THE EFFECTS OF CARDIOVASCULAR EXERCISE ON COLLEGE STUDENTS' LEARNING, RECALL, AND COMPREHENSION

by

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This manuscript has been read and accepted for the Graduate Faculty in Educational Psychology in satisfaction of the dissertation requirement for degree of Doctor of Philosophy.

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Abstract

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Research on physical activity and cognition is based on the existing theoretical and empirical evidence which indicates that engaging in cardiovascular exercise improves cognitive capabilities, by increasing neural functioning which improves learning (cognitive development). The question this research sought to answer was to determine whether or not (a) increased amounts of exercise improves cognitive *recall* and *comprehension* and (b) there is a difference in cognitive recall and comprehension abilities when engaging in exercise occurs *before* a learning activity as compared to *after* a learning activity.

This experimental pretest-posttest study examined whether or not a physical activity intervention improved community college students' *recall* and *comprehension* of recently learned information. The cardiovascular exercise intervention included two levels: moderate and light exercise. In one sequence the rehearsal of information (i.e., learning) took place *before* the students' engaged in exercise and in an alternate sequence, *after* the students have engaged in exercise.

The results of the study demonstrated that performing a moderate amount of exercise *before* or *after* rehearsing for a *comprehension* test significantly improved test results. The moderate exercise group also scored higher on the *recall* posttest than the no

exercise group, yet this difference was not found to be significant. Performing a light amount of exercise demonstrated improvement in comparison to not performing any exercise. Yet, this difference was not found to be significant. Overall, the results of the research demonstrated a significant positive linear trend between increased levels of physical activity and *comprehension*.

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CHAPTER 1

Introduction

The American College of Sports Medicine (2006) recommends that individuals engage in a minimum of 20 minutes of vigorous physical activity at least three days a week. Yet many students do not engage in regular physical activity (less than 50% of young persons aged 12 to 21 meet the recommended guidelines). They cite a lack of time as a reason for not exercising on a regular basis. Students also cite a lack of energy or lack of motivation for why they fail to incorporate regular physical activity into their lives, notwithstanding their awareness of the potential health benefits that exercising would provide them. The physical health benefits from engaging in regular exercise include weight loss and improved cardiorespiratory function, which can help prevent the risk of developing some of the leading causes of death in the United States today, including heart disease, stroke, diabetes and certain cancers (e.g., breast cancer and colon cancer) (National Center for Health Statistics, 2007). The psychological health benefits from engaging in regular physical activity include a reduction in stress, anxiety and depression (Berger, 1996; Shephard, 1996). Although students, faculty and administrators may know that engaging in exercise will benefit students' health, they may not be aware that our brains function better when our bodies are physically fit (Diamond, 2009).

This chapter begins with a description of the neurological and other neurologically-related changes in the body that occur from engaging in cardiovascular exercise (defined as increasing a person's heart rate between 50% to 90% of his or her maximum heart rate). These changes have been shown to increase cognitive performance. This is followed by an explanation of the cognitive processes and measures that have been tested to determine the effects of physical activity on cognition and academic achievement. The next section describes the physical activity measures used to test performance and physical fitness level. Finally, an experiment, based on the neurological, neurologically-related, and cognitive evidence is proposed to help determine the effects of cardiovascular exercise on college students' learning, recall, and comprehension.

Neurological Responses to Cardiovascular Exercise

The neurological responses to cardiovascular exercise include: (1) the production of neurotrophins, including, brain-derived neurotophic factor (BDNF), insulin-like growth factor (IGF-I) and vascular endothelial growth factor (VEGF) that regulate the survival, growth, and differentiation of neurons during development (Barde 1989; Ploughman 2008; Vaynman and Gomez-Pinilla 2006); (2) synaptogenesis (i.e. the production of chemical synapses) that occurs concurrently with myelination (i.e. the production of the myelin sheath around the axon of a neuron which increases the speed of impulse transmission) (Huttenlocher 1994; Huttenlocher and Dabholkar 1997); and (3) increases in levels of neurotransmitters (i.e. chemicals in the brain that are responsible for the transmission of signals from one brain cell to the next), serotonin, norepinephrine, and dopamine.

Neurotrophins (i.e., BDNF, IGF-1 and VEGF) are proteins that have been identified as mediators of neuronal survival and differentiation during development. Each neurotrophin regulates specific populations of neurons during development.

Neurotrophins have been shown to maintain their viability of neurons in adulthood and protect and restore neurons in response to injury and aging (Ploughman, 2008).

BDNF has been found to be associated with long-term potentiation (LTP), a neural analogue of long-term memory formation, and for the growth and survival of new neurons, where BDNF is produced in the brain and has been shown to increase with exercise. BDNF has been associated with enhanced learning and memory processes that are associated with exercise treatments in rodent laboratory testings (Vaynam, S. et al.). IGF-1 is a hormone that is produced mainly in the liver and works closely with human growth hormone (HGH) and insulin to stimulate cell growth and counteract natural cell deterioration (Ratey, 2008). VEGF is a neurotrophin that is produced and released throughout the body when tissues are taxed from exercise and there is not enough blood flow to fuel the demand. VEGF has also been found to be produced in the brain and is involved in storing memories (Ding, 2004). This human and non-human research strongly supports the positive effects of exercise on cognition as exercise has been shown to increase (a) the secretion of key neurochemicals associated with synaptic plasticity, and (b) the development of new neuronal architecture (Hillman, et al. 2008).

Studies which examine the electrophysiological activity of neurotransmitters such as serotonin neurons indicate that during periods of low motor activity, serotonin neurons may be suppressed, and that when exercise is increased, serotonin neuronal activity may activate brain serotonin (Meeusen, 2001).

Engaging in exercise has also been shown to increase cerebral blood volume (CBV) in the dentate gyrus of the hippocampus and this has been associated with improvements in verbal learning and memory and cardiorespiratory fitness (Pereira, A. C. et al. 2007).

Further, it has been shown that vigorous exercise can cause older nerve cells to form dense, interconnected webs that increase brain function and efficiency which may stave off the beginnings of Alzheimer's, Attention Deficit Hyperactivity Disorder (ADHD) and other cognitive disorders (Hillman, et. al., 2005). The following section describes the neuroelectric indices used to measure the neurological changes that occur in the brain as a result of engaging in exercise.

Neuroelectric Indices

Event-related brain potentials (i.e., P3 amplitude and latency, N2 and error-related negativity (ERN)) are neuroelectric indices used to measure the effects of exercise on the brain. ERP and other brain-activity are measured by neuroimaging techniques including (a) structural and functional magnetic imaging (sMRI and fMRI respectively), (b) nuclear magnetic resonance imagery (NMRI), (c) positron emission tomography (PET) and (d) electroencephalograms (EEGs).

ERP refers to a time-locked index of neuroelectric activation that is associated with specific cognitive processes (e.g., attention and working memory). One measure of ERP, P3, is a positive deflection in a stimulus-locked ERP that reflects changes in the neural representation of the stimulus environment. It is proportional to the amount of attention that is required to encode a given stimulus evaluation. According to the research, P3 appears to be generated by a network of neural structures, including the frontal lobe, the anterior cingulated cortex, the infero-temporal lobe and the parietal cortex, each of which are involved in cognitive operations, including stimulus processing and memory updating (Polich, 2004).

P3 amplitude has been found to be proportional to the amount of attentional resources devoted to a stimulus, with increased amplitude related to increased attention toward a stimulus. P3 latency refers to the neuroelectric measure that occurs after a stimulus has been discriminated and categorized, with a shorter latency indicating a faster cognitive processing speed (Buck, 2005). Error-related negativity (ERN) is a negative deflection in a response-locked ERP that reflects neural correlates of action monitoring that is associated with the evaluation of conflict. N2 is another neurological measure of the stimulus-locked ERP that is found to be involved in response inhibition or conflict (Hillman et al. 2008).

Research that has examined students' functional neuroanatomy of reading comprehension revealed an activation of the prefrontal cortex (PFC) and parietal/posterior cingulated cortex (PCC) (Maguire, et al., 1999). Likewise, mathematical calculations and numerical magnitude processing have been linked to bilateral regions of the PFC (Ansari, D., and Dhital, B., 2006; Rivera, S., et. al, 2005).

fMRI techniques, when used to examine brain volume, have shown that exercise modified brain function in the anterior circulated cortex, a PFC area of the brain involved in the regulation and control of behavior (Colcombe *et al*. 2004a, b). Overall, regular exercise has been shown to be positively associated with neuroelectric indices of attention, working memory and response in cognitive processing speed (Hillman, et. al., 2005). The next section describes neurologically-related responses to exercise that affect brain functioning.

Neurologically-Related Responses to Cardiovascular Exercise

Regular cardiovascular exercise has been shown to result in a host of biological responses that, in turn, modify and regulate the structure and functions of the brain (Dishman et al. 2006). For example, angiogenesis is a biological process that causes growth of new blood cells from pre-existing blood cells. Angiogenesis influences glucose and oxygen distribution (Black, et al. 1990), which in turn affects the brain.

The measures to test neurologically-related responses to engaging in exercise include (a) blood tests to measure insulin levels and c-reactive protein levels, (c) plasma adrenaline and nonadrenaline concentrations taken during exercise (Chmura et al., 1994), (d) volume of oxygen consumed (VO2 max) during exercise to measure level of aerobic fitness and (f) body composition (e.g. body mass index (BMI) and central adiposity). Insulin measures have shown that exercise improves insulin sensitivity and reduces inflammation which may increase synaptic plasticity and stimulation of neurofacilitory pathways in the brain (Witte et al. 2009).

VO2 max is a measurement of aerobic fitness which refers to the maximal capacity of the cardiorespiratory system to take in and use oxygen (Hillman, *et al*. 2008). Aerobic fitness can also be measured by heart rate (i.e., target heart rate range (THRR), recovery heart rate and resting heart rate) and other standardized fitness tests. THRR (the desired heart range for the participant during aerobic exercise) is based on age and ranges from 60% to 90% of an individual's maximum heart rate. Recovery heart rate refers to how quickly an individual's heart rate can return to a normal rate after exercise (Tuker, 2002). Resting heart rate is an individual's heart rate during periods of inactivity. Higher aerobically-fit individuals (a) are able to maintain aerobic activity at the higher end of their THRR, (b) have quicker recovery heart rates and (c) have lower resting heart rates. Also, increased heart rates have been associated with increased delivery of oxygen to the brain (Scholey, et. al 1999).

BMI is a measure of a person's mass based on their height and weight. Evidence has shown that BMI levels may affect certain cognitive processes (Davis et al. 2007) and that central adiposity, as measured by waist circumference and waist/hip ratio, are found to be inversely related to cognition. However, when exercise level is factored in, this inverse relationship is attenuated (Dore, G. et al. 2008). This provides further evidence of the importance of exercise on cognitive functioning. The following section discusses several cognitive processes that have been tested in relation to engaging in exercise.

Cognitive Processes

Cognitive processes that have been tested in research concerning exercise and cognition include: (a) executive control (i.e., executive function), (b) visuospatial processing (i.e., perception), (c) speed processing (i.e., reaction time), (d) accuracy, (e) attention, (f) memory, (g) information processing, (h) response inhibition, and (i) creativity.

Executive control refers to a subset of goal-directed processes that include the selection, scheduling, and coordination of cognitive processes that are involved in perception, memory and action (Meyer and Kieras 1997; Norman and Shallice, 1986). Executive control has also been described to involve response inhibition, planning and working memory (Chodzko-Zajko and Moore 1994). Its functions are involved in the planning and selection of strategies that organize goal-directed actions (Das et *al*. 1994). This differs from information processing theory, which involves (a) encoding, (b) stimulus evaluation, (c) response selection and (d) and response execution (Kramer et *al*. 1999a, b). There is a general consensus among researchers that executive functioning is not a unitary process. Rather it consists of several elemental underlying processes. The next section describes cognitive and academic achievement measures, which are designed to test the various cognitive processes.

Cognitive and Academic Achievement Measures

The cognitive measures that have been used to test the different types of cognitive processes in relation to exercise include (a) the Cognitive Assessment System (CAS) (Tomporowski, 2008), (b) the Eriksen flanker task (Eriksen and Eriksen 1974; Hillman, 2009; Tomporowski, 2008), (c) the Stroop task performance (Adleman et al. 2002), (d) a category switching task, (e) a countermanding task, (f) auditory and visual discrimination tasks (i.e., Bender-Gestalt test or Maze Tracing Speed test (Tuckman and Hinkle 1986)) (Hawkins, H. L. et al. 1992), (g) creativity tests (i.e., alternate uses test and Torrance Test of Creative Thinking (Hinkle *et al*. 1993), (h) verbal and math tests (Tomporowski, 2008), and (i) computerized design-matching task. Academic achievement measures include grades, academic records, standardized achievement tests and teacher evaluations.

The cognitive measure, (CAS), refers to a standardized test of cognitive function that provides four scales: (1) planning (which assesses executive function; i.e., cognitive control, utilization of processes and knowledge, intentionality, and self-regulation); (2) attention (which assesses focused, selective cognitive activity and resistance to distraction); (3) simultaneous (which assesses spatial and logical processing of nonverbal and verbal material); and (4) successive (which assesses processing of sequential information) (Tomporowski, et al. 2008).

The Eriksen-flanker task measures executive functioning, and it involves responding as quickly as possible to an array of stimuli presented on a computer monitor from a distance. For example, the target stimulus (< and >) required participants to press a button with their right and left thumbs, respectively. Congruent trials appeared as <<<<< or >>>> and incongruent trials appeared as <<><< or <<><<<.

The Stroop task measures reaction time of a task. When a word such as blue, green, red, etc., is printed in a color different from the color expressed by the word's semantic value (e.g., the word "red" printed in blue ink), naming the color of the word takes longer and is more prone to errors than when the meaning of the word is congruent with its ink color. The next section describes the exercise treatment conditions, for experiments, which include an intervention of exercise.

Exercise Measures

The exercise measures to test performance and physical fitness level include (a) acute bouts of exercise, (b) regular exercise, (c) self-assessments and (d) criterion-based assessments. Acute bouts of exercise (Tomporowski, 2003) involve short segments of exercise lasting from ten minutes to two hours and where cognitive and/or neurological tests are performed soon after or during the treatment. Regular exercise treatment conditions are designed to specifically improve participants' physiological functioning (e.g., cardiorespiratory function, metabolism, muscular strength) via repeated training sessions that last several weeks or months (Willmore and Costill 2004). Then cognitive, neurological and academic achievement measures are administered after several weeks or months of training.

Physical fitness levels are measured by self-assessments including questionnaires and seven-day recall measures. Criterion-based assessments are exercise measures designed to test students' level of physical fitness from a specific criterion. Based on the previous sections of the neurological, cognitive and exercise processes and measures, the next section describes the purpose for the proposed research.

