THE EFFECT OF AN ACUTE BOUT OF PHYSICAL ACTIVITY ON SPECIFIC COGNITIVE PROCESSES

by

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(Under the Direction of Phillip D. Tomporowski)

ABSTRACT

The current study was designed to assess the effects of an acute bout of physical activity on specific cognitive processes. It was hypothesized that an acute bout of physical activity would facilitate participants' performance on elements of tasks that involve executive control, but would not facilitate participants' performance on non-executive tasks. Eighteen young adults' (9 women and 9 men) performance on an executive function task (Switch Task) and two memory tasks (Brown-Peterson and Free Recall) was assessed before and immediately after 40 minutes of exercise at 60% VO_{2peak} ($ml \cdot kg \cdot min^{-1}$), exercise-control, and quiet rest. Results indicated no difference in performance from pretest to posttest on the Switch or Brown-Peterson Tasks. Delayed recall of primacy and recency words was preserved following exercise compared to exercise-control and rest interventions.

INDEX WORDS: Cognition, exercise, acute, physical, activity, executive function, attention, memory, free-recall.

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DEDICATION

This thesis is dedicated to my Mom and Dad.

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The effects of an acute bout of physical activity on cognitive function are thought to depend on the type, duration, and intensity of the physical activity. Long duration aerobic and anaerobic exercise that lead to fatigue have been predicted to impede cognitive function; whereas, bouts of aerobic exercise performed at a moderate intensity over a relatively short period, have been predicted to facilitate cognitive function (Tomporowski & Ellis, 1986). Empirical studies have been conducted that directly assess the immediate after effects of an acute bout of physical activity on cognitive function. The results of these studies, however, have been ambiguous. Several researchers have reported that acute bouts of moderate intensity aerobic exercise lead to improved cognitive function, while others have failed to corroborate these findings (see reviews by Tomporowski, 2003; Brisswalter, Collardeau, & Arcelin, 2002)

Several explanations have been proposed to explain discrepancies reported in studies that have examined the effect of an acute bout of physical activity on cognitive function. Arousal theory hypothesizes an inverted "U" relation between arousal and performance. According to Arousal Theory, the level of physiological arousal induced by exercise of different intensities will differentially influence cognitive function. Proponents of Arousal theory predict that cognitive performance will improve to an optimum level as exercise intensity increases to a certain point, after which cognitive performance begins to deteriorate.

Other theorists explain discrepant findings in terms of the relation between physical activity and performance on tasks that measure simple cognitive processing. The Additive

Factors Model (Sternberg, 1969) has been used by researchers to trace and isolate specific cognitive processes. This model assumes that the flow of information travels through a series of independent and serial (non-overlapping) processing stages. These stages include basic information processes such as stimulus identification, response selection, and response initiation; all of which are considered lower-level cognitive processes (Arcelin, Delignieres, & Brisswalter, 1998; Davranche & Audiffren, 2004). Results from these types of studies have lead researchers to propose that the effects of physical activity differentially influence specific stages of information processing.

Recently it has been proposed that the lack of agreement among published studies may be explained in terms of the selection of the tests used to measure higher-level cognitive functions. Proponents of the Executive Function Theory hypothesize that physical activity will result in the facilitation of performance on tasks that require executive control processes; that is, those required for planning, initiating, sequencing, and monitoring of complex goal-oriented behaviors (Royall et al., 2002). Cognitive tests that measure executive functions have been hypothesized to be influenced by both acute physical activity (Magnie, Bermon, & Martin, 2000; Hillman, Snook, & Jerome, 2003; Tomporowski, 2003) and chronic exercise training (Kramer, Hahn, McAuley, Cohen, Banich, Harrison et al., 2002).

A series of experiments have been conducted to test the Executive Function hypotheses (Tomporowski, Cureton, Armstron, Kane, Sparling, & Millard-Safford, 2005; Tomporowski & Ganio, 2005). However, the results of these studies fail to provide clear support for the Executive Function Hypothesis. Two experiments reported improvements in executive processes (Paced Auditory Serial Addition Task (PASAT)) after a short bout of moderate aerobic exercise (Tomporowski et al., 2005). A systematic replication of this study, which included measures of both executive and non-executive processes (Tomporowski & Ganio, 2005), however, failed to support the Executive Functioning Hypotheses.

The goal of the current study was to clarify the purported link between acute physical activity and specific components of cognitive function. Participants' cognitive performance was measured immediately following 40 minutes of exercise at 60% of his or her VO_{2peak}. Cognitive performance was assessed via an executive (category switch) and non-executive (short-term memory and long-term memory) tasks. Participants' performance on the tasks immediately after exercise was compared to participants' performance following a 40-minute quiet rest intervention and following a 40-minute exercise control condition.

The current study, therefore, was designed to 1) assess the effects of an acute bout of aerobic activity on cognitive function and 2) to determine whether these effects are global or if they are linked to specific cognitive processes. It was hypothesized, based on Executive Function Theory, that an acute bout of physical activity would facilitate participants' performance on elements of tasks that involve executive control, but would not facilitate participants' performance on non-executive tasks.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The beneficial effect of physical activity on mental health has been of interest to researchers for several decades. Folkins and Sime (1981) conducted a pivotal review of research assessing the effect of physical activity on mental health. The authors concluded that exercise training appeared to promote improved mental (cognitive) function during and after physical stress. They also noted that, studies that observed improvements in cognition were those conducted with geriatric mental patients and that, in general, the reviewed studies were poorly designed. A narrative review conducted by Tomporowski and Ellis (1986) evaluated 27 studies that examined the relation between chronic and acute bouts of physical activity and cognitive processes. These studies were classified into three groups on the basis of the duration and intensity of the exercise protocol. Although the authors noted that there was some evidence for improved short-term facilitative effects in response to physical activity, they concluded that the data obtained from the studies failed to provide clear support for the notion that exercise influences cognitive processes. .

Since the review by Tomporowski and Ellis (1986), several studies have been conducted to assess the relation between physical activity and cognitive processing. Etnier, Salazar, Landers, Petruzzello, Han, and Nowell (1997) conducted a meta-analytic review of research in this area. They concluded from this analysis that exercise has a small positive effect on cognitive function which equates to an improvement of one-fourth standard deviation (ES = 0.25). Effect sizes for both chronic (ES=0.33) and acute (ES = 0.16) exercise, while small, were significantly different from zero. Since the Etnier et al. (1997) review, there has been a resurgence of studies that address the relation between an acute bout of physical activity and cognitive function (see reviews by McMorris & Graydon, 2000; Brisswalter, Collardeau, & Arcelin, 2002; Tomporowski, 2003). Importantly, the majority of recent studies conducted in this area have been theory based. Currently, three approaches have been used to explain how acute bouts of physical activity may influence cognition.

Arousal Theory

Arousal theory dates back to the classic experiment conducted by Yerkes and Dodson (1908). Mice were placed in a box consisting of several compartments; one of which they were trained to enter. Arousal was manipulated via electric shock of differing intensities (high, media, and low). It was concluded that medium-level intensity shock resulted in the fastest learning. Observations of the animals' behavior suggest that performance increased with arousal up to a optimal point after which it subsequently declined (Yerkes & Dodson, 1908).

The view that there is a optimal level of stress, whether physiological or emotional, spawned several areas of research. Acute exercise has been predicted to result in an inverted U-effect on humans' performance of cognitive tasks. Lactate threshold has been used by some researchers as a method of defining exercise intensity. Lactate threshold is defined as the point at which blood lactate begins to accumulate above resting levels during exercise of increasing intensity (Wilmore & Costill, 1994). Moderate intensity aerobic exercise has been defined as physical work that is below lactate threshold, whereas heavy exercise corresponds to physical work above lactate threshold. Arousal Theory assumes that these changes in exercise intensity are associated with changes in central nervous system (CNS) arousal (Brisswalter, Collardeau, & Arcelin, 2002).

Levitt and Gutin (1971) were two of the first researchers to directly assess the effects of exercise-induced arousal on cognitve performance variables. They had particpants walk on a treadmill at workloads that elicited 80 (standing), 115, 145, and 175 beat per minute (bpm). During each of the work rates, participants performed a 5-choice response time task. Reaction time (RT) and movement time (MT) were recorded. The results indicated a inverted U-function for RT and a linear improvement in MT with increased intensity. Salmela and Ndoye (1986) conducted a similar experiment in which they examined the effects of incremental cycling on participants' performance on a 5-choice reaction time task. They, too, observed an inverted U-shaped function with reaction time being fastest at moderate cycling intensities (115 bpm) compared to rest or heavier intensity (145 bpm).

Smith and Reilly (1986) performed experiments that examined the effect of cycling at intensites eliciting 0%, 25%, 40%, 55%, and 85% VO_{2max} on psychomotor (pursuit-rotor) and cognitive (arithmatic computation) performance. Both psychomotor and cognitive performance corresponded to the inverted U-shaped function. Optimal performance of the psychomotor task was observed in response to cycling at 40%VO_{2max}, while optimal cognitive performance was observed in response to intensities lying between 25 and 75% VO_{2max}. An inverted U-shaped function has also been observed for simple reaction time tasks in response to increased pedal rate (Brisswalter, Durand, Delignieres, & Legros, 1995).

Others have assessed the relation between exercise-induced catecholamines and performance on information-processing tasks. Chmura, Nazar, and Kaciuba-Ulscilko (1994) assessed participants' performance of 5-choice reaction time task under incremental stages of cycling to exhaustion. Blood samples of lactate, epinephrine, and norepinephrine were taken between each interval. Results indicated that reaction times conformed to the inverted U-shaped function and were related to plasma catecholamines (epinephrine and norepinephrine).

Although results from these studies supported the inverted U-effect of exercise-induced arousal on cognitive performance, other studies have failed to obtain clear evidence of this type of relation. Paas and Adam (1991) examined cyclists' performance of a decision task and a perceptual task during incremental exercise. They found that, as workload increased, decision-making performance improved while performance on the perceptual task deteriorated. Delignieres, Brisswalter, and Legros (1994) had 20 expert fencers and 20 non-fencers, matched on fitness, perform a two-choice reaction time task while cycling at intensities determined to elicite 20, 40, 60, and 80% of maximal power output (MPO). They found that as intensity increased, performance on the reaction task improved for experts and deteriorated for non-experts. There was no curvilinear relation.

McMorris and Graydon (2000) conducted a review of literature that assesses the effect of incremental exercise on cognitive performance. This review describes results from a series of studies conducted by McMorris and colleagues that systematically examined the impact of exercise intensity on speed and accuracy of decision-making. These studies were similar in the methods and tests used. McMorris and Graydon (1996) developed a soccer decision-making test in which specific game scenarios were presented visually via a projector for 2 seconds and the participant was asked to choose, as quickly as possible, a viable play response. McMorris and Graydon (1996a;1996b) had experienced soccer players cycle at 70% and 100% of their MPO. In the first study (1996a), participants were tested on the soccer-specific decision-making test while they were cycling. The speed of the experienced and inexperienced players' responses and the accuracy of their choices were recorded on several trials during exercise. Results indicated that experienced players’decision-making performance during exercise to be faster than during rest; Accuracy was unaffected.

