goal of America becoming a world leader in science and mathematics. As educators rushed to meet the increased academic demands placed upon them by such legislation, opportunities for youth PA and PE were further reduced. However, evidence relating PA and children's performance in school indicates that a reduction in PA may be a step in the wrong direction for both the

academic and physical health of school-aged youth. In fact, in a longitudinal study of over 5,000 students from kindergarten through fifth grade, small, positive changes in academic achievement (AA) were seen in girls who were enrolled in higher amounts of PE per week (Carlson et al., 2008). In this same study, it was important to note that while only girls demonstrated an increase in AA, boys who were also enrolled in greater amounts of PE time per week did not exhibit any decrease in AA compared to their peers in reduced PE schedules. Similar results have been demonstrated throughout the literature, giving an indication that up to an hour of increased curricular time in PA and PE do not negatively impact academic performance in youth (Trudeau & Shephard, 2008). Importantly, additional time allocated to courses that do not contain an activity component do typically show a decrement in academic performance in youth (Trudeau & Shephard, 2008).

Much of the research related to PA and AA has dealt with chronic PA and its association with school-aged children's performance in the classroom. The consensus from such work indicates that children who participate in greater levels of PA typically have small, positive performance differences from their more sedentary peers in the areas of cognition, academic achievement, behavior, and psychosocial functions (Lees & Hopkins, 2013). In addition to research on chronic PA, the effects of acute exercise on measures of cognition and AA have also been studied extensively. Similar to findings on chronic exercise, acute exercise seems to have a consistently small, positive impact on measures of cognition (Castelli, Hillman, Hirsch, Hirsch, & Drollette, 2011), academic achievement (Hillman et al., 2009b), attention (Budde, Voelcker-Rehage, Kendziorra, Ribeiro, & Tidow, 2008), and memory (Pesce, Crova, Cereatti, Casella, & Bellucci,

2009). While such results are encouraging for proponents of PA, there remain many unknown variables related to exercise and executive functions as a whole.

Statement of the Problem

One of the variables left largely unstudied in the realm of acute PA, cognition, and AA is that of exercise type. Specifically, the vast majority of research has been performed utilizing the modality of aerobic exercise (AE) as the primary intervention. Acute AE has demonstrated small, positive results in measures of AA, such as the Wide Range Achievement Test (Hillman et al., 2009b), and mathematics computation scores (Gabbard & Barton, 1979). Despite such findings, no research exists documenting the effects of acute resistance exercise (RE) on measures of AA. Prior research, while limited, has identified the ability of acute RE to effectively influence cognition in adult populations (Alves et al., 2012; Chang & Etnier, 2009b). Additionally, pilot data collected by the author have lent further support for the ability of acute RE to significantly improve measures of cognition in a youth sample. The study containing these data is currently under review and would be the first of its kind to demonstrate cognitive changes in youth following acute RE. The above evidence gives reason to believe that RE may provide similar benefits to AE in measures of AA following an acute bout.

Study Purpose

This project took a three-study approach to examine the effects of acute RE, AE, and a nonexercise (NE) control on grade-level appropriate standardized mathematics tests and a test of cognition in: (a) 5^{th}-, (b) 8^{th}-, and (c) 10^{th}-grade students. Given the

profound development that occurs during the late elementary, middle, and early high school years, it was believed that these age groups would be critical to study and would provide additional evidence of the potential impact that AE and RE might have on youth AA.

Significance

The significance of this project lies primarily in the potential to expand current findings related to youth PA and AA. Space and equipment are often limiting factors in the PE and scholastic environment. The addition of RE as another exercise modality that could improve academic proficiency would address such a need, as well as provide additional outlets for students to pursue a healthy lifestyle while achieving greater academic success. Should RE be found to have similar effects as AE on measures of AA, it could have a profound effect on future legislation, classroom scheduling, and overall academic practice.

Hypothesis

The primary hypothesis for this study is that mathematics test performance will increase significantly following AE and RE, but not NE. The secondary hypothesis is that both AE and RE will exhibit significantly improved test results compared to the NE control in each form of the Stroop Test. It is hypothesized that these results will be similar across all three age groups.

Definition of Terms

Physical activity is any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure (Darst & Pangrazi, 2009).

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

Acute exercise is a single session of exercise, typically short, but lasting up to four hours (Dishman, Washburn, & Heath, 2004).

Resistance exercise is a specialized method of conditioning that involves the progressive use of resistance to increase one's ability to exert or resist force (Baechle & Earle, 2008, p. 170).

CHAPTER 2

LITERATURE REVIEW

For the purposes of this paper, the term executive function (EF) will be used to characterized a broad array of controlled cognitive outcomes including, but not limited to, academic achievement, working memory, arousal, problem solving, selective attention, and general higher level thought processing. Historically, Spirduso (1975) was the first to study the association between cardiovascular fitness and memory. Since that time, the exploration of the effects of varying interventions relating exercise and executive functions have developed into a substantial research interest. Much of the foundational research in this spectrum has been correlational in nature, stemming largely from the works of Kramer et al. (1999). However, in recent years, more attention has been paid to the effects of acute exercise and its role in advancing EF. While a large percentage of this body of literature has emphasized aerobic work as the primary exercise mode, evidence has been brought to light giving credence to the notion that resistance exercise may also play a role in EF and cognition. The distinctions between these forms of exercise and their EF effects will be analyzed according to subject age group (youth, adult, senior) in the following paragraphs. Age groupings will be broken down as follows: youth < 18 years old, adult 18-64 years old, seniors > 65 years old. Additionally, for the sake of this work, all studies that utilize EF testing during, or

immediately following exercise bouts will be examined under the realm of acute exercise.

Youth Populations

Acute Aerobic Exercise and EF

The origins of the study of youth EF following acute AE can be traced back to the work of Gabbard and Barton (1979) who investigated the relationship between physical exertion and mathematics computation scores in 2nd-grade boys and girls. Students were asked to perform standard relay-type activities in a cyclical method for the following intervals: no exertion (pretest), 20, 30, 40, and 50 minutes, followed by another no-exertion posttest. Mathematics computations were administered 5 minutes after each exertion period, and consisted of 36 questions that did not require borrowing or carrying functions. Significant differences were found in mean scores following only the 50-minute treatment, which led the authors to conclude that aerobic exercise of specific (50-minute) duration could positively affect mental performance in youth. Interestingly, despite the positive results found by Gabbard and Barton, acute AE was not studied as an EF intervention in youth for quite some time. Zervas, Danis, and Klissouras (1991) demonstrated a significant difference in matching ability measured before and following acute exercise bouts between 9 sets of twin boys. The boys were exposed to either a 6-month aerobic exercise regimen or a standard school PE program, with nontwin peers in a nonexercising control group. Several years later, Gabbard and McNaughten (1993) continued exploration of exertion on math computation in youth, looking specifically at mathematics computation among 6th-grade boys and girls following bouts of paced walking for 20, 30, and 40 minutes at varying times throughout the school day. Tests

were performed at 8:30 am, 11:50 am, and 2:20 pm for 3 weeks, after which students would perform 90-second tests of math computation. Results indicated that scores were significantly higher at 11:50 am and 2:20 pm following the 30- and 40-minute bouts of aerobic exercise.

Re-emergence of the study of acute AE on youth EF arrived in the mid- to late 2000's, and has since become a hot topic. Hillman et al. (2009b), one of the leading researchers in the area of youth activity and academic achievement, demonstrated cognitive improvements in pre-adolescent children following 20 minutes of treadmill walking at 60% of the child's max heart rate. Response accuracy, P3 amplitude, and increased performance on a measure of academic achievement all significantly differed in the aerobic exercise group over that of a nonexercising control. Similarly, Best (2012) showed a cognitive enhancement as measured by response time and accuracy in resolving visual stimuli in children aged 6 to 10 years old following 10 minutes of exergaming. Results from such research demonstrate reason for inclusion of aerobic physical activity in schools for the sake of cognition and academic achievement. Further, classroom teachers may be directly impacted by research findings from Budde et al. (2008), who showed an increase in attention and concentration among 115 adolescent students in an elite performance school following just 10 minutes of coordinative exercise. Interestingly, this study also compared the effects of a normal sport lesson matched for heart rate on the same outcome variables and found that while both exercise modes improved concentration and attention, results were greater in the coordinative exercise group. These findings may provide valuable information as to the type of aerobic exercise that best elevates student achievement in the classroom. Continuing this trend,

Tine and Butler (2012) focused their efforts on improvements in selective attention in children from low-income homes. This work was especially important, as youths from lower income families have typically been shown to exhibit poor EF skills in relation to their higher-income peers. However, Tine and Butler demonstrated that after a 12-minute session of aerobic exercise, 6th- and 7th-grade students from both low- and high-income backgrounds were able to increase their selective attention, with low-income students showing significantly greater improvements. Finally, with ADD and ADHD being an ever-increasing dilemma that classroom teachers must deal with on a daily basis, the work of Chang, Pan, Chen, Tsai, and Huang (2012) was a great step forward for the field of physical activity as related to AA and EF. This study examined youths aged 8-15 who had been classified as ADHD by a clinical psychologist and found that following an acute bout of 30-minutes of moderate-intensity treadmill running, students in the exercise group significantly out-performed their nonexercising peers in tests of executive function, specifically the Stroop test and the Wisconsin Card Sorting Test. Results indicate that acute aerobic exercise may better help allocate executive attention resources in children with ADHD. It is clear that while this field of research is still relatively young and under-studied, many positive results have been discovered in the quest to increase youth learning and EF, and as such, acute aerobic exercise appears to play an important role in many aspects of brain function and cognition.

Acute Resistance Exercise and EF

To date, there have yet to be any published studies performed on youth populations looking at acute resistance exercise and EF. As mentioned previously, pilot

data from the principal investigator has established initial evidence to support equal efficacy between AE and RE on measures of cognition in high school youth. Additionally, resistance exercise has received recognition as an appropriate and viable form of youth fitness from the National Strength and Conditioning Association (Faigenbaum et al., 2009). Additionally, RE has been shown to impact such variables as self-esteem (Courneya et al., 2007), body composition (Garber et al., 2011), coordination (Garber et al., 2011), strength (Kraemer, Ratamess, & French, 2002), cognitive arousal (Chang & Etnier, 2009), improved quality of life (Kraemer et al., 2002), and protection against health- and age-related disease (Garber et al., 2011). Thus, there is reason to suspect that a well-designed resistance training program could have a similar effect to that of traditional aerobic exercise on executive function. Future research should target both chronic and acute resistance exercise as a means of effecting change in EF in youth, especially as this line of research continues to grow with the utilization of aerobic exercise.

Adult Populations

Acute Aerobic Exercise and EF

The paucity of studies completed in the examination of EF in youth populations is quite the opposite of what is seen among adults. In fact, quite a large body of literature exists documenting acute aerobic and anaerobic exercise and numerous measures of cognitive function. In a review done by Tomporowski (2003), an interesting theme came to light, highlighted by several studies from Cian and colleagues (Cian et al., 2000; Cian, Barraud, Raphel, & Melin, 2001) who discovered that EF (specifically short-term

memory) was attenuated following acute bouts of intense aerobic exercise leading to dehydration. In fact, the studies in which subjects were in a dehydrated state were the only examples that did not show either an increase in EF or no change between groups studied, indicating that there may be a link between hydration and cognition, at least as related to acute aerobic exercise. Tomporowski found several other aspects of EF that were positively influenced by AE, including reaction time, mathematics computations, Stroop testing, perception, decision making, concentration, and memory (2003). The majority of the examined studies of acute AE made use of modalities such as treadmill running (Heckler & Croce, 1992; Lichtman & Poser, 1983; Marriott, Riley, & Miles, 1993; Tomporowski, Elis, & Stephens, 1987), or cycling (Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Tomporowski, 2003) at various intensities and durations. Facilitation in measures of EF were seen in the majority of these studies, while at worst, no effect was seen in measures of choice reaction time, tapping (Hogervorst et al., 1996), and free recall memory (Tomporowski et al., 1987).

Following publication of Tomporowski's review, the literature on this topic continued its growth as researchers made attempts to discover the underlying factors that related EF to acute exercise. Hillman, Snook, and Jerome (2003) examined the neuroelectric response of 20 undergraduate subjects to an acute 30-minute bout of graded treadmill exercise. P3 amplitude and performance on the Eriksen Flanker test were evaluated when subjects' heart rates had returned to 10% of pre-exercise levels. Results indicated that following acute AE, P3 amplitude was increased significantly above baseline levels, hinting at the possibility of increased cognition via elevated allocation of neuroelectric resources and speed of executive processing. Similar, positive results

following acute exercise were found by Tomporowski and Ganio (2006), who discovered an increase in performance of a task-switching test among male and female undergraduate students upon completion of 40 minutes of submaximal AE. The task-switching test was also perceived to be less frustrating to students following acute exercise as compared to a resting condition. Interestingly, while students performed better on the measure of processing speed, short-term memory was not affected in either males or females following completion of acute AE. A possible explanation for this discrepancy lies in the executive processing theory explained by Kramer et al. (2003), which states that physical activity most likely impacts operations in the prefrontal cortex of the brain, which is responsible for information processing. Short-term memory functions, on the other hand, are the primary responsibility of the hippocampal region of the brain, which does not appear to be affected in the same manner by physical activity, chronic or acute. With such information in mind, Coles and Tomporowski (2008) investigated the impact of 40 minutes of acute AE on aspects of long-term memory in undergraduate students. Similar in nature to the protocol used by Tomporowski and Ganio in 2006, this study also observed changes in primacy and recency portions of a word-recall list, or the ability of the students to recall items in the first and last parts of a word list, which appears to be an indicator of increased long-term memory storage. Indeed, after acute bouts of AE on a cycle ergometer, students were able to recall significantly more of these first and last items in the test as compared to a resting and nonexercising control. Authors believed that arousal levels were influenced in a positive way by the exercise intervention, leading to greater cognitive encoding and consolidation of working memory. Caution must be used when interpreting these results, however, as

long- and short-term memory did not actually increase as a result of this intervention; subjects simply performed less poorly in these measures following acute AE.

An additional aspect of acute exercise of interest to researchers hoping to observe changes in EF is that of exercise intensity. In this regard, there seems to be some conflicting evidence relating the ability of acute AE to consistently influence EF. Much of the research in this regard has dealt with arousal levels, indicating the possibility of an inverted U-shaped curve as arousal increases related to exercise intensity. This U-shaped relationship was first observed by Levitt and Gutin (1971), who found an improvement in men's reaction times during treadmill walking at speeds that produced 115 heartbeats per minute. As heart rate increased to 145 beats per minute, reaction time returned to baseline levels and, at 175 beats per minute, was further attenuated below basal levels. Similarities were observed in studies by Salmela and Ndoye (1986), Cote, Salmela, and Papathanasopoulu (1992), Brisswalter, Durand, Delignieres, and Legros (1995), Kamijo et al. (2004), and Chmura, Nazar, and Kaciuba-Uscilko (1994).

While the inverted U-shaped curve has been observed in multiple studies of EF and arousal resulting from acute AE, a more common theme seen in the literature is that subjects are able to make quicker responses while performing acute AE as compared to nonexercise or low-intensity exercise (Tomporowski, 2003). Results corroborating the notion that response time is hastened while exercising at moderate intensities include studies done by McMorris and Keen (1994), Aks (1998), Allard, Brawley, Deacon, and Elliot (1989), Arcelin, Brisswalter, and Delignierres (1997), McGlynn, Laughlin, and Bender (1977), and McMorris et al. (1996, 1997, 1999). The vast majority of these studies utilized cycle ergometer protocols with subjects performing cognitive tasks during

or after completion of exercise at various intensities.

One of the more recent hypotheses regarding EF and higher intensity acute exercise is known as the transient hypofrontality theory. This theory was developed and further explored by Dietrich (Dietrich, 2006; Dietrich & Sparling, 2004) in an attempt to explain the findings that indicated a reduction in EF capabilities during acute exercise. The primary premise behind Dietrich's hypothesis was that the brain operates on a limited metabolic supply, and during exercise, while the brain is occupied with the performance of complex movement patterns, there is limited availability for EF to be directed towards other tasks. This notion was further supported by DelGiorno, Hall, O'Leary, Bixby, and Miller (2010), who examined EF in a cohort of male and female adults during, immediately following, and 20 minutes postexercise. Acute exercise bouts were performed at ventilatory threshold (VT) and 75% VT for 30 minutes followed by a performance task test and the Wisconsin Cart Sorting Test. A significant increase in errors and false alarms was seen during both exercise intensities. Interestingly, errors remained elevated after 20 minutes in the VT group, but not in the 75% VT group, indicating that EF may indeed be negatively impacted by high-intensity acute exercise, and that additional recuperation time is needed to observe the cognitive benefits associated with exercise. These findings were corroborated by Labelle, Bosquet, Mekary, and Bherer (2012), who found that cognitive control, as measured by the Stroop test, decreased as exercise intensity increased from 60% to 80% of peak power output. These findings must be taken into account when designing AE interventions targeted at adult populations.

Acute Resistance Exercise and EF

As was seen in the comparison of acute resistance and aerobic exercise in youth populations, a great disparity exists between the number of studies examining the same variables in adult populations. While the reason for this disparity is unclear, there at least exist a small number of adult studies looking at RE and its effects on EF. The first study to examine the effects of RE on EF in adults was performed by Krus, Wapner, and Werner (1958). This work utilized a protocol that required participants to push against a spring-loaded board for 20 seconds, after which they were given a test of perceptual sensitivity. Results indicated a significant decrease in perceptual sensitivity, leading authors to assume that the positive associations observed following acute AE may be task dependent. Not until 2009 was this acute exercise modality again studied in adult populations, when Pontifex, Hillman, Fernhall, Thompson, and Valentini compared the effects of resistance and aerobic exercise on measures of reaction time and working memory. Subjects completed EF related tasks before, immediately after, and 30 minutes after completion of the exercise protocol. Response time was significantly shorter in the time periods immediately after and 30 minutes after aerobic exercise, with no observed changes for resistance exercise or seated rest control. A larger decrease in reaction time was also seen in the aerobic exercise modality for those conditions requiring increased working memory. No differences were found in this regard for resistance exercise or resting control. Authors speculated that differences in cerebral blood flow between aerobic and resistive exercise may be the underlying cause behind the null response of acute strength training and EF. It should be noted, however, that another study examining acute resistance exercise and cognitive function was being performed at the

same time by Chang and Etnier (2009b), with contrarian results. The work by Chang and Etnier focused solely on RE compared to a resting control, and determined that 2 sets of 10 repetitions of 6 exercises induced a significantly different response in measures of the Stroop test and the Trail Making Test. These findings give credence to the notion that RE may indeed have an effect on cognition, albeit specifically in terms of processing speed and task shifting. Additional study of such measures of EF were examined by Alves et al. (2012), who observed a cohort of 42 healthy middle-aged women in a counterbalanced, crossover, randomized trial design. Each subject was exposed to the aerobic, resistance, and nonexercise treatments and analyzed for performance on the Stroop Test and Trail Making Test. Subjects performed significantly better on the Stroop Test but not the Trail Making Test for both the aerobic and resistance interventions as compared to the nonexercise control. As with other studies, authors concluded that while increases in EF can be seen with RE as well as AE, changes may be task-specific.

