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The primary purpose of the present research was to explore the dose-response relationship between acute resistance exercise intensity and cognitive performance. A secondary purpose of this study was to use directly statistical techniques to explore the role of exercise-induced arousal as a mediator of the relationship.

Sixty-eight participants were recruited and randomly assigned into rest, 40%, 70% or 100% of 10 repetition maximal (10-RM) groups. One-way ANOVA was computed for demographic variables and baseline measures, and regression analyses were computed to examine the effect of exercise intensity as well as exercise-induced arousal on cognitive performance. In addition, mediation analysis was applied to examine exercise-induced arousal as a mediator of this relationship.

The results indicated that a 30-minute bout of resistance exercise has a positive impact on both information processing speed and executive function. Specifically, there is a significant linear relationship between exercise intensity and information processing speed. On the other hand, a significant quadratic trend for both exercise intensity and exercise-induced arousal was observed for executive function measures that assess inhibition, selective attention, working memory and attentional flexibility. Exercise-induced arousal was a significant mediator when tested using one of the heart-rate indexes and for one measure of executive function performance.

Thus, an acute bout of resistance exercise benefits cognitive performance and there

is a dose-response effect of both exercise intensity and exercise-induced arousal on cognitive performance. Future research should explore other potential mediators of the relationship to further our understanding of mechanisms.

EXPLORING THE DOSE-RESPONSE RELATIONSHIP BETWEEN ACUTE RESISTANCE EXERCISE INTENSITY AND COGNITIVE FUNCTION

by

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APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

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“*Insight is the most important part of one’s thesis as well as one’s life. However, one should not only strive for insight, but also experience and enjoy the whole process during the struggl*e.”

I have written these words for my thesis a few years ago. However, I feel that I have come to a more in depth understanding of what this means only recently, now that my dissertation is finished.

I am indebted most of all to my mentor, Dr. Jennifer L. Etnier. I have truly been fortunate to study under her tutelage. While studying with her, she has been not only a great resource of knowledge and advice, but also a very influential role model for my future academic life. Her kind-hearted guidance and positive energy have been the biggest inspiration to me as I have made my way throughout the program and my dissertation. I also wish to thank Dr. Diane Gill for her crucial advice in helping me to complete the program and my dissertation in addition to her choosing to accept me as a doctoral student a few years ago. Her diligent work ethic and devotion to the advancement of academic knowledge are exemplary of what makes a great professor.

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CHAPTER I

INTRODUCTION

Cognitive ability, which includes the functions of perception, learning, remembering, reasoning, problem solving, decision making and communicating (Herrmann, Yoder, Gruneberg, & Payne, 2006), is important for daily living and is a main component of health-related quality of life (Lox, Ginis, & Petruzzello, 2006). However, cognitive ability declines with age as evidenced by the deterioration of memory, information processing speed, and reasoning, beginning in early adulthood (Salthouse, 2003, 2004).

Fortunately, research indicates that the rate of age-related cognitive decline varies. Using a linear structural- relations modeling technique, research indicates there are at least four endogenous model variables that can predict cognitive change with advancing age. These endogenous variables are education, strenuous activity, peak pulmonary expiratory flow rate, and self-efficacy. Of these variables, physical activity has received particular attention. This is likely because physical activity, as a lifestyle behavior, has been linked to a variety of health outcomes including the improvement of cardio-respiratory ability, health-related physical fitness, personal enjoyment, health-related quality of life, and the reduction of coronary heart disease, obesity, Type II diabetes and all cause mortality (Kesaniemi et al., 2001; Pate et al., 1995).

Research designed to examine the relationship between physical activity and cognition includes studies examining the effects of both acute and chronic physical exercise on cognition. Narrative and meta-analytic reviews tend to support a positive relationship between acute physical exercise and cognitive performance (Brisswalter, Collardeau, & Arcelin, 2002; Etnier et al., 1997; McMorris & Graydon, 2000; Tomporowski, 2003) and between chronic physical exercise and cognitive performance (Colcombe et al., 2003; Etnier et al., 1997; Hall, Smith, & Keele, 2001; Heyn, Abreu, & Ottenbacher, 2004). The relationship between acute exercise and cognition has received particular attention as researchers have attempted to identify the effects of a single bout of exercise on cognition. Etnier et al. (1997) conducted a meta-analysis on the relationship between physical activity and cognition. In this review, nearly 200 studies were analyzed, and 134 effect sizes were calculated. The effect size for acute exercise on cognitive performance was 0.16, which demonstrated a significant small positive effect of acute exercise on cognitive performance.

Although a positive relationship between acute physical exercise and cognition was demonstrated meta-analytically, narrative reviews provide a clear indication of the conflicting nature of the results of individual empirical studies. One approach that has been used by many narrative reviewers is to categorize the research based upon the design of the study as those comparing cognitive performance: a) at rest versus at maximal exercise intensity; b) at rest versus at single sub-maximal exercise intensity, and c) with several different exercise intensities.

Several studies have been designed to compare cognitive performance at rest with cognitive performance at maximal intensity. Most of these studies define maximal exercise intensity as the point at which voluntary exhaustion is achieved. Results from studies using this approach are ambiguous. Some research indicates that there is no maximal exercise effect on cognitive performance (Bard & Fleury, 1978; Chmura, Nazar, & Kaciuba-Uscilko, 1994; Fleury, Brad, Jobin, & Carriere, 1981; Tomporowski, Ellis, & Stephens, 1987; Travlos & Marisi, 1995), whereas other research shows either an impairment effect (Fery, Ferry, Vom-Hofe, & Rieu, 1997; Isaacs & Pohlman, 1991; McMorris, 1995; McMorris & Keen, 1994; Wrisberg & Herbert, 1976) or demonstrates a mixed effect (Fleury & Brad, 1987; Gutin & DiGennaro, 1968; Hancock & McNaughton, 1986; McMorris & Graydon, 1996a, 1996b, 1997a, 1997b; McMorris et al., 1999; McMorris, Tallon, & Williams, 2003). Generally speaking, although results are conflicting, research tends to demonstrate that maximal intensity exercise has a negative or limited positive effect on cognitive performance.