The second study (1996b) was comprised of two experiments. In the first experiment, decision-making speed on simple and complex tasks improved with exercise intensity. No effect on accuracy was observed. In the second experiment, participants were tested only on a complex decision-making test. Half were instructed to respond as quickly and accurately as possible while half were asked to just respond as accurately as possible. Their results indicated quicker respone times during MPO compared to rest. There was no effect of exercise on accuracy and no difference between instructional set. Similar results were obtained in another study conducted by McMorris and Graydon (1997). This study also included two experiments. The first experiment assessed visual search speed under rest, 70% MPO, and 100% MPO. The results revealed that performance was faster at maximal exercise compared to rest and 70% MPO. In the second experiment, the effects of exercise on speed of search, speed of decision following ball detection, overall speed of decision, and accuracy of decision were assessed. Performance during exercise was improved compared to rest.

In another study, McMorris et al. (1999) assessed the performance of male cyclists on a decision-making test during rest, exercise at adrenaline threshold, and maximal MPO. There was no effect of exercise on accuracy, but speed of decision-making was facilitated. Speed of decision-making during exercise at adrenaline threshold and max MPO did not differ.

The review of the literature led McMorris and Graydon (2000) to conclude that there was little support for the inverted U-effect on performance. The authors proposed, instead, that cognitive performance, particularly speed of processing, depends both upon the complexity of the cognitive task and on production levels of peripheral epinephrine (adrenaline threshold). A subsequent study was recently conducted to further assess the impact of peripheral catacholamine levels on decision-making performance. Nine participants performed a 4-choice non-compatible response time task following rest and during exercise at 70% and at 100% of their MPO. Reaction and movement times were the dependent variables. The results revealed a significant effect of exercise intensity on movement time. Movement time during maximal-intensity exercise was significantly faster than in the other two conditions; further, catecholamine concentrations were significant predictors of movement time. There was little support, however, for the notion that peripheral concentrations of catecholamines directly induce a central nervous system response (McMorris et al., 2003).

Energetics Theory

Energetics Theory has been used to explain the effect of acute exercise on cognitive functioning. Energetics Theory has made extensive use of methods of mental chronometry to assess the effects of an experimental manipulation on specific mental processes. Mental chronometry is based on early research conducted during the mid-ninetieth century by the Dutch physiologist F. C. Donders. He proposed a general method for measuring internal thought processes (Donders, 1868). He hypothesized that the time between the presentation of a stimulus and a motoric response could serve as the basis for inferring mental processes. A simple reaction time task requires an individual to respond to a stimulus by pressing, as quickly as possible, a corresponding key. A choice- reaction task requires a discrimination and selection of a specific response. Since simple reaction takes less time to perform than a choice reaction, the subtractive method, therefore, assumes that the remaining time provides an index of the time necessary to make discriminations and select the response. This method, therefore, provided a way to isolate each mental process so that it could be measured.

Early critics of Donders's subtractive method argued that the procedure could not guarantee the isolation of specific mental processes, however. A century later, Saul Sternberg proposed the Additive Factors Method to remedy this problem (1969). This model assumes that the flow of information travels through a series of independent and serial (non-overlapping) processing stages. These stages include basic information processes such as stimulus identification, response selection, and response initiation. The Additive Factors Model assumes that if a task consists of serial stages, it is possible to examine the degree to which specific manipulations affect each stage. This model predicts that if two variable affect different stages, their influence on overall reaction time will be additive.

Sanders (1983) proposed that the duration of processing for a stage is affected by both the physiological state of the subject and by task demands. Sanders' cognitive-energetical model proposed four serial computational stages that occur during a choice-reaction process. Each of these stages is linked to variables that can be manipulated to affect the stage by shortening or lengthening the stage duration. The stages include stimulus preprocessing (which is affected by signal intensity), feature extraction (which is affected by signal quality), response choice (which is affected by stimulus-response (S-R) compatibility) and motor adjustment (which is affected by time uncertainty). Sanders' cognitive-energetic model assumes that task demands and a persons' physiological state differentially affect specific information-processing stages.

Researchers, have proposed that physical activity may influence individual's physiological state in a manner similar to that of stimulant drugs and that both physical activity and stimulant drugs will differentially influence specific stages of information-processing (Allard, Brawley, & Deakin, 1989; Arcelin, Delignieres, & Brisswalter, 1998; Davranche & Audiffren, 2004). Studies that have assessed the impact of psychoactive drugs on individual's physiological state and subsequent mental processing provide support for the Additive Factors Model. Naylor, Halliday, and Callaway (1985) assessed the effects of methylphenidate (MPH) on stages of information processing using both reaction time and P300 latency within an AFM framework. Four doses of MPH were used in a within-subjects design to examine the effects of MPH on stimulus and response processing. The authors concluded that stimulant drugs affect the response stage of processing rather than stimulus-evaluation stage.

Norepinephrine, a major neuromodulator, which is influenced by drugs and physical activity, has also been implicated in the effect of both exercise and stimulant drugs on cognitive processes. Stimulant drugs and physical activity increase the levels of circulating norepinephrine (NE) which results in increased sympathetic drive. Stimulant drug also influence dopamine, a neurotransmitter which plays a critical role in motivation and motor functions, both which are regularly required for repeated execution of cognitive tasks. Information about increases in heart rate, blood pressure, and respiratory rate, associated with increased sympathetic activity, is relayed by peripheral afferents to the CNS. This system, therefore, is a feedback system in which information from the periphery results in subsequent changes in neurotransmitter function in the CNS.

Muscular activity signals the release of catecholamines, epinephrine (EPI) and norepinephrine (NE), from the adrenal medulla. Low levels of sustained exercise result in rapid release of NE while exercise above 60% of VO_{2max} results in a rapid increase in EPI release. NE returns to resting levels following termination of exercise while EPI stays elevated for several hours. Brain NE has been linked to phasic (transient) arousal and has been implicated in mediating perceptual responses to stimuli through its affect on response orientation and selective attention (Theirry, Mantz, & Glowinski, 1992).

Several studies have been conducted to assess the effects of exercise on specific stages of information-processing. Allard, Brawley, and Janice Deakin (1989) conducted 2 experiments to assess the effects of acute exercise on visual attention. The first experiment was designed to assess feature detection. Detection of single and conjoined targets was observed to be faster during exercise at high intensity (60% VO_{2max}) compared to rest or exercise at a lower intensity (30% VO_{2max}). Participants in the second experiment performed a letter-matching task at low (30% VO_{2max}) and high (70% VO_{2max}) intensity exercise. Observations from this experiment led the authors to conclude that exercise influences response preparation rather than encoding. Arcelin, Delignieres and Brisswalter (1998) used an Additive Factors approach to assess the effects of an acute bout of moderate aerobic exercise on information-processing stages. The aim of their study was to analyze and compare combined influences of task variables and physical activity on computational processes. Participants cycled at a moderate intensity (60% of their VO_{2max}) while performing a manual two-choice reaction task. Signal intensity, stimulus-response compatibility, and time uncertainty were manipulated. Exercise influenced performance only during the time uncertainty manipulations, suggesting that the primary influences of acute aerobic exercise are exerted during the response preparation stage of processing. They concluded from the results that moderate aerobic exercise had selective rather than general influences on information-processing.

Davranche and Audiffren (2004) replicated this study. Participants performed a choice-reaction task in which signal intensity, stimulus-response compatibility, and time uncertainty were manipulated. Participants were tested at rest and during cycling at 30% and 50% of their maximal aerobic power. Improvements from rest to exercise were seen at both intensities. No significant interaction, however, was observed between exercise and any of the stimulus variables that were manipulated. The results led the authors to conclude that the facilitating effect of exercise does not affect specific stages of information processing, as was reported in Arcelin et al. (1998); instead, improvements in reaction time are due to peripheral motor processes affected by circulating catecholamines.

Executive Function Theory

It has been hypothesized, based on the Executive Function Theory that physical activity will result in the facilitation of performance on tasks that require control processes; that is, those required for selection, scheduling, and coordination of computational processes responsible for perception, memory, and action (Kramer et al., 1999). Executive control processes are thought to be functionally distinct, resource limited, and associated with conscious awareness (Rogers & Monsell, 1995). It has also been hypothesized, based on Executive Function Theory, that physical activity will have less of a facilitative effect on tasks that do not rely on executive processing (e.g., stimulus encoding, response selection, response initiation, and response execution).

Executive functions include both attention and memory processes. Attention is a multifaceted construct that can be classified into three distinct types: focused attention, which involves selective processing of information; divided attention, which involves processing two or more sources of information; and sustained attention, which involves vigilance (Davies & Parasuraman, 1982). A classic series of papers by Shiffrin and Schnieder (1977) propose that there are two types of processing modes that mediate our performance on tasks; automatic and controlled. Automatic processes are rapid, occur in parallel and often occur without our awareness. These processes, therefore, occur with little effort. Controlled processes, however, are effortful, slower, occur in serial, and have a limited capacity of resources. Executive processing includes controlled processes of attention which can also be thought of as "higher-level" processes. It is these higher-level processes that are central to performing executive function tasks that require individuals to respond quickly and accurately to stimuli based on current goals that may vary from trial to trial (Norman & Shallice, 1986). For example, tasks that require a person to switch attention and response patterns based on rules that vary from trial to trial.

Working memory refers to an information-processing system that allows one to keep information consciously available while making it accessible for manipulation by other cognitive processes, such as attention. Baddeley (1986) hypothesized a model of working memory that consists of a central executive that regulates two slave systems. The two slave systems include the phonological loop and the visuospatial sketchpad. The phonological loop is thought to be responsible for keeping rehearsable verbal information active and readily accessible for retrieval while the visuospatial sketchpad is thought to be responsible for keeping images accessible. The role of the central executive is to perform operations required to complete a task and for keeping that task goal in mind. While working memory keeps relevant information and goals accessible, attention allows a person to select, sequence, and inhibit responses to stimuli.

Executive processes have been linked to prefrontal cortical areas. It is believed that the frontal lobe is the only cortical region capable of integrating motivational, mnemonic, emotional, somatosensory, and external sensory information into unified, goal-directed action (Royall et al., 2002). A review by Royall et al. (2002) discusses evidence from animal studies, clinical research studies, and neuroimaging studies that executive function processes are controlled by structures in the frontal and prefrontal cortical regions of the brain. A more recent review by Goethals, Audenaert, Van de Wiele, and Dierckx (2004), discusses evidence from functional neuroimaging studies in terms systems of working memory and isolated executive control processes such as updating, inhibition, attentional-shifting, and dual-task performance. The reviewed studies reported activation of the prefrontal cortex, anterior frontal cortex, ventrolateral prefrontal cortex, and dorsolateral prefrontal cortex in response to executive control tasks.

The goal of many contemporary researchers has been to determine which components of cognition (attention, short-term memory, long-term memory, or working memory) are influenced by acute physical activity interventions. Researchers and clinicians have developed several tests to measure executive processes. Two of the most widely used tests include the Wisconsin Card Sorting Test (WCST) (Berg, 1948) and the Stroop Color and Word Interference Test (Golden, 2002).