Senior Populations

Acute Aerobic Exercise and EF

While clear benefits exist across all ages for increasing cognition and EF, it seems that young and old populations could benefit to the greatest degree for both health purposes and increased mental functioning. To this end, there exists encouraging evidence that older adults display similar increases in EF to those already discussed in this review. Specifically, Molloy (1988) found an increase in cognition as measured by logical memory test following 45 minutes of moderate intensity AE in older adults. Emery, Leatherman, and Burker (2001) found similar results in a cohort of elderly COPD

patients who were exposed to 20 minutes of a cycling protocol followed by a cool-down period. These subjects demonstrated increased verbal processing via the Verbal Fluency Test. Interestingly, a comparison was made to healthy older adults and only those with COPD were found to demonstrate an increase following acute exercise. Light and moderate cycling exercise was also used as a modality in determining response to a Flanker task test and P3 amplitude in a study of young and old males by Kamijo et al. (2009). Both groups demonstrated a reduction in reaction time following moderate exercise, and a decrease in P3 latency following light and moderate exercise. P3 amplitude was found to increase only among the younger subjects, however, lending credence to the idea that some aspects of cognition may be age dependent. Other increases seen in cognitive tests performed among seniors following acute AE include the Stroop Test (Hyodo et al., 2012) and measures of reaction time and task switching (Kimura & Hozumi, 2012). Increases in these areas of cognition were seen after bouts of cycle ergometry and free and choreographed dance, respectively.

Acute Resistance Exercise and EF

As was seen among youth populations, no studies to date have been performed utilizing acute bouts of RE in senior populations to affect EF or cognition. However, there have been a handful of studies looking at the chronic effects of resistance training on EF in seniors, which indeed sheds light on the possibility of RE to affect cognition in older adults. Facilitation in measures such as the Stroop Test (Liu-Ambrose et al., 2008), free recall (Perrig-Chiello, Perrig, Ehrsam, Staehelin, & Krings, 1998), reaction time (Brown, Liu-Ambrose, Tate, & Lord, 2009), and memory (Cancela-Carral & Ayan-Perez,

2007) have all been documented following longer term RE programs in older adults. Cassilhas et al. (2007) also demonstrated that 24 weeks of either moderate or high-intensity RE had equal, positive effects on cognition in elderly adults. Similar results were also found by Nagamatsu, Handy, Hsu, Voss, and Liu-Ambrose (2012), who discovered that twice-a-week RE had a countering effect towards the customary decline in cognition seen among aging adults. Clearly there is a need for more research in this area examining these or similar measures of cognition and EF following acute RE in elderly subjects.

CHAPTER 3

STUDY 1: EFFECTS OF ACUTE EXERCISE ON MATHEMATICS PERFORMANCE IN 5th-GRADE STUDENTS

Introduction

It has been established that increasing youth physical activity (PA) is an important step in combatting overweight and obesity (Strong et al., 2005). Additionally, regular participation in PA has been positively associated with academic achievement (AA) (Singh, Uijtdewilligen, Twisk, Van Mechelen, & Chinepaw, 2012). Such associations, while consistent, are still being explored in an effort to determine the underlying mechanisms. The current academic environment in the United States is strongly centered around test results, even going so far as to include incentive programs that aim to increase student performance (Figlio & Kenny, 2007). In light of such an environment, it is in the best interest of educators and health professionals alike to determine the best practices that may enhance students' physical health and academic performance concurrently.

Within the context of elementary-aged students, there have been a number of studies examining various aerobic exercise (AE) interventions aimed at increasing AA. Traditional AE (Coe, Pivarnik, Womack, Reeves, & Malina, 2006), physical education (PE) participation (Carlson et al., 2008), and such interventions as exergaming - video

game exercise – (Gao, Hannan, Xiang, Stodden, & Valdez, 2013) have demonstrated positive outcomes on select measures of AA. Tests of mathematics and reading are the most frequently utilized academic outcomes, with mathematics being the most consistently tested academic measure following acute exercise (McNaughten & Gabbard, 1993).

While acute AE has been established as having positive effects on AA in elementary-aged students, researchers have yet to examine the effects of resistance exercise (RE) as an intervention that could have similar results. RE has been shown to be a safe, effective part of a well-rounded exercise program for children and adolescents (Faigenbaum et al., 2009). Additionally, research across populations including seniors, adults, and high school youth indicate that RE has the ability to positively affect cognition to the same degree as AE (Alves et al., 2012; Chang & Etnier, 2009b). With such evidence in mind, there is reason to explore the effects of acute RE as another potential outlet for elementary-aged students to improve performance in measures of AA. Thus, the purpose of this study was to compare the acute effects of AE, RE, and a non-exercise (NE) control on measures of AA in 5th-grade boys and girls. It was hypothesized that both AE and RE would improve students' performance on a standardized test of mathematics over the NE control.

Method

Participants and Setting

The participants of this study were 5th-grade students sampled from an elementary school in the southwestern United States. Results of an *a priori* power analysis (G Power

Statistical Software) indicated a minimal sample size of 60 participants ($\alpha = 0.05$, $\eta^2 = 0.3$). Seventy participants were recruited, but after accounting for drop out, the total was reduced to $N = 63$ (38 girls, 25 boys). Participants were asked to provide written assent in conjunction with written consent from a parent or legal guardian. Participants were all apparently healthy as defined by their enrollment in PE class, and able to participate in regular exercise. The study was conducted in accordance with institutional, district, and American College of Sports Medicine (ACSM) ethical guidelines.

Instruments

Academic achievement was measured in this study using a battery of four 10-question math tests taken from New York State Testing Program 5th-grade exams that have been used in the last five years (http://www.p12.nysed.gov/assessment/). The tests are therefore current, and come with technical manuals that verify the multiple choice content with Cronbach's Alpha coefficient scores. The tests have internal consistency coefficients of $r = 0.85$ (2012), $r = 0.86$ (2011), and $r = 0.89$ (2010). The tests were assembled with assistance from the 5th-grade classroom teachers to insure the content had been covered in the current school year. The content of each test covered similar material, but the questions were purposely different so as to avoid a practice effect. Students were given 5 minutes to complete each 10-question test, mimicking the demands of a classroom setting and utilizing the speed-test concept developed by Brown (1970).

Procedures

This study utilized a randomized crossover design. Participants were required to perform one familiarization session on the mathematics test and exercise protocols. Seven days after the familiarization session, participants performed one of three experimental sessions (AE, RE, NE) in a randomized order, completing all three interventions over the course of three weeks. The math tests were administered between 5 and 20 minutes after completion of each intervention in accordance with prior research (Hillman et al., 2009). Data collection was performed by the author and trained research assistants.

The AE and RE protocols were based on previous work by Alves et al. (2012). The RE protocol involved two sets of 15 repetitions in each of the following six exercises: bodyweight squat, walking lunge, pushup, band pull down, band row, and band overhead press. If participants were not able to complete 15 repetitions per set, a reduction in weight on subsequent sets was allowed (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009) via an alteration of resistance band length or modification of leverage for exercises using bodyweight alone. Participants in this study did not have access to a traditional weight room, so a variety of resistance elements were utilized, such as body weight and resistance bands. Such a procedure also served to better mimic the traditional equipment provisions in a typical elementary PE program. A 1-minute rest interval was assigned between sets. The RE intervention was 20 minutes in length. The AE protocol was matched for time and consisted of 20 minutes of walking or jogging at an estimated exercise intensity of 50-60% heart rate max. In the NE control, participants sat quietly doing other schoolwork in their home classroom. Participants were monitored to insure they did not fall asleep or move around (Pontifex et al., 2009). During both exercise

interventions, participants were assessed using Borg's Rating of Perceived Exertion (RPE) scale (1-10) in an effort to match exercise intensity across experimental interventions (Borg, 1970).

Data Analysis

Repeated measures analysis of variance (ANOVA) was used to determine whether differences existed among the treatments (AE, RE, NE). An alpha of 0.05 was used to determine statistical significance. All analysis was completed using SPSS 22.0.

Results

After accounting for subject dropout, total sample size was $N = 63$ (38 girls, 25 boys) with a mean age of 10.65 +/- .485 years. Exercise intensity as measured by RPE was not statistically different between RE and AE ($F_{1,62} = 2.630$, $p = .116$; $AE_{\mu} = 2.66$, $RE_{\mu} = 2.74$). Repeated measures ANOVA revealed a significant difference in mean math test performance between RE and NE ($F_{1,62} = 22.34$, $p < .001$, $\eta^2 = .265$), and RE and AE ($F_{1,62} = 4.96$, $p = .03$, $\eta^2 = .074$). Repeated measures ANOVA revealed no significant differences in mean math test performance between AE and NE ($F_{1,62} = 2.94$, $p = .09$, $\eta^2 = .045$). Similar results were seen when the sample was separated by gender; however, girls approached statistically significant differences between AE and NE ($F_{1,37} = 3.569$, $p = .067$, $\eta^2 = .088$). Results are illustrated in Figure 1.

Discussion

To our knowledge, this was the first study comparing the acute effects of RE and AE on measures of mathematics performance in a youth sample. Results confirmed part of our primary hypothesis in that RE improved elementary school-aged children's performance on a test of mathematics over the NE control. While AE did not statistically significantly improve mathematics performance compared to NE, results appear to be practically significant ($\eta^2 = .045$), as mean scores following AE were 0.651 points higher than those following NE. The authors believe that such an improvement (out of 10 points possible) warrants the consideration of both AE and RE as worthwhile modalities to acutely influence mathematics performance. Such results are in agreement with previous research on acute AE and mathematics performance (Gabbard & Barton, 1979; McNaughten & Gabbard, 1993; Travlos, 2010).

RE results from this study are novel in that they provide initial evidence that RE also positively influences academic achievement, as measured by a test of mathematics. Importantly, RE has demonstrated significant improvement in measures of cognition, typically as a complementary modality to AE in adult populations (Alves et al., 2012; Chang & Etnier, 2009b). To date, in only one other instance has acute RE been found to induce a greater cognitive response than either AE or NE. Ozkaya et al. (2005) found that RE increased senior citizens' processing speed, as measured by event-related potential (ERP), to a significant degree over both AE and NE. While the authors were unable to uncover mechanistic explanations for this finding, they hinted at the possibility that the more complex sensorimotor tasks completed during RE as compared to AE forced greater attention to external stimuli, thereby resulting in greater neurocognitive

excitation. Whether such an explanation could be applied to findings from the present study is unknown. However, it seems reasonable that less frequently rehearsed tasks such as those performed during the RE protocol could account for an elevation in executive function and AA as compared to the more basic walk/jog used during the AE protocol. More research is warranted to examine this contention.

While research related to exercise and AA has grown tremendously in the last decade, much about the underlying mechanisms is still unknown. Despite this, it is important to try to understand potential causative factors that support the ability of various forms of exercise to positively influence executive function and AA. In the case of RE, the neurotrophic-stimulation hypothesis described by Hillman et al. (2009) has come to light as a potential explanation for results consistent with findings from this study. This hypothesis states that neuromuscular activity stimulates areas of the brain that control executive function, resource allocation, and speed of processing. While neuromuscular activity is not limited to RE alone, the ability of various forms of RE to induce significant neuromuscular adaptations is well documented (Hakkinen et al., 2003). Such adaptations may hint at greater neuronal excitability during RE as compared to AE or NE, and could potentially explain the greater executive function response following RE seen in this study.

Because much of the research in the area of executive function, AA, and exercise has utilized AE, one of the primary mechanistic hypotheses used to explain findings has been the cerebral blood flow hypothesis. This hypothesis refers to the increase in blood flow to the brain seen during moderate exercise below 60% VO_{2max} (Querido & Sheel, 2007). It is postulated that such an increase in blood volume keeps the brain in an

optimal physiological state, which, in turn, aids efficacy of higher ordered cognition (Guiney, Lucas, Cotter, & Machado, 2015). This hypothesis could certainly help to explain why participants in both AE and RE exhibited greater performance than NE on the mathematics test in this study. While we were unable to measure heart rate or intensity as $\%VO_{2max}$, student-reported RPE was statistically similar in both groups, indicating that each protocol induced moderate exercise loads consistent with findings from previous literature on exercise and AA.

While results from the current study are encouraging, several limitations need to be considered. The primary limitation in this study was the lack of an objective measurement of exercise intensity between RE and AE. While attempts were made to utilize heart rate monitors in conjunction with RPE, it was not possible given the very brief nature of class periods at the elementary school level. With only 40 minutes of PE time to work with once a week, students did not have sufficient time to go to the bathrooms to put the heart rate monitors on and still complete the entirety of the exercise protocol and the math test. While RPE was statistically similar between groups, it is possible that students' exercise intensities were either too high or too low during AE, which could negatively affect executive function (Querido & Sheel, 2007). A second potential limitation to this study was that of exercise duration. Because of the time-sensitive nature of collecting data during a 40-minute window, exercise duration, which was originally targeted at 30 minutes, had to be reduced to 20 minutes. Existing literature is conflicting when it comes to exercise duration and executive function. Early work indicated that students performed better on a test of mathematics following AE of 30 and 40 minutes duration as compared to 20 minutes (McNaughten & Gabbard, 1993),

and 50 minutes as compared to 20, 30, and 40 minutes (Gabbard & Barton, 1979). More recently however, Hillman et al. (2009a) demonstrated improved AA as measured by the Wide Range Achievement Test in adolescent youth following only 20 minutes of AE. With such results in mind, it appears the 20-minute duration used in this study was sufficient.

In conclusion, our findings demonstrate that both AE and RE improved 5th-grade students' performance on a test of mathematics over a NE control, with RE demonstrating the greatest improvement. Such findings are novel in that they mark the first instance of a RE intervention being used to positively influence AA in youth. It is the hope of the authors that these findings will influence activity recommendations and daily scheduling among elementary school aged children to improve student health and AA concurrently.

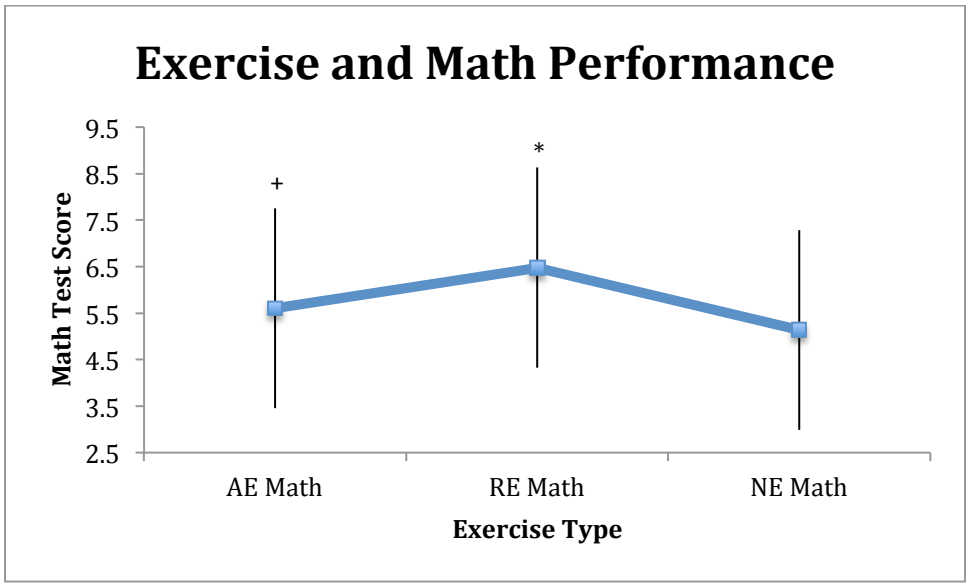


Figure 1. Mean math test score following various exercise interventions. * denotes statistical significance ($p < .05$); + denotes practical significance ($\eta^2 > .04$)

CHAPTER 4

STUDY 2: EFFECTS OF ACUTE EXERCISE ON MATHEMATICS PERFORMANCE AND COGNITION IN 8th-GRADE STUDENTS

Introduction

Research has established that when students maintain greater levels of physical activity, their academic performance improves over their more sedentary peers (Singh, Uijtdewilligen, Twisk, Van Mechelen, & Chinepaw, 2012). Longitudinal studies show consistently small, positive associations between exercise and academic achievement (AA)(Nelson & Gordon-Larsen, 2006). Additionally, acute exercise demonstrates a significant effect on executive functions across children, adolescents, and adults (Verburgh, Königs, Scherder, & Oosterlaan, 2014). While such findings are encouraging, there remain numerous questions related to the impact of acute exercise on AA in youth.

One important question that has yet to be sufficiently answered is whether a difference in AA exists following varying modalities of exercise. Within the context of middle-school-aged students, there have been several studies examining various aerobic exercise (AE) interventions aimed at increasing AA. Sport and PE participation (Nelson & Gordon-Larsen, 2006), as well as traditional AE such as walking and jogging

(Wittberg, Northrup, & Cottrell, 2013), have demonstrated positive outcomes on select measures of AA in this age group, most often measured via mathematics or reading ability (McNaughten & Gabbard, 1993).

While AE has been established as having positive effects on AA in middle-school-aged students, there is a complete absence of research examining the effects of resistance exercise (RE) on such measures. RE has, however, been shown to be a safe, effective component of an exercise program for adolescents (Faigenbaum et al., 2009). Further, research in seniors, adults, and high school youth point to the ability of RE to positively influence cognition following an acute bout (Alves et al., 2012; Chang & Etnier, 2009b). Finally, RE has been shown to be effective in reducing anxiety and depression (Strong et al., 2005) in conjunction with a host of other health benefits (Garber et al., 2011). As such, there is ample reason to explore the effects of acute RE as a means to improve markers of cognitive function and AA among middle-school aged students. Thus, the purpose of this study was to compare the acute effects of AE, RE, and a nonexercise (NE) control on measures of AA and cognition in 8th-grade boys and girls. It was hypothesized that both AE and RE would improve students' performance on 1) a standardized test of mathematics and 2) a test of cognition over the NE control.

Method

Participants and Setting

Participants were 8th-grade students sampled from a middle school in the southwestern United States. Results of an *a priori* power analysis (G Power Statistical Software) indicated a minimal sample size of 60 participants ($\alpha = 0.05$, $\eta^2 = 0.3$).

Seventy participants were recruited, but after accounting for drop out, the total was reduced to $N = 63$ (57 boys, 6 girls). Participants were asked to provide written assent in conjunction with written consent from a parent or legal guardian. Participants were all apparently healthy as defined by their enrollment in PE class, and able to participate in regular exercise. The study was conducted in accordance with institutional, district, and American College of Sports Medicine (ACSM) ethical guidelines.