Purpose for the Proposed Research

The purpose for the proposed research is based on the evidence that cardiovascular exercise affects neurological responses and improves cognition and academic achievement. This could be valuable for college students where the need for cognitive improvement is clear. In 2002, it was reported that more than 30% of first-year college students did not return for their second year of college, and only 40% of them graduated earning their intended degree (Smith, 2002). Further, a significant proportion of college students failed to attain or maintain an acceptable level of academic achievement and ultimately withdrew from college (Mansfield, et. al, 2004).

Studies on two sub-populations of college students, first generation college students (students whose parents did not attend or graduate from college), and students taking remedial courses along with college courses, provide further evidence of the need for students' cognitive improvement. Pascarella et. al (2004) conducted a study on the academic outcomes of first-generation college students reported that *53%* of students starting at two-year colleges were first-generation college students. Also, compared to students whose parents are college graduates, first-generation college students are more likely to leave a four-year institution at the end of the first year, less likely to remain enrolled in a four-year institution or be on track toward earning a bachelor's degree by the third year and are less likely to stay enrolled or attain a bachelor's degree after five years.

Further, Pascarella et al. (2004) found that first-generation college students had lower grades through the third year of college than did peers with parents who had both graduated from college. Also, first-generation college students had lower levels of extracurricular involvement, athletic participation and significantly lower levels of non-course-related interactions with peers in their third year of college.

Terenzini et al. (1996) also compared first-generation college students to students whose parents attended college and reported that first generation college students completed fewer first-year credit hours, took fewer humanities and fine arts courses, studied fewer hours, worked more hours per week and made smaller first-year gains on a standardized measure of reading comprehension.

Illich et al. (2004) conducted a study of college students who were enrolled in college-level courses as well as in remedial courses. Remedial courses refer to courses in reading, writing, and mathematics for college students lacking those skills necessary to perform college-level work at the level required by the institution. The study revealed that the college-level pass rates were much lower among students who are also enrolled in remedial courses and who do not successfully complete one or more of the remedial courses. Further, a reported *41%* of freshmen enrolled in community colleges were enrolled in at least one remedial course (Lewis and Farris, 1996).

Illich and colleagues (2004) hypothesized that offering more developmental support including student placement, orientation, study skills training, and freshman seminars could help those students more than remediation alone. They explain that focusing on remedial courses only represents a relatively narrow approach to developmental education. In contrast, a broad approach to developmental education involves the application of many strategies designed to address academically under-preparedness holistically. Based on the findings of the proposed research, one of several strategies that may be helpful to underprepared students could be engagement in exercise.

Research has demonstrated the need for under-prepared college students to improve cognitive performance, academic achievement, retention rates and graduation rates, including first-generation college students and students taking remedial courses. This dissertation seeks to provide evidence that a cardiovascular exercise intervention would help such college students improve their cognitive performance.

The author wishes to acknowledge that there are multiple reciprocal factors involved in the amount and level of students' participation in exercise. These factors are based on Social Cognitive Theory (SCT), which is a comprehensive theory of human behavior, where an important principle of SCT is reciprocal determinism. Reciprocal determinism includes three factors (a) behavior, (b) the environment, and (c) the person which simultaneously influence each other (Bandura, 1986). These interrelated factors affect students' engagement in exercise and subsequent cognitive performance by (a) the physiological and the neurological changes that occur in the body, (b) the students' social and physical interaction with their environment (c) their thoughts and feelings regarding exercise. Students' thoughts and feelings regarding exercise include their self-efficacy (one’s personal beliefs concerning one's capabilities to learn or perform behaviors at designated levels (Bandura, 1997) for engaging in regular exercise. Self-efficacy is an important determinant of whether or not an individual will choose to incorporate exercise into his or her daily life. Therefore, students may need to improve their self-efficacy in order to engage in regular exercise.

Taken together, neurological, cognitive and lifestyle factors affect students’ behavior and students’ decisions regarding their engagement in exercise. Given the scope of this dissertation, the focus on the author’s research will be based on the neurological and cognitive evidence for why engaging in exercise helps to improve cognition and academic achievement. Once evidence of a prescribed amount of exercise is shown to improve cognition and academic achievement, researchers, students, teachers and administrators can use this information, together with other lifestyle factors that affect students’ engagement in exercise, to promote self-regulated (self-generated thoughts, feelings, and actions that are planned and cyclically adapted for the attainment of personal goals (Zimmerman, 1998)) exercise.

This dissertation is based, in part, on existing theoretical and empirical evidence which indicates that engaging in exercise improves cognitive capabilities, by increasing neural functioning which improves learning (cognitive development). Much of the prior experimental and correlational research focused either on exercise and cognitive measures, or exercise and academic achievement. Overall, the limitations of the several experimental studies which have been conducted on exercise and cognition included (a) lack of a control group, (b) small sample size and (c) mixed results. In one example of mixed results involving changes in response accuracy, one study revealed improvement in response accuracy when the participants engaged in exercise (Lichtman and Poser, 1983). By contrast, another study showed no improvement in response accuracy when the participants engaged in exercise (Heckler and Croce, 1992). These studies differed in the cognitive tests selected (i.e., the Stroop task versus an addition and subtraction computation task), and the level of precise measurements for the jogging treatment condition (i.e., jogging class versus participants jogging at various specified VO2 levels).

Alternatively, much of the correlational studies on exercise and academic achievement have involved the participants' (a) engagement in regular exercise and/or (b) physical fitness level in conjunction with an analysis of their academic achievement (e.g. grades, standardized achievement tests, etc.). As stated by Taras (2005), "the [correlational] studies showed either significant but weak associations between activity level and better academic performance or no correlation at all. It is difficult to know if the association is causal and if so, the direction of the cause-effect." (p. 215).

Taken together, both prior experimental and correlational research on the effects of exercise on cognition have focused on general cognitive outcomes (i.e., test scores and responses on cognitive tests). The issue of the causal direction of exercise on the proactive learning process has received little attention to date. From a social cognitive theoretical perspective, a key issue in self-regulating one's learning effectively is the issue of the causal direction of exercise. To use exercise as a strategy for learning, it is important to know if engagement in exercise *before* learning has a proactive effect on cognition and/or if exercise *after* learning has a reactive effect on cognition. The proposed research described in this dissertation is an experimental study that focuses on the effectiveness of exercise on cognitive learning and performance, using authentic measures of academic performance, such as students' recall and comprehension of recently learned information.

More specifically, this dissertation explores the forward (i.e., proactive) and backward (i.e., reactive) effects of exercise on students' ability to recall and comprehend recently learned information, and the level of exercise needed to enhance cognitive performance. Whereas, examining the forward effect answers the question "does exercise increase learning?", whereas, the backward effect answers the question, "if you already learned something, does engaging in exercise help you to retrieve the previously learned information?" In other words, the forward effect (i.e., sequence B) is proactive, which prepares the mind for future learning. The backward effect (i.e., sequence A) is retroactive and seeks to preserve learning traces and the accessibility of previously learned information. This dissertation seeks to provide new research findings on the forward and backward effects of exercise on cognition which has not been adequately examined in the previous literature. By examining the forward and backward effects of exercise on cognitive recall and comprehension, I can determine whether or not (a) exercise increases cognitive learning, recall and comprehension and (b) there is a difference in cognitive recall and comprehension abilities when engaging in exercise *before* learning occurs (i.e., forward effect) as opposed to *after* learning occurs (i.e., backward effect). Whereas, the prior research focused on high and low levels of exercise, this dissertation seeks to determine the effects of moderate and light exercise on cognitive learning, recall and comprehension.

Prior research has focused on vigorous cardiovascular exercise in order to increase physical fitness and students' cognitive performance. However, if there were evidence to suggest that engaging in light to moderate cardiovascular exercise significantly increases students' ability to retain or acquire information, this information could be used to benefit students who are not yet physically fit to engage in vigorous cardiovascular exercise.

If it were demonstrated that by engaging in prescribed amount of cardiovascular exercise, performed at optimal times (i.e., before or after learning), students can significantly improved their academic achievement. This self-regulatory outcome would be greatly appreciated by both parents and school staff members and school administrators would have important evidence that should play an important role in the school's education curricula. Were this to happen, not only would students' grades improve but they would become more physically fit and healthier.

Based on the above discussion, this study seeks to answer the following research questions:

Research Questions

1. Will college students who engage in cardiovascular exercise demonstrate better recall and comprehension of recently learned information?
2. Will college students who engage in cardiovascular exercise *after* rehearsing the information demonstrate better recall and comprehension?
3. Will college students who engage in cardiovascular exercise *before* rehearsing the information demonstrate better recall and comprehension?
4. What level of cardiovascular exercise is necessary to improve information recall and comprehension?

CHAPTER 2

Literature Review

Chapter 2 describes the significant findings from previous research relating cognition, neurological functioning and/or academic achievement to (a) acute bouts of exercise, (b) regular exercise and (3) physical fitness level. As previously mentioned in chapter 1, acute bouts of exercise (Tomporowski, 2003) involve short segments of exercise lasting from ten minutes to two hours where cognitive tests are performed soon after or during the treatment. Regular exercise, via repeated training sessions that last several weeks or months is designed to specifically improve participants' physiological functioning (e.g., cardiorespiratory function, metabolism, muscular strength) (Willmore and Costill 2004). Then cognitive and/or academic achievements tests are administered to determine the effects of several weeks or months of training on the participants' cognitive functioning and academic achievement.

Several cross-sectional studies in this literature review had participants grouped into "high-fit" and "low-fit" categories according to their physical fitness level. The distinction between "high"- and "low"-fit participants was determined by their self-assessments, specifically, questionnaires regarding exercise recall or physical fitness tests, either administered by the researchers or as part of the schools' standard physical fitness test protocols (e.g., graded exercise test (GXT), progressive aerobic cardiovascular run (PACER), etc.).

In addition to fitness level, the participants also differed in age, from children to adults. The research varied with respect to specific cognitive, neurological, academic achievement, and exercise measures. For example, acute bouts of exercise included short segments of aerobic activity such as cycling and running at various intensities. Whereas, regular exercise measures included either participation in (a) physical education, (b) extracurricular physical activity, or (c) both. Among the different research studies, regular exercise differed in intensity, type and duration.

Acute Bouts of Cardiovascular Exercise and Cognition

This section reviews experimental studies on the effects of acute bouts of cardiovascular exercise on cognition. It is divided into four sub-sections based on the various measures included in the studies: (1) information processing; (2) physical fitness level, reaction time, and accuracy; (3) reaction time; and (4) reaction time and BDNF.

Information Processing

In 2003, Tomporowski conducted a review of experimental studies related to the effects of acute bouts of cardiovascular exercise on cognition, based on information processing (IP) theory. He explained that IP theory assumes that information is extracted from the environment and processed through a series of three non-overlapping stages, each operating independently of the others. The three stages include: (1) the stimulus-indentification stage, which involves a number of discrete processes through which sensory events are transformed and given meaning; (2) the response-selection stage, which is characterized by processes that determine what response, if any, will be made to an environmental event; and (3) the response-programming stage, which prepares the motor system for movement. For Tomporowski, IP theory provided a useful framework for reviewing research on the effects of exercise on various cognitive tasks.

Based on this framework, Tomporowski suggested that aerobic exercise improved the operation of specific stages of IP, including processes that are involved in complex problem-solving and attentional processes which are involved in response inhibition (the ability to block irrelevant information and select and respond to task relevant information). Tomporowski also reported that in previous studies, participants improved their speed, accuracy and creativity on various cognitive measures including (a) short-term memory, (b) alternate uses, (c) visual search, (d) choice discrimination, (e) mathematics computations, (f) perception task, (g) decision task and (h) response inhibition.

Improvement in cognitive functioning was found among studies involving submaximal aerobic exercise, whereas, intense levels of exercise using maximal anaerobic exercise protocols led to a decrease in cognitive functioning. One group of studies was based on the inverted-U hypothesis (also known as the "Yerkes and Dodson Law") (Yerkes and Dodson, 1908) which asserted that cognitive performance improves but then is followed by a decline in performance, as the level of exercise increases from less intense to more intense.

Five studies which were reviewed by Tomporowski demonstrated that participants' speed of responding and decision-making increased with increased demands from exercise, but that after a certain point was reached, intense exercise resulted in declines in performance. Reilly and Smith (1986) studied the effects of different exercise workloads on 10 young men's cognitive performance, where the participants cycled for 6 minutes against resistance loads that corresponded to 0%, 25%, 40%, 55%, 70% and 85% maximum oxygen volume uptake (VO2 max). The participants performed an arithmetic computation task during the latter part of each cycling bout and their performance improved with workloads between 25% and 70% VO2 max but their performance declined when they reached 85% VO2 max. This repeated measures design demonstrates that the participants improved their cognitive performance with increasing workloads up to 70% VO2 max, however, use of a control group to perform the same arithmetic tasks (in order to rule out practice effects) together with a larger sample size may increase support for the researchers' findings.

Other studies which were reviewed by Tomporowski involved "steady-state" exercise where the participants performed extended periods of exercise (i.e. 20 minutes to two hours) and performed cognitive tasks either during or shortly after exercising. Eleven of the studies reviewed indicate that aerobic-type exercise of moderate intensity, lasting between 20 to 60 minutes, influences cognitive functioning.

In Tomporowski's (2003) review, he stated, "It will be important for researchers to identify specific parameters of aerobic activity that facilitate cognitive function. Demonstrating that relatively short bouts of submaximal (i.e., 20 – 60 minutes) exercise have salutary effects on information processing and cognition has direct application to those involved in promoting educational and work environments conducive to optimal performance. Very little is known, for example, of the impact of periods of physical activity on students' class attention and academic performance." (p. 315).

In 2008, Tomporoski conducted a review of studies on exercise, cognition and academic achievement and concluded that there is a lack of agreement among the research findings due to the following reasons. First, researchers may not have selected the proper cognitive measures to determine the effects of exercise and mental functioning. Global assessments of academic achievement may be too broad to determine the effects of exercise. In contrast, specific measures of cognitive functioning, such as executive function, provided more information on the effects of exercise. Second, certain types of exercise training may facilitate cognitive functioning more than others. Studies that involved aerobic activities were shown to positively effect cognition, whereas, other types of training, such as, balance and coordination training, perceptual-motor training or strength training produced mixed results. Third, there are substantial differences among samples of participants in the studies reviewed and the effect of an exercise intervention may depend on age, and thus developmental level of the participants.

In addition to the limitations of the reviewed experiments, the use of IP theory is not without its' shortcomings. Schunk (2004) described four assumptions of IP as (a) being less concerned with external conditions and focused more on the internal or mental processes which intervene between stimuli and responses, (b) occurring in stages which intervene between receiving a stimulus and producing a response, (c) analogous to a computer, where individuals receive information, store it in their memory and then retrieve it when needed and (d) being involved in all cognitive activities (i.e. perceiving, rehearsing, thinking, problem solving, remembering, forgetting, and imaging). The stage-like assumptions of IP and IP may be too limited in its scope to explain the complexities of the internal and external effects on cognition and metacognition.