The WCST is a complex task that requires a person to match 128 cards to one of four stimulus cards on the basis of a "sorting rule" given by the examiner. The person must deduce the rule based on feedback from the examiner about his/her performance. After the person matches 10 cards consecutively, the examiner changes the rule and the person must deduce the new rule. The Stroop Test, named after the original developer, John Ridley Stroop (1935), has been used in research and clinical settings to assess executive control function. The most widely used version of the Stroop consists of three pages. The first page, the word page, consists of words red, green, and blue printed in black ink. The second page, the color page, consists of red, green, and blue colored ink printed as "XXXX". The final page, the color-word page, consisted of the words red, green, and blue printed in an incongruent color (Golden, 2002). The final page creates a cognitive interference in which the more automatic response of reading the word must be inhibited in order to report the color of the word. For example, a participant may be asked to report the color of the word "red" printed in green. Interference is calculated by subtracting the time it takes a participant to complete naming the colors on the color-word page from the time it takes the participants to name colors on the colors only page. This interference has been linked to the activation of frontal cortical areas such as the anterior cingulated cortex and is thought to be an executive control function because it requires response inhibition.

A task-switching paradigm has also been used to measure executive control processes. This paradigm employs a task that measures a participant's ability to disengage rapidly from one task and switch to another. A variant of this task was developed by Kramer and colleagues (2002). For this task, letter-number pairs are presented counterclockwise in a two by two matrix. Participants must switch from making odd/even numerical judgment when the pair is presented in the top of the matrix to making vowel/consonant judgments when the pair is presented at the bottom of the matrix. This task relies heavily on several executive processes including planning (participant's can anticipate the next location of the letter-number pair and therefore, plan a response), response inhibition (participants must inhibit the previous response pattern), decision-making, and monitoring of goal-directed actions.

Chronic exercise has been linked to improvements in cognitive performance. Kramer and his colleagues have, in a series of studies, made the case that improvements in fitness of older adults, achieved through chronic exercise training, result in selective improvements in executive control processes that include planning, scheduling, coordination, and inhibition (Kramer et al., 2002). A meta-analysis performed by Colcombe and Kramer (2003) included results from eighteen fitness intervention studies. The results of this analysis revealed that fitness training had a facilitative effect on cognition in older adults with an effect size of almost one-half standard deviation. These effects were greatest for executive and control processes, which provided support for the Executive Functioning Hypothesis.

A study by Colcombe and his associates (2003) used magnetic resonance imaging (MRI) to examine the relation between the density of grey and white brain matter and aerobic fitness in older adults. Their findings indicated that cardiovascular fitness levels significantly moderated the trajectory of age-related brain tissue loss. Specifically, older adults who had greater levels of fitness had the least grey matter loss in the frontal, temporal, and parietal lobes and the least white matter loss in the anterior and posterior white matter tracts. More recently, Colcombe, Kramer, Erickson, Scalf, McAuley, Cohen et al. (2004) conducted two experiments that demonstrated that increasing cardiovascular fitness results in increased functioning of key aspects of the attentional network of the brain during a cognitively challenging task. Specifically, highly fit or aerobically trained persons showed greater task-related activity in regions of the prefrontal and parietal cortices that are involved in spatial selection and inhibitory functioning, when compared with low-fit or non-aerobic control participants.

Acute exercise has been demonstrated to influence areas of the brain that are believed to underlie cognitive performance. Magnié et al. (2000) assessed the effects of maximal aerobic exercise on men's event related potentials (ERP's) before and after a graded VO_{2max} test. Measures of the P300 wave form were significantly larger, and latency was significantly shorter after the VO_{2max} test suggesting greater resource allocation and increased speed of information-processing. The authors concluded that acute exercise enhances general arousal. Hillman, Snook, and Jerome (2003) assessed the P300 component of ERP following exercise while participants' performed the Eriksen Flankers task (Eriksen & Eriksen, 1974). The Ericksen Task is a test purported to measure executive control functions. It requires participants to respond as quickly as possible to a stimulus cue under conditions of response conflict. For example, in this study, when 'F' was the target stimulus, participants were instructed to respond with their left index finger. When ‘X’ was the target stimulus, a right finger response was required. For the incompatible condition, the target response was flanked by the opposing target stimulus (i.e. FXF or XFX). The neutral target response was flanked by letters with no response assignment (i.e., LFL, LXL). Performance on the task was measured at baseline and when heart rate returned from normal after a 30-minute bout of submaximal, treadmill exercise. P300 amplitude was higher following acute exercise compared to baseline. Longer latencies were found for the P300 component for incompatible conditions compared to neutral conditions in the baseline session only. The authors concluded acute bouts of cardiovascular exercise affect neuroelectric processes underlying executive control through the increased allocation of neuroelectric resources and through changes in cognitive processing and stimulus classification speed (Hillman et al., 2003).

A series of studies that assess the impact of acute bouts of aerobic physical activity on young adults’ performance on cognitive tests that demand executive control processes has been conducted by Tomporowski and his associates. In the first study, participants performed two experiments that assessed the effects of a bout of aerobic physical activity on young adults’ performance of the Paced Auditory Serial Addition Task (PASAT), an executive function task that requires rapid information processing and the capability to focus on task-relevant information and to inhibit attention to distractions (Tomporowski et al., 2005). The PASAT involves presenting auditorily a random series of numbers ranging from 1 to 9, and the task is to add pairs of number such that each number is added to the one immediately preceding it. Correct performance requires a person to inhibit his or her verbal report and to attend only to the digits presented in the series. In the first study, nine young men performed the PASAT prior to and after exercising on a cycle ergometer for 40 minutes at 60% of their VO_{2max} and prior to and after rest. Performance was measured once under the influence of cold medication (Phenegran VC) and once under placebo. PASAT performance was improved after exercise compared to rest under both conditions. Unfortunately, the relation between the acute bout of exercise and performance on the PASAT was not completely clear due to a ceiling effect for the test.

In the second study, ten highly-trained women performed four exercise sessions during which they cycled for two hours, alternating 15-minute periods at power outputs designed to elicit 60% and 75% VO_{2max}. A fifth session was a non-exercise control session during which participants were allowed to leave the laboratory but were instructed not to engage in exercise or to drink beverages other than water. The PASAT was administered prior to and 30 minutes after each of the four exercise bouts and prior to and following the non-exercise period. Results indicated improved performance on the PASAT after exercise compared to rest. It could also be argued that this study did not employ a true exercise control condition since participants' activities were not controlled or monitored in the non-exercise condition.

The third study was designed as a direct test of the Executive Function hypothesis. Tomporowski and Ganio (2005) assessed the effect of 40 minutes of submaximal aerobic exercise on young adults' executive processing and memory-retrieval (non-executive) processes. Twenty-two young adults performed a Task-Switching executive processing test and a Brown-Peterson short-term memory test prior to and following cycling at 60% VO_{2max} or rest. Results indicated improved performance after exercise on the Switch Task, but not the short-term memory task. The hypothesis that physical activity influences executive function was not confirmed as performance on the Switch Task also improved after the rest period.

The goal of the current study was to clarify the purported link between acute physical activity and specific components of cognitive function. Tests designed to measure both executive (category switch) and non-executive (short-term memory and long-term memory) processes were administered prior to and after three experimental protocols. Each participant's cognitive performance was measured immediately following 40 minutes of exercise at 60% of his or her VO_{2max}. Performance after exercise was compared to performance following a 40-minute quiet rest intervention and following a 40-minute exercise control condition. The current study, therefore, was designed to (1) assess the effects of an acute bout of aerobic activity on cognitive function and (2) to determine whether these effects are global or if they are linked to specific cognitive processes. It was hypothesized, based on Executive Function Theory, that an acute bout of physical activity would facilitate participants' performance on elements of tasks that involve executive control, but have no facilitative effect on participants' performance of non-executive tasks.

CHAPTER 3

THE EFFECT OF AN ACUTE BOUT OF PHYSICAL ACTIVITY ON SPECIFIC COGNITIVE PROCESSES

Introduction

The effects of an acute bout of physical activity on cognitive function are thought to depend on the type, duration, and intensity of the physical activity. Long duration aerobic and anaerobic exercise that lead to fatigue have been predicted to impede cognitive function; whereas, bouts of aerobic exercise performed at a moderate intensity over a relatively short period have been predicted to facilitate cognitive function (Tomporowski & Ellis, 1986). Empirical studies have been conducted that directly assess the immediate after effects of an acute bout of physical activity on cognitive function. The results of these studies, however, have been ambiguous. Several researchers have reported that acute bouts of moderate intensity aerobic exercise lead to improved cognitive while others have failed to corroborate these findings (see reviews by Tomporowski, 2003; Brisswalter, Collardeau, & Arcelin, 2002)

Several explanations have been proposed to explain discrepancies reported in studies that have examined the effect of an acute bout of physical activity on cognitive function. Arousal theory hypothesizes an inverted "U" relation between arousal and performance. According to Arousal Theory, the level of physiological arousal induced by exercise of different intensities will differentially influence cognitive function. Proponents of Arousal theory predict that cognitive performance will improve to an optimum level as exercise intensity increases to a certain point, after which cognitive performance begins to deteriorate.

Other theorists explain discrepant findings in terms of the relation between physical activity and performance on tasks that measure simple cognitive processing. The Additive Factors Model (Sternberg, 1969) has been used by researchers to trace and isolate specific cognitive processes. This model assumes that the flow of information travels through a series of independent and serial (non-overlapping) processing stages. These stages include basic information processes such as stimulus identification, response selection, and response initiation; all of which are considered lower-level cognitive processes (Arcelin, Delignieres, & Brisswalter, 1998; Davranche & Audiffren, 2004). Results from these types of studies have lead researchers to propose that the effects of physical activity differentially influence specific stages of information processing.

Recently it has been proposed that the lack of agreement among published studies may be explained in terms of the selection of the tests used to measure higher-level cognitive functions. Proponents of Executive Function Theory hypothesize that physical activity will result in the facilitation of performance on tasks that require executive control processes; that is, those required for planning, initiating, sequencing, and monitoring of complex goal-oriented behaviors (Royall et al., 2002). Cognitive tests that measure executive functions have been hypothesized to be influenced by both acute physical activity (Magnie et al., 2000; Hillman et al., 2003; Tomporowski, 2003) and chronic exercise training (Kramer et al., 2002).

A series of experiments has been conducted to test the Executive Function hypotheses (Tomporowski, Cureton, Armstron, Kane, Sparling, & Millard-Safford, 2005; Tomporowski & Ganio, 2005). However, the results of these studies fail to provide clear support for the Executive Function Hypothesis. Two experiments reported improvements in executive processes (Paced Auditory Serial Addition Task (PASAT)) after a short bout of moderate aerobic exercise in two separate experiments (Tomporowski et al., 2005). A systematic replication of this study, which included measures of both executive and non-executive processes (Tomporowski & Ganio, 2005), however, failed to support the Executive Functioning Hypotheses.

The goal of the current study was to clarify the purported link between acute physical activity and specific components of cognitive function. Participants' cognitive performance was measured immediately following 40-minutes of exercise at 60% of his or her VO_{2peak}. Cognitive performance was assessed via an executive (category switch) and non-executive (short-term memory and long-term memory) tasks. Each participant's performance on the tasks immediately after exercise was compared to his or her performance following a 40-minute quiet rest intervention and following a 40-minute exercise control condition.

The current study, therefore, was designed to (1) assess the effects of an acute bout of aerobic activity on cognitive function and (2) to determine whether these effects are global or if they are linked to specific cognitive processes. It was hypothesized, based on Executive Function Theory, that an acute bout of physical activity would facilitate participants' performance on elements of tasks that involve executive control, but have no facilitative effect on participants' performance of non-executive tasks.