Instruments

Academic achievement was measured in this study using a battery of four 10-question math tests taken from New York State Testing Program 8th-grade exams used in the last 5 years (http://www.p12.nysed.gov/assessment/). The tests are therefore current, and come with technical manuals that verify the multiple choice content with Cronbach's Alpha coefficient scores. The tests have internal consistency coefficients of $r = 0.85$ (2012), $r = 0.85$ (2011), and $r = 0.87$ (2011). The tests were assembled with assistance from 8th-grade math teachers to insure the content had been covered in the current school year. The content of each test covered similar material, but the questions were slightly different so as to avoid a practice effect. Students were given 5 minutes to complete each 10-question test, mimicking the demands of a classroom setting and utilizing the speed-test concept developed by Brown (1970). Cognition was measured using the Stroop Test (Victoria version). The Victoria version of the Stroop Test is a validated means of assessing selective attention and cognitive flexibility over the course of three increasingly demanding tasks (Spreen, 1998), and has been utilized frequently in research with children, high school youth, and adults (Bub, Masson, & Lalonde, 2006; Comalli,

Wapner, & Werner, 1962). Participants were asked to identify stimulus flash cards beginning with colored dots, progressing to common words printed in the same color as dots, and finally color words printed in noncorresponding colors. Each task contains 24 items, and challenges participants to deal with an interference effect, which is marked by significantly slower reaction time.

Procedures

This study utilized a randomized crossover design. Participants were required to perform one familiarization session on the mathematics test and exercise protocols. Seven days after the familiarization session, participants performed one of three experimental sessions (AE, RE, NE) in a randomized order, completing all three interventions over the course of 3 weeks. The math tests were administered between 5 and 20 minutes after completion of each intervention in accordance with prior research (Hillman et al., 2009b). Data collection was performed by the first author and trained research assistants.

The AE and RE protocols were based on previous work by Alves et al. (2012). The RE protocol involved two sets of 15 repetitions in each of the following six exercises: squat, lunge, pushup, band pull down, band row, and overhead press. If participants were not able to complete 15 repetitions per set, a reduction in weight or modification in technique on subsequent sets was allowed (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). Participants in this study did not have access to a traditional weight room, so a variety of resistance elements were utilized, such as body weight and resistance bands. A 1-minute rest interval was assigned between sets. The RE intervention was 20 minutes in length. The AE protocol was matched for time and

consisted of 20 minutes of walking or jogging at an intensity of approximately 50-60% age-predicted heart rate max. In the NE control, participants sat quietly for 20 minutes while viewing a sports-related DVD. Participants were monitored to insure they did not fall asleep or move around (Pontifex et al., 2009). Participants were also assessed using Borg's original Rating of Perceived Exertion (RPE) scale in an effort to more closely monitor exercise intensity across experimental conditions (Borg, 1970).

Data Analysis

Repeated measures analysis of variance (ANOVA) was used to determine whether differences existed among the treatments (AE, RE, NE). An alpha of 0.05 was used to determine statistical significance. All analysis was completed using SPSS 22.0.

Results

After accounting for subject dropout, total sample size was 63 (6 girls, 57 boys) with a mean age of 13.68 +/- .471 years. Repeated measures ANOVA revealed a significant difference in mean math test performance between RE and NE ($F_{1,62} = 4.50$, $p = .038$, $\eta^2 = .068$). Repeated measures ANOVA revealed no significant differences in mean math test performance between AE and NE ($F_{1,62} = 2.43$, $p = .124$, $\eta^2 = .04$) or AE and RE ($F_{1,62} = .214$, $p = .645$, $\eta^2 = .003$). Results are illustrated in Figure 2.

Results of separate repeated measures ANOVAs revealed significant differences between RE and NE in the Stroop Dot test ($F_{1,62} = 8.14$, $p = .006$, $\eta^2 = .116$), Stroop Word test ($F_{1,62} = 9.90$, $p = .003$, $\eta^2 = .138$), and Stroop Color test ($F_{1,62} = 7.57$, $p = .008$, $\eta^2 = .109$). Significant differences were also found between AE and NE in the Stroop

Word test ($F_{1,62} = 91.63$, $p < .001$, $\eta^2 = .596$) and Stroop Color test ($F_{1,62} = 14.53$, $p < .001$, $\eta^2 = .19$). Finally, significant differences were found between RE and AE in the Stroop Dot test ($F_{1,61} = 9.18$, $p = .004$, $\eta^2 = .129$), Stroop Word test ($F_{1,62} = 14.73$, $p < .001$, $\eta^2 = .192$), and Stroop Color test ($F_{1,62} = 20.14$, $p < .001$, $\eta^2 = .245$) . Results are illustrated in Figure 3.

Discussion

The purpose of this paper was to compare the acute effects of AE, RE, and a non-exercise (NE) control on measures of AA and cognition in 8th-grade boys and girls. In accordance with part of our primary hypothesis, acute RE demonstrated improvement in mean math test performance as compared to AE and NE. Such a finding is novel in that it marks the first time acute RE has been shown to positively influence a measure of AA in a youth sample. AE also resulted in a mean math score increase of 0.44 points (out of 10), which can be considered practically significant ($\eta^2 = .04$)(Ferguson, 2009). Previous research has identified the ability of AE to positively influence AA and cognition in youth (Gabbard & Barton, 1979; McNaughten & Gabbard, 1993; Travlos, 2010). Given the importance placed on test results in today's academic environment, the 12% increase in mean math test performance from AE to NE should not be ignored.

A second purpose of this study was to examine the effects of differing exercise modalities on cognition in 8th-grade students. In partial agreement with our second hypothesis, RE significantly improved performance over AE and NE in the Stroop Dot, Word, and Color tests. No statistical differences were found between AE and NE. As seen with math test performance, results following RE in this study are novel in that there

are currently no published studies utilizing RE as an acute exercise modality to influence cognition in a youth sample. It is the author's hope that the findings exhibited in this study will be used as justification for the inclusion of RE as a viable exercise pursuit during the typical school day to improve student academic performance at the 8th-grade level.

The ability of acute exercise to positively influence AA and cognition has just begun to be studied at an in-depth level. Much of the mechanistic properties of acute exercise and its effect on brain function remain in the early stages of discovery. However, several hypotheses have been established in the literature that offer potential explanation for findings exhibited in this study. Of principal importance to the current study, Hillman et al. (2009a) put forth the neurotrophic-stimulation hypothesis, which states that neuromuscular activity stimulates areas of the brain that control executive function, resource allocation, and speed of processing. Given the significant neuromuscular adaptations that occur as a result of a RE training program, especially at the onset (Hakkinen et al., 2003), it appears reasonable to conclude that this hypothesis best explains why RE elevated math and cognitive performance over AE and the NE control. Further, RE has been shown to significantly elevate brain-derived neurotrophic factor (BDNF) following an acute bout (Yarrow, White, McCoy, & Burst, 2010), which may have additional implications towards increased brain health and function. In a similar vein, there is evidence to suggest that the more complex and novel nature of acute RE as compared to AE or NE may play a role in elevating cognitive response. Ozkaya et al. (2005) found that RE increased cognition as measured by event-related potentials (ERP) to a greater degree than AE or NE. Their explanation for their findings was that the

complexity of the RE task forced greater attention to external stimuli, which in turn elevated neurocognitive markers. A final hypothesis that has garnered much attention in the literature related to acute exercise and executive function is the cerebral blood-flow hypothesis. During moderate exercise up to 60% VO_{2max}, increased blood flow has been observed, leading researchers to postulate that such a physiologic response could explain increases in cognitive function (Querido & Sheel, 2007). It is also possible that increased blood flow to the brain works in a synergistic manner with previously mentioned mechanisms such as BDNF to produce the positive performance increases seen in AA and cognition in the current study. Additional research should be directed at isolating the precise mechanisms that drive the changes seen in executive function throughout the literature.

Despite positive findings, the current study was not without limitations. Perhaps the biggest limitation was the lack of an objective measure of exercise intensity during the RE and AE protocols. At the onset of the study, the author's goal was to outfit each student with a heart rate monitor to provide an additional measure of intensity beyond RPE alone. However, due to time limitations and a lack of sufficient monitors for each student in class, it was not possible to complete this aspect of the study. While there were no statistical differences between the exercise protocols and student reported RPE ($F_{1,61} = 2.76$, $p = .102$), it is possible that the exercise protocols were not matched for intensity. Given the influence of cerebral blood flow on executive functions, such a limitation could skew results. It is the author's hope that findings such as those exhibited in the present study may help extend daily and weekly time for physical education (PE), in particular RE, as current allowances are often simply too short for teachers or

researchers to accomplish health and exercise goals with students on a consistent basis.

A second limitation of this study was that of student motivation. While motivation was not directly measured in this study, it was apparent that not all participants took their responsibilities in this study seriously. These observations are in agreement with previous work by Castelli, Hillman, Buck, and Irwin (2007), who noted that students who enjoy the academic nature of the school day may perform better on tests of AA, which could explain some of the variance credited to the individual exercise protocols themselves. Future studies should make an effort to measure or control for student motivation, especially at the middle school level, as it seems students at this age may be especially prone to a lack of motivation in order to appear "cool."

In conclusion, our results demonstrate that acute RE, and to a lesser degree acute AE, positively impact AA as measured by standardized math tests, and cognition as measured by the Stroop test, repectively. These results are novel in that they mark the first published example of acute RE being utilized to enhance executive functions among an 8th-grade youth sample. The importance of such findings should not be downplayed, but should be utilized in an effort to fuel the fight to reintroduce a greater amount and variety of physical activity in the American school system. It is the hope of the author that both RE and AE outlets will be made more available to school-aged youth, as evidence clearly indicates that not only can exercise enhance student health, but can also make a significant difference on academic outcomes as well.

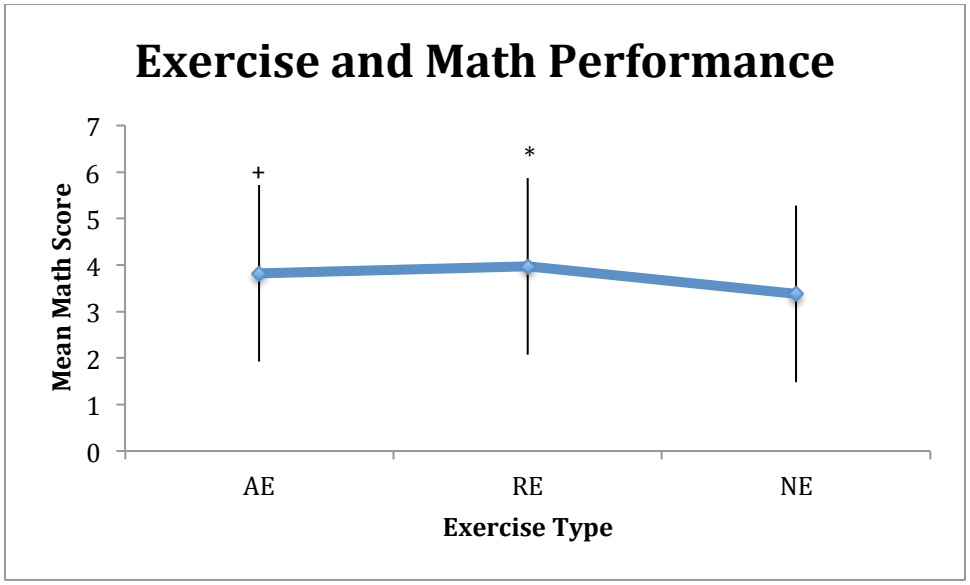


Figure 2. Mean math test score following various exercise interventions. * denotes statistical significance ($p < .05$); + denotes practical significance ($\eta^2 > .04$)

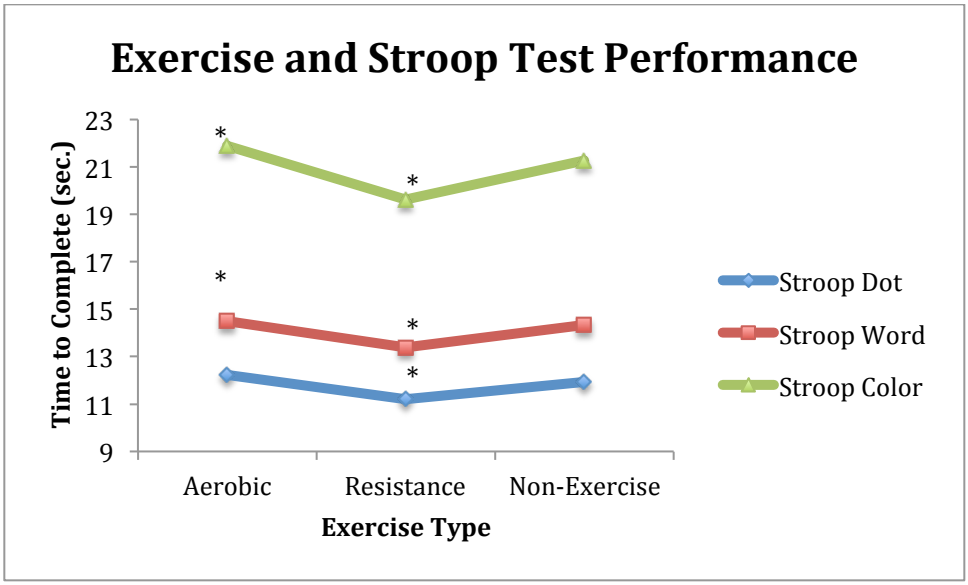


Figure 3. Time to complete Stroop Dot, Word, and Color tests following various exercise types. * denotes statistical significance ($p < .05$)

CHAPTER 5

STUDY 3: EFFECTS OF ACUTE EXERCISE ON MATHEMATICS PERFORMANCE AND COGNITION IN 10th-GRADE STUDENTS

Introduction

Current research trends in the area of youth physical activity (PA) have highlighted the relationship between students who meet or exceed activity guidelines with improved academic results (Carlson et al., 2008). Numerous studies have established that when students maintain greater levels of PA, their performance in academic areas improves over their peers who fail to meet the recommended PA guidelines (Howie & Pate, 2012). Given both the high levels of importance currently being placed on academic test results as well as the rising rates of overweight and obesity among students, it behooves educators, students, and PA proponents to explore the mechanisms that underscore exercise and academic achievement (AA).

A review of the literature linking exercise and AA shows significant relationships between both chronic and acute exercise and student improvement in school. Studies of chronic exercise show consistently small, positive associations between exercise and AA (Nelson & Gordon-Larsen, 2006). Acute exercise has demonstrated similarly small,

significant effects on measures of cognition and other executive functions across children, adolescents, and adults (Verburg et al., 2014). While such findings lend credence to the ability of exercise to influence AA, a number of questions related to the impact of acute exercise on AA in youth still exist. One important question that deserves exploration is whether a difference in AA exists following bouts of differing types of exercise, specifically resistance and aerobic exercise. Aerobic exercise (AE) has been used almost exclusively among youth studies that utilized a measure of executive function or AA as the dependent variable. Among high school-aged students specifically, researchers have targeted AA with such AE interventions as sport and PE participation (Nelson & Gordon-Larsen, 2006), extracurricular PA (Crosnoe, 2002), and traditional AE such as walking or jogging (Wittberg, Northrup, & Cottrell, 2013). Each of the above variations of AE demonstrated positive outcomes on select measures of AA including mathematics, reading ability, and GPA.

While AE has shown consistently positive effects on AA in high-school-aged students, there is a paucity of research examining the effects of resistance exercise (RE) in this age group. Research in senior citizens and adults (Alves et al., 2012; Chang & Etnier, 2009b), as well as pilot data from the author (in review) indicate that acute RE has the ability to positively influence cognition. Additionally, RE is a mode of exercise that effectively complements AE (Pollock et al., 2007). With the above research in mind, indications are such that acute RE may be an effective intervention to positively influence AA in high-school-aged students. As such, the purpose of this study is to compare the acute effects of AE, RE, and a nonexercise (NE) control on measures of AA and cognition in 10th-grade boys and girls. It is hypothesized that both AE and RE will

improve students' performance on a standardized test of mathematics and a test of cognition over the NE control.

Method

Participants and Setting

The participants of this study were 10th grade students sampled from a high school in the southwestern United States. An *a priori* power analysis (G*power) indicated a minimal sample size of 60 participants. After accounting for subject drop out, the total number of participants was 91 (63 boys, 28 girls), with a mean age of 15.89 +/- .65 years. Participants were asked to provide written assent in conjunction with written consent from a parent or legal guardian. Participants were all apparently healthy as defined by their enrollment in PE class, and able to participate in regular exercise. The study was conducted in accordance with institutional, district, and American College of Sports Medicine (ACSM) ethical guidelines.

Instruments

Academic achievement was measured in this study using a battery of four 10-question math tests taken from New York State Testing Program exams used for high schoolers in the last 5 years (http://www.p12.nysed.gov/assessment/). The tests are therefore current, and come with technical manuals that verify the multiple choice content with Cronbach's Alpha coefficient scores. The tests have internal consistency coefficients of $r = 0.85$ (2012), $r = 0.84$ (2011), and $r = 0.86$ (2010). The tests were assembled with assistance from high school math teachers to insure the content had been

covered in the current school year. The content of each test covered similar material, but the questions were slightly different so as to avoid a practice effect. Students were given 5 minutes to complete each 10-question test, mimicking the demands of a classroom setting and utilizing the speed-test concept developed by Brown (1970). Cognition was measured using the Stroop Test (Victoria version). The Victoria version of the Stroop Test is a validated means of assessing selective attention and cognitive flexibility over the course of three increasingly demanding tasks (Spreen, 1998), and has been utilized frequently in research with children, high school youth, and adults (Bub, Masson, & Lalonde, 2006; Comalli, Wapner, & Werner, 1962). Participants were asked to identify stimulus flash cards beginning with colored dots, progressing to common words printed in the same color as dots, and finally color words printed in noncorresponding colors. Each task contained 24 items, and challenged participants to deal with an interference effect, which is marked by significantly slower reaction time.

Procedures

This study utilized a randomized crossover design. Participants were required to perform one familiarization session on the mathematics test and exercise protocols. Seven days after the familiarization session, participants performed one of three experimental sessions (AE, RE, NE) in a randomized order, completing all three interventions over the course of 3 weeks. The math tests were administered between 5 and 20 minutes after completion of each intervention in accordance with prior research (Hillman et al., 2009b). Data collection was performed by the author and trained research assistants.

The AE and RE protocols were based on previous work by Alves et al. (2012).

The RE protocol involved two sets of 15 repetitions in each of the following six exercises: leg press, bench press, lat pull down, cable row, back extension, and biceps curl. If participants were not able to complete 15 repetitions per set, a 5% reduction in weight was allowed (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009). A 1-minute rest interval was assigned between sets. The RE intervention was 30 minutes in length. The AE protocol was matched for time and consisted of 30 minutes of walking/jogging at an intensity of 50-60% age-predicted heart rate max. In the NE control, participants sat quietly for 30 minutes while viewing a sports-related DVD. Participants were monitored to insure they did not fall asleep or move around (Pontifex et al., 2009). Participants were also monitored via heart rate telemetry during both exercise interventions using Polar E600 Heart Rate Monitors, which are designed and recommended for classroom PE use. Participants were also assessed using Borg's original Rating of Perceived Exertion (RPE) scale in an effort to more closely monitor exercise intensity across experimental interventions (Borg, 1970).