Physical Fitness Level, Reaction Time and Accuracy

A study by Heckler and Croce in 1992 tested groups of women with varying levels of cardiorespiratory fitness. The participants performed addition and subtraction computations (a) at rest, (b) following a 20-minute run, and (c) following a 40-minute run. The problem-solving tasks were administered immediately, five minutes after each, and 15 minutes after each run. The results showed that with exercise, problem-solving speed increased while accuracy remained the same. “High-fit” women’s speed of problem-solving improved following 20 minute runs and 40 minute runs, whereas, “low-fit” women’s speed of problem solving improved only following a 20 minute run. The significance of this is that an individual’s fitness level play’s a role with respect to the potential benefits that exercise has on cognition.

Reaction Time

A study conducted by Lichtman and Poser (1983) evaluated the effects of an aerobic jogging program on young adults’ Stroop task performance. As described in chapter 1, the Stroop task measures the participants’ reaction time. When this task has words such as blue, green, red, etc., printed in a color which is different from the color expressed by the word's semantic value (e.g. the word "red" printed in blue ink), and naming the color of the word takes longer and participants are more likely to make errors than when the meaning of the word is congruent with its ink color. In this study, 64 students were randomly assigned to participate in an aerobic exercise program or a hobby class. Then the Stroop task was administered to a subgroup of 10 students in each group. The participants performed the word naming, color naming and color-word portions of the Stroop task prior to, and immediately following, exercise activities or hobby activities. The two groups did not differ in the number of items named during the pre-test. However, the participants in the exercise group named significantly more color names and color-word names than the participants of the hobby activity group.

Reaction Time and BDNF

Ferris et al. (2006) conducted a study on the effects of acute exercise on blood serum brain-derived neurotrophic factor (BDNF) levels and cognition. As described in chapter 1, BDNF is a type of neurotrophin (proteins that been identified as mediators of neuronal survival and differentiation during development, Ploughman, 2008). BDNF is produced in the brain and has been shown to increase with exercise. BDNF has been found to be associated with long-term potentiation (LTP), a neural analogue of long-term memory formation, and for the growth and survival of new neurons. BDNF has been associated with enhanced learning and memory processes that are associated with exercise treatments in rodent laboratory testings (Vaynam, S. et. al, 2004).

In Ferris' study, 15 physically active participants were given a graded exercise test (GXT) on a stationary bicycle to determine the work rate that corresponded to their target intensity on two 30-minute endurance cycle tests. The cycle tests were administered at random to the participants where on one test, the participant would cycle at either a high intensity or low intensity. Then the participants were administered the Stroop color and word pre- and posttests and their blood serum was taken both pre- and posttest in order to test their BDNF levels. The participants repeated the experiment a second time, where they would cycle at the opposite intensity as they did on the first test. The results revealed that BDNF level is positively associated with exercise intensity. That is, the higher intensity exercise test yielded a higher BDNF blood serum level. The participants' responses on the Stroop color and word test scores increased after exercise after engaging in high intensity exercise (Ferris et al., 2006). This study focused on low- and high-levels of exercise. It is unknown whether or not the participants would have scored as well if a moderate level of exercise was tested. The next section describes the research on the relationship between participants' overall physical fitness level and their performance on cognitive tasks where there is no exercise intervention.

Physical Fitness Level, Cognition and Neurological Function

In 2005, Buck et al. conducted a cross-sectional study of 24 children, preadolescents, and adults, where participants' physical fitness level was assessed by the FITNESSGRAM test (Welk, Morrow, & Falls, 2002) and were grouped into four categories according to their fitness level and age (i.e., "high-fit" children, "low-fit" children, "high-fit" adults, and "low-fit adults). The FITNESSGRAM test measures multiple aspects of physical fitness, including (a) aerobic capacity (i.e., the PACER (progressive aerobic cardiovascular run)), (b) muscle fitness (i.e., push-ups and curl-ups), (c) flexibility fitness (i.e., sit and reach test) and (d) BMI. The purpose of Buck's study was to determine whether or not a high level of fitness was associated with better cognitive performance and a superior neuroelectric profile, as measured by the visual discrimination "oddball" task and ERP.

The participants were given the "oddball" task which presented two stimuli with varying probability in a random series, one of which occurred frequently (i.e., 80% probability), the other, relatively infrequently (i.e., 20% probability). The participants were required to distinguish between the stimuli (i.e., black and white drawing of a cat and dog) and to respond to the infrequent (i.e., dog) stimulus via a button press and were instructed not to respond to the frequent stimulus (i.e., cat). Concurrently, their ERP, P3 amplitude and latency was tested using EEG recordings.

The results demonstrated that “high-fit” children and adults had greater P3 amplitude and latency, which are associated with attention and working memory. Based on the responses to the “oddball” task, “high-fit” participants demonstrated faster cognitive processing speed and response accuracy relative to “low-fit” participants.

Since Buck et al.’s (2005) study was correlational, causality cannot be determined between physical fitness level and cognitive performance. Further, a larger sample size could have strengthened their findings.

In 2006, Hillman et al. performed a cross-sectional study of participants between 15 and 71 years of age to examine the relationship between exercise and executive control. Engagement in exercise was assessed through a categorical “sweat index” ranging from 0 to 4. Participants were asked “Are you at least once a week sufficiently physically active to start sweating?” If the participant answered “yes,” he or she was then asked to indicate the approximate number of times per week this occurred, either: “once a week,” “twice a week,” “three times a week” or “four or more times a week”.

As previously described in chapter 1, executive control refers to a subset of goal-directed processes that include the selection, scheduling, and coordination of cognitive processes that are involved in perception, memory and action (Meyer and Kieras 1997; Norman and Shallice, 1986). Executive control has also been described as involving response inhibition, planning and working memory (Chodzko-Zajko and Moore 1994). Executive control functions are involved in the planning and selection of strategies that organize goal-directed actions (Das et al. 1994). In Hillman’s 2006 study, executive control was measured by the Eriksen-flanker test (Eriksen & Eriksen, 1974). The Eriksen-flanker test involves responding as quickly as possible to an array of stimuli presented on a computer monitor from a distance. The target stimulus (< and >) required participants to press a button with their right and left thumbs, respectively. Congruent trials appeared as <<<<< or >>>> and incongruent trials appeared as <<><< or <<><<<. The four conditions were administered with 30 trials for each condition. Other measures which were recorded include (a) age, (b) height and weight and (c) IQ scores (WAIS III).

The results of Hillman's 2006 study showed that exercise was negatively associated with reaction time and positively associated with response accuracy for both the congruent and incongruent conditions of the flanker test. Further, the study's findings indicated that exercise was more strongly related to performance during task conditions requiring greater amounts of interference control (i.e., incongruent trials).

Similarly in 2009, Hillman et al. conducted cross-sectional research on higher- and lower-fit participants, using children between the ages of 8 and 11 to determine the relationship between aerobic fitness and executive control. Aerobic fitness levels were measured by the Progressive Aerobic Cardiovascular Run (PACER) test of the FITNESSGRAM (Welk, Morrow, & Falls, 2002). The objective of the PACER test is to run as long as possible back and forth across a 20 meter space at a specified pace, which increased in speed each minute. Neurological techniques were used to test the ERP measures, P3 and ERN. Other baseline measures which were recorded include (a) age, (b) BMI, (c) Intelligence Quotient (IQ) scores, (d) socioeconomic status (SES) and (e) attention deficit and hyperactivity disorder (ADHD).

Similar to Hillman's 2006 study, Hillman (2009) administered the Eriksen-flanker test to measure participants' executive control. In Hillman's 2009 study, the Eriksen-flanker test involved the target stimulus (H and S) and required participants to press a button with their right and left thumbs, respectively. Congruent trials appeared as HHHHHH or SSSS and incongruent trials appeared as HHSHH or SSHSSS. The two conditions were administered at random. Six blocks of 52 trials were administered with a 2-minute rest period between blocks. The participants were engaged in the task for 20 minutes including practice trials and completion of the task. The neuroelectric index, ERP was measured by EEG during the task performance.

In Hillman's 2009 study, the results indicated that across the various flanker task conditions (a) "higher-fit" children performed more accurately than for the "lower-fit" children, (b) P3 amplitude was larger for the "higher-fit" children than for the "lower-fit" children and (c) "higher-fit" children exhibited reduced ERN amplitude and increased error positivity. Hillman asserted that these findings suggest that fitness level is related to achieving better cognitive performance on an executive control task through increased cognitive control, having better attention during stimulus encoding and achieving a subsequent reduction in conflict during response selection. The next section discusses how regular exercise and physical fitness level affect academic achievement.

Regular Physical Activity

This section reviews the research on the relationship between regular physical activity, academic achievement and (a) physical fitness level, (b) college students, (c) children, (d) physical education, (e) extracurricular physical activity, (f) physical education and extracurricular activity and (g) lifestyle.

Physical Fitness Level and Academic Achievement

In 1997, Symons provided a review of correlational studies of exercise and academic achievement which suggested that exercise is associated with increased concentration and improved mathematics, reading, and writing scores. The measures used in connection with these findings included: (a) graduation rates, (b) class grades, (c) performance on standardized tests and (d) attendance rates.

In a similar study to the Symons' study (1997), Taras (2005) provided a review of 14 research studies on academic achievement and physical activity. Taras' review of studies demonstrated that short-term cognitive improvements may result from physical activity. However, the review of studies did not demonstrate that engaging in more vigorous exercise led to achieving long-term improvement with respect to academic achievement. Eight studies compared reports on exercise levels with reported academic achievement. The remaining six studies addressed the impact of physical education programs, sports or other extracurricular physical activities on academic achievement. However, for the most part, Taras concluded that, "the studies showed either significant but weak associations between activity level and better academic performance or no correlation at all. It is difficult to know if the association is causal and if so, the direction of the cause-effect." (p. 215) Taras added that, "Relatively few studies have explored the relationship between physical activity and academic outcome, and more investigation is warranted before researchers can better understand the effect of physical activity on student performance." (p. 216)

Academic Performance among College Students

Irandoust and Karlsson's 2002 correlational study of 161 Swedish undergraduate university students and their learning strategies and academic success, explored how individual preferences (e.g. the amount of time spent on physical training and on studying) affect student performance. Irandoust and Karlsson found that a student's academic performance depends on (a) the time spent in a physical activity, (b) the courses chosen by the student, and (c) the studying of previously given examinations (as a learning strategy).

The above study included the students' (a) study techniques (e.g., studying from previously given exams), (b) interest in the course, (c) grade point average, (d) number of hours spent involved in physical activity and (e) amount of time spent studying per week. Irandoust and Karlsson hypothesized that physical activity increases academic performance since it promotes concentration, ability, and well-being. In previous studies, the researchers Svarto and Sjostrom (as cited in Irandoust and Karlsson) had also hypothesized that the above factors affected academic performance and found that the number of hours spent on physical training per week is related to academic performance. The findings of Irandoust and Karlsson's study revealed a positive linear relationship between academic performance and the number of hours spent on physical activity per week. They noted that there is a positive relation between physical activity and academic performance for up to six hours per week. However, when physical activity increases beyond six hours per week, the effect becomes negative.

Irandoust and Karlsson's study demonstrates the importance of physical activity as a method of improving academic achievement. However, this was a correlational study, based on self-reported physical activity, and the study did not specify the type or intensity level of the chosen physical activity.

Academic Performance among School Children

A cross-sectional study among diverse, urban public school children, using the Massachusetts Comprehensive Assessment System (MCAS) test and physical activity was conducted by Chomitz et al. (2009) to determine the relationship between physical fitness level and academic achievement. The MCAS consists of two standardized tests: one for math and one for English and language arts. In this study, the scores for the MCAS were described as, (1) advanced, (2) proficient, (3) needs improvement, and (4) warning. Scores ranging from 1 – 3 were considered passing while a score of 4 was considered failing.

In the Chomitz et al (2009) study, physical fitness was measured by a fitness test with five domains adapted from the Amateur Athletic Union (AAU) and the Fitnessgram test. The five domains included (a) a cardiovascular endurance test, (b) an abdominal strength test, (c) a flexibility test, (d) an upper body strength test and (e) an agility test. The students who completed the physical fitness tests earned a score of either (1) “participant,” (2) “attainment,” or (3) “outstanding”. A student that earned a score of “participant” completed the test but did not achieve the criterion for passing the test. Whereas, a student that earned a score of “attainment” or “outstanding”, met or exceeded the criterion for passing the test. Overall, the results of the study demonstrated a significant positive relationship between physical fitness level and academic achievement. Further, students’ physical fitness level was more strongly associated with Math achievement than English achievement scores.

Chomitz et al. (2009) offered five plausible hypotheses as to why students with higher physical fitness levels also achieved higher academic achievement scores.

First they asserted that a “relationship between fitness and academic achievement may reflect the achievement orientation of motivated students.” Second, they asserted that “a student’s physical fitness may reflect better overall health - better nutrition, physical activity, and/or weight status – and good health may contribute positively to academic achievement.” Third, they stated that, “physical activity and fitness may enhance students’ concentration and classroom behavior in school, which may contribute positively to academic achievement.” Fourth, they asserted that, “physical activity may improve mental health and self-esteem.” Finally, they concluded that “exercise and fitness may affect brain function and improve cognitive functioning.” (p. 35). Any or all of these hypotheses may help to explain how being physically fit improves cognitive functioning and academic achievement. As in Chomitz et al.’s (2009) study, the first four hypotheses lend themselves to correlational studies. Whereas, the fifth hypothesis that, “exercise and fitness may affect brain function and improve cognitive function” can be the theoretical basis for an experimental study.

Yu, et al.’s (2006) study of physical activity and academic performance found there was no relationship between them. The participants in this study were 333 randomly selected Chinese pre-adolescents between the ages of 8 and 12 in Hong Kong. These students were from low to middle income families. The students’ academic performance was measured by their test results and their classroom behavior was measured by their teachers. Physical activity was measured by the *Physical activity questionnaire for older children* (PAQ – C) (Crocker *et al*., 1997). The PAQ – C is a self-administered seven-day recall questionnaire designed to assess habitual moderate to vigorous physical activity in children older than the third-grade level. The PAQ – C consists of nine questions which included an activity checklist consisting of common physical activities and games, and questions related to assessing physical activity level in physical education classes, at lunchtime, after school, in the evenings and during weekends.

The results of Yu et al.'s (2006) study showed no correlation between the level of physical activity and academic achievement. As with the previous studies in this literature review, this study was a cross-sectional design, which limits the findings to correlational relationships. It is also important to take into account cultural differences between students in the United States and students in Hong Kong. In Hong Kong, academic achievement is emphasized above other achievements and finding that engaging in physical activity does not decrease academic achievement can be of importance for schools and parents.

There may be other cultural differences for why there is no positive relationship between physical activity and academic achievement among students in Hong Kong. Yu et al.'s study revealed no gender differences with respect to the amounts of physical activity that the students engaged in. This study further revealed that female students did not have higher self-esteem than male students even when they had higher academic achievement than the boys. However, the male students demonstrated higher self-esteem when they had higher academic achievement and when they had greater engagement in physical activity.