Methods

Participants

18 students were recruited from the Department of Kinesiology at the University of Georgia. Fourteen students were recruited from academic classes and received 2 percentage points to their final class grade for their participation in this study. The remaining participants were graduate students in the Department of Kinesiology who volunteered and did not receive any extrinsic reward for their time. The students were pre-screened by the researcher in person, via phone, or via e-mail. During the pre-screening, each individual was asked two sets of questions: 1) whether he/she would be willing to perform a test of maximal aerobic capacity and a submaximal exercise bout of 40 minutes and 2) whether he/she had a medical condition that might prevent participation (e.g., asthma, injury). A student was accepted for additional screening if he/she: 1) had no contraindications for maximal exercise (e.g., hypertension,

cardiovascular disease, and recent injury and 2) was willing to perform a maximal graded exercise test (GXT) and a 40-minute cycling ride.

Volunteers were screened a second time for eligibility during the first visit to the Cognition and Skill Acquisition Lab at the University of Georgia. Individuals were selected for participation if they were judged capable of performing continuous cycling exercise for 40 minutes and were free of any contraindications to exercise, as assessed by Medical History Questionnaire and physical activity questionnaire (Appendix A). The Medical History Questionnaire provides information about an individual's medical profile, current medications, and potential risk factors that would make it unwise for them to participate in physical exertion. The Seven-Day Physical Activity Recall was used to assess weekly time spent in moderate, high, and very high physical activities (Appendix B).

Participants ranged in age from 20 to 25 years (mean = 22.22 years; SD = 1.63). On average, women (60.72 kg ± 7.51) weighed less than men (76.00kg ± 12.25) and were shorter (166.51cm ± 8.62) than men (176.11 ± 7.41). Men had a significantly higher VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) (45.70 ± 10.13) compared to women (34.72 ± 4.04), $t = 3.02$; $p = .008$). See Appendix I. Participants' average weekly energy expenditure was similar 267.4, 272.58, and 271.53 $kcal \cdot kg^{-1} \cdot day^{-1}$ respectively across exercise-control, rest, and exercise interventions and is comparable to weekly energy expenditure of a sample of 94 college students classified as 'low active' (see Dishman & Steinhardt, 1988).

Measures

Brown-Peterson. This test provides a measure of visual short-term memory. The test was modeled on a test developed by Brown (1958) and Peterson and Peterson (1959). It consists of 1 block of 20 trigrams (e.g. KYZ). The consonant trigrams were selected from a normative list provided by Witmer (1935). To decrease the risk of a ceiling effect, trigrams with low (8 to 17%) association values were selected for the test. On each trial, a 1-second cue was presented on the center of the computer screen. This cue served as a prompt to direct the participants' visual attention and directly preceded the presentation of a trigram. The trigram was presented in 48-point arial font in the center of the computer screen for 2 seconds. Timing and presentation of cues were accurate to the millisecond and were programmed specifically for this task using SuperLabPro version 2.0 Experimental Lab Software (Cedrus Corp., 1999). The trigram was followed by one of four delay periods; immediate, 3, 9, or 18 seconds. To prevent rehearsal during the 3, 9, and 18-second delay periods, the participant was asked to count backwards by 3's from a 3-digit number that was presented in 60-point system font in the center of the computer screen. After the delay period, three question marks were presented on the computer screen which served as a visual prompt for the participants to recall and verbally report the previous trigram. The question marks remained on the screen for a 6-second period during which the participant was instructed to recall the trigram. After the 6-sec recall period, the question marks disappeared and the cue for the next trigram appeared. This procedure was repeated until twenty trigrams were presented. Short-term memory performance was defined as the number of letters recalled correctly and in the correct position.

Switch task. The switch task was a visual decision-making test similar to one developed by Kramer et al. (2002) and modified by Tomporowski and Ganio (2005). This task involved the presentation of a 2 x 2 matrix on the center of the computer screen. The participant was instructed to respond to a series of 120 letter-number pairs (e.g. A-8) that were presented individually in one of four quadrants of the matrix. The presentation of each letter-number pair occurred in a clockwise manner and was, therefore, predictable by the participants. The participant was informed that if the letter-number pair was presented in one of the top two quadrants of the 2 X 2 matrix, the number of the letter-number pair was the relevant category. The participant was asked to indicate whether the number was even or odd by pressing the corresponding key on a computer mouse. The participant was informed that if the letter-number pair was presented in the bottom of the 2 X 2 matrix, the letter of the letter-number pair was the relevant category. The participant was asked to indicate whether the letter was a consonant or a vowel by pressing a corresponding key.

Response times were recorded using SuperLabPro software which was able to record responses with 1ms accuracy for each letter-number pair. Response time scores were assessed by the methods suggested by Kramer et al. (2002). Average response time was calculated separately for trials that required making successive discriminations *within* categories (number-number/letter-letter) and trials that required making successive discriminations *between* categories (number-letter/letter-number). A switch cost was determined by calculating the difference between within (non-switch) and between (switch) response times. The stability of repeated Switch Task performance within a single session has been reported to be relatively high with intraclass correlations ranging from R = .86 - .96, n = 18 (Tomporowski & Ganio, 2005).

Free Recall. A free recall task was a visual test that was similar to that developed by Nielsen, Radtke and Jensen (1996). Seven 40-item word lists were created by selecting 280 highly concrete and imageable nouns from a normative list provided by Paivio, Yuille, and Madigan (1968). An attentional cue ("ready"), presented in the center of the computer screen, preceded the presentation of each 40-item word list. Each word from the list was presented individually in 48-point arial font on the computer screen. Words were presented in succession for five seconds each. Following the last word from the list, a 100-second consolidation period was provided. During the consolidation period, participants were allowed, but not specifically instructed, to rehearse the list. After the consolidation period, a sentence presented on the computer, instructed participants to recall as many words, in any order, as possible. Free recall was assessed for 100 seconds.

A delayed recall task was administered approximately 12 minutes later (after the completion of the Brown-Peterson and Switch tasks). During the delayed memory test, participants were given 100 seconds to recall as many words as possible, in any order, from the original list. The number of correct words recalled and the number of intrusion errors made during the immediate and delayed recall tests served as an index of free-recall memory. Words were considered correct if they were present in the to-be remembered list, with minor pronunciation errors and plural-singular substitutions ignored (Martin, Murphey & Puff, 1982). Additional information regarding free-recall was obtained by determining the number of primacy words (those presented at the beginning of a word list) and recency words (those presented at the end of a word list) recalled for immediate and delayed portions of the Free-Recall test.

Anthropomorphic Measures. Anthropometric measures were determined for each participant. Measures included height in centimeters as reported by the participant and weight in kilograms measured on a digital scale (Seca BMI Scale 882 Body Mass Index Scale, Medical Scales and Measuring Systems, Hanover, MD).

Perceived Exertion (RPE). Perceived exertion was measured using the Borg 15-point category scale (Borg, 1998). Participants were instructed to rate their perception of exertion (i.e. how heavy and strenuous the exercise feels to them) according to directions provided by Borg (1998). Participants were directed to base their perception of exertion on strain and fatigue in the muscles and feelings of breathlessness or aches in the chest. Anchors were provided for several of the points on the scale. For example, participants were told that 9 on the scale corresponded to very light exercise which would be similar to a healthy person walking at his or her own pace for several minutes. The scale ranges from 6 to 20 (9 = very light, 13 = somewhat hard, 17 = very hard, and 20 = maximal exertion).

Test of Maximal Oxygen Consumption (GXT). The participant cycled on an electronically-braked cycle ergometer (Lode BV, Goningen, The Netherlands) The GXT began with a 5-minute warm-up at 25 Watts and increased to 50 Watts at the start of the test. Wattage increased continuously at a rate of 23 Watt per minute thereafter. Respiratory gases were continuously sampled using open-circuit spirometry on a PARVO Medics TrueOne 2400 Metabolic Measurement System (Parvo Medics, Inc., Salt Lake City, UT). Heart rate (HR) was measured every 30 seconds using a Polar T61 chest strap transmitter (Polar Electro Inc, Woodbury, NY). The test was terminated when the participant acknowledged voluntary exhaustion or could not maintain the minimum cadence of 40 RPM. Verbal encouragement was given to the participant throughout the GXT, especially after the participant reported a RPE of 17 or higher. VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) was defined by the attainment of 2 out of 3 criteria: (1) RER $\geq$ 1.15; (2) rating of perceived exertion $\geq$ 18, or (3) A failure to increase with further exercise intensity (American College of Sports Medicine, 2000). The GXT were administered at room temperature (21- 23° C).

7-Day Physical Activity Recall. The 7-Day Physical Activity Questionnaire was used to calculate energy expenditure. It requires participants to report the amount of time spent sleeping, engaged in moderate, hard, and very hard activities during the prior week. Raw data from the questionnaire (hours engaged in an activity) were used to calculate energy expenditure according to methods suggested by Blair (1984).

Design

A two-way within subjects repeated measures design was employed to assess the impact of 3 interventions on cognitive performance. Measures of cognitive function were taken prior to and immediately following each intervention. Each subject attended four sessions. Session one involved the GXT and practice on the cognitive tasks. Sessions 2 through 4 were experimental sessions that were designed to assess the impact of 40 minutes of exercise, rest, and exercise-control interventions on cognitive function. The experimental sessions were counterbalanced and separated by approximately 7 days (±2). Each test session occurred at approximately the same time of day for each participant. The order of the Brown-Peterson and the Switch Task were counterbalanced across test sessions. The order of the Free-Recall test did not vary across sessions, but instead occurred in two parts, one occurring prior to the other tests (immediate recall), and the final part occurring after the other tests (delayed recall). In this study, the intervention was the primary independent variable and performance on each of the three cognitive tests was the primary dependent variable. Secondary dependent measures included blood pressure, heart rate, and VO_2 ($L \cdot min^{-1}$) associated with the exercise and control interventions.

Procedure

Session 1. The participant arrived at the Cognition and Skill Acquisition Laboratory at the University of Georgia where he/she was informed about the details and time commitment for the study. The participant was then asked to fill out the medical history form and the 7-Day

Physical Activity Questionnaire (Appendix, B). If the subject volunteered to participate, and was judged capable of performing maximal exercise, signed consent was obtained.

After consent was obtained and participants filled out the questionnaires, they were escorted to a small quiet room in the back of the laboratory used for cognitive testing. All cognitive tests were performed in this room with the participant seated approximately 2 feet in front of the computer monitor and the researcher seated directly to the right of the participant. Instructions were provided for each of the cognitive tests and the participant was asked to practice each test. The Free-Recall test (immediate recall) was always performed first and was followed by either the Switch Task or the Brown-Peterson task. The delayed recall portion of the Free-Recall test was always performed after practice for the other tests had been completed. During all practice trials, the participant was provided detailed instructions and was encouraged to stop during practice test to ask questions. The Free Recall practice trial was identical in form to the actual test. Practice on the Brown-Peterson test required participants to complete 5 pre-practice trigrams followed by one block of twenty practice trigrams. The Switch Task required the participants to practice responding to numbers and letters separately, before being presented with letter-number pairs. Seventeen pre-practice trials were performed followed by 2 blocks of 60 trials. The practice trials for the cognitive tests averaged approximately 35 minutes. The goal of the practice tests was to make sure the participant understood the requirements of each test and was comfortable, performing each of the tests. Performance was monitored on all practice tests to assure the participant understood the requirements. If it appeared that the participant was confused about the procedures or instructions for a given test, testing was stopped and clarifications were made until the participant acknowledged understanding and understanding was observed in behavioral responses.