Data Analysis

Repeated measures analysis of variance (ANOVA) was used to determine whether differences existed among the treatments (AE, RE, NE). An alpha of 0.05 was used to determine statistical significance. All analysis was completed using SPSS 21.0.

Results

Repeated measures ANOVA revealed no significant difference in mean math test performance between RE and NE ($F_{1,86} = 2.81$, $p = .098$, $\eta^2 = .032$), AE and NE ($F_{1,86} =$

2.03, $p = .158$, $\eta^2 = .023$), or AE and RE ($F_{1,86} = .04$, $p = .837$, $\eta^2 < .001$). Results are illustrated in Figure 4.

Results of separate repeated measures ANOVAs revealed significant differences between RE and NE in the Stroop Dot test ($F_{1,86} = 4.31$, $p = .041$, $\eta^2 = .048$), and approached statistical significance in the Stroop Word test ($F_{1,86} = 3.66$, $p = .059$, $\eta^2 = .041$). Significant differences were also found between AE and NE in the Stroop Dot test ($F_{1,86} = 10.402$, $p = .002$, $\eta^2 = .108$) and Stroop Color test ($F_{1,86} = 6.85$, $p = .01$, $\eta^2 = .074$). Differences between AE and NE approached statistical significance in the Stroop Word test ($F_{1,86} = 3.63$, $p = .06$, $\eta^2 = .040$). Results are illustrated in Figure 5.

Discussion

Contrary to our primary hypothesis, acute AE and RE did not demonstrate statistically significant improvements in mean math test performance as compared to NE. While practical significance as measured by effect size greater than $\eta^2 = .04$ (Ferguson, 2009) was not achieved statistically, both exercise interventions resulted in greater mean performance than the NE control by nearly 1/2 point out of 10 points possible. As such, the author believes an argument could be made for the present findings being practically significant for day-to-day classroom achievement. Such findings are in agreement with prior literature, which has consistently indicated that acute exercise exhibits small, positive changes in AA and cognition (Chang, Labban, Gapin, & Etnier, 2012; Hillman, Kamijo, & Scudder, 2011; Travlos et al., 2010). Considering the test-centered approach that exists in today's educational environment, such findings should be of interest to parents, educators, administrators, and legislators. In partial agreement with our

secondary hypothesis, RE significantly improved performance over NE in the Stroop Dot test, and approached statistically significant improvement over NE in the Stroop Word test. Significant differences were also found between AE and NE in the Stroop Dot and Color tests, and approached statistical significance in the Stroop Word test. While findings related to AE are in agreement with prior literature, this study marks the first instance of acute RE being utilized to effect improvement in AA in a high school-aged sample. While AA and cognitive performance increases were modest following both exercise interventions, it is the author's hope that such results will further strengthen the argument supporting increased physical activity, be it RE or AE, in the typical school day among high school-aged students.

While the existing literature has demonstrated consistently small, positive changes in AA and cognition following acute exercise, the mechanisms underlying such changes are still being explored. Given that both AE and RE resulted in modest increases in AA and cognition in this study, it appears that exercise type may not play a selective role in boosting higher ordered brain processes. Rather, it is likely that a wide variety of physical activity types have the ability to produce increases in executive functions. Support for such an idea may have been inadvertently established by Hillman et al. (2009a), who introduced the neurotrophic-stimulation hypothesis. This hypothesis states that neuromuscular activity stimulates areas of the brain that control executive function, resource allocation, and speed of processing. While the hypothesis was developed based on studies of AE, it has logical application to RE as well, given the nature of RE and its development of the neuromuscular system (Hakkinen et al., 2003). Similarly, both acute RE and AE have been shown to elevate brain-derived neurotrophic factor (BDNF)

(Seifert et al., 2010; Yarrow et al., 2010). BDNF has been shown to protect against neurodegeneration, enhance neural plasticity, and improve learning and memory (Yarrow et al., 2010), making it a prime candidate for label as a causative agent behind the increase in AA and cognition seen following acute exercise. Finally, one of the more documented hypotheses related to acute exercise and its ability to enhance executive functions is the cerebral blood-flow hypothesis. This hypothesis states that during moderate exercise up to 60% VO_{2max}, there is an increase in blood flow to the brain, delivering additional oxygen and nutrients that appear to optimize the physiologic state of the brain and benefit cognition and AA (Guiney, Lucas, Cotter, & Machado, 2014). Given the greater oxygen uptake levels associated with AE as compared to RE, this hypothesis has frequently been cited in the literature as a primary mechanism underlying the small, positive changes in cognition and AA seen in existing research. It is also possible that increased cerebral blood flow works in a synergistic manner with previously mentioned mechanisms such as BDNF to produce the increased performance in AA and cognition in the current study. Additional research should be directed at isolating the precise mechanisms that drive the changes seen in executive function throughout the literature.

While results of the present study bolster the current literature, one limitation must be addressed. Specifically, student motivation appeared to be an issue, especially during mathematics testing. Motivation was not directly measured in this study, but it was apparent to the author that many of the students were not overly concerned with doing their best on the math tests, as they knew there were no academic repercussions for poor performance. Motivation has also been discussed in previous research by Castelli et

al. (2007), who noted that students who typically enjoy academics may perform better on tests of AA than their peers who are less academically inclined. Thus, the construct of motivation could explain some of the variance credited to the individual exercise protocols utilized in this study. Future research would be wise to measure or control for student motivation to eliminate as much variance as possible.

In conclusion, our results demonstrate that acute AE and RE lead to small, positive changes in AA and cognition in a high school youth sample. These results are novel in that they mark the first example of acute RE being utilized to enhance AA among a high school-aged sample. Additionally, our findings should expand youth school-based physical activity recommendations to include RE as a means to influence AA and cognition. Our findings may be valuable for PE teachers, educators, and administrators who are involved in daily programming to maximize student effectiveness in the classroom. Given that equipment and available space are often primary considerations in school physical activity settings, the option of utilizing RE or AE could be of value for physical educators seeking to influence their students' academic success, while improving health concurrently.

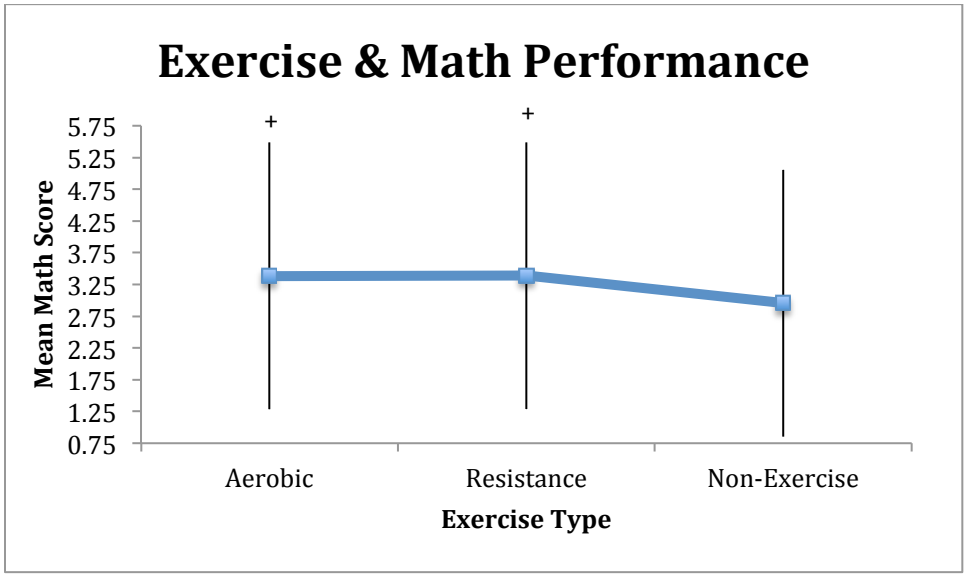


Figure 4. Mean math scores following various exercise type. + denotes practical significance ($\eta^2 > .04$)

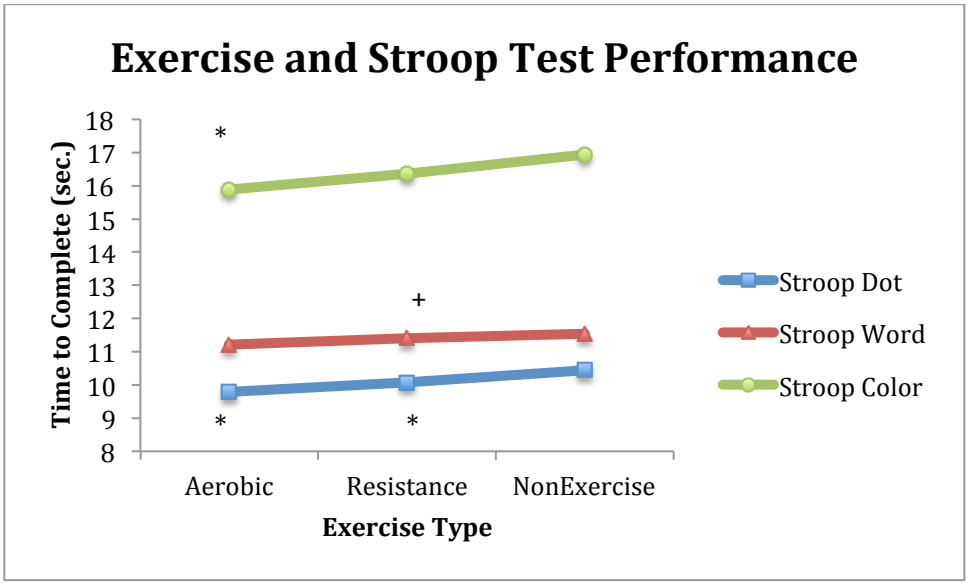


Figure 5. Time to complete Stroop Dot, Word, and Color tests following various exercise types. + denotes practical significance ($\eta^2 > .04$)

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

As seen across all three age groups, acute RE and AE had a modestly positive influence on academic achievement and cognition in youth. Given the highly test-driven climate that exists currently in youth education, such findings could have a significant impact on day-to-day operations at the elementary, middle, and high school levels. Results from these studies are novel in that they mark the first known instance of RE enhancing academic achievement in youth populations. Current results also serve to verify pilot data from the author, which indicated significant improvements in cognition following acute RE and AE in a high school sample. Taken together, such findings should be of interest to legislators, administrators, educators, parents, and students looking to improve student performance in the classroom while simultaneously increasing student PA. It is the hope of the author that findings from these studies will influence academic scheduling to include acute bouts of RE and AE for students prior to classroom based subject matter such as science or mathematics in order to maximize student learning and achievement.

Future research in the area of acute exercise and academic achievement would be wise to include measures of student motivation to account for variance in the results of academic testing. If possible, academic achievement would be better measured by the

students' classroom teachers, using subject matter and assessment that coincide with what the students are currently learning. Such a tactic could control for more of the variance of student motivation, and give a more accurate picture of the potential impact acute exercise may have on academic achievement.

APPENDIX A

IRB PERMISSION FROM ELEMENTARY AND MIDDLE SCHOOL

SALT LAKE CITY
SCHOOL DISTRICT
Your Best Choice

ASSESSMENT & EVALUATION

440 East 100 South
Salt Lake City, Utah 84111

p 801.578.8249
f 801.578.8681

February 18, 2015

Andrew Harveson
250 S 1850 E
HPER-N, Rm 241
Salt Lake City, UT 84112

Re: *Acute Exercise and Academic Achievement in Youth*

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 *Acute Exercise and Academic Achievement in Youth.*

We can see the value of the focus of your research request and the information that would be gained from such research. You have permission to conduct research within the Salt Lake City School District from March 5, 2015 through May 2, 2015.

In addition, you will be required to submit your findings to the Assessment and Evaluation Department at the conclusion of your research no later than June of 2018. We look forward to hearing from you regarding your research.

Sincerely,

Christine Marriott

Christine Marriott
Director, Assessment and Evaluation
Salt Lake City School District

APPENDIX B

IRB PERMISSION FROM HIGH SCHOOL

Research & Assessment
Hal L. Sanderson, Ph.D., Director
9150 S. 500 West Sandy, UT 84070
T: 801-826-5090 | F: 801-826-5065 | www.canyonsdistrict.org

March 2, 2015

Andrew Harveson
250 S. 1850 E., HPER-N Room 241,
Salt Lake City, UT 84112

Dear Andrew,

The Canyons School District Research Review Committee has reviewed your request to conduct research titled, "Acute Exercise and Academic Achievement in High School Youth." The committee **has approved** your research. This approval is for the next 12 months.

Please contact me if you have any follow up questions.

Sincerely,

Hal L. Sanderson, Ph. D.
Director of Research & Assessment
Canyons School District
9150 S. 500 W.
Sandy, UT 84070

APPENDIX C

IRB FROM SUPERVISING UNIVERSITY

INSTITUTIONAL REVIEW BOARD
THE UNIVERSITY OF UTAH

75 South 2000 East Salt Lake City, UT 84112 | 801.581.3655 | IRB@utah.edu

IRB: IRB_00061661

PI: Andrew Harveson

Title: Acute exercise and cognition in youth

This Amendment Application (Academic Achievement) qualifies for an expedited review by a designated University of Utah IRB member according to University IRB policy. The designated IRB member has reviewed and approved your amendment request for this study on 1/12/2015 . The approval of the amendment is effective as of 1/12/2015. The approval of this amendment request does NOT change the expiration date of this research study as noted below.

Your study will expire on 1/21/2016 12:00 AM .
Any future changes to this study must be submitted to the IRB prior to initiation via an amendment form.

APPENDIX D

ASSENT/CONSENT FORMS

Assent to Participate in a Research Study

Who are we and what are we doing?

We are from the University of Utah. We would like to ask you to participate in a project that will examine the impact of exercise on your mathematics and cognitive performance. The program will include resistance exercise, aerobic exercise, one brief test of cognition, and a series of 10-question mathematics tests.

Why are we asking you to be in this project?

We are asking you to be in this project because we want to find out if a certain type of exercise plays a bigger role in improving academic achievement and cognition.

What happens in the project?

If you decide to participate in the project and your parent or guardian agrees, this is what will happen:

- You will have the chance to participate in both aerobic and resistance exercise
- You will also be asked to complete a series of short tests that will look at your ability to process information quickly, and complete 10 grade-level appropriate math questions.

Will any part of the research study hurt you?

There are no foreseeable risks to this project. However, there is a possibility of a loss of confidentiality, though measures will be taken to avoid such a possibility.

Will the project help you or anyone else?

We do not know for sure if being in this project will help you. We think that you will become more aware of what type of exercise will help you learn better.

Who will see the information about you?

Only the investigator from the University of Utah and your physical education teacher will see any of your information. You may also have access to the information.

What if you have any questions about the project?

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 Andrew Harveson at (509)901-2802 or ask us the next time we see you.

Do you have to be in the project?

You do not have to be in this project if you don't want to. Being in this project 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. Choosing not to participate will not impact your grade in physical education class. If you decide you don't want to be in the project, you will be allowed to read quietly in PE class.

Agreeing to be in the project

I was able to ask questions about this study. Signing my name at the bottom means that I agree to be in this study.

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.

Parental Permission Document

for Minimal Risk Research

BACKGROUND

We are researchers from the University of Utah. You are being invited to have your child take part in an investigational research study to help us learn more about the effects of physical activity on academic achievement and cognition in youth. Please take time to read the following information carefully and discuss it with your child and anyone else you wish. Please ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you would like your child to take part in this research study. Participation is voluntary. This study is being done so we can study how acute bouts of exercise impact mathematics and cognitive performance in school-aged youth. Evidence exists to show that aerobic and resistance exercise increases brain circulation and function. However, studies have yet to be done detailing the effects of these different types of exercise in students and the effect they may have on test results immediately following activity. Before you decide if you want your child to participate in this research project, it is important for you to understand what will be asked of your child. Please 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 project.

STUDY PROCEDURE

Your child is enrolled in physical education classes at _____ School. We have chosen to work with this school, and as such, your child qualifies for inclusion in the study if you allow them. To be included, students must be enrolled in PE class and

capable of performing standard exercises that take place in these classes. Your child will attend PE class as usual and participate in the day's lesson. Activity will be monitored by the primary investigator, as well as the PE teacher who will be assisting with the lesson. Following the lesson, all students will take a previously validated test of cognition, and a 10-question math test previously standardized for your child's grade level. These tests will take approximately 10 minutes for your child to complete. This will take place during one PE class period per week for four weeks. Scores will be collected by the primary investigator and held on a secure, encrypted device to be analyzed for significance. This will mark the end of your child's involvement in the study.

RISKS

There are no foreseeable risks of this project. However there is a possibility of a loss of confidentiality.

BENEFITS

The primary benefit of this study to society is the advancement in knowledge to the field of physical activity research and education. Student participants may also benefit in that their test scores and academic performance may increase as a result of the findings of this study.

CONFIDENTIALITY

We will keep all records that identify your child private to the extent allowed by law. Records about your child will be kept on computers protected with passwords. Only the principal investigator from the University of Utah and your child's physical education teacher will be allowed access to your child's information.

PERSON TO CONTACT

If you have questions, complaints or concerns about this project, or if you feel you have been harmed as a result of participation please call Andrew Harveson at (509) 901-2802. Institutional Review Board: Contact the Institutional Review Board (IRB) if you have questions regarding your rights as a 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 project. 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 child's grade in any way.

COSTS AND COMPENSATION TO PARTICIPANTS

There are no costs and compensations for participation in this project.

CONSENT

If you do not want your child to participate in this research you can opt-out by contacting the primary investigator via phone or email. Andrew Harveson can be contacted at (509) 901-2802 or Andrew.harveson@hsc.utah.edu

APPENDIX E

MATH TESTS

5th-Grade Test 1

134050083_2

Which statement is true about the values of the two expressions below?

Expression A: $3 \times (8 + 4)$
Expression B: $8 + 4$

A The value of Expression B is three times the value of Expression A.

B The value of Expression A is three times the value of Expression B.

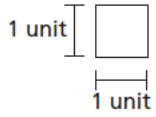
C The value of Expression A is three more than the value of Expression B.

D The value of Expression B is three more than the value of Expression A.

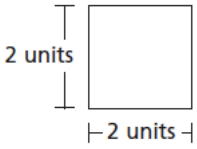
134050060_4

Which diagram represents a volume of one cubic unit?

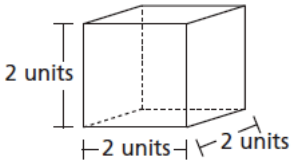
A



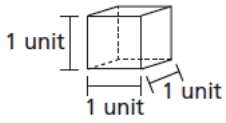
B



C



D



124050047_2

Which phrase describes the volume of a 3-dimensional figure?

A the number of square units it takes to fill a solid figure

B the number of cubic units it takes to fill a solid figure

C the number of square units it takes to cover the outside of a solid figure

D the number of cubic units it takes to cover the outside of a solid figure

134050026_1

A recipe for 1 batch of muffins included $\frac{2}{3}$ cup of raisins. Ina made $2\frac{1}{2}$ batches of muffins. How many cups of raisins did she use?