Physical Education and Academic Achievement

In a similar study to Chomitz et al. (2009), Tremarche, et al. (2007) conducted a cross-sectional study on the relationship between students' test scores on the MCAS and the number of hours of physical education (PE). This study included 293 fourth-grade students from two large schools located in southeastern Massachusetts. The two schools reported similar physical education curricula but differed in the amount of time they each allotted for students' physical education. School 1 provided students with 28 hours of physical education each year, whereas school 2 provided students with 56 hours of physical education each year. The researchers surveyed the students' level and frequency of physical activity outside of the schools' physical education curricula and the number of hours that students received tutoring to control for tutoring as a possible intervening variable.

The results of this study demonstrated that the students from school 2 scored significantly higher on the English and liberal arts test (61%) as compared to school 1 (43%). The students from school 2 also performed better on the math test than school 1, but the difference between the two math scores was not found to be significant. There were no significant differences found between (a) the students' reported level and frequency of physical activity outside of the physical education curriculum and (b) the number of hours that the students received tutoring. The researchers concluded that time spent in PE was positively correlated with "certain" components (i.e. English and liberal arts test) of the MCAS test.

Tremarche's et. al. (2009) correlational study was not without its limitations. For example, the study relied only on student-reported measures of the level and frequency of their physical activity outside of PE. A second limitation was that examining the differences between students two different schools may not have adequately accounted for intervening variables which were not controlled for in the study. Indeed, Tremarche and his colleagues recognized this limitation, and they recommended that a future experiment be conducted in which the students within one class, (within one school), receive extra hours of physical education or exercise before and during the MCAS testing periods, while another class, (within the same school), does not receive any PE.

Extracurricular Physical Activity and Academic Achievement

Somerset (2007), compared the relationship between sixth grade students' extracurricular physical activities (i.e., outside of PE) with their students' grades in math, English, science, and world studies and standardized academic tests. The results of the study demonstrated that the students' involvement in vigorous physical activity correlated with their achievement of higher academic scores. That is, students who self-reported engaging in vigorous activity outside of school for at least 20 minutes per day, three times per week, were found to have higher academic scores than those who did not. The study provided evidence that there is a positive correlation between physical activity and academic achievement. However, Somerset noted that a "causal relationship between physical activity and academic achievement remains uncertain." (p. 11).

PE, Extracurricular Physical Activity, and Academic Achievement

Stevens' et al. (2008) study examined the relationship between academic achievement (i.e., math and reading scores), physical activity and PE. Physical activity and PE were selected as separate variables based on the assumption that physical education classes may not provide students with an environment to which vigorous prolonged physical activity is possible (Crews, Lochbaum, and Landers 2004).

In the study, physical activity was assessed by asking the parents of third grade students' three questions. The first item asked parents to rate their child's frequency of aerobic activity on a consistent basis in comparison to other children the same age (i.e., 3 = more aerobic activity, 2 = the same aerobic activity and 1 = less aerobic activity). In this study, aerobic activity was defined at "exercise that makes the heart work very hard and makes people break out in a sweat" (p. 374). The second item asked parents, to disclose, how many days in a typical week their child engages in exercise that causes rapid breathing, perspiration, and rapid heartbeat for 20 continuous minutes or more. Third, parents were asked whether their child was engaged in regular exercise through sports teams or leagues.

The students' PE was measured by questioning school administrators on how many times each week students have physical education. The students' achievement in mathematics and reading were measured by standardized test scores. The results of the study showed that engaging in extracurricular physical activity was more positively correlated with math and reading achievement than was participation in PE (Stevens et al. 2008).

However, one limitation of this correlational study was relying only on parent-reported measures of the frequency and intensity of their children's physical activity. A second limitation was not providing specific information about the school's PE program by simply asking school administrators how often students have PE. Specific information of the PE program would include a description of the type and level PE activities and the methods in which the students were physical fitness were assessed.

Similar to Stevens et. al (2008), the American College of Sports Medicine (2006) had conducted a study of 214 middle school-aged students to determine the effects of physical education class participation and overall physical activity and academic achievement. The students were randomly assigned to a physical education course for one semester and researchers measured the students' physical activity in and out of school in 30-minute time blocks. The researchers then compared the students' physical activity levels with grades in English, world studies, science, and mathematics.

The study's results demonstrated that students' participation in physical education was positively related to higher grades, in the above mentioned areas. The results also indicated that students who participated in sports or vigorous activity for at least 30 minutes, three times per week, had the highest grades. The strengths of this study included the randomization of students into one of two conditions (i.e., physical education and no physical education) and having an adequate sample size of 214. However, the researchers did not have control over the students' physical activities, nor did they have control over the grading criteria used to measure academic achievement. Finally, the study could not demonstrate a causal link that participation in sports or other vigorous physical activity directly improves students' grades because other uncontrolled factors, such as student motivation and parental involvement, may have affected the study's findings.

Similar to the American College of Sports Medicine (2006) study, Coe, et al. (2006) conducted a study on the effects of PE class enrollment and physical activity on academic achievement in middle school children. The study involved 214 sixth-grade students who were randomly assigned to either PE or a non-PE course during their first semester of the school year. During the second semester, students who had been assigned to PE in the first semester, were assigned a non-PE course and those students had been assigned a non-PE course in the first semester, were assigned to a PE course. The students were given a three-day physical activity recall test to assess their usual participation in moderate (i.e., active recreation, such as hiking, skateboarding, rollerblading, bicycle riding, brisk walking, etc.) and vigorous (i.e., active games involving running and chasing, such as tag, bicycle riding, jumping rope, martial arts, such as karate, running, sports such as soccer, ice or field hockey, basketball, swimming, tennis, cross-country skiing, etc.) extracurricular physical activity. Academic achievement was assessed from academic classes and standardized test scores.

The results of Coe's, et al. (2006) study indicated that there was no significant difference in the students' academic achievement when students were either enrolled or not enrolled in physical education. However, the study indicated that the students who engaged in vigorous physical activity had significantly higher grades than those students who did not participate in vigorous physical activity. In contrast, there was no significant difference in the students' academic achievement with respect to engagement in moderate physical activity. Although the students were randomly assigned into physical education classes, the correlational analyses of self-reported physical activity and grades did not address the issue of causality. The following section discusses the relationship between academic achievement and student lifestyle measures.

Academic Achievement and Lifestyle

In 2007, Sigfusdottir, et al. examined the relationship between various health behaviors and academic achievement among 5810, Icelandic students between 14 and 15 years of age. The data for that study was taken from the 2000 Icelandic study, *Youth in Iceland*. The health behavior measures included (a) BMI, (b) diet, (c) physical activity, (d) depressed mood, and (e) self-esteem. Other measures, including parental education were also assessed.

Academic achievement was assessed by the students' self-reported average grades in mathematics, English and one of Danish, Swedish or Norwegian. BMI was measured by students' self-reported heights and weights. Students answered questions on how often they ate (a) sweets, (b) crisps (i.e., chips), (c) French fries, (d) hamburgers or hotdogs and (e) pizza. The students were also asked how often they ate (a) fruits, (b) vegetables or (c) both.

In Sigfusdottir's, et al study, physical activity was assessed by students' responses to four questions: (1) "How often do you participate in sports of physical activity apart from the compulsory classes in school?"; (2) "How often do you participate in sports with a sports club or team?"; (3) "How often do you participate or train in sports that are neither organized by your school nor a sports club/team?" and (4) "How often do you physically test yourself so you wind yourself significantly or sweat?". The choices of responses were 1 = "almost never"; 2 = "less than once a week"; 3 = "once a week"; 4 = "2 – 3 times a week; 5 = "4 – 5 times a week; and 6 = "almost every day".

The results of Sigfusdottir's et al. (2007) study showed that BMI was most strongly associated with academic achievement, followed by diet and then, physical activity. Among the other variables that were tested, parental education was found to be highly, positively correlated with students' academic achievement. This correlational study relied solely on the students' self-reported grades, height, weight, food intake, and participation in physical activity. Therefore, the study could not address causality between the effects of physical activity and academic achievement.

In 2009, Kristjansson et al. conducted a similar study to the Sigfusdottir study on the relationship between sedentary lifestyle, physical activity, BMI, academic achievement and school contentment (i.e., "To capture how content the adolescents generally were in their schools" p. 72). The purpose of that study was to determine the extent to which students' sedentary lifestyle, physical activity and BMI, contribute to academic achievement and school contentment. The data for that study was also taken from the 2000 Icelandic study, *Youth in Iceland,* which included Islandic students 14 and 15 years old.

In that study, physical activity was measured by students' self-reported answers to three questions: (1) "How often do you participate in sports in school outside the compulsory lessons?"; (2) "How often do you participate in sports with a sports club or a team?"; and (3) How often do you physically test yourself so you wind yourself significantly or sweat?". In addition to self-reported physical activity, students participated in compulsory physical activity lessons in Iceland once per week (Krisjansson et al., 2009).

In the study, sedentary lifestyle was assessed by questioning students on the amount of time they spent watching “videotapes”. More specifically, the students responded to three questions: (1) “How many hours do you usually spend on Saturdays watching videotapes?”; (2) “How many hours do you usually spend on Sundays watching videotapes?”; and (3) “How many hours do you usually spend on working days watching videotapes?”.

Academic achievement was assessed by the students’ self-reported average grades in mathematics, English and one of Danish, Swedish or Norwegian. School contentment was assessed by the students’ responses to the statements: (1) “I want to quit school”; (2) “I want to switch schools”; and (3) I feel bad at school”.

The results of Krisjansson and colleagues’ correlational study revealed a positive relationship between physical activity and academic achievement and also between school contentment and academic achievement. However, the study also revealed a negative relationship between a higher BMI, a sedentary lifestyle on the one hand, and school contentment and academic achievement, on the other.

Kritjansson’s et al. (2009) research is another example of a correlational study, based on cross-sectional data from students’ self-reported academic achievement, school contentment, BMI, physical activity and sedentary lifestyle. Therefore, as with the other studies discussed thus far, a causal relationship could not be determined. The study also had several other limitations. For example, the measures used to assess physical activity and sedentary lifestyle did not require the students or the researchers to monitor and record the students' actual behaviors. Rather, the students were given three questions to answer which meant that they would have had to have an accurate recall of how often they engage in physical activity or watch videotapes. Furthermore, students' participation in "physical activity" is not limited to sport activities, which was the emphasis of the physical activity questions. Also, it is questionable to measure sedentary lifestyle by a limited inquiry on how many hours are spent to watching videotapes. Further research, with measures of greater validity, is needed to more accurately assess the relationship between physical activity and academic achievement. The following section provides a synthesis of the research studies described in this chapter.

Synthesis

Chapter 2 described the significant findings from previous research relating cognition, academic achievement and/or neurological functioning to (a) acute bouts of cardiovascular exercise, (b) regular exercise, and/or (c) physical fitness level.

Chapter 2 began with Tomporowski's (2003) review of experimental studies related to the effects of acute bouts of cardiovascular exercise on cognition, based on IP theory. From this review, he suggested that aerobic exercise improved the operation of specific stages of IP, including processes that are involved in complex problem-solving and attentional processes that are involved in response inhibition. Tomporowski also reported that in previous studies, participants who engaged in aerobic exercise improved their speed, accuracy and creativity on various cognitive measures. Further, five studies reviewed by Tomporowski demonstrated that the participants' response time and decision-making improved with increased demands from exercise, up to a certain point, after which continued intense exercise then resulted in declining performance. Overall, the 11 studies, which were reviewed, indicated that aerobic-type exercise of moderate intensity (lasting 20 to 60 minutes) increased cognitive functioning.

In Tomporowski's (2003) review, he stated, "It will be important for researchers to identify specific parameters of aerobic activity that facilitate cognitive function. Demonstrating that relatively short bouts of submaximal (i.e., 20 – 60 minutes) exercise have salutary effects on information processing and cognition has direct application to those involved in promoting educational and work environments conducive to optimal performance. Very little is known, for example, of the impact of periods of physical activity on students' class attention and academic performance" (p. 315).

In 2008, Tomporoski's conducted a review of studies on exercise, cognition and academic achievement and concluded that there is a lack of agreement among the research findings due to the following reasons. First, he explained that researchers may not have selected the proper cognitive measures to determine the effects of exercise and mental functioning. Global assessments of academic achievement may be too broad to determine the effects of exercise. In contrast, specific measures of cognitive functioning, such as executive function, provided more information on the effects of exercise. Second, certain types of exercise training may facilitate cognitive functioning more than others. Studies that involved aerobic activities were shown to positively effect cognition, whereas, other types of training, such as, balance and coordination training, perceptual-motor training or strength training produced mixed results. Third, there were substantial differences among samples of participants in the studies reviewed and the effect of an exercise intervention may depend on age, and thus developmental level of the participants.

IP theory is not without its shortcomings. For example, cognitive processing may be more complex than the stage-like assumptions of IP theory. Also, IP theory may be too limited in its scope to explain the complexities of the internal and external effects on cognition and metacognition.

Overall, the limitations of the several experimental studies which have been conducted on exercise and cognition included (a) lack of a control group, (b) small sample size and (c) mixed results. In one example of mixed results involving changes in response accuracy, one study revealed improvement in response accuracy when the participants engaged in exercise (Lichtman and Poser, 1983). By contrast, another study showed no improvement in response accuracy when the participants engaged in exercise (Heckler and Croce, 1992). These studies differed in the cognitive tests selected (i.e., the Stroop task versus an addition and subtraction computation task), and the level of precise measurements for the jogging treatment condition (i.e., jogging class versus participants jogging at various specified VO2 levels).

The cross-sectional studies reviewed in this literature review had participants grouped into “high-fit” and “low-fit” categories according to their physical fitness level. The distinction between “high”- and “low”-fit participants was determined by their self-assessments, specifically, questionnaires regarding exercise recall or physical fitness tests, either administered by the researchers or as part of the schools’ standard physical fitness test protocols (e.g., graded exercise test (GXT), progressive aerobic cardiovascular run (PACER), etc.).

In addition to fitness level, the participants in the cross-sectional studies reviewed in this literature review also differed in age, from children to adults. The research varied with respect to the measures tested, including, specific cognitive, neurological, academic achievement, and exercise measures. For example, acute bouts of exercise included short segments of aerobic activity such as cycling and running at various intensities. Whereas, regular exercise measures included either participation in (a) physical education, (b) extracurricular physical activity, or (c) both. Among the different research studies, regular exercise differed in intensity, type and duration.

The cognitive measures which were tested in correlational studies, examined differences in students' level of fitness (i.e., "high-fit" versus "low-fit") included the Stroop color and word test, the "oddball" visual discrimination task and the Eriksen-flanker test. The neurological measures that were tested included ERP and BDNF. The results of these studies indicated that "higher-fit" students had faster cognitive processing speed, better executive control (i.e., cognitive control, attention during stimulus encoding and a reduction in conflict during response selection), faster reaction time and better response accuracy, than "lower-fit" students. "Higher-fit" students demonstrated higher P3 amplitude and BDNF serum levels than "lower-fit" students. Further, exercise level was more strongly related to performance during task conditions requiring greater amounts of interference control (e.g., incongruent trials on the Eriksen-flanker task).