Following completion of practice of the cognitive tasks, the participant was escorted back into the laboratory to perform the GXT. Prior to performing the GXT proper seat and handlebar height was determined, a heart rate monitor was attached, and instructions were given regarding the procedures and ratings of perceived exertion. The specific instructions are provided in Appendix E. The participant donned the heart-rate monitor, positioned himself/herself on the cycle ergometer and began the GXT. Ratings of perceived exertion were obtained every two minutes during the GXT using the Borg scale. Ratings were obtained by asking the participant to point to the number on the scale that corresponded to how they perceived their level of exertion at that time. The participant was not asked to report their perceived exertion during the test after a rating of 17 or above was reported. Immediately after cessation of the GXT test, participants were asked “what was your perceived exertion at the very end of the test?” and their responses were recorded. Approximately 5 minutes following the termination of the GXT, the participant was escorted back into the cognitive testing room where the Brown-Peterson and Switch tasks were practiced a second time. This additional practice consisted of one block of twenty trials (trigrams) for the Brown-Peterson and one block of 60 trials for the Switch Task.

Experimental test sessions. During each experimental session, the participant performed cognitive tests prior to and following a 40-minute intervention (exercise, exercise control or rest). The exercise intervention required participants to perform 40 minutes of continuous cycling. The intervention consisted of a 5-min warm-up period at a work rate determined to elicit 30% of the participant’s VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$), a 30-min period at a work rate determined to elicit 60% of his/her VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$) and a 5-minute cool-down period at a work rate determined to elicit 30% of the participant’s VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$). Heart rate was recorded every 30 seconds while measures of blood pressure, VO_2 ($L \cdot min^{-1}$) and RPE were taken during the last minute of every 5 minutes. The exercise control intervention was identical to the exercise intervention with the exception of the exercise. During the exercise control intervention, the participant sat on the cycle ergometer for 40 minutes while heart rate, blood pressure, VO_2 ($L \cdot min^{-1}$), and RPE measures were taken. During both the exercise and exercise-control interventions, a researcher was always present in the laboratory with the participant. During the rest intervention, the participant sat alone in an adjacent room while watching a 40-minute educational documentary. The participant was asked to refrain from doing school work or performing any other task during the rest intervention period. After each 40-minute manipulation, the participant was escorted back to the cognitive testing room to perform post-intervention cognitive tests. Following the final session, participants were debriefed about hypotheses made regarding the study and methodologies used in the study. At this time, information regarding cardiovascular fitness and cognitive performance was made available for participants.

Statistical analysis. Each primary dependent measure was analyzed via a 3 (intervention: exercise, control, rest) X 2 (Time: pre, post) two-way analysis of variance (ANOVA) with repeated measures. Potential sex-related differences in performance (female, male) were not assessed. An α of 0.05, moderate correlations across repeated measures ($r = 0.80$), and moderate to high effects sizes were used to determine the sample size ($n=18$) necessary to detect moderate main effects an interaction effects.

Subjects' performance on the cognitive tests across the three test sessions was examined to assess test-retest reliability and the presence of practice effects. Test-retest reliability of each measure was assessed using SPSS v.11 for windows. Intraclass correlations (ICC) were computed for each test using a two-way random consistency model. An ICC (2, k) was selected for the Switch Task since performance is based on an average measure of performance for each test. An ICC (2, 1) was selected for the Brown-Peterson and Free-Recall Tasks since both tests provide single measures of performance. One-way ANOVAs were also performed for each of the cognitive measures to determine whether test sessions had a significant effect on performance. When a main effect for session was significant for a given test, post hoc comparisons and trend analyses were performed to determine the sessions in which performance differed.

Statistical analyses were performed using SPSS v.11 for windows (SPSS, Inc., Chicago, IL). Data are reported as means ± standard deviations. Separate two-way repeated measures ANOVA were used to test the main effect of the intervention (exercise, control, rest) and time (pre/post) condition on performance on the cognitive tests. When necessary, violations of sphericity were corrected for by adjusting degrees of freedom according to the Greenhouse-Giesser test. The Bonferroni alpha correction was used when appropriate. An alpha of .05 was used for all significance tests. An analysis of interaction effects was performed on performance on cognitive tests to assess whether the effect of time differed as a result of intervention.

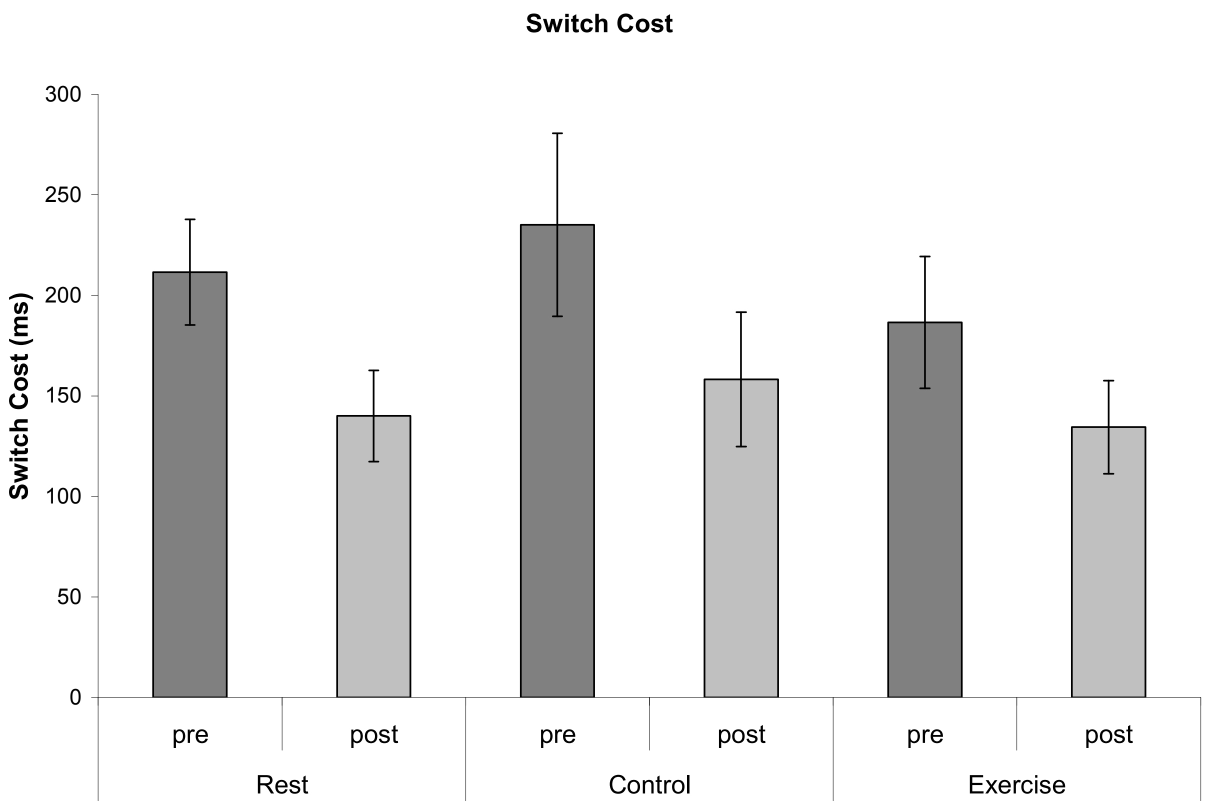
CHAPTER 4

RESULTS

Switch Task

A two-way ANOVA conducted on switch-time costs revealed a significant main effect of time (pre vs. post) on participants' performance $F (1, 17) = 27.59$; $p < .001$, $\eta^2 = .62$. Switch costs averaged across the three intervention conditions decreased from pretest (211.07 ms; ±142.05) to posttest (144.23 ms; ± 106.57). As seen in Figure 1, and the statistical summary (Appendix F), there were no statistically significant interactions among the three intervention conditions and switch-time costs. Switch-Task performance was stable ($\alpha = .88$) across test sessions. A one-way ANOVA assessing Switch Task performance across repeated testing sessions revealed that average Switch-time costs differed, $F (2,34) = 5.85$; $p = .007$, $\eta^2 = .26$. A trend analysis conducted on switch-time costs revealed a positive linear trend (RT decreased) for Switch Task performance across three test days, $F (1,17) = 12.56$; $p = .002$ $\eta^2 = .43$.

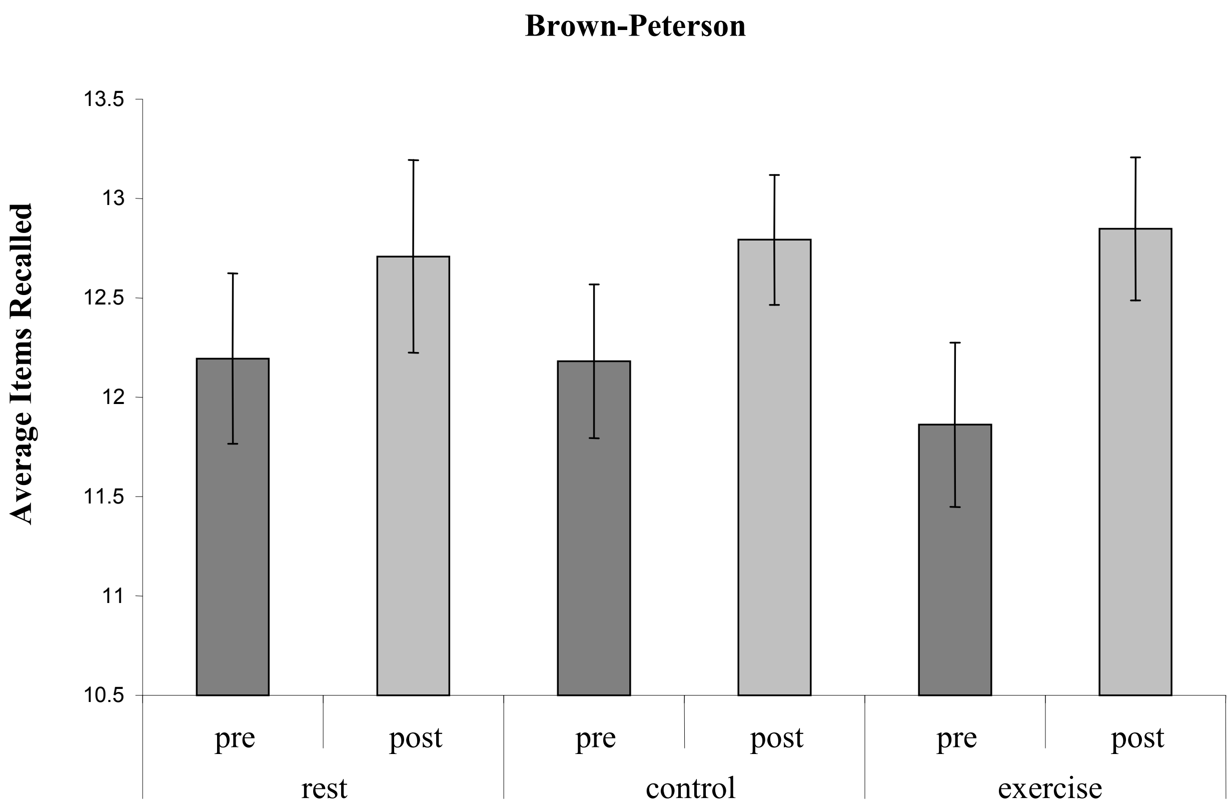
Figure 1.