A $1\frac{4}{6}$

B $1\frac{5}{6}$

C $2\frac{2}{6}$

D $3\frac{1}{6}$

124050043_1

Mani, James, and Isidro equally shared $\frac{1}{2}$ of a pie. Which fraction of the whole pie did each of them receive?

A $\frac{1}{6}$

B $\frac{1}{5}$

C $\frac{2}{3}$

D $\frac{3}{2}$

134050036_2

A number is given below.

136.25

In a different number, the 6 represents a value which is one-tenth of the value of the 6 in the number above. What value is represented by the 6 in the other number?

A six hundredths

B six tenths

C six ones

D six tens

134040001_2

Which model is shaded to represent a fraction equivalent to $\frac{1}{2}$?

A

B

C

D

134040404_4

What is 735,286 rounded to the nearest ten thousand?

A 700,000

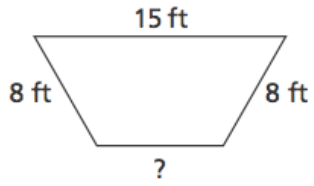
B 730,000

C 735,000

D 740,000

134030093_1

The figure below has a perimeter of 37 feet.



What is the length, in feet, of the unknown side?

A 6

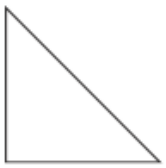
B 8

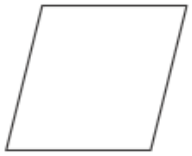
C 14

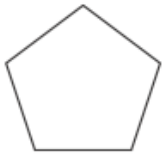
D 31

124040056_1

Which figure appears to have one right angle?

A 

B 

C 

D 

5th-Grade Test 2

134050027_1

Austin collected $30\frac{9}{10}$ kilograms of glass for recycling. Exactly $\frac{2}{3}$ of the glass he collected was blue. What was the total amount, in kilograms, of blue glass Austin collected?

A $20\frac{3}{5}$

B $27\frac{2}{3}$

C $30\frac{3}{5}$

D $30\frac{11}{13}$

124050521_2

What number goes in the blank to make the statement below true?

3,840 ounces = _____ pounds

A 24

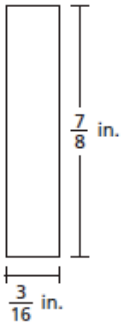
B 240

C 480

D 61,440

134050019_1

What is the area, in square inches, of a rectangle with the dimensions shown in the diagram below?



A $\frac{21}{128}$

B $\frac{3}{14}$

C $\frac{10}{24}$

D $\frac{24}{112}$

124050019_2

What is the value of the expression below?

1,536 ÷ 24

A 57

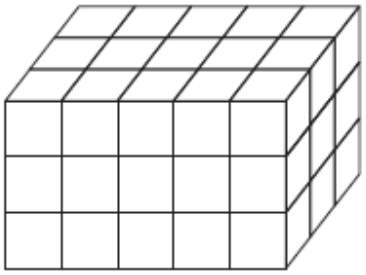
B 64

C 65

D 68

124050049_4

What is the volume, in cubic centimeters, of the figure below?



= 1 cubic centimeter

A 15

B 24

C 30

D 45

134040038_2

In the number 344,586, how many times greater is the value represented by the 4 in the ten thousands place than the value represented by the 4 in the thousands place?

A 1

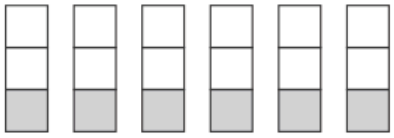
B 10

C 1,000

D 10,000

134040050_2

The fraction model below represents 6 whole units.



Which number sentence represents the amount of the fraction model that is shaded?

A $6 \times \frac{1}{2} = \underline{?}$

B $6 \times \frac{1}{3} = \underline{?}$

C $3 \times \frac{1}{6} = \underline{?}$

D $3 \times \frac{1}{2} = \underline{?}$

134040060_4

A school has 17 tables in the cafeteria. Each table seats 12 students. What is the greatest number of students that can be seated at these tables?

A 114

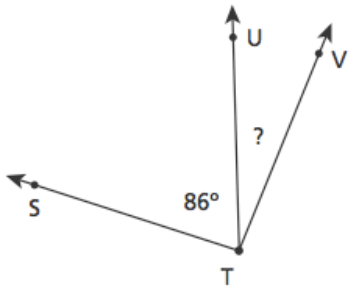
B 184

C 194

D 204

134040091_1

The measure of angle STV is 117°. What is the measure of angle UTV?



[not drawn to scale]

A 31°

B 63°

C 157°

D 203°

134040041_4

Which expression represents the number 13,809 written in expanded form?

A $13 + 80 + 9$

B $13{,}000 + 800 + 90$

C $9 + 1{,}300 + 80$

D $3{,}000 + 10{,}000 + 9 + 800$

5^{th}-Grade Test 3

134050018_4

Millie designed a rectangular label to put on the front of her scrapbook. The label was $\frac{5}{12}$ foot wide and $\frac{5}{6}$ foot long. What was the area, in square feet, of the label?

A $2\frac{6}{12}$

B $1\frac{3}{12}$

C $\frac{10}{18}$

D $\frac{25}{72}$

124050003_2

Which expression means the same as the phrase below?

Subtract 3 from the product of 8 and 5

A $(5 \times 8) + 3$

B $(5 \times 8) - 3$

C $5 \times (8 - 3)$

D $5 \times (8 + 3)$

134050079_2

Jim gave the following description of a figure:

- It is a quadrilateral.
- All sides are equal in length.
- There are two equal obtuse angles and two equal acute angles.

Which figure **could** match Jim's description?

A rectangle

B rhombus

C square

D pentagon

134050039_2

Which expression is equivalent to 100,000?

A 10^4

B 10^5

C 10^6

D 10^7

134050056_4

Lincoln had 2 books in his backpack. One book had a mass of 3 pounds 7 ounces, and the other book had a mass of 2 pounds 10 ounces. What was the total mass, in ounces, of the books?

A 60

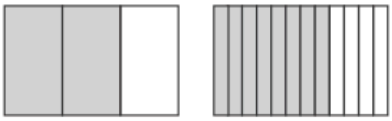
B 77

C 80

D 97

134040411_4

Carter shaded the two same-sized models below to represent the fractions $\frac{2}{3}$ and $\frac{8}{12}$.



Carter believed that $\frac{2}{3}$ is equivalent to $\frac{8}{12}$. Why is he correct or incorrect?

A He is incorrect because the numerator and denominator are different in $\frac{2}{3}$ and $\frac{8}{12}$.

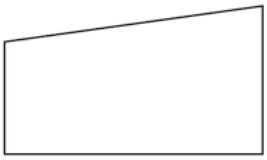
B He is incorrect because the numerator and denominator in $\frac{8}{12}$ are greater than in $\frac{2}{3}$.

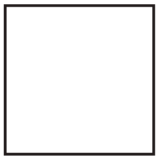
C He is correct because adding the same number to the numerator and denominator in $\frac{2}{3}$ equals $\frac{8}{12}$.

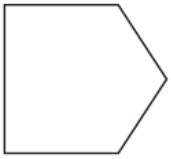
D He is correct because multiplying the numerator and denominator in $\frac{2}{3}$ by the same number equals $\frac{8}{12}$.

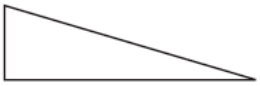
124040060_3

Which figure appears to have exactly one line of symmetry?

A 

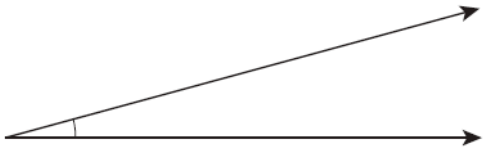
B 

C 

D 

134040087_1

What is the measurement of the angle below?



A 15°

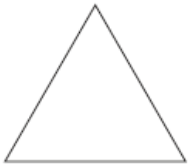
B 25°

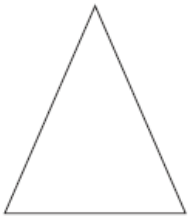
C 165°

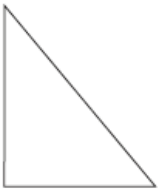
D 175°

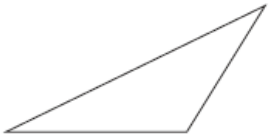
134040099_3

Which figure appears to be a right triangle?

A 

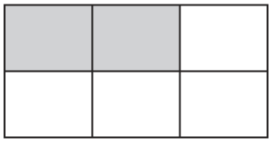
B 

C 

D 

134040003_2

The model below is shaded to represent a fraction.



Which fraction is equivalent to the one represented by the model?

A $\frac{1}{6}$

B $\frac{1}{3}$

C $\frac{2}{4}$

D $\frac{2}{3}$

5th-Grade Test 4

124050617_3

A box contains 512 grams of cereal. One serving of cereal is 56 grams. How many servings of cereal does the box contain?

A $9\frac{1}{4}$

B $9\frac{1}{8}$

C $9\frac{8}{56}$

D $9\frac{8}{512}$

134050057_1

Lori and Maria bought juice to make fruit punch. Maria bought 5 bottles of juice, each containing 750 milliliters. Lori bought 4 liters of juice. Based on this information, which sentence is true?

A Lori bought 0.25 liter more juice than Maria.

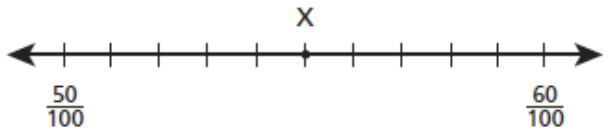
B Maria bought 0.75 liter more juice than Lori.

C Maria bought 33.5 liters more juice than Lori.

D Lori bought 36.25 liters more juice than Maria.

134040030_2

Which decimal best represents the location of point X on the number line below?



A 0.5

B 0.55

C 0.56

D 0.6

134050025_2

Clark made a model of his house. His house is $30\frac{1}{2}$ feet long. The dimensions of the model were $\frac{1}{25}$ the dimensions of Clark's actual home. What is the length, in feet, of the model?

A $1\frac{10}{50}$

B $1\frac{11}{50}$

C $30\frac{23}{50}$

D $30\frac{27}{50}$

124050042_4

Deb has a board that measures 5 feet in length. How many $\frac{1}{4}$-foot-long pieces can Deb cut from the board?

A 1

B 9

C 10

D 20

8^{th}-Grade Test 1

134080011_2

Which number is equivalent to $\frac{3^4}{3^2}$?

A 2

B 9

C 81

D 729

134080064_1

A sequence of transformations was applied to an equilateral triangle in a coordinate plane. The transformations used were rotations, reflections, and translations. Which statement about the resulting figure is true?

A It must be an equilateral triangle with the same side lengths as the original triangle.

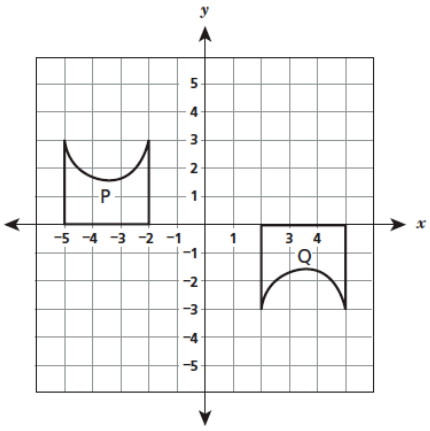
B It must be an equilateral triangle, but the side lengths may differ from the original triangle.

C It may be a scalene triangle, and all the side lengths may differ from the original triangle.

D It may be an obtuse triangle with at least one side the same length as the original triangle.

134080067_1

Figure Q was the result of a sequence of transformations on figure P, both shown below.



Which sequence of transformations could take figure P to figure Q?

A reflection over the *x*-axis and translation 7 units right

B reflection over the *y*-axis and translation 3 units down

C translation 1 unit right and 180° rotation about the origin

D translation 4 units right and 180° rotation about the origin

134080404_4

Determine the product.

$$800.5 \times (2 \times 10^6)$$

A 1.7×10^7

B 1.601×10^7

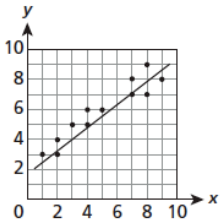
C 1.7×10^9

D 1.601×10^9

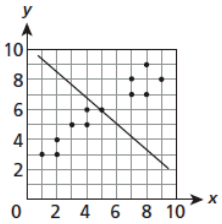
124080054_1

Which line represents the best fit for the scatter plot data?

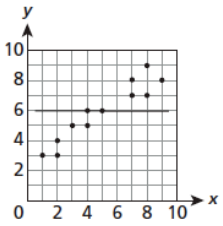
A



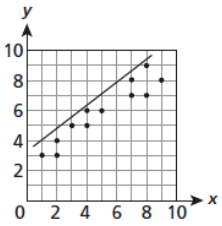
C



B



D



124070037_1

Craig went bowling with $25 to spend. He rented shoes for $5.25 and paid $4.00 for each game. What was the greatest number of games Craig could have played?

A 4

B 5

C 6

D 7

134070039_2

The label on a $1\frac{1}{2}$-pound bag of wildflower seeds states that it will cover an area of 375 square feet. Based on this information, what is the number of square feet that 1 pound of wildflower seeds will cover?

A $\frac{1}{250}$

B 250

C $562\frac{1}{2}$

D 750

124070026_4

Which expression is equivalent to $(7x - 5) - (3x - 2)$?

A $10x - 7$

B $10x - 3$

C $4x - 7$

D $4x - 3$

124070012_2

The Lions won 16 games last year. This year the Lions won 20 games. What is the percent increase in the number of games the Lions won from last year to this year?

A 20%

B 25%

C 80%

D 125%

124070507_3

The table shows prices for shoe rental, games, and snacks at the bowling alley.

BOWLING ALLEY PRICES

Item	Price
Shoe rental	$2.75
One game of bowling	$2.50
Small soda	$0.95
Large soda	$1.50
Nachos	$1.75

Gina rented shoes, bowled 3 games, and bought 1 order of nachos. She used a coupon for $\frac{1}{2}$ off the price of her bowling games. What was Gina's total cost before tax was added?

A $5.75

B $6.00

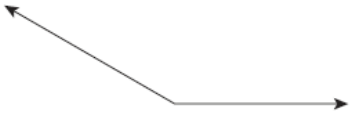
C $8.25

D $12.00

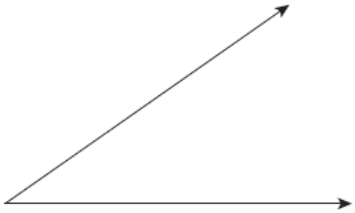
134040089_4

Which angle measures 25°?

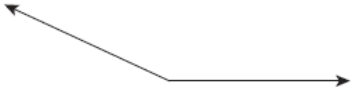
A



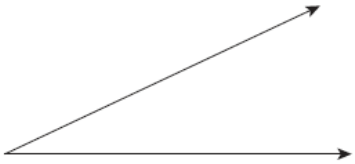
B



C



D



124040614_3

4 thousands + 3 tens + 5 hundreds is less than which number below?

A 4 thousands + 5 tens + 3 hundreds

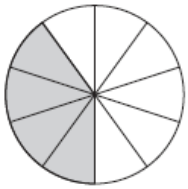
B 8 hundreds + 3 thousands + 8 ones

C 4 thousands + 7 ones + 8 tens + 6 hundreds

D 9 hundreds + 9 tens + 2 thousands

134040412_2

The figure below is divided into equal sections.



Which expression represents the fraction of the figure that is shaded?

A $\frac{1}{10}+\frac{2}{10}+\frac{3}{10}$

B $\frac{1}{10}+\frac{1}{10}+\frac{2}{10}$

C $\frac{3}{10}+\frac{3}{10}+\frac{4}{10}$

D $\frac{4}{10}+\frac{4}{10}+\frac{4}{10}$

134040413_4

What is $8\frac{3}{5}+8\frac{1}{5}$?

A $8\frac{4}{10}$

B $8\frac{4}{5}$

C $16\frac{4}{10}$

D $16\frac{4}{5}$

134040036_2

Which number has a 5 that represents a value ten times greater than the value represented by the 5 in 41,253?

A 31,254

B 41,523

C 43,125

D 51,324

8th-Grade Test 2

124080604_4

At a given time, Saturn was 9.1×10^8 miles from the Sun and Earth was 9.3×10^7 miles from the Sun. By what distance is one planet closer to the Sun than the other planet?

A 2×10^1

B 2×10^{15}

C 8.17×10^7

D 8.17×10^8

134080405_3

The combined volume of all the tanks at an aquarium is 1.25×10^6 gallons. The aquarium plans to install a new dolphin tank with a volume of 250,000 gallons. What will be the total volume of all of the tanks at the aquarium after the new dolphin tank is installed?

A 1.5×10^5

B 3.75×10^5

C 1.5×10^6

D 3.75×10^6

124080041_2

Rectangle *R* undergoes a dilation with scale factor 0.5 and then a reflection over the *y*-axis. The resulting image is Rectangle *S*. Which statement about Rectangles *R* and *S* is true?

A They are congruent and similar.

B They are similar but not congruent.

C They are congruent but not similar.

D They are neither congruent nor similar.

124080031_1

The table below shows the cost of different numbers of goldfish at a pet store.

COST OF GOLDFISH

Number of Goldfish	Cost
5	$1.50
10	$3.00
15	$4.50
20	$6.00

The cost is a linear function of the number of goldfish. Which statement describes the rate of change of this function?

A The cost increases $0.30 each time 1 goldfish is added.

B The cost increases $1.50 each time 1 goldfish is added.

C The cost increases $3.00 each time 5 goldfish are added.

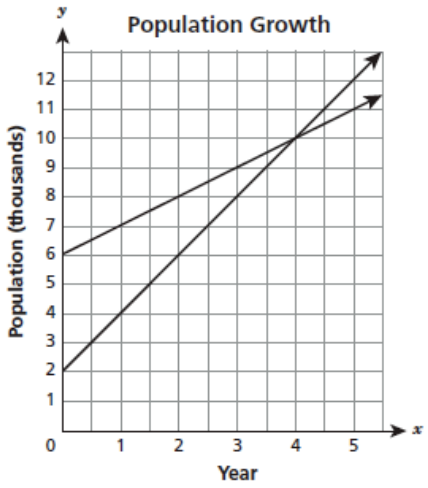
D The cost increases $6.00 each time 5 goldfish are added.

134080028_2

The population growth of two towns over a period of five years is represented by the system of equations below, both algebraically and graphically.

$y = x + 6$

$y = 2x + 2$



Which ordered pair is the solution to the system of equations?

A (2, 6)

B (4, 10)

C (6, 2)

D (10, 4)

124070607_2

The population of a city is expected to increase by 7.5% next year. If p represents the current population, which expression represents the expected population next year?