The correlational studies on physical fitness level and cognition could not demonstrate causality between physical activity and cognition. By categorizing students into "high-fit" and "low-fit" levels of fitness, it is unknown whether or not the correlations would be different if a moderate level of physical fitness was included. Also, the cognitive measures tested did not include actual academic measures to assess the potential effects of exercise on academic achievement.

Taras (2005) provided a review of 14 research studies on academic achievement and physical activity. Taras' review of studies demonstrated short-term cognitive improvements may result from physical activity. However, the review of studies did not demonstrate that engaging in more vigorous exercise led to achieving long-term improvement with respect to academic achievement. Taras concluded that, "the studies showed either significant but weak associations between activity level and better academic performance or no correlation at all. It is difficult to know if the association is causal and if so, the direction of the cause-effect" (p. 215). Taras added that, "Relatively few studies have explored the relationship between physical activity and academic outcome, and more investigation is warranted before researchers can better understand the effect of physical activity on student performance" (p. 216).

Irandoust and Karlsson's (2002) reported that the amount of time that college students spent on physical training and studying affects their performance. Irandoust and Karlsson demonstrated that a positive linear relationship exists between academic performance and the number of hours spent on physical activity per week. They noted that there is a positive relation between physical activity and academic performance for up to six hours per week. However when the time spent in a physical activity increases beyond six hours per week, the relationship becomes negative. Irandoust and Karlsson hypothesized that engaging in physical activity increases academic performance since it promotes concentration, ability, and well-being.

Stevens' et al. (2008) and Coe's et al. (2006) studies treated physical activity and physical education courses as separate variables. There reasoned that physical education classes may not provide students with an environment in which vigorous, prolonged physical activity is possible (Crews, Lochbaum, and Landers 2004).

Conversely, another study relied on the amount of time that students spent in physical education class as the measure of physical activity and demonstrated that more time spent in physical education class was positively related to significantly higher on English and liberal arts test scores but did not lead to significantly higher math test scores (Tremarche, et al., 2007).

Other related findings from these descriptive retrospective studies were that BMI was most strongly associated with academic achievement, followed by diet and exercise. Chomitz's, et al. (2009) study demonstrated a positive relationship between physical activity and school contentment and academic achievement.

Overall, Somerset stated that a "causal relationship between physical activity and academic achievement remains uncertain" (p. 11). Much of the research on physical activity, physical fitness level and academic achievement were correlational studies which were based on self-reported exercise measures and which lacked specific information such as the type or intensity of the chosen physical activity.

The prior research described in chapters 1 and 2 provides evidence that engaging in exercise promotes neurological activity and cognitive improvements with respect to various cognitive tasks and academic achievement measures. This dissertation is based, in part, on existing cognitive and neurological evidence, which indicates that engaging in exercise improves cognitive capabilities, by increasing neural functioning which improves learning (cognitive development). Much of the prior research has focused either on exercise and cognitive measures, or on exercise and academic achievement. The experimental studies which focused on exercise and cognition, involved participants engaged in acute bouts of cardiovascular exercise followed by cognitive and/or neurological tests (e.g. Eriksen-flanker test, Stroop task, etc.) which were performed during or soon after the treatment. Whereas, the correlational studies which focused on exercise and academic achievement, involved participants who reported engagement in regular physical activity and their academic achievement (e.g. grades, standardized achievement tests, etc.). The following section describes the rationale for the proposed study.

Rationale for Current Study

Both prior experimental and correlational research on the effects of exercise on cognition have focused on general cognitive outcomes (i.e., test scores and responses on cognitive tests). The issue of the causal direction of cardiovascular exercise on the proactive and reactive learning process has received little attention to date. From a social cognitive theoretical perspective, a key issue in self-regulating one's learning effectively is the issue of causal direction of exercise. To use exercise as a strategy for learning, it is important to know if engagement in exercise *before* learning has a proactive effect on cognition and/or if exercise *after* learning has a reactive effect on cognition. The proposed research described in this dissertation is an experimental study that focuses on the effectiveness of exercise on cognitive learning and performance, using authentic measures of academic performance such as students' recall and comprehension of recently learned information.

More specifically, this dissertation explores the forward (i.e., proactive) and backward (i.e., reactive) effects of cardiovascular exercise on students' ability to recall and comprehend recently learned information, and the level of exercise needed to enhance cognitive performance. Whereas, examining the forward effect of answers the question "does exercise increase learning?" The backward effect of answers is assessed by the question, "if you already learned something, does engaging in exercise help you to retrieve the previously learned information?" In other words, the forward effect (i.e., sequence B) is proactive, which prepares the mind for future learning. The backward effect (i.e., sequence A) is retroactive and seeks to preserve learning traces and the accessibility of previously learned information. This dissertation seeks to provide new research findings on the forward and backward effects of exercise on cognition, which has not been adequately examined in the previous literature.

By examining the forward and backward effects of cardiovascular exercise on cognitive recall and comprehension, I can determine whether or not (a) cardiovascular exercise increases cognitive recall and comprehension and (b) there is a difference in cognitive recall and comprehension abilities when engaging in cardiovascular exercise *before* learning occurs (i.e., forward effect) as opposed to *after* learning occurs (i.e., backward effect). Whereas, the prior research focused on high and low levels of physical activity, this dissertation seeks to determine the effects of moderate and light exercise on cognitive recall and comprehension.

Prior research has focused on vigorous exercise in order to increase physical fitness and students' cognitive performance. However, if there were evidence to suggest that engaging in light to moderate exercise significantly increases students' ability to retain or acquire and comprehend information, this information could be used to benefit students who are not yet physically fit to engage in vigorous exercise.

If it were demonstrated that by engaging in increased levels of exercise, at optimal times (i.e., before or after learning), students can significantly improve their academic achievement, then this self-regulatory outcome would be greatly appreciated by both parents and school staff members and school administrators would have important evidence that should play an important role in the school's education curricula. Were this to happen, not only would students' grades improve but they would become more physically fit and healthier.

Based on the above rationale, this study proposes the following four hypotheses:

Hypotheses

1. There will be a significant linear trend between students' engagement in cardiovascular exercise *before* learning and their *recall* of recently learned information (Sequence A).
2. There will be a significant linear trend between students' engagement in cardiovascular exercise *after* learning and their *recall* of recently learned information (Sequence B).
3. There will be a significant linear trend between students' engagement in cardiovascular exercise *before* learning and their *comprehension* of recently learned information (Sequence A).
4. There will be a significant linear trend between students' engagement in cardiovascular exercise *after* learning and their *comprehension* of recently learned information (Sequence B).

CHAPTER 3

Methodology

This chapter describes the methodology of this study which was to examine whether or not a cardiovascular exercise intervention improved students' recall and comprehension of recently learned information. The cardiovascular exercise intervention included two levels: moderate and light exercise. Recall and comprehension was tested at the same time and scored as a separate *recall* score and *comprehension* score for each student. The rehearsal of information (i.e., learning) took place *before* the students' engaged in cardiovascular exercise and in an alternate sequence, *after* the students have engaged in cardiovascular exercise. This chapter begins with the selection of participants, followed by a description of the measures and the procedures used for conducting the study. Finally, the chapter concludes with a section on data analysis.

Participants

Undergraduate CUNY - Queensborough Community College (QCC) students who were over 18 years of age and capable of participating in light to moderate cardiovascular exercise were recruited from three aerobic, physical education courses. Each course consisted of approximately 30 students for a total of 90 potential participants for this study. The students from the aerobics, physical education courses were randomly assigned to one of three groups, (a) moderate exercise (i.e., continuous cardiovascular exercise where the student's heart rate is between 141 and 161 beats per minute), (b) light exercise (i.e., continuous cardiovascular exercise where the student's heart rate is between 120 and 140 beats per minute) and (3) no exercise (i.e., the control group).

The QCC student population for the study had one-year retention rates of full-time freshman at 68.4% and graduation rates with an Associates degree of 11.8% after three years and 26.2% graduation rate with an associates degree after six years. The ethnic diversity of the campus was 23.4% Asian, 22.5% Hispanic, 27.8% Black and 25.1% White (QCC Institutional Research Data Base, 2008).

Measures

The *dependent* measures for this study included (a) heart rate measures, (b) *recall* posttest A, (c) *comprehension* posttest A, (d) *recall* posttest B and (e) *comprehension* posttest B. The *independent* variables were (a) moderate exercise, (b) light exercise, (c) no exercise. The *covariates* were (d) *recall* pretest A, (e) *comprehension* pretest A, (f) *recall* pretest B, and (g) *comprehension* pretest B.

Profile Questionnaire

Undergraduate students from QCC voluntarily completed the following profile questionnaire.

1. What is your age? _______
2. What is your gender? (circle one) M F
3. What is your ethnicity? (check one)

   Black ________ Hispanic/Puerto Rican ________ White _____

   Asian/Pacific Island ________ Native American ________ Other ______
4. What is your current GPA? _____
5. Is English your first language? (circle one) Yes No If no, then what is your first language? ____________

6. Did you pass, fail, or were you exempt from the Compass Placement Reading Test?

   (circle one)   pass   fail   exempt

7. What is your weight in pounds? _________   What is your height in inches? _____

8. What is your waist circumference in inches? ________

9. How many days do you exercise per week on a regular basis? (circle one)

   0   1   2   3   4   5   6   7 days

   How many minutes do you exercise per week on a regular basis? (circle one)

   less than 30   30 – 60   60 – 90   90 – 120   more than 120

10. How many hours of sleep did you get last night? _________

11. What did you eat and/or drink within the past two hours? ________

12. Do you smoke? (Circle one)   Yes   No

Questions 1 -12 were selected to control for any mediating variables such as, height and weight (question 7), waist circumference (question 8) and exercise history (question 9), which could have affected how well one performs cardiovascular exercise. The variables of height and weight were used to calculate BMI and prior studies have reported BMI to be inversely related to cognitive performance (see page 6). The variable waist circumference was used as an indicator of overall health when factored with gender and height (Corbin, 2009). Individuals with high waist circumference ratings for their gender and height were at greater health risk. The variables of GPA (question 4), whether or not English is the student's first language (question 5) and the Compass Placement Reading Test (question 6) which measures students' reading comprehension (i.e., determining the meaning of words through context, determining implicit meanings, to draw conclusions and making comparisons and generalizations) was questioned to indicate how well the students perform on cognitive tests.

Additional variables of the study included how much sleep (question 10) the students received the night before testing, what (if anything) the students ate and/or drank (question 11) before engaging in cardiovascular exercise and the students' smoking habits (question 12), as they might have affected the students' physical and cognitive performance. The students were asked not to drink any caffeine within two hours before the tests were administered because caffeine is a stimulant and may affect the students' level of cardiovascular exercise and performance on the recall and comprehension tests.

Heart Rate

As described in chapter 1, heart rate is a measure of the number of heart beats per minute and can be used to measure resting heart rate and target heart rate range (THRR). Resting heart rate refers to an individual's heart rate while inactive. THRR is the desired heart beat range for the participants during aerobic exercise. A person's THRR is based on their age and ranges from 50% to 90% of an individual's maximum heart rate. In this study, the students' heart rates were measured by the Polar E600 electronic heart rate monitor. The students' resting heart rates were measured before they engaged in their assigned activity. The students engaged in light exercise maintained a THRR between 120 and 140 beats per minutes, and those students who were engaged in moderate exercise maintained THRR of 141 to 161 beats per minutes. The students' engaged in no cardiovascular exercise also had their heart rates measured during their period of inactivity.

Pretests and Posttests A

Recall and *comprehension* pre- and posttests A were tests to measure verbal performance prior to, and subsequent to the experimental condition, respectively. *Recall* and *comprehension* pre- and posttests A consisted of 10 randomly selected Scholastic Aptitude Test (SAT) words that the students defined and used in their own sentence that showed the meaning of the word, to the best of their ability within 10 minutes. The students' posttest word definition and use in a sentence scores measured their recall and comprehension, respectively.

Recall and *comprehension* pre- and posttests A included the following instructions and SAT words.

Please define and use each of the following 10 words in your own sentence that shows the meaning of the word:

1. Acclaim
2. Austere
3. Contentious
4. Discordant
5. Enigma
6. Fanaticism
7. Induce
8. Prodigal
9. Rancor
10. Scrutinize

(See scoring criteria below).

Pretests and Posttests B

Similar to the *recall* and *comprehension* pre- and posttest A, the *recall* and *comprehension* pre- and posttests B was a measure of verbal performance prior to and subsequent to the experimental condition, respectively. The *recall* and *comprehension* pre- and posttests B consisted of another 10 randomly selected SAT words that the students were asked to define and use in their own sentence that showed the meaning of the word to the best of their ability in 10 minutes. Students completed the posttests B following the second intervention phase.

The *recall* and *comprehension* pre- and posttests B included the following instructions and SAT words.

Please define and use each of the following 10 words in your own sentence that shows the meaning of the word:

1. Ambiguous
2. Coercion
3. Denounce
4. Divergent
5. Exhaustive
6. Gregarious
7. Placate
8. Reprimand
9. Surpass
10. Vacillate

The students' answers on the pretests and posttests were scored from 0 to 50 points for recall and 0 to 50 points for comprehension. Their score was based on the number of word definitions that they get correct, or partially correct, and the number of sentences in which they have correctly or partially correctly used the SAT words, within the given time period, according to the table 1, recall rubric and comprehension rubric in table 2.

Table 1

Recall Rubric

Defined word correctly	5 points per word
Defined word mostly correct	3 – 4 points per word
Indicates some recognition of the definition	1 – 2 points per word
Defined word incorrectly (or no answer)	0 points per word

Table 2

Comprehension Rubric

Correctly used the word in a sentence that shows the meaning of the word.	5 points per word
Mostly correct use of the word in a sentence that shows the meaning of the word.	3 - 4 points per word
Used the word in a somewhat correct sentence that indicates the meaning of the word.	1 – 2 points per word
Incorrectly uses the word in a sentence (or no answer)	0 credit

Research Design

The research design of this study was a single factor model with moderate, light, and no exercise serving as the independent variables and recall and comprehension for posttest A and posttest B serving as the dependent measures. The pretest scores on these same dependent measures served as covariates in the research design to control for differences in difficulty of word lists.

Procedures

Informed consent phase. At the beginning of the research study, the instructor (a) gave the students information sheets I and II (see Appendix A and B), and (b) read from the instructor script (see Appendix C), which described the purpose and procedures for this study. Then, the students read and sign the informed consent (see Appendix D), which described the study for which the students were asked to be participants. The students were assigned a number to use on all other forms.

Profile questionnaire and physiological measures. Each student from the three aerobics classes completed the profile questionnaire and had their weight, height, waist, and resting heart rates measured.