Brown-Peterson Task

A two-way ANOVA of average (all delays) number of letters recalled correctly and in the correct position revealed a significant main effect of time (pre vs. post) for participants' performance on the Brown-Peterson Task, $F(1, 17) = 11.36$; $p = .004$, $\eta^2 = .40$. Participants' performance improved from pretest (12.41 ±1.69) to posttest (12.78 ± 1.61). As seen in Figure 2, and the statistical analysis (Appendix F), there were no statistically significant interactions among the three intervention conditions and short-term memory performance. An evaluation of the test-retest reliability yielded an α of .67. A one-way ANOVA revealed that performance of the Brown-Peterson Task was not influenced by practice across the three test sessions.

Figure 2.



Free-Recall Task

A two-way ANOVA conducted on the number of words recalled revealed a significant main effect of time (pre vs. post) for participants' immediate free-recall performance, $F\ (1, 17) = 7.03$; $p < .017$, $\eta^2 = .29$. Across the three intervention conditions, the average number of words recalled immediately after list presentation declined from pretest (17.63 ±6.18) to posttest (16.02 ± 6.75). As seen in Figure 3, and the statistical analysis (Appendix F), there were no statistically significant interactions among the three intervention conditions and immediate long-term memory performance. A significant main effect for time (pre vs. post) was also observed for delayed free-recall performance during the Free-Recall test, $F\ (1, 17) = 20.19$; $p < .001$, $\eta^2 = .54$. Participants' performance declined from pretest (17.24 ± 6.91) to posttest (14.74 ± 6.98). As seen in Figure 4, there were no statistically significant interactions among the three intervention conditions and overall delayed long-term memory performance. The test-retest reliability of immediate free recall performance was $\alpha = .77$ the test-retest reliability for delayed free recall was $\alpha =.75$. One-way ANOVAs conducted on free-recall memory performance across the three test sessions revealed a significant main effect for the test session for delayed free recall, $F(2,34) = 5.68$; $p = .013$, $\eta^2 = .25$. Trend analyses conducted on participants' performance across test session revealed a quadratic trend for delayed free recall, $F(1,17)= 7.95$; $p = .012$, $\eta^2 = .32$. Delayed free-recall performance improved from session one to session two and remained improved on session three. Immediate free recall performance did not vary systematically across test sessions.

Figure 3.

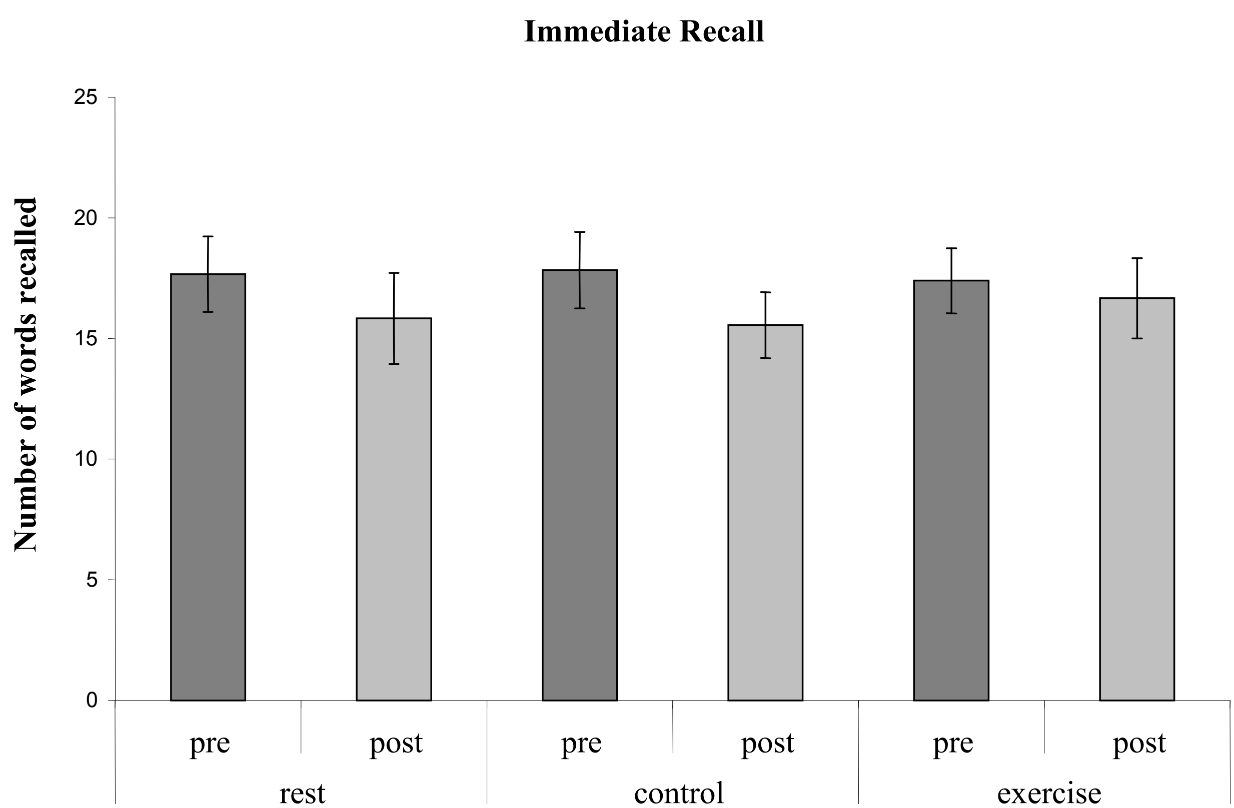
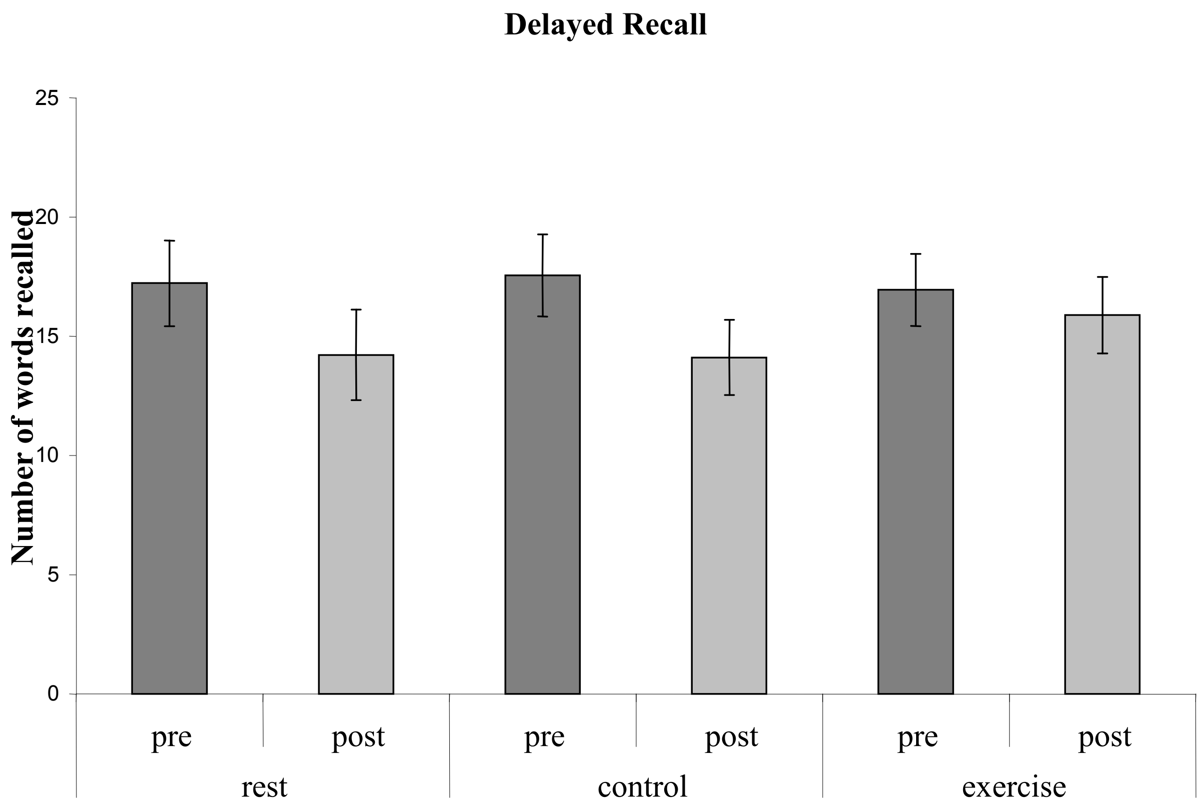
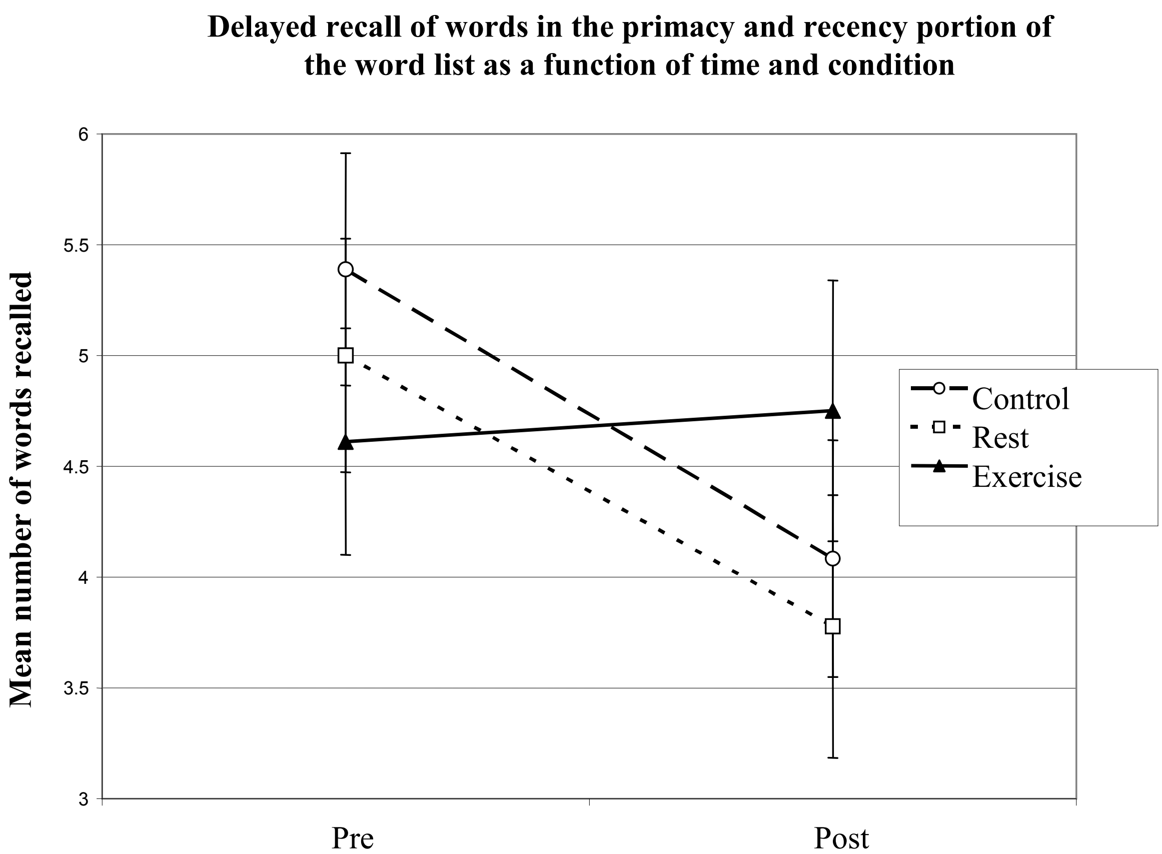


Figure 4.