A $1.75p$

B $1.075p$

C $p + 0.075$

D $1 + 0.075$

134070034_4

Laticia randomly selected 25% of the seventh-grade students in her school and asked them their favorite season. Of the students surveyed, 51 chose summer as their favorite season. Based on the data, what is the most reasonable prediction of the number of seventh-grade students in her school who would choose summer as their favorite season?

A 15

B 75

C 150

D 200

134070037_3

Ms. Graves gave her class 12 minutes to read. Carrie read $5\frac{1}{2}$ pages in that time.

At what rate, in pages per hour, did Carrie read?

A $1\frac{1}{10}$

B 22

C $27\frac{1}{2}$

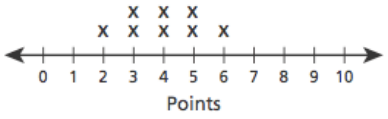
D 66

134070087_2

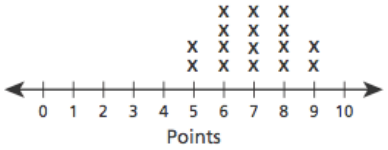
Ms. Andrews made the line plots below to compare the quiz scores for her first-period math class and her second-period math class. She gave the same quiz to each class.

QUIZ SCORES

First-Period Class



Second-Period Class



What conclusion can Ms. Andrews make about the performance of her first- and second-period classes?

A The first-period class had a higher median score than the second-period class.

B The second-period class scores had a higher mean than the first-period class scores.

C The first-period class scores had a greater range than the second-period class scores.

D The second-period class scores had a greater mean absolute deviation than the first-period class scores.

134070422_4

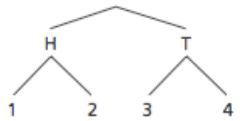
Which tree diagram shows all of the possible outcomes for tossing a coin and rolling a fair number pyramid that has four sides labeled 1 through 4?

A

Coin toss

Roll of number pyramid

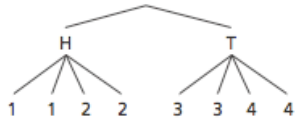
B



Coin toss

Roll of number pyramid

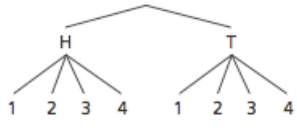
C



Coin toss

Roll of number pyramid

D



Coin toss

Roll of number pyramid

8th-Grade Test 3

124080609_4

The four tables below show relationships in which the x values represent inputs and the y values represent the corresponding outputs.

Q

x	y
–2	–3
1	3
3	–3
5	3

R

x	y
–1	–5
2	4
3	7
4	10

S

x	y
–2	3
1	3
3	3
5	3

T

x	y
3	4
4	5
3	–4
4	–5

Which table represents a relationship that is **not** a function?

A Q

B R

C S

D T

124080026_2

Madison created two functions.
For Function A, the value of y is two less than four times the value of x.
The table below represents Function B.

Function B

x	y
–3	–9
–1	–5
1	–1
3	3

In comparing the rates of change, which statement about Function A and Function B is true?

A Function A and Function B have the same rate of change.

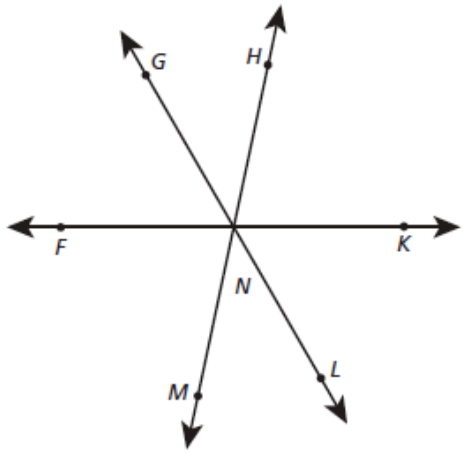
B Function A has a greater rate of change than Function B has.

C Function A and Function B both have negative rates of change.

D Function A has a negative rate of change and Function B has a positive rate of change.

124070047_3

In the diagram below, three lines intersect at N. The measure of $\angle GNF$ is 60°, and the measure of $\angle MNL$ is 47°.



What is the measure of $\angle HNK$?

A 47°

B 60°

C 73°

D 107°

134080001_2

Which expression is equivalent to $4^7 \times 4^{-5}$?

A 4^{12}

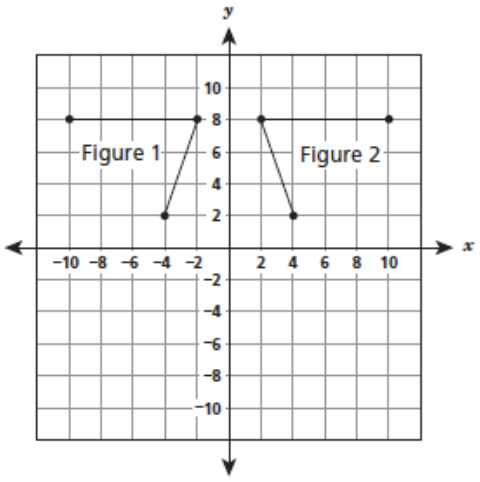
B 4^2

C 4^{-2}

D 4^{-35}

134080418_3

Figure 1 can be transformed to create Figure 2 using a single transformation.



Which transformation can be used to accomplish this?

A dilation

B rotation

C reflection

D translation

134070417_1

An owner of a small store knows that in the last week 54 customers paid with cash, 42 paid with a debit card, and 153 paid with a credit card. Based on the number of customers from last week, which fraction is closest to the probability that the next customer will pay with cash?

A $\frac{1}{5}$

B $\frac{1}{4}$

C $\frac{1}{3}$

D $\frac{1}{2}$

134070074_3

Scientists determined that Antarctica's average winter temperature was −34.44°C. The difference between this temperature and Antarctica's highest recorded temperature was 49.44 degrees. What was Antarctica's highest recorded temperature?

A −83.88°C

B −15°C

C 15°C

D 83.88°C

134070383_1

The expression below was simplified using two properties of operations.

$5(11z + 29 + 6z)$

Step 1 $5(11z + 6z + 29)$

Step 2 $5(17z + 29)$

Step 3 $85z + 145$

Which properties were applied in Steps 1 and 3, respectively?

A commutative property, then distributive property

B commutative property, then identity property

C associative property, then distributive property

D associative property, then commutative property

134070406_1

For her cell phone plan, Heather pays $30 per month plus $0.05 per text. She wants to keep her bill under $60 per month. Which inequality represents the number of texts, t, Heather can send each month while staying within her budget?

A $t < 600$

B $t > 600$

C $t < 1,800$

D $t > 1,800$

134070001_2

Solve for x.

$0.5x + 78.2 = 287$

A $x = 104.4$

B $x = 417.6$

C $x = 495.8$

D $x = 730.4$

8th-Grade Test 4

124080607_4

What is the solution to the system of equations below?

$$\begin{cases} 3x + 4y = -2 \\ 2x - 4y = -8 \end{cases}$$

A $x = 2,\ y = -2$

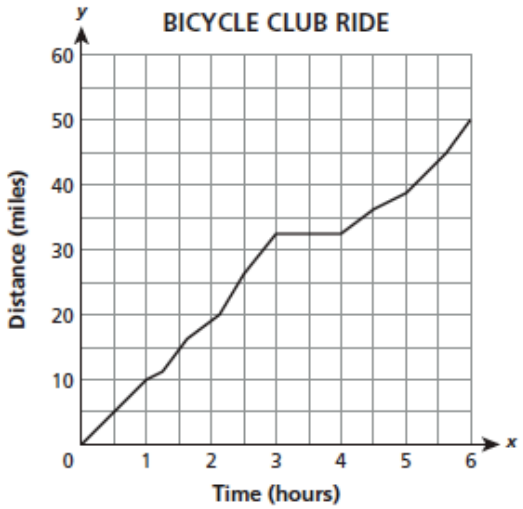
B $x = 6,\ y = -5$

C $x = 4,\ y = 4$

D $x = -2,\ y = 1$

124080033_2

A bicycle club went on a six-hour ride. The graph below shows the relationship between the number of hours spent on the trails and the number of miles traveled.



Which statement best interprets information provided by the graph?

A The club members rode at a constant speed for the entire ride.

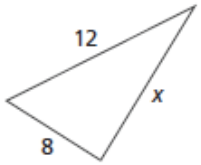
B The club members stopped for a rest during their ride.

C The number of miles traveled increased continuously throughout the ride.

D The number of miles traveled increased some of the time and decreased some of the time.

134070025_4

Which number could **not** be a value of x?



[not drawn to scale]

A 8

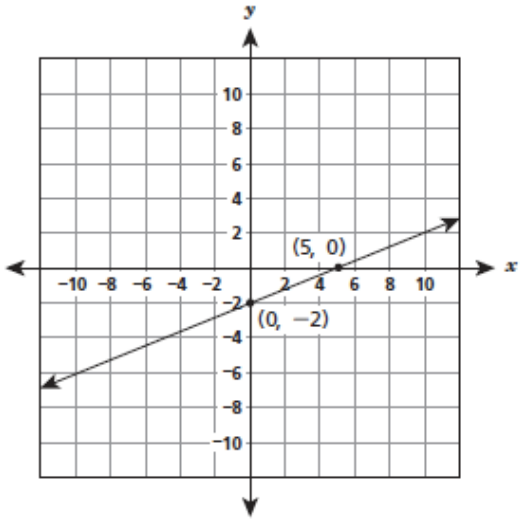
B 9

C 12

D 21

134080010_1

Which equation represents the line shown on the coordinate grid below?



A $y = \frac{2}{5}x - 2$

B $y = \frac{2}{5}x + 5$

C $y = -\frac{2}{5}x - 2$

D $y = -\frac{2}{5}x + 5$

124070036_2

Katie bought 4 sweaters that each cost the same amount and 1 skirt that cost $20. The items she bought cost a total of $160 before tax was added. What was the cost of each sweater?

A $20

B $35

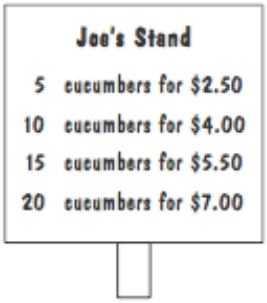
C $40

D $45

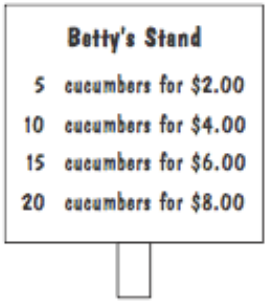
1340700041_3

Jocelyn was shopping at a farmers' market. She observed the prices of cucumbers at several stands. Which sign shows a proportional relationship in the pricing of the cucumbers?

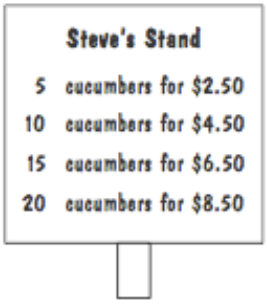
A



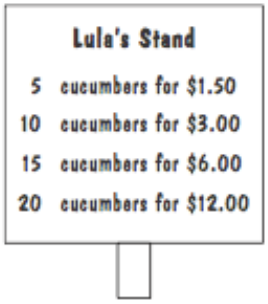
C



B



D



134070015_4

Doug earns $10.50 per hour working at a restaurant. On Friday he spent $1\frac{3}{4}$ hours cleaning, $2\frac{1}{3}$ hours doing paperwork, and $1\frac{5}{12}$ hours serving customers. What were Doug's earnings?

A $46.97

B $47.25

C $53.00

D $57.75

134070060_1

A store sold 650 bicycles last year. This year the store sold 572 bicycles. What is the percent decrease in the number of bicycles sold from last year to this year?

A 12%

B 14%

C 78%

D 88%

134070086_2

Sammy drew a rectangle that was w inches wide. The expression $2(2w) + 2(w)$ represents the perimeter of the rectangle that Sammy drew. Which statement relates the perimeter to the width of the rectangle?

A The perimeter is 6 inches more than the width.

B The perimeter is 6 times the width.

C The perimeter is 2 inches more than the width.

D The perimeter is 2 times the width.

134070057_3

Charis invested $140. She earned a simple interest of 3% per year on the initial investment. If no money was added or removed from the investment, what was the amount of interest Charis received at the end of two years?

A $4.20

B $6.00

C $8.40

D $12.60

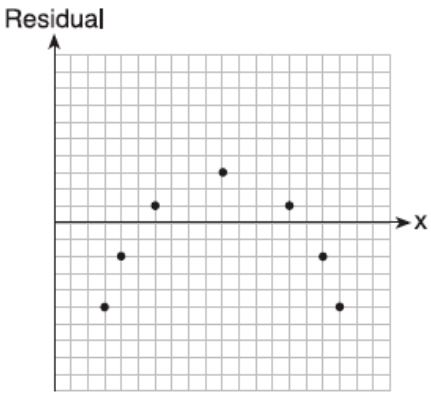
High School Test 1

Which statistic would indicate that a linear function would *not* be a good fit to model a data set?

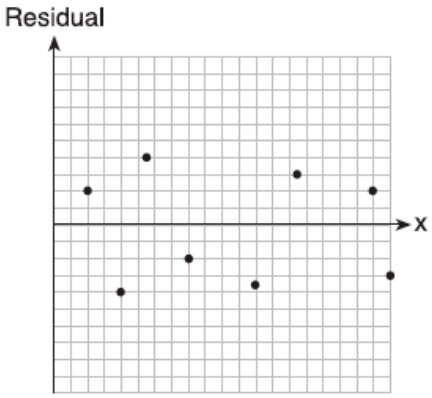
(1) $r = -0.93$

(2) $r = 1$

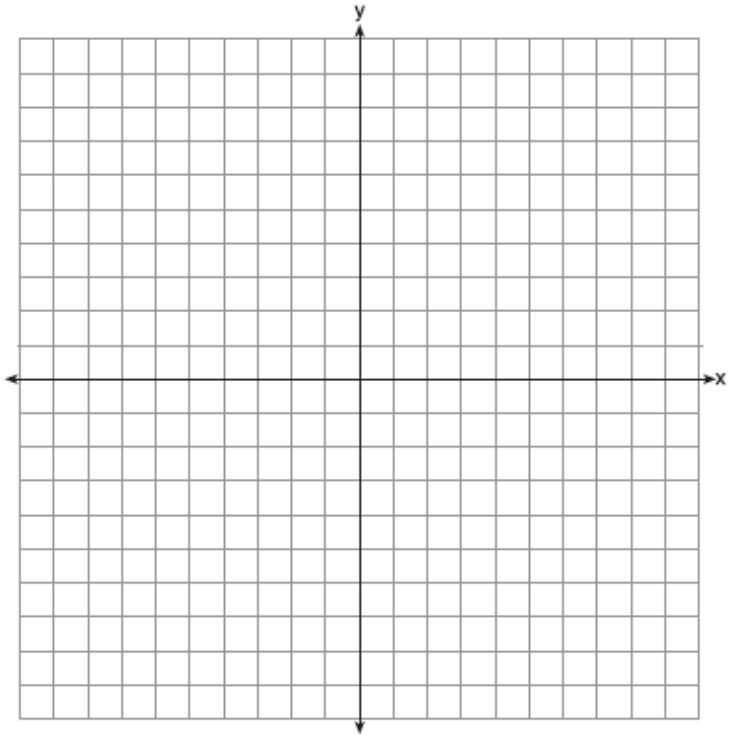
(3)



(4)

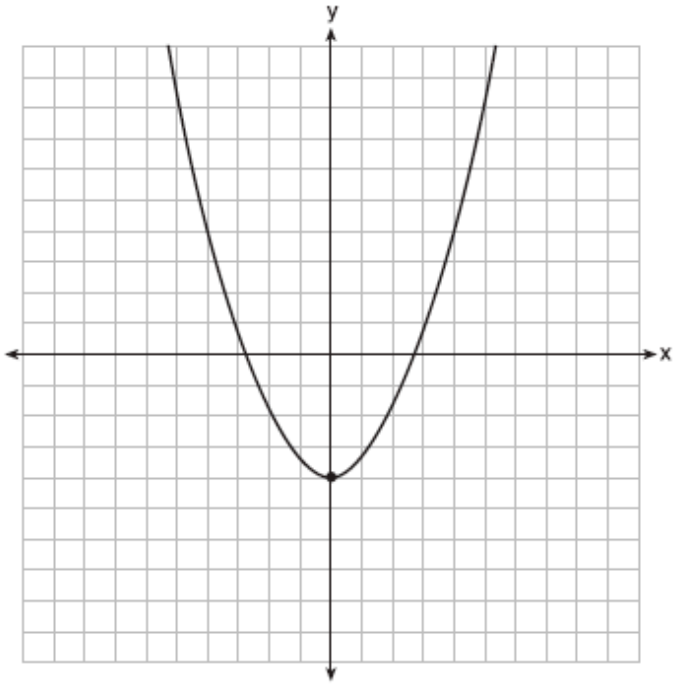


On the set of axes below, graph the function represented by $y = \sqrt[3]{x-2}$ for the domain $-6 \leq x \leq 10$.



Solve $8m^2 + 20m = 12$ for m by factoring.

Ryker is given the graph of the function $y = \frac{1}{2}x^2 - 4$. He wants to find the zeros of the function, but is unable to read them exactly from the graph.



Find the zeros in simplest radical form.

124080609_4

The four tables below show relationships in which the x values represent inputs and the y values represent the corresponding outputs.

Q

x	y
–2	–3
1	3
3	–3
5	3

R

x	y
–1	–5
2	4
3	7
4	10

S

x	y
–2	3
1	3
3	3
5	3

T

x	y
3	4
4	5
3	–4
4	–5

Which table represents a relationship that is **not** a function?

A Q

B R

C S

D T

124080026_2

Madison created two functions.
For Function A, the value of y is two less than four times the value of x.
The table below represents Function B.

Function B

x	y
–3	–9
–1	–5
1	–1
3	3

In comparing the rates of change, which statement about Function A and Function B is true?

A Function A and Function B have the same rate of change.

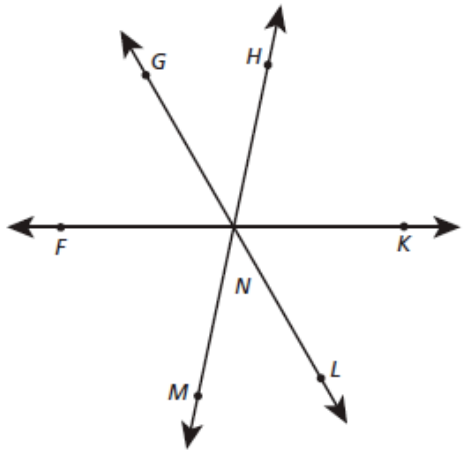
B Function A has a greater rate of change than Function B has.

C Function A and Function B both have negative rates of change.

D Function A has a negative rate of change and Function B has a positive rate of change.

124070047_3

In the diagram below, three lines intersect at N. The measure of $\angle GNF$ is 60°, and the measure of $\angle MNL$ is 47°.



What is the measure of $\angle HNK$?