Random assignment phase. After the students completed the profile questionnaire, they were randomly assigned into three groups: (a) *moderate exercise*, (b) *light exercise* and (c) *no exercise*. In this study, students in the moderate exercise group were required to maintain a heart rate between 140 and 160 beats per minute during the activity and students in the light exercise group were required to maintain a heart rate between 120 and 139 beats per minute.

Intervention phase. After the participants completed the profile questionnaire, they were given recall and comprehension pretests A. Once they completed the pretests, they were given 20 minutes to rehearse the pretest words by using pre-made flash cards with the words on one side and the definitions and examples of how the words are used in a sentence on the other (see appendix A). The cardiovascular exercise groups were given a three minute warm-up and then the moderate exercise group engaged in step aerobics on 8-inch platforms performed at a cadence of 132 - 136 beats per minute for 20 minutes. The light exercise group engaged in step aerobics on 4-inch platforms performed at a cadence of 124 – 128 beats per minute for 20 minutes. The no exercise group spent 20 minutes doing simple puzzles but did not engage in any cardiovascular activity. All the students had their heart rates measured by Polar E600 heart rate monitors. Then, all participants were given the recall and comprehension posttests A.

Pretest/posttest B phase. On the following week, the students completed the recall and comprehension pretests B and then engaged in the activity they have previously been assigned (i.e., “moderate” exercise, “light” exercise or “no” exercise). Then, the students spent 20 minutes rehearsing the definitions and word-sentence examples on pre-made flash cards (see appendix B). Finally, they took the recall and comprehension posttests B. The study’s alternate sequence procedure was designed to examine whether or not engaging in cardiovascular exercise will improve the forward and/or backward effects of cardiovascular exercise on student learning, recall and comprehension. As previously mentioned in this dissertation, examining the forward effect answers the question “does exercise increase learning?” whereas, the backward effect answers the question, “if you already learned something, does engaging in exercise help you to retrieve the previously learned information?" In other words, the forward effect (i.e., sequence B) is proactive, which prepares the mind for future learning. The backward effect (i.e., sequence A) is retroactive and seeks to preserve learning traces and the accessibility of previously learned information. Table 3 provides a flow chart for the experimental procedures, based on the three groups.

Table 3

Flow chart for experimental groups and procedures

Group

Moderate Exercise	Light Exercise	No Exercise
Administered: profile questionnaire and recall and comprehension pretests A	Administered: profile questionnaire and recall and comprehension pretests A	Administered: profile questionnaire and recall and comprehension pretests A
Students engaged in moderate cardiovascular exercise for 20 minutes	Students engaged in light cardiovascular exercise for 20 minutes	Students took a non-physically active break for 20 minutes
Students were given 20 minutes to rehearse the information	Students were given 20 minutes to rehearse the information	Students were given 20 minutes to rehearse the information
Students took posttests A on the material they just learned	Students took posttests A on the material they just learned	Students took posttests A on the material they just learned
Students were given recall and comprehension pretests B	Students were given recall and comprehension pretests B	Students were given recall and comprehension pretests B
Students were given 20 minutes to rehearse the information	Students were given 20 minutes to rehearse the information	Students were given 20 minutes to rehearse the information
Students engaged in moderate cardiovascular exercise for 20 minutes	Students engaged in light cardiovascular exercise for 20 minutes	Students took a non-physically active break for 20 minutes
Students took posttests B on material they just learned	Students took posttests B on material they just learned	Students take posttests B on material they just learned

Data Analysis

The present researcher used descriptive statistics to calculate the means and standard deviations for (a) heart rate, (b) GPA, (c) BMI, (d) waist circumference, (e) number of hours of sleep received the night before testing, and (f) food/drink ingested by the student prior to the test. Next, I tested means and frequencies for (a) gender, (b) ethnicity, (c) waist rating, (d) pass/fail or exempt from the Compass Placement Reading Test, (e) exercise history and (f) smoking habits.

I determined whether or not there were any significant differences between the three exercise groups prior to the intervention. This included *recall* pretests A and B, *comprehension* pretests A and B, and resting heart rate measures.

Then I performed analyses of variances (ANOVA) for each of the dependent measures and I calculated partial η^2 to determine the effect size of the group differences. Next, I conducted trend analyses to test for linear trends across the three groups (ranging from no exercise to light exercise to moderate exercise) and I calculated partial η^2 . Subsequently, I ran Tukey multiple comparisons to determine which of the groups scored significantly different from the other.

I ran Pearson correlations on the dependent measures to determine the relationship between the variables. Finally, a 2 X 2 ANOVA was conducted for task A and B to explore whether or not there was a significant difference in the level of cognitive difficulty between the comprehension and recall tasks.

CHAPTER 4

RESULTS

Descriptive Statistics

Ninety students were recruited to participate in this study and 69 students completed the study, including, 22 from the light exercise group, 19 from the moderate exercise group and 28 from the no exercise group. 64 were female and five were male. The ethnic diversity of the participants included 16 Black, 18 Hispanic/Puerto Rican, 14 White, nine Asian/Pacific Island, and 12 other. 49 of the students (71%) spoke English as their first language and 20 of them (29%) listed another language as their first language. The means and standard deviations for the recall and comprehension pre- and posttests, resting heart rates and target heart rate scores from each group appear in table 4.

Table 4

Group means and standard deviations for recall and comprehension pre- and posttest scores, resting heart rates and target heart rates

	Groups					
	Moderate exercise (n = 19)		Light exercise (n = 22)		No exercise (n = 29)	
Measures	M	SD	M	SD	M	SD
Pretest recall A	7.53	7.65	3.41	5.43	6.18	9.37
Pretest comprehension A	7.47	7.95	2.36	4.79	4.25	7.21
Posttest comprehension A	29.89	17.47	20.64	19.12	14.07	18.83
Resting HR A	80.88	11.52	81.46	12.05	82.90	13.55
Target HR A	161.64	5.84	139.96	9.56	83.50	11.78
Pretest recall B	7.05	9.37	3.41	5.65	6.18	7.18
Pretest comprehension B	8.79	9.44	3.82	7.65	5.61	6.98
Posttest recall B	31.74	16.85	29.73	16.41	27.57	12.86
Posttest comprehension B	33.37	17.32	22.09	17.87	17.79	16.14
Resting HR B	76.80	11.93	81.00	11.91	82.55	11.27
Target HR B	160.44	4.78	139.54	8.64	83.54	10.65

Table 5 lists the overall means and standard deviations for independent and dependent measures (N = 69).

Table 5

Means and standard deviations for independent and dependent measures

	Mean	Standard deviation
Age	21.63	4.08
GPA	2.79	0.70
Weight (pounds)	146.61	35.59
Height (inches)	64.16	2.99
BMI	25.11	5.54
Waist Circumference (inches)	32.09	5.06
Number of hours of sleep	6.18	1.37
Recall pretest A	5.67	7.89
Comprehension pretest A	4.54	6.96
Recall posttest A	26.99	17.97
Comprehension posttest A	20.52	19.39
Recall pretest B	5.54	7.47
Comprehension pretest B	5.91	8.05
Recall posttest B	29.41	15.06
Comprehension posttest B	23.45	17.96

Note. N = 69

The mean BMI for the participants was 25.41, which just falls within the "overweight" category that ranges from 25.00 – 29.99. The mean waist circumference for the participants was 32.09 inches. Out of the 69 participants who completed the study, 43 (62.32%) had a waist measurement that rated as "too high" for their gender and height. Further, the mean number of hours of sleep (6.18) is nearly one hour less than the recommended 7 or more of hours of sleep needed each night (Corbin et al., 2009).

Of the 69 participants who completed the study, 35 passed the reading placement test, 24 were exempt and 6 students failed. Overall, 92% of the participants who completed the study either passed or were exempt from taking the reading placement test. Twenty-three participants reported that they exercised three or more times or 90 minutes or more per week, 18 participants reported that they exercised twice per week or at least 60 minutes and 28 reported that they exercised less than twice per week or 30 minutes. That is, more than 40% of the participants reported not engaging in any exercise beyond attending their mandatory physical education aerobics course in which all of the participants are concurrently enrolled. In total, 2/3 of the participants reported not getting the recommended amount of exercise. Of the 69 participants, 61 (88%) reported that they do not smoke. Forty-one of the participants (60%) reported that they ate or drank something within two hours of the intervention and 27 of the participants (39%) reported that they did not.

Preliminary Analyses

Students in the three exercise groups were tested to determine whether or not there were any significant differences between them prior to the intervention. The group difference for recall of pretest A and comprehension pretest A were found not to be significant, F (2, 66) = 1.51 ns and F (2, 66) = 2.95, ns. Similarly, the ANOVA for recall pretest B and comprehension pretest B respectively were found not to be significant F (2, 66) = 1.40, ns and F (2, 66) = 2.04, ns. These results demonstrated that the exercise groups were comparable before training commenced and that random assignment procedures were effective.

The resting heart rate measures were tested to determine whether or not significant differences occurred between the groups at baseline. The results of an ANOVA for the resting heart rate measures (i.e., sequence A and sequence B respectively) were found to not be significant F (2, 66) = 1.49, ns and F (2, 66) = 0.15, ns. However, as expected, the target heart rate measures for the three groups were significantly different for sequence A and sequence B respectively F (2, 66) = 417.45, $p < .05$ and F (2, 66) = 518.83, $p < .05$. Similarly, the trend analysis for the target heart rate measures (i.e., sequence A and sequence B respectively) demonstrated significance with F (1, 67) = 411.76, $p < .05$ and F (1, 67) = 520.76, $p < .05$. The target heart rates demonstrated a large effect size, partial η^2, 0.45 for sequence A and partial η^2, 0.47 for sequence B. No other independent measures demonstrated a significant difference between the three groups.

Correlation Analyses

Pearson correlation coefficients for the dependent measures are reported in Table 6. *Recall* A correlated significantly with *comprehension* A, (r = .59) and *recall* B and *comprehension* B were correlated (r = .46). When comparing test A with test B, *recall* A and *recall* B were correlated (r = .54) and *comprehension* A and *comprehension* B correlated at (*r* = .69). The dependent measures that were not as highly correlated were *recall* A and *comprehension* B (*r* = .35) and *comprehension* A and *recall* B (*r* = .42).

Table 6

Intercorrelations Between Dependent Measures

Measures	1	2	3	4
1. Recall A	-			
2. Comprehension A	.59**	-		
3. Recall B	.60**	.42**	-	
4. Comprehension B	.35**	.69**	.46**	-

Note. N = 69
** $p < .01$ level

Main Analyses for Sequence A

Analyses of variances were conducted for sequence A to determine the differences between the exercise groups. Table 7 lists the ANOVA and effect size for *recall* and *comprehension* posttests A.

Table 7

ANOVA test for each dependent measure for sequence A

Posttest Measures	df	F	Partial η^2	Sig.
Recall A	2	1.72	0.05	ns
Comprehension A	2	4.11*	0.11	.02

*$p < .05$

The ANOVA for student exercise group differences in posttest A *recall* scores did not show a significant effect, F (2, 66) = 1.72, ns. However, regarding the ANOVA for posttest A *comprehension* scores, there was a significant difference between exercise groups, F (2, 66) = 4.11, $p < .05$. The statistical effect size for comprehension A scores between the groups demonstrated moderate effect (partial η^2, 0.11) according to Cohen's (1988) definition of a moderate effect size of partial η^2, 0.06 – 0.13. Table 8 lists the trend analysis summary for *recall* and *comprehension* A.

Table 8

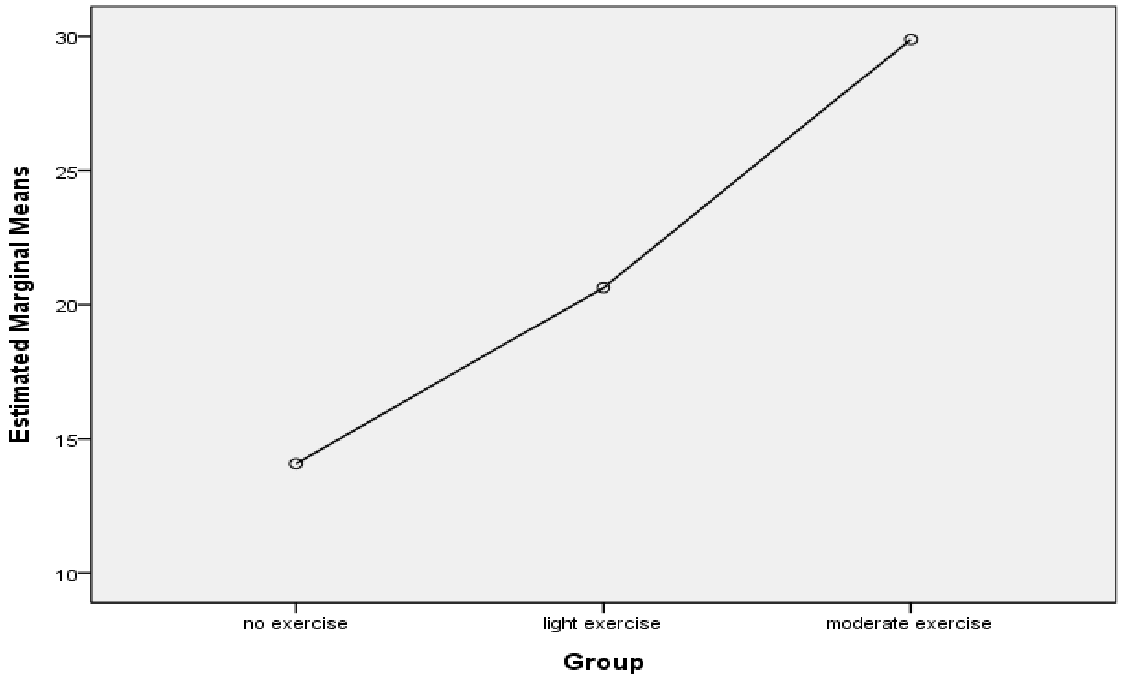
Linear trend analysis summary for dependent measures A

Dependent Measures	Mean Difference	Standard Error	df	F	Partial η^2	Sig.
Recall A	6.39	3.74	1	2.91	0.05	ns
Comprehension A	11.19	3.90	1	8.23*	0.11**	.01

*p < .05

Figure 1 presents the overall positive linear trend of *comprehension* A scores.

Figure 1. Estimated marginal means of posttest *comprehension* A.



The linear trend of the dependent measures demonstrates an increase in comprehension test scores with an increase in exercise. To compare specific means of the groups in Figure 1, pairwise comparisons were conducted. I ran the Tukey multiple comparison test for posttest *comprehension* A scores which demonstrated a significant effect between the moderate and no exercise groups. Table 9 lists the pairwise comparisons for dependent measure comprehension A. The contrast of moderate versus no exercise groups was statistically significant.

Table 9

Pairwise comparisons for dependent measure comprehension A

Group Comparisons	Mean Difference	Standard Error	Sig.
Moderate vs. light	9.26	5.81	ns
Moderate vs. no	15.82*	5.52	.02
Light vs. no	6.56	5.23	ns

* $p < .05$

Main Analyses for Sequence B

Analyses of variances were conducted for sequence B to determine the differences between the groups. Table 10 lists the ANOVA and effect size for *recall* and *comprehension* posttests B.