There was also a main effect for delay, $F(1,17)= 9.62$; $p = .006$, $\eta^2 = .36$, in which participants' recalled more words when tested 100 seconds after list presentation (4.86, SD = 0.55) compared to a delay of approximately 12 minutes (4.60 ± 0.91). An analysis of delayed free recall as a function of serial position revealed a main effect for word position $F(1,17) = 5.66$; $p = .029$, $\eta^2 = .25$). Participants' recalled more word in the beginning, or primacy section, of the list (5.28, SD = 2.56) compared to the end, or recency section of the list (4.24± 2.03). There was also a significant interaction among time (pre/post) x condition (exercise-control, rest, exercise) x recall (immediate/delayed), $F(2,34) = 4.80$; $p = .021$, $\eta^2 = .22$. Delayed recall of words from the primacy and recency portion of the word list decreased from pre to posttest for rest and exercise control conditions and was maintained following the exercise intervention.

Figure 5.



See Appendix G for participants' physiological responses and ratings of perceived exertion under maximal exercise conditions. See appendix H for participants' physiological responses and ratings of perceived exertion under exercise-control and exercise interventions.

CHAPTER 5

DISCUSSION

This study examined the effect of an acute bout of submaximal exercise on short-term memory, long-term memory, and executive functioning processes. Comparisons were made with exercise-control and quiet rest interventions. It was hypothesized, based on Executive Function Theory, that an acute bout of physical activity would facilitate participants' performance on cognitive tasks purported to measure executive control processes (Switch Task). Further, it was hypothesized, based on Executive Functioning Theory, that an acute bout of physical activity would not influence performance on cognitive tasks believed not to measure executive control processes (i.e. Free-Recall and Brown-Peterson Tasks). A finding of the current study was a failure to detect differences in posttest performance across the three interventions (exercise-control, rest, exercise) on the Switch Task and the Brown-Peterson Task. There was, however, evidence for a facilitative effect of exercise on specific characteristics of free-recall memory. An analysis of participants' delayed free-recall performance revealed that recall of words presented at the beginning (primacy) and end (recency) portions of the word list increased from pretest following exercise but declined from pretest following exercise-control and rest interventions.

The results of the present study do not support predictions derived from Executive Function theory. There were no differences in post-test performance on the Switch Task. The current results differ from those obtained in previous studies in which an acute bout of physical activity facilitated performance on tests of cognitive function on that emphasize mental speed and decision making (Gutin & DiGennaro, 1968b; Fleury et al., 1981; Fleury & Bard, 1987;

Lichtman & Poser, 1983; Gondola, 1987; Heckler & Croce, 1992; Marriott, Reilly, and Miles; 1993; Cian, Barraud, Melin, & Raphel, 2001; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996, Tomporowski & Ganio, 2005; Tomporowski et al., 2005).

In a previous study conducted by Tomporowski et al. (2005), participants performed four exercise sessions during which they cycled for two hours, alternating 15-minute periods at power outputs designed to elicit 60% and 75% VO_{2max}. Results indicated improved performance on the Paced Auditory Serial Addition Task (PASAT), an executive functioning task, following exercise compared to a control condition. The current study differed from this previous study in three ways. First, the executive task used in this previous study differed from the Switch Task used in this study. The PASAT is purported to measure response inhibition, whereas the Switch task measures reconfiguration processes. It may be the case that the processes necessary to perform the PASAT are more sensitive to the influence of acute physical activity than are processes necessary to perform the Switch task. Second, this previous study examined performance of highly fit women, whereas the current study examined the performance of women and men of average fitness. Improvements in cognitive function as a results exercise have been observed primarily with fit individuals (Sjoberg, 1980; Heckler & Croce, 1992; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996) which suggests that a persons' fitness level may moderate the relation between acute physical activity and performance of cognitive tasks. Third, the timing of the test administration differed. The women in the study by Tomporowski et al. (2005) performed the test 30-minutes after the cessation of exercise, whereas testing in the current study occurred shortly (3-5 minutes) after the cessation of exercise. It may be the case that facilitative effects of cognition accrued from an acute bout of physical activity occur only after the immediate physiological responses to exercise return to resting levels.

The current results are similar in some ways to those obtained from the study conducted by Tomporowski and Ganio (2005) which was designed as a direct test of the Executive Function hypotheses. The results revealed an improvement in Switch Task performance after exercise. The hypothesis that physical activity specifically influences executive function, however, was not confirmed as performance on the Switch Task also improved after a rest period. The current study, which was a systematic replication of the research conducted Tomporowski and Ganio (2005), included an additional memory task and it implemented a true exercise-control condition in which participants' were monitored for 40-minutes while sitting on a cycle ergometer. Similar to the results reported by Tomporowski and Ganio (2005), acute bouts of physical activity do not conform to predictions based on Executive Functioning Theory as Switch Task performance improved from pre to posttest under all three experimental interventions.

Improved performance on the Switch and Brown-Peterson Tasks may be the result of a "time out" period since improvements were observed regardless of intervention. It has been suggested that a 'time out' period, whether it be used to perform physical activity, such as recess for children, or whether it is used for rest, results in improved cognitive performance. Similarly, a "time out" hypothesis has been proposed to explain the positive effect of acute exercise on anxiety (Bahrke & Morgan, 1978; Breus & O'Connor, 1998).

Another consideration is that the Brown-Peterson and Switch Tasks, or the processes used to perform them, are sensitive to learning. It is known that the performance of many cognitive skills and motor skills reflect both conscious effortful processes and nonconscious automatic processes (Schnieder & Shiffrin, 1977; Shiffrin & Schneider, 1977). Further, it is known that the relation between effortful processes can change with practice; particularly on tasks that have consistent mapping of stimulus response pairings (Schneider & Fisk, 1983), such as the Switch task. Practice effects are also particularly likely on memory tests (Lezak, 1995). No studies are available, however, that assess the degree to which the task sets are influenced by practice. The decreased switch costs and improved short-term memory of consonant trigrams over repeated sessions may be explained in terms of learning.

Early evidence of practice effects on performance of tasks that are thought to measure aspects of executive function (interference) may also help explain the improvements in the current study. The Stroop Color and Word Test (Golden, 2002), has been used in research and clinical settings to assess executive control function despite reports of practice effects by the original developer (Stroop, 1935) and from Jensen, 1965. Jensen (1965) reported that tests-retest correlations for interference scores, were unsatisfactory (R = .56).

Learning, or practice, effects have also been problematic for those using neuropsychological test batteries which are repeatedly administered to the same individual to assess changes in cognitive performance related to disease progression or some form of treatment (Lowe & Rabitt, 1998; Wilson, Watson, Baddeley, Emsile, & Evans, 2002. Wilson et al., (2002) provide small but consistent evidence of practice effects over 20 successive trials on tests that measure speed of information processing.

Some have suggested that tests that assess cognitive function only ‘work’ when they are novel because they usually assess an individuals’ ability to discover and apply strategies, monitor performance, and plan ahead (Lowe & Rabbit, 1998). In the current study, participants may have become more efficient at these processes through learning or practice.

A single bout of physical activity may, however, influence specific types of long-term memory. In the current study, participants’ recall for primacy and recency words was preserved following exercise compared to non-exercise control interventions. The exercise-related memory effects were specific to measures of delayed free recall. The decline in overall delayed free recall following rest and control interventions can be explained by proactive interference. Proactive interference occurs when information presented on a previous word list competes with information on a subsequent word list (Underwood, 1957). Exercise appears to have delayed the accumulation of proactive inhibition during the encoding of new words. The memory enhancing results, in response to exercise, are compatible with predictions derived from Arousal Theory.

Few studies have been conducted that assess the short-term after effects of exercise-induced arousal on memory functions. The majority of published research has employed measures of processing speed rather than memory storage (Levit & Gutin, 1971; Samela & Ndoye, 1986; Reilly & Smith, 1986; Chmura, Nazar, & Kaciuba-Ulscilko, 1994; Brisswalter, Durand, Delignieres, & Legros, 1995, Paas & Adam, 1991; Delignieres, Brisswalter, Legros, 1994, McMorris & Graydon, 1996a; 1996b; 1997; 1999; McMorris et al., 2003). The few published studies that have examined the effects of exercise-induced arousal on free-recall memory processes, are difficult to interpret. Memory performance in studies conducted by Cian, Koulamann, Barraud, Raphel, Jimenez, and Melin (2000) and Cian, Barraud, Melin, and Raphel (2001) was assessed following exercise that also induced levels of dehydration known to impede cognitive function. Free-recall memory performance was assessed by Tomporowski, Ellis, and Stephens (1986); however, they reported only the effects of exercise on immediate free recall.

There is, however, evidence that arousal will influence memory functions. Improved memory storage has been observed by researchers who have examined how physiological arousal, induced by methods other than exercise influence memory processes (e.g., administration of stimulant drugs, peripheral and intracerebroventricular administration of glucose, and electrical stimulation of the human vagus nerve).

Circulating catecholamines, such as epinephrine (Gold & McCarty, 1981), and pituitary hormones (see reviews by McGaugh, 1983; 1989) have been shown to modulate memory storage processes. Evidence obtained from animal studies implicates catecholamines in memory modulation (Martinez, Vasquez, Rigter, Messing, Jensen, Liang, McGaugh, 1980; Introini-Collison, Saghafi, Novack, & McGaugh, 1992). A study of human memory also implicates catecholamines in memory modulation. Cahill and Alkire (2003) reported improved delayed recognition memory for pictures in response to infusions of epinephrine. The effect was dose related, with higher doses of epinephrine resulting in a greater enhancement of memory.

Glucose has also been implicated in modulating memory storage. Evidence has been obtained that links changes in blood glucose to hippocampal neurogenesis (Gold, McIntyre, McNay, Stefani, & Korol, 2001). Evidence obtained from numerous studies conducted with humans supports the memory-modulating role of glucose (Lapp, 1981; Gonder-Frederick, Hall, Vogt, Cox, Green, & Gold, 1987; Manning, Hall, & Gold, 1990; Benton & Sargent, 1992; Craft, Zallen, & Baker, 1992; Manning, Parson, & Gold, 1992; Benton & Owens, 1993; Craft, Murphy, & Wemstrom, 1994; Blake, Varnhagen, & Parent, 2001).

Knowledge of memory storage processes and evidence obtained from neurophysiological research provide a rationale to explain why a bout of physical activity may influence delayed free recall performance, but not immediate free recall performance. Memory consolidation requires a series of molecular events that lead to changes in pre- and post-synaptic neuronal activity. Further, for memory consolidation to occur, it is critical that the sequencing of molecular events be timed appropriately (Routtenberg, 2001). Thus, the delay between memory encoding and memory retrieval may be critical for assessing the impact of arousal on learning. Consider that in the current study, the better recall for words from the primacy and recency portions of the word lists following exercise was observed only after a 12-minute delay between presentation and recall. Likewise, Neilsen, Radtke, and Jensen (1996) assessed the impact of arousal on both immediate and delayed free-recall and found improvements only following a 5-minute delay between study and test conditions. It can be hypothesized that improvements in memory processes will become apparent only when sufficient time is allowed for the molecular process required for memory consolidation. The exact timing of memory consolidation processes, however, remains to be determined.