A 47°

B 60°

C 73°

D 107°

134080001_2

Which expression is equivalent to $4^7 \times 4^{-5}$?

A 4^{12}

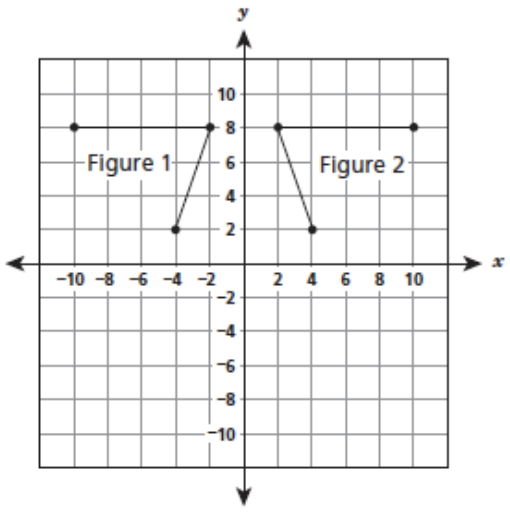
B 4^2

C 4^{-2}

D 4^{-35}

134080418_3

Figure 1 can be transformed to create Figure 2 using a single transformation.



Which transformation can be used to accomplish this?

A dilation

B rotation

C reflection

D translation

High School Test 2

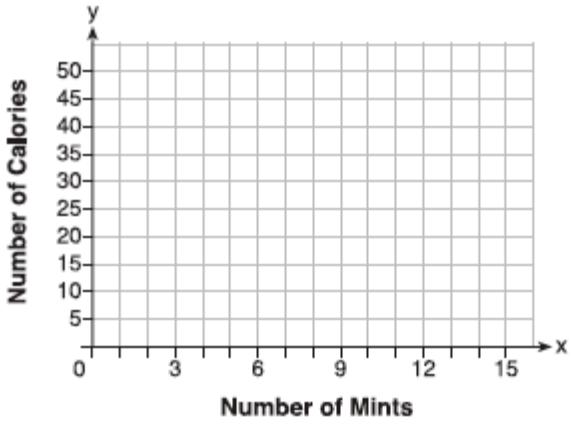
Emma recently purchased a new car. She decided to keep track of how many gallons of gas she used on five of her business trips. The results are shown in the table below.

Miles Driven	Number of Gallons Used
150	7
200	10
400	19
600	29
1000	51

Write the linear regression equation for these data where miles driven is the independent variable. (Round all values to the ***nearest hundredth***.)

Max purchased a box of green tea mints. The nutrition label on the box stated that a serving of three mints contains a total of 10 Calories.

On the axes below, graph the function, C, where $C(x)$ represents the number of Calories in x mints.



Write an equation that represents $C(x)$.

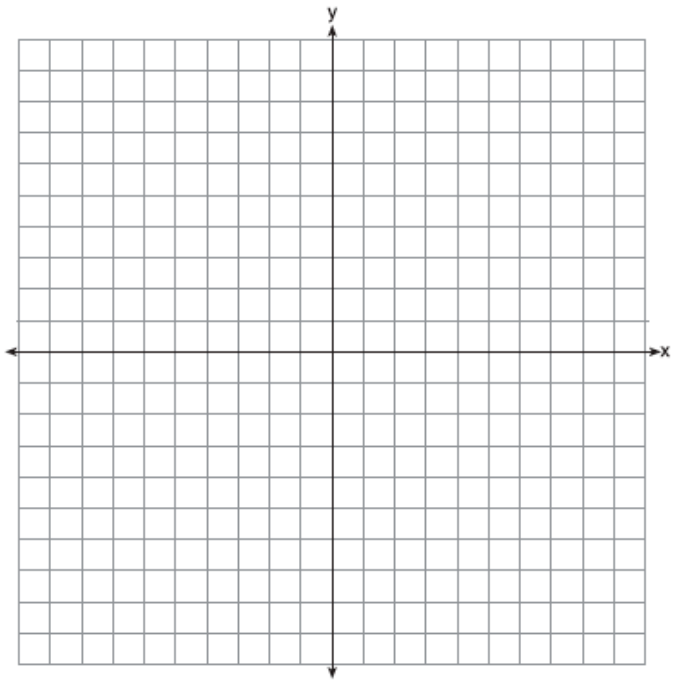
A full box of mints contains 180 Calories. Use the equation to determine the total number of mints in the box.

David has two jobs. He earns $8 per hour babysitting his neighbor's children and he earns $11 per hour working at the coffee shop.

Write an inequality to represent the number of hours, x, babysitting and the number of hours, y, working at the coffee shop that David will need to work to earn a minimum of $200.

David worked 15 hours at the coffee shop. Use the inequality to find the number of full hours he must babysit to reach his goal of $200.

On the set of axes below, graph the function $y = |x + 1|$.



State the range of the function.

State the domain over which the function is increasing.

134080096_2

Annette plans to visit an amusement park where she must pay for admission and purchase tickets to go on the rides. Annette wants to find the total cost for a day at the amusement park. She wrote the equation $c = 1.50x + 12$ to predict c, the total cost for a day at the amusement park. What could the number 12 represent in Annette's equation?

A the number of rides

B the cost of admission

C the cost of each ticket

D the number of tickets

124080604_4

At a given time, Saturn was 9.1×10^8 miles from the Sun and Earth was 9.3×10^7 miles from the Sun. By what distance is one planet closer to the Sun than the other planet?

A 2×10^1

B 2×10^{15}

C 8.17×10^7

D 8.17×10^8

134080405_3

The combined volume of all the tanks at an aquarium is 1.25×10^6 gallons. The aquarium plans to install a new dolphin tank with a volume of 250,000 gallons. What will be the total volume of all of the tanks at the aquarium after the new dolphin tank is installed?

A 1.5×10^5

B 3.75×10^5

C 1.5×10^6

D 3.75×10^6

124080041_2

Rectangle *R* undergoes a dilation with scale factor 0.5 and then a reflection over the *y*-axis. The resulting image is Rectangle *S*. Which statement about Rectangles *R* and *S* is true?

A They are congruent and similar.

B They are similar but not congruent.

C They are congruent but not similar.

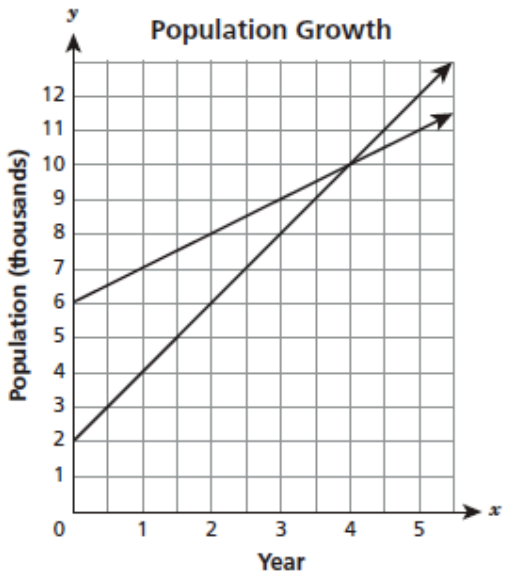
D They are neither congruent nor similar.

134080028_2

The population growth of two towns over a period of five years is represented by the system of equations below, both algebraically and graphically.

$y = x + 6$

$y = 2x + 2$



Which ordered pair is the solution to the system of equations?

A (2, 6)

B (4, 10)

C (6, 2)

D (10, 4)

124080031_1

The table below shows the cost of different numbers of goldfish at a pet store.

COST OF GOLDFISH

Number of Goldfish	Cost
5	$1.50
10	$3.00
15	$4.50
20	$6.00

The cost is a linear function of the number of goldfish. Which statement describes the rate of change of this function?

A The cost increases $0.30 each time 1 goldfish is added.

B The cost increases $1.50 each time 1 goldfish is added.

C The cost increases $3.00 each time 5 goldfish are added.

D The cost increases $6.00 each time 5 goldfish are added.

High School Test 3

1.

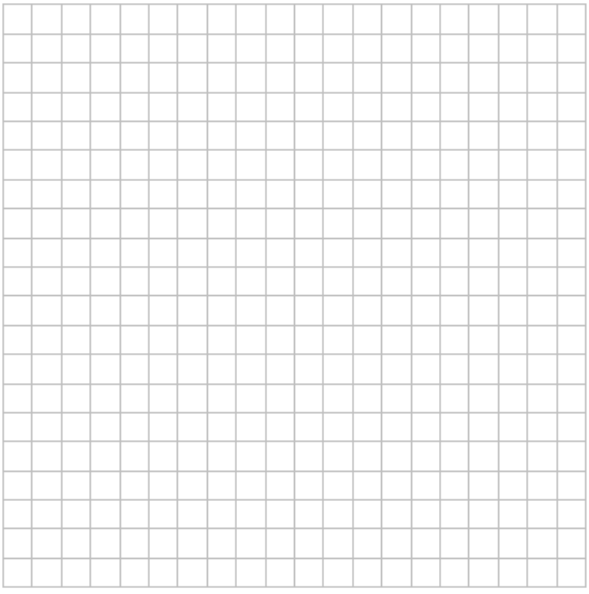
A high school drama club is putting on their annual theater production. There is a maximum of 800 tickets for the show. The costs of the tickets are $6 before the day of the show and $9 on the day of the show. To meet the expenses of the show, the club must sell at least $5,000 worth of tickets.

Write a system of inequalities that represent this situation.

2.

During a snowstorm, a meteorologist tracks the amount of accumulating snow. For the first three hours of the storm, the snow fell at a constant rate of one inch per hour. The storm then stopped for two hours and then started again at a constant rate of one-half inch per hour for the next four hours.

On the grid below, draw and label a graph that models the accumulation of snow over time using the data the meteorologist collected.



3. If the snowstorm from Question 2 started at 6 pm, how much snow would have accumulated by midnight?

4.

Next weekend Marnie wants to attend either carnival *A* or carnival *B*. Carnival *A* charges \$6 for admission and an additional \$1.50 per ride. Carnival *B* charges \$2.50 for admission and an additional \$2 per ride.

In function notation, write $A(x)$ to represent the total cost of attending carnival *A* and going on x rides. In function notation, write $B(x)$ to represent the total cost of attending carnival *B* and going on x rides.

5. Using information from question 4, Marnie wants to go on five rides. Determine which carnival would have the lower total cost. Show your work.

6.

124080607_4

What is the solution to the system of equations below?

$$\begin{cases} 3x + 4y = -2 \\ 2x - 4y = -8 \end{cases}$$

A $x = 2,\ y = -2$

B $x = 6,\ y = -5$

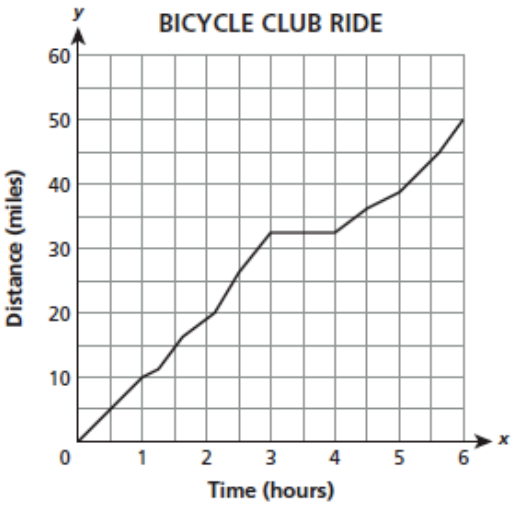
C $x = 4,\ y = 4$

D $x = -2,\ y = 1$

7.

124080033_2

A bicycle club went on a six-hour ride. The graph below shows the relationship between the number of hours spent on the trails and the number of miles traveled.



Which statement best interprets information provided by the graph?

A The club members rode at a constant speed for the entire ride.

B The club members stopped for a rest during their ride.

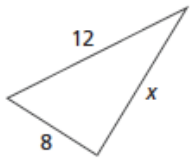
C The number of miles traveled increased continuously throughout the ride.

D The number of miles traveled increased some of the time and decreased some of the time.

8.

134070025_4

Which number could **not** be a value of x?



[not drawn to scale]

A 8

B 9

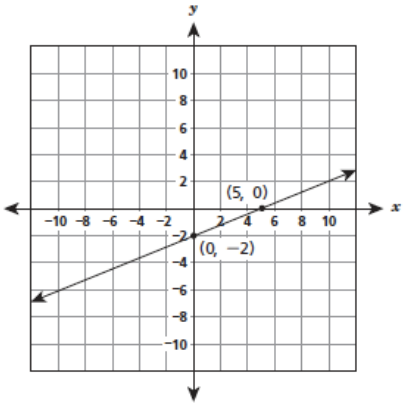
C 12

D 21

9.

134080010_1

Which equation represents the line shown on the coordinate grid below?



A $y = \frac{2}{5}x - 2$

B $y = \frac{2}{5}x + 5$

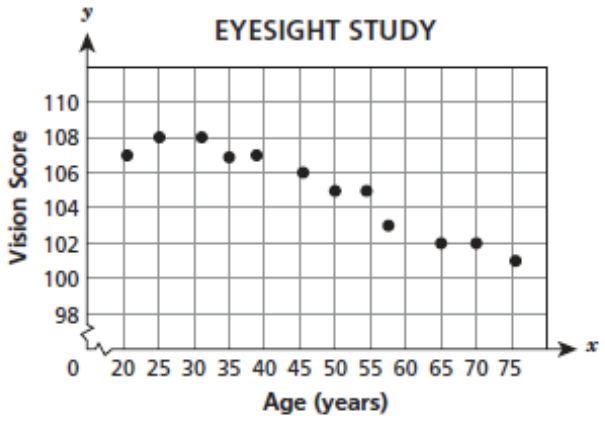
C $y = -\frac{2}{5}x - 2$

D $y = -\frac{2}{5}x + 5$

10.

134080300_2

A researcher studied the eyesight of people at different ages. She calculated a vision score for each person in the study and plotted the data on the graph below.



The researcher used the line $y = -0.1x + 110$ to model the data. When she substituted the value $x = 65$ into this equation, what did the result tell her?

A the exact value for the vision score of a 65-year-old

B the predicted value for the vision score of a 65-year-old

C the minimum possible value for the vision score of a 65-year-old

D the maximum possible value for the vision score of a 65-year-old

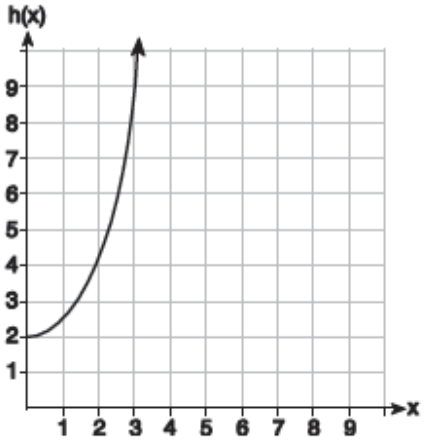
High School Test 4

1.

Given the functions g(*x*), f(*x*), and h(*x*) shown below:

$g(x) = x^2 - 2x$

x	f(x)
0	1
1	2
2	5
3	7



The correct list of functions ordered from greatest to least by average rate of change over the interval $0 \le x \le 3$ is

(1) f(*x*), g(*x*), h(*x*)
(2) h(*x*), g(*x*), f(*x*)
(3) g(*x*), f(*x*), h(*x*)
(4) h(*x*), f(*x*), g(*x*)

2.

Donna wants to make trail mix made up of almonds, walnuts and raisins. She wants to mix one part almonds, two parts walnuts, and three parts raisins. Almonds cost $12 per pound, walnuts cost $9 per pound, and raisins cost $5 per pound.

Donna has $15 to spend on the trail mix. Determine how many pounds of trail mix she can make. [Only an algebraic solution can receive full credit.]

3.

134080011_2

Which number is equivalent to $\frac{3^4}{3^2}$?

A 2

B 9

C 81

D 729

4.

134080064_1

A sequence of transformations was applied to an equilateral triangle in a coordinate plane. The transformations used were rotations, reflections, and translations. Which statement about the resulting figure is true?

A It must be an equilateral triangle with the same side lengths as the original triangle.

B It must be an equilateral triangle, but the side lengths may differ from the original triangle.

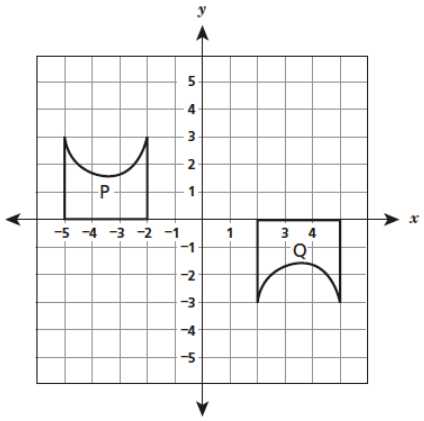
C It may be a scalene triangle, and all the side lengths may differ from the original triangle.

D It may be an obtuse triangle with at least one side the same length as the original triangle.

5.

134080067_1

Figure Q was the result of a sequence of transformations on figure P, both shown below.



Which sequence of transformations could take figure P to figure Q?

A reflection over the *x*-axis and translation 7 units right

B reflection over the *y*-axis and translation 3 units down

C translation 1 unit right and 180° rotation about the origin

D translation 4 units right and 180° rotation about the origin

6.

134080404_4

Determine the product.

$$800.5 \times (2 \times 10^6)$$

A 1.7×10^7

B 1.601×10^7

C 1.7×10^9

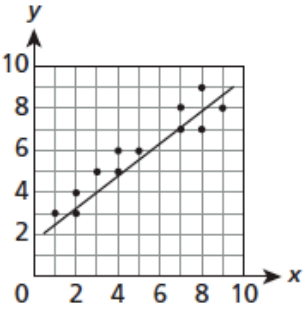
D 1.601×10^9

7.

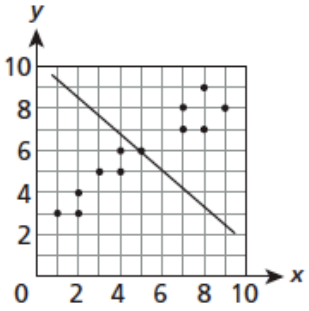
124080054_1

Which line represents the best fit for the scatter plot data?

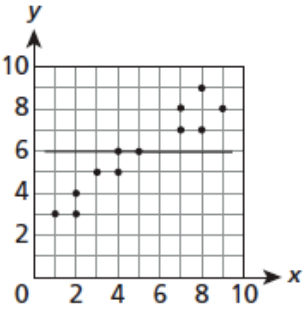
A



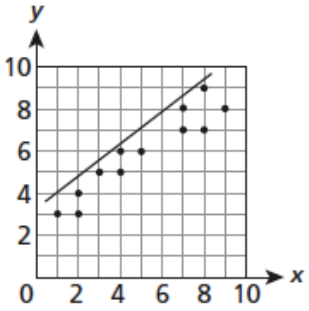
C



B



D



8.