Table 10

ANOVA for each dependent sequence B measure

Posttest Measures	df	F	Partial η^2	Sig.
Recall B	2	0.43	.01	ns
Comprehension B	2	4.82*	.13	.03

*$p < .05$

The ANOVA for student exercise group differences in posttest B *recall* scores did not show a significant effect, F (2, 66) = 0.43, ns. However, the ANOVA for posttest B *comprehension* scores there was a significant difference between exercise groups, F (2, 66) = 4.82, $p < .05$. The calculated effect size for *comprehension* B scores showed a moderate effect, partial η^2, 0.13. Table 11 lists the trend analysis summary for *recall* and *comprehension* B.

Table 11

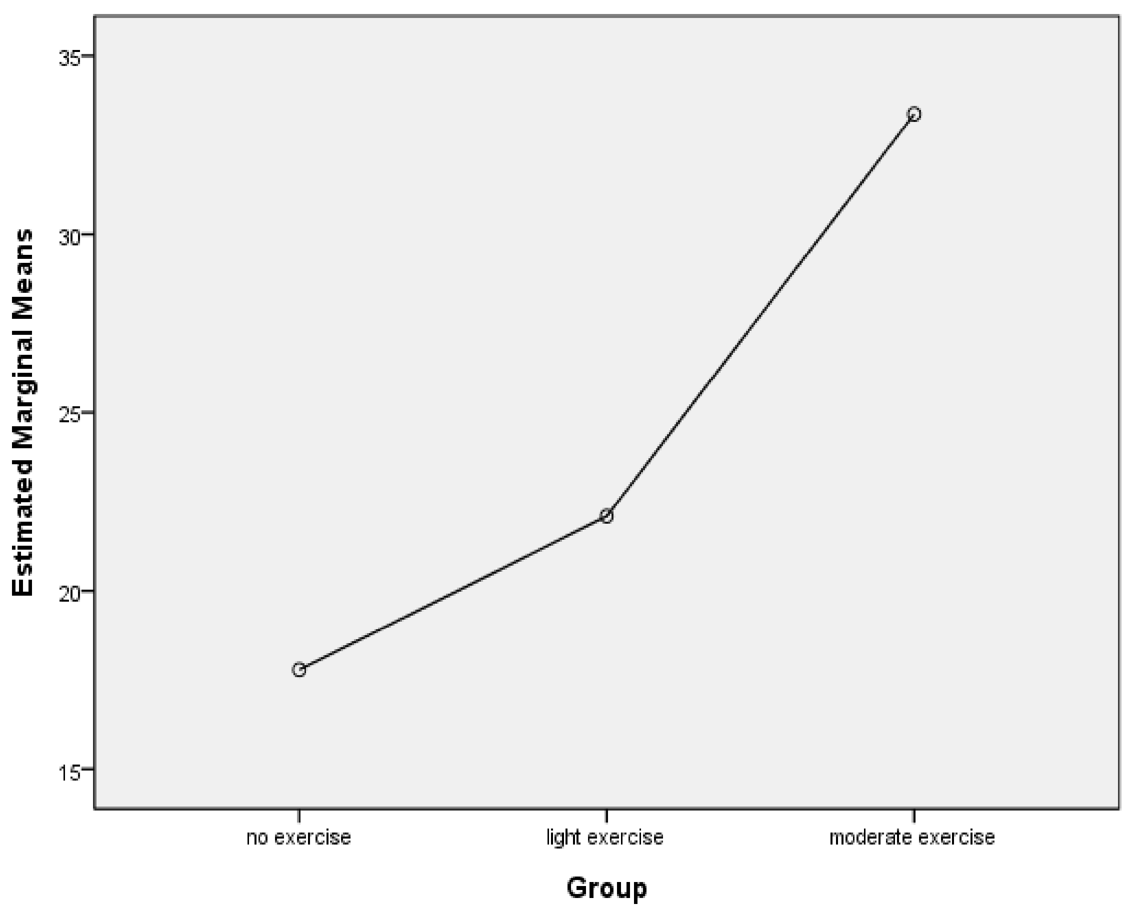
Linear trend analysis summary for dependent measures B

Dependent Measures	Mean Difference	Standard Error	df	F	Partial η^2	Sig.
Recall B	2.95	3.19	1	0.85	.01	ns
Comprehension B	11.02	3.58	1	9.47*	.13*	.01

*p < .05

Figure 2 presents the positive linear trend of *comprehension* B scores as the level of exercise increases.

Figure 2. Estimated marginal means of *comprehension* posttest B



The overall trend of the dependent measures demonstrates an increase in comprehension test scores with an increase in exercise. To compare specific means of the groups in Figure 2, pairwise comparisons were conducted. Tukey multiple comparison tests for posttest *comprehension* B scores revealed a significant effect between the moderate and no cardiovascular exercise group. Table 12 lists the pairwise comparisons for dependent measure comprehension B.

Table 12

Pairwise comparisons for dependent measure comprehension B

Exercise Group Comparisons	Mean Difference	Standard Error	Sig.
Moderate vs. light	11.28	5.33	ns
Moderate vs. no	15.58*	5.06	.01
Light vs. no	4.31	4.85	ns

$p < .05$

Level of Cognitive Difficulty Analysis

The discovery of a significant difference between the exercise groups for comprehension but not for recall was unexpected. To explore reasons for this outcome, a 2 X 2 ANOVA was conducted to explore whether or not the comprehension test was a significantly more difficult cognitive task than the recall test. The 2 X 2 ANOVA performed, consisted of two variables: the form of cognition and testing. Form of cognition involved two values: recall and comprehension. Testing involved two values: pre- and posttest scores.

The results of the ANOVA for sequence A revealed a significant main effect for form of cognition, F (1, 67) = 9.05, $p < .05$, partial $\eta^2 = 0.11$ with the mean of the free recall group (22.41) surpassing the mean for comprehension (16.68) There was also a significant main effect for testing, F (1, 67) = 103.40, $p < .05$, partial $\eta^2 = 0.60$ with the posttest mean (23.75) surpassing the pretest mean (5.10). However, the interaction between testing and form of cognition did not prove to be significant. This indicates that *comprehension* A task was a more difficult task for students to learn.

Similarly, the same 2 X 2 ANOVA compared form of cognition and testing for sequence B. The results of the ANOVA revealed a significant main effect for form of cognition, F (1, 67) = 5.87, $p < .05$, partial $\eta^2 = 0.08$ with the mean of the free recall condition (24.01) surpassing that of the comprehension condition (17.77). There was also a main effect for testing, F (1, 67) = 192.56, $p < .05$, partial $\eta^2 = 0.74$ with the mean of the posttest condition (26.50) surpassing that of the pretest condition (5.72). However, the interaction between testing and form of cognition did not prove to be significant. These findings indicate that the *comprehension* B task was the more difficult task for students to learn.

Student Dropout Analysis

To determine whether or not the difference between exercise groups for dropout rate was significant, a 3 X 2 nonparametric chi square analysis between the three exercise groups and dropout rate was conducted and showed a significant difference, $\chi^2 = 7.83$, $p < .05$. Therefore, further testing was conducted determine the comparability between the dropout and non-dropout students. A nonparametric chi-square analysis was conducted on the students' reading level using the Compass Placement Reading test. The results showed no statistically significant difference between dropouts and the non-dropouts, $\chi^2 = 1.96$, n.s. Further, Fisher's Exact Probability Test was conducted to confirm the non-significance between the groups since 50% of the cells tested had an expected frequency count of less than five (see table 13).

Table 13

Dropout versus non-dropout students' reading level

	Reading	
Dropout	Pass/exempt	Fail
Count	21	0
Expected Count	19.6	1.4
Non-dropout		
Count	63	6
Expected Count	64.4	4.6

A second nonparametric chi-square analysis was conducted on the students' fitness level to determine the comparability between the dropout and non-dropout students. Fitness level was measured from the data of how many students met the recommended criteria for engaging in cardiovascular exercise three or more times per week for at least 30 minutes. The results showed that the difference between dropout and the non-dropout students was not statistically significant, $\chi^2 = 2.10$, n.s. These results suggest that the dropouts were no different from the non-dropout students.

CHAPTER 5

DISCUSSION

General Discussion

The purpose of this study was to determine whether or not engaging in a light or moderate amount of exercise *after* rehearsal improves students' reactive *recall* and *comprehension.* This was labeled Sequence A, and it involved the backward effect of exercise on learning and involved retrieving information. The present author also sought to determine whether or not performing a light or moderate amount of exercise *before* rehearsal improves students' proactive *recall* and *comprehension.* This was labeled Sequence B and it involved a forward effect of exercise, which prepares the mind for learning and performance).

The results of the study demonstrated that engaging in at least a moderate amount of exercise *before* or *after* rehearsing for a *comprehension* test significantly improved test results. That is, moderate exercise improved: (a) the backward effect of learning and retrieving information and (b) the forward effect which prepares the mind for learning and performance.

In both sequence A and B, the students exercised prior to taking the *recall* and *comprehension* tests. In sequence A, the students engaged in exercise 20 minutes before being tested. In sequence B, the students engaged in exercise just prior to being tested. In both rehearsal sequences, comprehension test scores improved from engaging in moderate exercise within 20 minutes prior to performing a comprehension test.

The moderate exercise group scored higher on *recall* than the light and no exercise groups, but this difference was not found to be significant. Performing a light amount of exercise also demonstrated improvement in comparison to not performing any exercise. However, this difference was not found to be significant.

Hypothesis 1

The first hypothesis posited that there will be a significant linear trend between students' engagement in cardiovascular exercise *before* learning and their *recall* of recently learned information (Sequence A). This trend was not found to be statistically significant between the groups. Thus, hypothesis one was not confirmed.

Hypothesis 2

The second hypothesis stated that there will be a significant linear trend between students' engagement in cardiovascular exercise *after* learning and their *recall* of recently learned information (Sequence B). Similar to sequence A, *recall* B scores were not found to be statistically significant among the groups. Thus, hypothesis two was not confirmed.

Hypothesis 3

The third hypothesis posited that there will be a significant linear trend between students' engagement in cardiovascular exercise *before* learning and their *comprehension* of recently learned information (Sequence A). The findings from the analysis (i.e. ANOVA) indicated a statistically significant linear effect of exercise on *comprehension* A. Further, the Tukey pairwise comparisons demonstrated that the moderate exercise group scored significantly higher as compared to the no exercise group. That is, students in the moderate group scored 15.82 points higher on *comprehension* posttest A when compared to the no exercise group. The findings from the trend analysis demonstrated that the more vigorous the cardiovascular exercise level (i.e., from no exercise to light exercise to moderate exercise), the greater the *comprehension* A scores. In contrast to the *recall* A task, the significant ANOVA results indicate that the *comprehension* A task was a more difficult and a more sensitive measure of the cognitive and neurological effects of exercise *before* learning on students' ability. This test assessed students' ability to generate sentences for the given vocabulary words. Thus, hypothesis three was confirmed.

Hypothesis 4

Hypothesis four stated that there will be a significant linear trend between students' engagement in cardiovascular exercise *after* learning and their *comprehension* of recently learned information (Sequence B). The findings from the ANOVA indicated a statistically significant effect of cardiovascular exercise on the posttest *comprehension* B measures. Further, the Tukey pairwise comparisons demonstrated that the moderate exercise group scored significantly higher as compared to the no exercise group. That is, students in the moderate exercise groups scored 15.58 points higher on *comprehension* posttest B as compared to the no exercise group. The findings from the trend analysis demonstrated that increasing cardiovascular exercise (i.e., from no exercise to light exercise to moderate exercise) was associated with greater *comprehension* B scores. In contrast to the *recall* B task, the significant ANOVA results indicate that the *comprehension* B task was a more difficult task and a more sensitive measure of the cognitive and neurological effects of exercise *after* learning on students' ability. This test assessed students' ability to generate sentences for the given vocabulary words. Thus, hypothesis four was confirmed.

Sources of Cognitive Difficulty on the Comprehension Task

A qualitative analysis of pretest A revealed that many students recognized the word *fanaticism* as being related to "being a fan" or "obsessed." Yet, they had difficulty using the word *fanaticism* in a sentence. For example, one student wrote, "The movie star don't know how to talk with his *fanaticism* fan." Alternatively, the word *induce* was frequently used in a sentence as it relates to pregnancy, and giving birth, but many students could not actually define the word. Instead they gave definitions such as "to force something open" and "to take in." Also of interest was the word *scrutinize* where some students recognized the word but gave varied definitions such as "to put down," "punish," "to make smaller," "to make fun of or pick on someone (harshly)," "to torment," "to scold," "to mis-read something," "to look up and down," and "stubborn." The definition provided during the intervention phase for the word *scrutinize* was to "examine closely and critically." Many students could not identify the word *rancor* and one student gave the definition, "very rude" and wrote the sentence, "Now a days everyone is so rancor to one another." The definition provided during the intervention phase for the word *rancor* was "bitterness; hatred."

In the recall and comprehension pretests B, more students were able to define and/or use the words *reprimand* and *surpass* in a sentence as compared to the other words. They had difficulty with the other words and many students confused *exhaustive* with the word *exhausted* since their definitions made references to "being tired" instead of the actual meaning, "thorough; comprehensive."

The comprehension task required the students to create their own sentence that showed the meaning of the word. If the students memorized and merely recalled the sample sentence indicated on the pre-made flashcards on their posttest, then the students did not receive credit for their sentence. An item analysis of each word revealed that 28 out of 1,380 words, or 2%, of the sentences from the posttests A and B were not self-generated but were taken from the sample sentences given on the pre-made flashcards. In terms of the control and experimental groups, the sentences were repeated 14 times by four students in the no exercise group, seven times by three students in the light exercise group and seven times by two students in the no exercise group. The most repeated sentences involved the words were *divergent, vacillate, fanaticism* and *scrutinize*. The higher rate of recalled sentences primarily occurred in the control group, yet these differences were not widespread and did not affect the data.

Overall, the students from all three exercise groups had low pretest scores means (5.67 for *recall* A, 4.54 for *comprehension* A, 5.54 for *recall* B and 5.91 for *comprehension* B out of a possible 50 points for each test). This indicates that the community college students in this study lacked certain verbal skills, regardless of whether or not English was their first language or whether or not they passed the Compass Reading Test. (Over 70% of the students indicated that English was their first language and 92% of the students passed or were exempt from taking the Compass Reading Test), a gateway measure of reading skill. The students were able to improve their posttest scores in all three groups where the posttest grand means were 26.99 for *recall* A, 20.52 for *comprehension* A, 29.41 for *recall* B and 23.45 for *comprehension* B out of a possible 50 points. There were main effects but no interactions for the sequence A and sequence B measures. Further, the pretest scores for *recall* and *comprehension* were comparable at baseline and the mean differences between *recall* pre- and posttest A and *recall* pre- and posttest B were 21.32 and 23.87, respectively. In comparison, the mean differences between *comprehension* pre- and posttest A and *comprehension* pre- and posttest B were 15.98 and 17.54, respectively. Therefore, increases in learning were greater for *recall* measures than *comprehension* measures for all three experimental groups. This demonstrates that comprehension task was more difficult. These results suggest that physical exercise was particularly helpful when the task was difficult (i.e., comprehension task).