Results from the current study, although, unexpected, are intriguing. It appears that memory may be influenced by acute physical activity and that these influences may be specific to delayed memory. Physiological and neurological mechanisms for improved memory in response to exercise-induced arousal remain speculative. It appears, however, based on previous research, that the timing of an arousal stimulus, the intensity of the arousal stimulus, and the timing of presentation of to-be-learned material, may all influence memory storage. It will be important for future research to focus on the effects of acute physical activity on memory storage processes in relation to physiological markers of arousal. It will also be important, in light of current results a lack of information regarding test-retest reliability of cognitive tests, for future researchers in this area to design experiments that implement appropriate control conditions and that directly assess the stability of cognitive measures over repeated trials.

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APPENDICES

APPENDIX A

Medical History Questionnaire

MEDICAL HISTORY QUESTIONNAIRE

INSTRUCTIONS: The purpose of this questionnaire is to obtain information about your medical history. It is important that you answer each question honestly and completely in order to minimize the risks associated with you participation in this research. Please ask us if you need clarification about any of the questions. Put a question mark (?) next to any question you are not certain about.

1. __________ Gender

   a. __________ If female, are you pregnant?

3. __________ Age

3. __________ Height

5. __________ Weight

6. __________ Does your mother or father have high blood pressure (i.e., hypertension)?

7. __________ Do you have, or have you ever had, any heart trouble?

8. __________ Do you frequently suffer from pains in your chest?

9. __________ Do you often feel faint or have spells of severe dizziness?

10. __________ Do you now have, or have you ever had, high blood pressure?

11. __________ Do you have a bone or joint problem, such as arthritis, that has been aggravated by exercise, or might be made worse with exercise?

12. __________ Have you ever fainted during exercise?

13. __________ Has any member of your family died of a heart attack prior to the age of 50?

14. __________ Have you ever had a seizure?

15. __________ Do you regularly smoke cigarettes?

16. __________ Do you have any pain that you have been experiencing for more than a month?

17. __________ Is there a reason not mentioned above why you should not engage in vigorous physical activity?

    If so, describe it: ____

    ____

    ____

    ____

18. _________ Are you taking any substance/s that may affect your ability to participate in vigorous physical activity (including any drugs, prescriptions, over-the-counter medications, herbal supplements, and/ or diet pills)?

19. _________ When was you last physical? _______________ Was it normal? ___________

    a. If you answered "no" , please explain.

    ____

APPENDIX B

The 7-Day Physical Activity Questionnaire

SEVEN DAY PHYSICAL ACTIVITY RECALL

INSTRUCTIONS: We would like to know your physical activity during the past 7 days. But first we will ask you about your sleep habits.

1. **On the average how many hours did you sleep each night during the last 5 weekday nights (Sunday-Thursday)? Please record to the nearest quarter-hour.**

   _______________ Hours

2. **On the average, how many hours did you sleep each night on last Friday and Saturday nights?**

   _______________ Hours

INSTRUCTIONS: Now we are going to ask you about you physical activity during the past 7 days; that is, the last 5 weekdays and last weekend, Saturday and Sunday. We are not going to talk about light activities, such as slow walking, light homework, or non-strenuous sports such as bowling, archery, or softball. Please look at the attached list (back of sheet) which shows some examples of what we consider moderate, hard, and very hard activities. Please ask us if you need clarification about any of the questions or if you are not sure whether one of your activities fits into a specific category.

3. **First, let's consider moderate activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these moderate activities and others like them? Please record to the nearest half-hour.**

   _______________ Hours

4. **Last Saturday and Sunday, how many hours did you spend on moderate activities and what did you do? Please record to the nearest half-hour.**

   _______________ Hours

5. **Now let's look at hard activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these hard activities and others like them? Please record to the nearest half-hour.**

   _______________ Hours

6. **Last Saturday and Sunday, how many hours did you spend on hard activities and what did you do? Please record to the nearest half-hour.**

   _______________ Hours

7. **Now let's look at very hard activities. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these very hard activities and others like them? Please record to the nearest half-hour.**

   _______________ Hours

8. **Last Saturday and Sunday, how many hours did you spend on very hard activities and what did you do? Please record to the nearest half-hour.**

   _______________ Hours

MODERATE ACTIVITIES

Occupational Tasks:

1. Delivering mail or patrolling on foot
2. House painting
3. Truck driving (making deliveries – lifting and carrying light objects)

Household Activities:

1. Raking the lawn
2. Sweeping and mopping
3. Mowing the lawn with a power mower
4. Cleaning windows

Sports Activities:

1. Volleyball
2. Ping Pong
3. Brisk walking for pleasure or to work (3 mph or 20 min/mile)
4. Golf (walking and pulling or carrying clubs)
5. Calisthenics exercises

HARD ACTIVITIES

Occupational Tasks:

1. Heavy carpentry
2. Construction work (doing physical labor)

Household Activities:

1. Scrubbing floors

Sports Activities:

1. Doubles tennis
2. Disco, square, or folk dancing

VERY HARD ACTIVITIES

Occupational Tasks:

1. Very hard physical labor (digging or chopping with heavy tools)
2. Carry heavy loads, such as bricks or lumber

Sports Activities:

1. Jogging or swimming
2. Singles tennis
3. Racquetball
4. Soccer

APPENDIX C

Brown-Peterson Scoring Form

BROWN-PETERSON

PARTICIPANT #: _______

SESSION ___________ DATE: __________________

TIME: ___________ TESTER: __________________

BLOCK 1

EVENT	LETTERS	DELAY	RESPONSE	SCORE
1	HJC	0	________	________
2	XGK	18	________	________
3	JCF	0	________	________
4	GXQ	9	________	________
5	QJM	9	________	________
6	TFQ	3	________	________
7	FWQ	0	________	________
8	PJZ	3	________	________
9	QXH	9	________	________
10	QDJ	3	________	________
11	ZCJ	18	________	________
12	ZWC	18	________	________
13	HFJ	3	________	________
14	QZM	0	________	________
15	GZB	9	________	________
16	QGW	3	________	________
17	FQJ	18	________	________
18	GZQ	18	________	________
19	JHW	0	________	________
20	ZKH	9	________	________

BLOCK 1 SCORES

0	3	9	18
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____

APPENDIX D

Free-Recall Scoring Form

LTM Test
DAY1_pre
Katie-thesis-05

Participant #__________
Session______________
Date____________________

	Immediate	**Delayed**
cattle	______	______
limb	______	______
friend	______	______
camp	______	______
shotgun	______	______
fox	______	______
toast	______	______
palace	______	______
flesh	______	______
meadow	______	______
automobile	______	______
army	______	______
lawn	______	______
woods	______	______
river	______	______
wheat	______	______
policeman	______	______
pepper	______	______
peach	______	______
slipper	______	______
corpse	______	______
flag	______	______
ship	______	______
building	______	______
temple	______	______
earth	______	______
jail	______	______
wife	______	______
clothing	______	______
cradle	______	______
pianist	______	______
candy	______	______
lark	______	______
library	______	______
physician	______	______
salad	______	______
sea	______	______
alligator	______	______
cattle	______	______
hospital	______	______

APPENDIX E

Borg RPE Scale

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

APPENDIX F

ANOVA summary tables by time, condition, and time by condition for performance on the Switch Task, Brown-Peterson Task, and Long-term memory Tasks (Immediate and Delayed Recall).

ANOVA summary for Switch Task Performance by condition and time
*Greenhouse-Geisser correction was used

Source of Variation	SS	DF	MS	F	Sig. of F
Condition*	23624.52	1.76	11812.26	1.411	0.258
Within + Residual	284554.46	29.99	9487.772		
Time	120617.96	1	120617.96	27.589	0.000
Within + Residual	74322.788	17	4371.93		
Condition by Time*	3082.28	1.94	1541.14	0.501	.604
Within + Residual	99542.32	30.29	3285.90		

ANOVA summary for Brown-Peterson Performance by condition and time
*Greenhouse-Geisser correction was used

Source of Variation	SS	DF	MS	F	Sig. of F
Condition*	0.34	1.84	0.18	0.196	0.806
Within + Residual	28.92	29.42	0.98		
Time	13.37	1	13.37	11.36	0.004
Within + Residual	20.01	17	1.18		
Condition by Time*	1.12	1.64	0.68	0.60	0.526
Within + Residual	31.94	30.42	1.15		

ANOVA summary for Immediate Recall Performance by condition and time
*Greenhouse-Geisser correction was used

Source of Variation	SS	DF	MS	F	Sig. of F
Condition*	2.30	1.75	1.31	0.05	0.929
Within + Residual	719.37	29.82	24.13		
Time	70.08	1	70.08	7.03	0.017
Within + Residual	160.35	17	10.02		
Condition by Time*	11.56	1.53	7.56	0.59	0.517
Within + Residual	331.44	25.99	12.75		

ANOVA summary for Delayed Recall Performance by condition and time
*Greenhouse-Geisser correction was used

Source of Variation	SS	DF	MS	F	Sig. of F
Condition*	10.02	1.83	5.47	0.22	0.782
Within + Residual	762.65	31.16	24.48		
Time	168.75	1	168.75	20.19	0.000
Within + Residual	142.08	17	8.36		
Condition by Time*	29.06	1.84	15.76	1.34	0.274
Within + Residual	367.611	31.35	11.73		

APPENDIX G

Participant responses to maximal exercise

	N	Mean	SD
VO_{2peak} (ml·kg·min^{-1})	18	40.21	9.50
Men (ml·kg·min^{-1})	9	45.70	10.13
Women (ml·kg·min^{-1})	9	34.72	4.04
VO_{2peak} (L/min)	18	2.76	0.85
Peak RER	18	1.21	0.06
Peak HR (beats·min^{-1})	18	186.67	8.35
Perceived Exertion (RPE)	18	18.94	0.43

APPENDIX H

Participant Responses to control and exercise interventions

Control Intervention				Exercise Intervention			
	Mean	SD	N		Mean	SD	N
VO_2	0.27	0.09	18	VO_2	1.62	0.49	18
RPE	6.14	0.33	18	RPE	13.84	1.29	18
HR (beats·min-1)	75.34	11.77	18	HR (beats·min-1)	141.18	13.35	18
SBP (mm Hg)	109.04	9.17	18	SBP (mm Hg)	154.07	14.85	18
DBP (mm Hg)	74.90	8.69	18	DBP (mm Hg)	71.95	5.02	18
MAP (mm Hg)	86.28	8.45	18	MAP (mm Hg)	99.33	7.46	18
				Watts	112.39	34.05	18

APPENDIX I

Participant characteristics

	N	Mean	SD
Age (years)	18	22.22	1.63
Weight (kg)	18	68.36	12.61
Men (kg)	9	76.00	12.25
Women (kg)	9	60.72	7.51
Height (cm)	18	171.31	9.23
Men (cm)	9	176.11	7.41
Women (cm)	9	166.51	8.62