A local business was looking to hire a landscaper to work on their property. They narrowed their choices to two companies. Flourish Landscaping Company charges a flat rate of $120 per hour. Green Thumb Landscapers charges $70 per hour plus a $1600 equipment fee.

Write a system of equations representing how much each company charges.

9. Using the information from question 8 and the equations you created, determine and state the number of hours that must be worked for the cost of each company to be the same

10. Using the information from question 8, if it is estimated to take at least 35 hours to complete a job, which company will be less expensive, Flourish Landscaping or Green Thumb Landscapers? Show your work

APPENDIX F

STROOP TEST (VICTORIA VERSION)

STROOP TEST

Name _____ Date Tested _____ Tested By _____

DOTS

G B Y R
Y R G B
B G Y R
B Y R G
R G B Y
Y G B R

	Time	z	%ile
Dots			
Words			
Colors			

WORDS

G B Y R
Y R G B
B G Y R
B Y R G
R G B Y
Y G B R

	Errors	z	%ile
Dots			
Words			
Colors			

COLORS

G B Y R
Y R G B
B G Y R
B Y R G
R G B Y
Y G B R

REFERENCES

Aks, D. J. (1998). Influence of exercise on visual search: Implications for mediating cognitive mechanisms. *Perceptual and Motor Skills*, *87*, 771–783.

Allard, F., Brawley, L., Deakin, J., & Elliot, F. (1989). The effect of exercise on visual attention performance. *Human Performance*, *2*, 131–145.

Alves, C. R. R., Gualano, B., Takao, P. P., Avakian, P., Fernandes, R. M., Morine, D., & Takito, M. (2012). Effects of acute physical exercise on executive functions: A comparison between aerobic and strength exercise. *Journal of Sport & Exercise Psychology*, *34*(4), 539-549.

Arcelin, R., Brisswalter, J., & Delignierres, D. (1997). Effects of physical exercise duration on decision making performance. *Journal of Human Movement Studies*, *32*, 123–140.

Baechle, T., & Earle, R. (2008). *Essentials of strength training and conditioning* (Vol. 7). Champaign, IL: Human kinetics.

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology*, *48*(5), 1501-1511.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, *2*, 92-98.

Brisswalter, J., Durand, M., Delignieres, D., & Legros, P. (1995). Optimal and non-optimal demand in a dual-task of pedaling and simple reaction time: Effects on energy expenditure and cognitive performance. *Journal of Human Movement Studies*, *29*, 15–34.

Brown, F.G. (1970). *Principles of educational and psychological testing*. Hinsdale, Il: The Dryden Press.

Brown, A. K., Liu-Ambrose, T., Tate, R., & Lord, S. R. (2009). The effect of group-based exercise on cognitive performance and mood in seniors residing in intermediate care and self-care retirement facilities: A randomised controlled trial. *British Journal of Sports Medicine*, *43*(8), 608-614.

Bub, D. N., Masson, M. E., & Lalonde, C. E. (2006). Cognitive control in children: Stroop interference and suppression of word reading. *Psychological Science*, *17*(4), 351-357.

Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters*, *441*(2), 219-223.

Cancela-Carral, J.M., & Ayan Perez, C. (2007). Effects of high-intensity combined training on women over 65. *Gerontology*, *53*, 340–346.

Carlson, S. A., Fulton, J. E., Lee, S. M., Maynard, L. M., Brown, D. R., Kohl III, H. W., & Dietz, W. H. (2008). Physical education and academic achievement in elementary school: Data from the early childhood longitudinal study. *American Journal of Public Health*, *98*(4), 721-727.

Cassilhas, R. C., Viana, V. A., Grassmann, V., Santos, R. T., Santos, R. F., Tufik, S. E., & Mello, M. T. (2007). The impact of resistance exercise on the cognitive function of the elderly. *Medicine and Science in Sports and Exercise*, *39*(8), 1401-1407.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third-and fifth-grade students. *Journal of Sport and Exercise Psychology*, *29*(2), 239-252.

Castelli, D. M., Hillman, C. H., Hirsch, J., Hirsch, A., & Drollette, E. (2011). FIT Kids: Time in target heart zone and cognitive performance. *Preventive Medicine*, *52*, S55-S59.

Chang, Y.K., & Etnier, J. L. (2009a). Exploring the dose-response relationship between resistance exercise intensity and cognitive function. *Journal of Sport & Exercise Psychology*, *31*(5), 640-656.

Chang, Y. K., & Etnier, J. L. (2009b). Effects of an acute bout of localized resistance exercise on cognitive performance in middle-aged adults: A randomized controlled trial study. *Psychology of Sport and Exercise*, *10*(1), 19-24.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research*, *1453*, 87-101.

Chang, Y. K., Pan, C. Y., Chen, F. T., Tsai, C. L., & Huang, C. C. (2012). Effect of resistance-exercise training on cognitive function in healthy older adults: A review. *Journal of Aging and Physical Activity*, *20*(4), 497-517.

Chmura, J., Nazar, K., & Kaciuba-Uscilko, H. (1994). Choice reaction time during

graded exercise in relation to blood lactate and plasma catecholamine thresholds. *International Journal of Sports Medicine*, *15*, 172–176.

Cian, C., Barraud, P. A., Melin, B., & Raphel, C. (2001). Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. *International Journal of Psychophysiology*, *42*, 243–251.

Cian, C., Koulmannn, N., Barraud, P. A., Raphel, C., Jimenez, C., & Melin, B. (2000). Influences of variations in body hydration on cognitive function: Effects of hyperhydration, heat stress, and exercise- induced dehydration. *Journal of Psychophysiology*, *14*, 29-36.

Coe, D. P., Pivarnik, J. M., Womack, C. J., Reeves, M. J., & Malina, R. M. (2006). Effect of physical education and activity levels on academic achievement in children. *Medicine and Science in Sports and Exercise*, *38*(8), 1515-1519.

Coles, K., & Tomporowski, P. D. (2008). Effects of acute exercise on executive processing, short-term and long-term memory. *Journal of Sports Sciences*, *26*(3), 333-344.

Comalli Jr, P. E., Wapner, S., & Werner, H. (1962). Interference effects of Stroop color-word test in childhood, adulthood, and aging. *The Journal of Genetic Psychology*, *100*(1), 47-53.

Cote, J., Salmela, J., & Papathanasopoulu, K. P. (1992). Effects of progressive exercise on attentional focus. *Perceptual and Motor Skills*, *75*(2), 351-354.

Courneya, K. S., Segal, R. J., Mackey, J. R., Gelmon, K., Reid, R. D., Friedenreich, C. M., ... McKenzie, D. C. (2007). Effects of aerobic and resistance exercise in breast cancer patients receiving adjuvant chemotherapy: A multicenter randomized controlled trial. *Journal of Clinical Oncology*, *25*(28), 4396-4404.

Crosnoe, R. (2002). Academic and health-related trajectories in adolescence: The intersection of gender and athletics. *Journal of Health and Social Behavior*, *43*(3), 317-335.

Darst, P., & Pangrazi, R. (2009). *Dynamic physical education for secondary school students*. San Fransisco, CA: Benjamin-Cummings; Pearson Education

Del Giorno, J. M., Hall, E. E., O'Leary, K. C., Bixby, W. R., & Miller, P. C. (2010). Cognitive function during acute exercise: A test of the transient hypofrontality theory. *Journal of Sport & Exercise Psychology*, *32*(3), 312-323.

Delignierres, D., Brisswalter, J., & Legros, P. (1994). Influence of physical exercise on choice reaction time in sports experts: The mediating role of resource allocation. *Journal of Human Movement Studies*, *27*, 173–188.

Dietrich, A. (2006). Transient hypofrontality as a mechanism for the psychological effects of exercise. *Psychiatry Research*, *145*, 79–83.

Dietrich, A., & Sparling, P. B. (2004). Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain and Cognition*, *55*, 516–524.

Dishman, R., Washburn, R., & Heath, G. (2004). *Physical activity epidemiology* (4th ed.). Champaign, Il: Human Kinetics.

Emery C.F., Leatherman N.E., Burker E.J., & MacIntyre, N.R.. (1991). Psychological outcomes of a pulmonary rehabilitation program. *Chest*, *100*, 613-617.

Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J., Jeffreys, I., Micheli, L. J., Nitka, M., & Rowland, T. W. (2009). Youth resistance training: Updated position statement paper from the national strength and conditioning association. *The Journal of Strength & Conditioning Research*, *23*, S60-S79.

Ferguson, C. J. (2009). An effect size primer: A guide for clinicians and researchers. *Professional Psychology: Research and Practice*, *40*(5), 532-538.

Figlio, D. N., & Kenny, L. W. (2007). Individual teacher incentives and student performance. *Journal of Public Economics*, *91*(5), 901-914.

Gabbard C., & Barton J. (1979). Effects of physical activity on mathematical computation among young children. *Journal of Psychology, 103*, 287–288.

Gao, Z., Hannan, P., Xiang, P., Stodden, D. F., & Valdez, V. E. (2013). Video game–based exercise: Latino children's physical health, and academic achievement. *American Journal of Preventive Medicine*, *44*(3), S240-S246.

Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., & Lee, I.M., (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*, 1334–1359.

Guiney, H., Lucas, S. J., Cotter, J. D., & Machado, L. (2015). Evidence cerebral blood-flow regulation mediates exercise–cognition links in healthy young adults. *Neuropsychology*, *29*(1), 1-9.

Häkkinen, K., Alen, M., Kraemer, W. J., Gorostiaga, E., Izquierdo, M., Rusko, H., ... Paavolainen, L. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *European Journal of Applied Physiology*, *89*(1), 42-52.

Heckler, B., & Croce, R. (1992). Effects of time of posttest after two durations of

exercise on speed and accuracy of addition and subtraction by fit and less-fit women. *Perceptual and Motor Skills*, *75*, 1059–1065.

Hillman, C.H., Buck, S.M., Themanson, J.R., Pontifex, M.B., & Castelli, D.M. (2009a). Aerobic fitness and cognitive development: Event-related brain potential and task performance indices of executive control in preadolescent children. *Developmental Pyschology*, *45*(1), 114-129.

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

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009b). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, *159*(3), 1044-1054.

Hillman, C. H., Snook, E. M., & Jerome, G. J. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology*, *48*(3), 307-314.

Hogervorst, E., Riedel, W., Jeukendrup, A., & Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills*, *83*, 479–488.

Howie, E. K., & Pate, R. R. (2012). Physical activity and academic achievement in children: A historical perspective. *Journal of Sport and Health Science*, *1*(3), 160-169.

Hyodo, K., Dan, I., Suwabe, K., Kyutoku, Y., Yamada, Y., Akahori, M., & Soya, H. (2012). Acute moderate exercise enhances compensatory brain activation in older adults. *Neurobiology of Aging*, *33*(11), 2621-2632.

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *64*(3), 356-363.

Kamijo, K., Nishihira, Y., Hatta, A., Kaneda, T., Kida, T., Higashiura, T., & Kuroiwa, K. (2004). Changes in arousal level by differential exercise intensity. *Clinical Neurophysiology*, *115*(12), 2693-2698.

Kimura, K., & Hozumi, N. (2012). Investigating the acute effect of an aerobic dance exercise program on neuro-cognitive function in the elderly. *Psychology of Sport and Exercise*, *13*(5), 623-629.

Kraemer, W.J., Ratamess, N.A., & French, D.N. (2002). Resistance training for health and performance. *Current Sports Medicine Reports*, *1*(3), 165–171.

Kramer, A. F., Colcombe, S. J., McAuley, E., Eriksen, K. I., Scalf, P., Jerome, G. J., ... Webb, A. G. (2003). Enhancing brain and cognitive function of older adults through fitness training. *Journal of Molecular Neuroscience*, *20*(3), 213-221.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., & Colcombe, A. (1999). Ageing, fitness and neurocognitive function. *Nature*, *400*(6743), 418-419.

Krus, D. M., Wapner, S., & Werner, H. (1958). Studies in vicariousness: Effect of muscular involvement on visual threshold. *American Journal of Psychology*, *66*, 603–608.

Labelle, V., Bosquet, L., Mekary, S., & Bherer, L. (2013). Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level. *Brain and Cognition*, *81*(1), 10-17.

Lees, C., & Hopkins, J. (2013). Peer reviewed: Effect of aerobic exercise on cognition, academic achievement, and psychosocial function in children: A systematic review of randomized control trials. *Preventing Chronic Disease*, *10*, E174.

Levitt, S., & Gutin, B. (1971). Multiple choice reaction time and movement time during physical exertion. *Research Quarterly*, *42*, 405–411.

Lichtman, S., & Poser, E. G. (1983). The effects of exercise on mood and cognitive functioning. *Journal of Psychosomatic Research*, *27*, 43–52.

Liu-Ambrose, T., Donaldson, M.G., Ahamed, Y., Graf, P., Cook, W.L., Close, J., & Khan, K. (2008). Otago home-based strength and balance retraining improves executive functioning in older fallers: A randomized controlled trial. *Journal of the American Geriatrics Society*, *56*, 1821–1830.

Marriott, J., Reilly, T., & Miles, A. (1993). The effect of physiological stress on cognitive performance in a simulation of soccer. *Science and Football, II*, 261-264.

McGlynn, G. H., Laughlin, N. T., & Bender, V. L. (1977). Effect of strenuous to exhaustive exercise on a discrimination task. *Perceptual and Motor Skills*, *44*, 1139–1147.

McMorris, T., & Graydon, J. (1996). The effects of exercise on the decision-making performance of experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport*, *67*, 109–114.

McMorris, T., & Graydon, J. (1997). Effect of exercise on cognitive performance in soccer-specific tests. *Journal of Sports Sciences*, *15*, 459–468.

McMorris, T., & Keen, P. (1994). Effect of exercise on simple reaction times of

recreational athletes. *Perceptual and Motor Skills*, *78*, 123–130.

McMorris, T., Meyers, S., Macgillivary, W. W., Sexsmith, J. R., Fallowfield, J., Graydon, J., & Forster, D. (1999). Exercise, plasma catecholamine concentrations and performance of soccer players on a soccer-specific test of decision making. *Journal of Sports Sciences*, *17*, 667–676.

McNaughten, D., & Gabbard, C. (1993). Physical exertion and immediate mental performance of sixth-grade children. *Perceptual and Motor Skills*, *77*(3f), 1155-1159.

Molloy, G. N., (1989). Chemicals, exercise and hyperactivity: A short report. *International Journal of Disability, Development and Education*; *36*, 57-61.

Nagamatsu, L.S., Handy, T., Hsu, C., Voss, M., & Liu-Ambrose, T. (2012). Resistance training promotes cognitive and functional brain plasticity in seniors with probable mild cognitive impairment. *Archives of Internal Medicine*, *172*(8), 666-668.

NASPE (2010). *The shape of the nation: Status of physical education in the USA*. Reston, VA: AAHPERD,

Nelson, M. C., & Gordon-Larsen, P. (2006). Physical activity and sedentary behavior patterns are associated with selected adolescent health risk behaviors. *Pediatrics*, *117*(4), 1281-1290.

Özkaya, G. Y., Aydin, H., Toraman, F. N., Kizilay, F., Özdemir, Ö., & Cetinkaya, V. (2005). Effect of strength and endurance training on cognition in older people. *Journal of Sports Science & Medicine*, *4*(3), 300-313.

Perrig-Chiello, P., Perrig, W.J., Ehrsam, R., Staehelin, H.B., & Krings, F. (1998). The effects of resistance training on well-being and memory in elderly volunteers. *Age and Ageing*, *27*, 469–475.

Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity*, *2*(1), 16-22.

Pollock, M. L., Franklin, B. A., Balady, G. J., Chaitman, B. L., Fleg, J. L., Fletcher, B., ... Bazzarre, T. (2000). Resistance exercise in individuals with and without cardiovascular disease: Benefits, rationale, safety, and prescription. An advisory from the committee on exercise, rehabilitation, and prevention, council on clinical cardiology, American Heart Association. *Circulation*, *101*(7), 828-833.

Pontifex, M., Hillman, C., Fernhall, B., Thompson, K., & Valentini, T. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine and Science in Sports and Exercise*, *41*(4), 927-934.

Querido, J. S., & Sheel, A. W. (2007). Regulation of cerebral blood flow during exercise. *Sports Medicine*, *37*(9), 765-782.

Salmela, J.H., & Ndoye, O.D. (1986). Cognitive distortions during progressive exercise. *Perceptual and Motor Skills*, *63*, 1067–1072.

Seifert, T., Brassard, P., Wissenberg, M., Rasmussen, P., Nordby, P., Stallknecht, B., ... Secher, N. H. (2010). Endurance training enhances BDNF release from the human brain. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *298*(2), R372-R377.

Singh, A., Uijtdewilligen, L., Twisk, J. W., Van Mechelen, W., & Chinapaw, M. J. (2012). Physical activity and performance at school: A systematic review of the literature including a methodological quality assessment. *Archives of Pediatrics & Adolescent Medicine*, *166*(1), 49-55.

Spirduso, W.W. (1975). Reaction time and movement time as a function of age and physical activity level. *Journal of Gerontology*, *30*, 435-440.

Spreen, O. (1998). *A compendium of neuropsychological tests: Administration, norms, and commentary*. Oxford, United Kingdom: Oxford University Press.

Strong, W. B., Malina, R. M., Blimkie, C. J., Daniels, S. R., Dishman, R. K., Gutin, B., …Trudeau, F. (2005). Evidence based physical activity for school-age youth. *The Journal of Pediatrics*, *146*(6), 732-737.

Tine, M. T., & Butler, A. G. (2012). Acute aerobic exercise impacts selective attention: An exceptional boost in lower-income children. *Educational Psychology*, *32*(7), 821-834.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, *112*(3), 297-324.

Tomporowski, P. D., Ellis, N. R., & Stephens, R. (1987). The immediate effects of strenuous exercise on free recall memory. *Ergonomics*, *30*, 121–129.

Tomporowski, P. D., & Ganio, M. S. (2006). Short-term effects of aerobic exercise on executive processing, memory, and emotional reactivity. *International Journal of Sport and Exercise Psychology*, *4*(1), 57-72.

Travlos, A. K. (2010). High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology*, *8*(3), 302-311.

Trudeau, F., & Shephard, R. J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity*, *5*(1), 10.

Verburgh, L., Königs, M., Scherder, E. J., & Oosterlaan, J. (2013). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine*, *48*, 973-979.

Wittberg, R. A., Northrup, K. L., & Cottrell, L. A. (2012). Children's aerobic fitness and academic achievement: A longitudinal examination of students during their fifth and seventh grade years. *American Journal of Public Health*, *102*(12), 2303-2307.

Yarrow, J. F., White, L. J., McCoy, S. C., & Borst, S. E. (2010). Training augments resistance exercise induced elevation of circulating brain derived neurotrophic factor (BDNF). *Neuroscience Letters*, *479*(2), 161-165.

Zervas, Y., Danis, A., & Klissouras, V. (1991). Influence of physical exertion on mental performance with reference to training. *Perceptual and Motor Skills*, *72*(3c), 1215-1221.