Limitations of the Study

Due to IRB requirements, the enrollment process of this study was limited to students who were concurrently enrolled in a physical education aerobics course. Since this course is primarily attended to by females, the ratio of females to males in this study was very high.

Students were allowed to withdraw from the study at any time, and a statistically significant difference in the dropout rate occurred between the exercise groups. Yet, the results of further nonparametic chi-square analyses revealed no significant difference occurred with respect to reading and fitness level between the students who remained in the study and those who withdrew. Rather, students' decision to dropout was more likely due to their lack of motivation for engaging in voluntary cardiovascular exercise.

A future study should include a vigorous exercise group to determine whether or not the positive linear trend between level of exercise and recall and comprehension scores continues. IRB concerns about the medical dangers of vigorous exercise made inclusion of such an exercise group unfeasible in the present unfunded research.

Another limitation included not knowing what recall and comprehension strategies the students employed when rehearsing the definitions and sample sentences. For example, it could have been beneficial to know whether the students were passively rehearsing the words and definitions or if they were actively making associations between the words and their definitions. Then, it could be determined whether or not exercise significantly enhances the use of active rehearsal strategies.

Although, the vocabulary words were randomly selected from an SAT preparation workbook, the selected words were not assessed for individual level of difficulty. However, the word difficulty issue would not affect the interpretation of the present findings because all groups were exposed to the same lists of words.

Future Research

Tomporowski (2008) reported that authors of previous studies rarely provided or vaguely reported descriptions of the types of skills learned during exercise training. It is unknown whether or not engagement in exercise and the development of cardiovascular exercise skills, such as agility and coordination affect cognition. Therefore, I recommend that subsequent research be conducted to test various modes of cardiovascular exercise, such as, interval training and sports along with specific cardiovascular exercise skills and cognition.

An important issue for further research relates to why students do not engage in regular exercise. It is recommended that more research is needed to explain barriers to regular exercise, such as unhealthy eating habits (Sigfusdottir et al., 2007) or poor time planning and management Other considerations for future research include studying students' academic performance over the course of a semester while students self-monitor the sequence and amount of their exercise, study habits, and cognitive test outcomes.

Pascarella et al. (2004) conducted research on first-generation college students and theorized that extracurricular involvement and interaction with peers can play a significant role in both intellectual and personal development during college. The present researcher believes that students' nonacademic cultural experiences may also play a role in students' exercise activities and in turn on academic outcomes.

Educational Implications

The present research has shown that students who engaged in moderate exercise significantly increased their comprehension test scores. It was also shown that increased levels of exercise leads to better comprehension. In view of these findings, I recommend that students mix their studying with breaks that involve exercise. It can not only be a refreshing break from studying but also, it significantly improves comprehension of textual material. In this era of cuts in school budgets and increases in pressure for greater academic achievement, school board decisions to eliminate physical education would appear to be extremely unwise in light of the present research. Physical education training not only can enhance students' motivation and health, it also can affect their achievement. These implications of educational policy can be profound. Clearly, this research has important implications for school administrators and school boards as well as students.

Appendix A

Definitions and Sentences A

Word	Definition	Sample sentence for the word that shows the importance of the word
Ambiguous	*Adj*. Unclear or doubtful in meaning	His friend's *ambiguous* directions misled us; we did not know how which road to take.
Coercion	*N*. Use of force to get someone to obey	The employer used *coercion* to force his employee to take the blame for the mistake.
Denounced	*V*. Condemn; criticize	The candidate *denounced* the media for portraying her opponent as a better candidate.
Divergent	*Adj*. Differing; deviating	After law school, the two attorneys took *divergent* paths, one becoming a corporate attorney, the other dedicating himself to civic engagement.

Exhaustive	*Adj*. Thorough; comprehensive	We have made an *exhaustive* search of all the possible solutions to the problem.
Gregarious	*Adj*. Sociable	Typically, partygoers are *gregarious* and welcome opportunities to be with other people.
Placate	*V*. Pacify; conciliate	The manager tried to *placate* the employees by helping them come to a peaceful agreement.
Reprimand	*V*. Reprove severely; rebuke. Also *N*.	Every time the student spoke out in class, the teacher would *reprimand* her and make her stand in the back of the room for five minutes.
Surpassed	*V*..Exceed	Her hard work and dedication surpassed our expectations.
Vacillated	*V*. Waver; fluctuate	The woman *vacillated* back and forth between which dresses to buy.

Appendix B

Definitions and Sentences B

Word	Definition	Sample sentence for the word that shows the importance of the word
Acclaimed	*V*. Applaud; announce with great approval. Also *n*.	The media *acclaimed* the actress' performance in the award-winning film.
Austere	*Adj*. Forbiddingly stern; severely simple	The dean's *austere* demeanor tended to intimidate the students from speaking freely to him.
Contentious	*Adj*. Quarrelsome	The couple's arguments are so contentious, that no one understands why they are still married.
Discordant	*Adj*. Not harmonious; conflicting	The chorus sounded so *discordant* and not in harmony with each other.
Enigma	*N*. Puzzle; mystery	No one could figure out the meaning of the abstract painting, it was an enigma.

Fanaticism	*N*. Excessive zeal; extreme devotion to a belief or cause	The group's *fanaticism* to their cause led them to be thrown in jail.
Induce	*V*. Persuade; bring about	Cindy tried to *induce* her cousin to join her on a trip to the city.
Prodigal	*Adj*. Wasteful; reckless with money. Also *n*.	If you are *prodigal* with money, then you certainly will be in debt soon.
Rancor	*N*. Bitterness; hatred	The old woman could not let go of her *rancor* against the neighbors that betrayed her trust.
Scrutinized	*V*. Examine closely and critically	Searching for flaws, the food critic *scrutinized* every detail of the meal he was eating at the restaurant.

Appendix C

Queensborough Community College
OF THE CITY UNIVERSITY OF NEW YORK
Health, Physical Education, and Dance Department
222-05 56th Avenue Bayside, New York 11364-1497
Telephone: (718) 281-5146

INFORMATION SHEET PART I

My name is Andrea Salis, and I am a student in the Educational Psychology Ph.D. Program at The Graduate Center of the City University of New York (CUNY), and Principal Investigator of this project, entitled "The Effects of Cardiovascular Exercise on College Students' Learning, Recall, and Comprehension". This is a research study of CUNY students' ability to recall definitions after engaging in various levels of cardiovascular exercise. The study is expected to provide information helpful to improve academic achievement. I would like you to answer the questions in the profile questionnaire to the best of your ability. If you do not want to participate, you do not need to do so. Your grade in this course will not be affected by your decision. If there are questions to which you don't know the answers or would rather not provide the answers, you may leave those blank.

The survey should take about 10 minutes to complete. All information gathered will be kept strictly confidential, and will be stored in a locked file cabinet, to which only I, and my advisor, will have access. Again, at any time you may refuse to answer any questions on the survey. You have the right to withdraw without penalty from this study at any time.

The risks from participating in this survey are no more than encountered in everyday life. The benefit of your participation is that the information you provide may help researchers to assist CUNY students improve their academic achievement in the future.

I may publish results of the study, but names of people, or any identifying characteristics, will not be used in any of the publications. If you have any questions about this research, you may contact me at (718) 281-5146 or *asalis@gc.cuny.edu*, or my advisor Dr. Barry Zimmerman at (212) 817-8285 or *bzimmerman@gc.cuny.edu*. If you have questions about your rights as a participant in this study, you may contact Dean Paul Marchese, IRB Administrator, Queensborough Community College - City University of New York, at PMarchese@qcc.cuny.edu.

Thank you for your participation in the study. You may take this form with you.

____________________ _____

Investigator's signature Date

Appendix D

QUEENSBOROUGH COMMUNITY COLLEGE CUNY
Queensborough Community College
OF THE CITY UNIVERSITY OF NEW YORK
Health, Physical Education, and Dance Department
222-05 56th Avenue Bayside, New York 11364-1497
Telephone: (718) 281-5146

INFORMATION SHEET PART II

Now that you have successfully completed the profile questionnaire you will be randomly assigned to one of three groups (a) moderate exercise, (b) light exercise and (c) no exercise. Next you will receive recall and comprehension pretests A. This pretest is a baseline test to measure recall abilities prior to the experimental condition. The pretests will consist of 10 SAT words that you will be asked to define and give an example of each item in 10 minutes. You will be scored based on the number of definitions they get correct or partially correct within the given time period.
Following the pretests, you will be given 20 minutes to practice remembering the information to be recalled by using pre-made flash cards with the words on one side and the definitions and examples on the other. When you take the posttests, use the words in your own sentence that shows the meaning of the word.

You will then begin your course activity (a) moderate exercise, (b) light exercise, or (c) no physical exercise for 20 minutes. "Moderate" exercise is defined as continuous cardiovascular exercise where your heart rate reaches 141 – 161 beats per minute. "Light" exercise is defined as continuous exercise where your heart rate is between 120 and 140 beats per minute. Then, all participants will be given recall posttest A.

On the next week's meeting, you will be given recall and comprehension pretests B (i.e., another set of 10 words to define and give an example). Then you will be given an additional 20 minutes to practice remembering the information on pre-made flash cards. This will be followed by the activity based on your previously assigned group (i.e., moderate exercise, light exercise or no exercise). Finally, you will be given posttests B. The entire experiment should take approximately 2 hours to complete over the course of two meeting times. The first meeting will take approximately 1 hour and the second meeting will take approximately 1 hour to complete. Remember, you have the right to withdraw without penalty from this study at any time.

Appendix E

QUEENSBOROUGH COMMUNITY COLLEGE CUNY
Queensborough Community College
OF THE CITY UNIVERSITY OF NEW YORK
Health, Physical Education, and Dance Department
222-05 56th Avenue Bayside, New York 11364-1497
Telephone: (718) 281-5146

INSTRUCTOR'S SCRIPT

This is a survey, which is part of a research study of college students' ability to recall information after engaging in exercise. The study is expected to provide information helpful to improve academic achievement. It would be appreciated if you would fill out the survey to the best of your ability, but participation is voluntary. If you do not want to participate, you do not need to do so. Your grade in this course will not be affected by your decision. If there are questions to which you do not know the answers or would rather not provide the answers, you may leave those blank. Before you begin the survey, I will randomly assign a number to you and I would like you to write that number on your profile questionnaire and the pretests and posttests that will be part of this study. Your number will be used instead of your name. You may place the survey in this envelope on my desk when you are finished.

INSTRUCTOR SCRIPT II

Now that you have successfully completed the profile questionnaire you will be randomly assigned to one of three groups (a) moderate exercise, (b) light exercise and (c) no exercise. Next you will receive recall and comprehension pretests A. These pretests are baseline tests to measure recall and comprehension abilities prior to the experimental condition. The pretests will consist of 10 SAT words that you will be asked to define and give an example of each item in 10 minutes. You will be scored based on the number of definitions they get correct or partially correct within the given time period.
Following the pretest, you will be given 20 minutes to practice remembering the information by using pre-made flash cards with the words on one side and the definitions and examples on the other. When you take the posttest, use the words in your own sentence that shows the meaning of the word.

You will then begin your course activity (a) moderate exercise, (b) light exercise, or (c) no physical exercise for 20 minutes. "Moderate" exercise is defined as continuous cardiovascular exercise where your heart rate reaches 141 – 161 beats per minute. "Light" exercise is defined as continuous exercise where your heart rate between 120 and 140 beats per minute. Then, all participants will be given recall posttest A.

On the next week's meeting, you will be given recall and comprehension pretests B (i.e., another set of 10 words to define and give an example). Then you will be given an additional 20 minutes to practice remembering the information on pre-made flash cards. This will be followed by 20 minutes of the activity based on your previously assigned group (i.e., moderate exercise, light exercise or no exercise). Finally, you will be given posttests B. The entire experiment should take approximately 2 hours to complete over the course of two meeting times. The first meeting will take approximately one hour and the second meeting will take approximately 1 hour to complete. Remember, you have the right to withdraw without penalty from this study at any time.

Appendix F

QUEENSBOROUGH COMMUNITY COLLEGE CUNY
Queensborough Community College
OF THE CITY UNIVERSITY OF NEW YORK
Health, Physical Education, and Dance Department
222-05 56th Avenue Bayside, New York 11364-1497
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CONSENT FORM

Project Description, Risks and Benefits:

Researchers at Queensborough Community College are asking you to take part in a study because they want to learn the effects of exercise on memory and learning.

During this class, you will be given an anonymous survey to answer questions about yourself. Any questions that you choose not to answer can be left blank. Next week you will take recall and comprehension pretests and be randomly assigned to one of three groups (a) moderate exercise, (b) light exercise and (c) no exercise. You will then participate in your groups' activities. Next, you will be given flash cards with the same ten words and definitions to review. Finally, you will re-take the same tests again. You will repeat the procedure one additional time.

This study will present no risks to you because it only examines your regular class work and your ability to define words. It will not cost you any money, and you will not be paid anything. You do not have to take part in this study. Your participation is voluntary. If you do not participate, it will not affect your grade in this course. You can also drop out of this study at any time, and still take these courses. To be a part of this study you must be at least 18 years of age.

The researchers are:
Project Director: Andrea Salis, Lecturer, Health and Physical Education
Co-Project Directors: Lana Zinger, Associate Professor, Health Education; Alicia Sinclair, Assistant Professor, Health Education; Gloria McNamara, Instructor, Health Education, BMCC.

Confidentiality: Professor Zinger will explain this study to you. Then she will ask you to sign the consent forms. Professor Zinger will collect and hold the consent forms in a locked cabinet. After the semester is completed and your grades have been submitted, the researcher will be given the consent forms. Information collected from students who chose not to take part in the study will be destroyed.

Your personal identity will be protected throughout this study. You will be assigned a number so that no one will know your name. If you are mentioned in any published articles, your real name will not be used. The information collected for this study will be stored in a locked cabinet in the researchers' offices, and only the researchers will have access to it. After five years, all this information will be destroyed.

Contacts

If you have questions about your rights as a participant in this study, you may contact Dean Paul Marchese, IRB Administrator, Queensborough Community College - City University of New York, at PMarchese@qcc.cuny.edu.
If you have any questions about this research, you may contact Andrea Salis at (718) 281-5146 or *asalis@qcc.cuny.edu*, or my advisor Dr. Barry Zimmerman at (212) 817-8285 or *bzimmerman@gc.cuny.edu*.

By signing this consent form, you agree to take part in this study. You can stop participating in this study at any time without any problem. **By not signing this form, you are choosing not to participate.**

The purpose, procedures, risks and benefits have been explained to me. I understand the study requirements; I am at least 18 years of age and agree to participate.

Print your Name

Signature of Participant

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