When comparing cognitive performance at rest to a single sub-maximal exercise intensity, the results of this literature are also equivocal. Several studies indicate there is a positive effect of sub-maximal exercise on cognitive performance using choice reaction time (Arcelin, Brisswalter, & Delignieres, 1997; Gondola, 1987) or pre-frontal dependent measures of cognitive performance (Lichtman & Poser, 1983; Tomporowski et al., 2005). However, the majority of these studies report a combination of effects, with some reporting both positive and negative effects, others reporting positive effects and negligible effects, and still others reporting negative and negligible effects on cognitive performance (Adam, Teeken, Ypelaar, Verstappen, & Paas, 1997; Arcelin, Delignieres, & Brisswalter, 1998; Cian, Barraud, Melin, & Raphel, 2001; Cian et al., 2000; Davranche, Burle, Audiffren, & Hasbroucq, 2005, 2006; Dietrich & Sparling, 2004; Fery et al., 1997; Fleury & Brad, 1987; Heckler & Croce, 1992; Hillman, Snook, & Jerome, 2003; Hogervorst, Riedel, Jeukendrup, & Jolles, 1996; Marriott, Reilly, & Miles, 1993; Paas & Adam, 1991). Exercise intensity is recognized as a potential moderator of the relationship between acute exercise and cognitive performance and thus provides a likely explanation for the conflicting results. When using a moderate intensity exercise protocol (40% to 60% of the participant's $VO_{2\ max}$, maximal aerobic output, or maximal heart rate) with duration from 20 to 60 minutes, most research supports a positive effect for the relationship.

The third approach in addressing this relationship is to test the effect of incremental changes in exercise intensity on cognitive performance. The purpose of these studies is not only to demonstrate the effect of exercise on cognitive function, but also to depict the dose-response nature of the relationship. In addition, potential underlying mechanisms induced by exercise (i.e., heart rate, arousal, and plasma catecholamines) have been indirectly examined to further our understanding of mechanisms that potentially underlie the dose-response relationship. This idea of using the relationships between exercise-intensity and cognitive performance and between arousal and cognitive performance was originally used in the psychology literature. In this literature, drive theory and the inverted-U hypotheses have been proposed to explain the linear or inverted-U dose-response relationship between increasing arousal levels induced by external stimuli such as caffeine, heat, or audience and cognitive performance (Humphreys & Revelle, 1984). When relationships with cognitive performance were observed for the external stimulus and for the measures of arousal, conclusions regarding mediation were drawn. Similarly, in the exercise psychology literature, physical exercise results in increasing arousal and some studies have reported a relationship between increasing exercise intensity or exercise-induced arousal and cognitive performance and have used these to draw conclusions on mediation (Aks, 1998; Arent & Landers, 2003; Brisswalter, Durand, Delignieres, & Legros, 1995; Chmura et al., 1994; Levitt & Gutin, 1971; McMorris & Graydon, 2000; Reilly & Smith, 1986; Salmela & Ndoye, 1986; Tenenbaum, Yuval, Elbaz, Gar-Eli, & Weinberg, 1993).

In addition to the drive theory and the inverted-U hypothesis, Easterbrook's cue utilization theory of attention and the plasma catecholamine hypothesis have been proposed to explain the effects of acute exercise on cognitive performance. These two hypotheses also predict a dose-response relationship between exercise intensity and cognitive performance, and they also pose that attention and plasma catecholamines underlie the relationship. Based on Easterbrook's study (1959), both exceedingly high and low arousal following exposure to a stressor (i.e., exercise) is predicted to result in a loss of attentional flexibility. In terms of the plasma catecholamine hypothesis, Chmura et al. (1994) indicated that an inverted-U dose-response was found, not only between incremental exercise work load and reaction time, but also between plasma catecholamines and reaction time. Moreover, the optimal cognitive response was found at 75% $VO_{2\ max}$, which significantly exceeded the blood lactate and plasma adrenaline thresholds. Similarly, McMorris and his colleagues (2003) have also demonstrated the relationship between peripheral concentrations of catecholamines and cognitive performance, where participants exercising above adrenaline threshold had significantly higher speeds of performance.

While the benefits of exercise and potential mediators on cognition have been proposed, most of the previous studies have used continuous exercise modalities, such as jogging or cycling (Brisswalter et al., 2002; McMorris & Graydon, 2000; Tomporowski, 2003), and to date only one published study has examined the acute effects of resistance exercise on cognitive performance (Chang & Etnier, in press).

Resistance exercise, an exercise type recommended in the American College of Sports Medicine guidelines in 1990, is an important mode of exercise because it benefits at least three main components of health-related physical fitness (Buckworth & Dishman, 2002). In addition, it also provides a protective effect against some health-related diseases such as osteoporosis, low back pain, hypertension, diabetes, and blood lipids (Kraemer, Ratamess, & French, 2002; Winett & Carpinelli, 2001).

As already described, exercise-induced arousal and plasma catecholamines are recognized as the most likely potential mechanisms for explaining the relationship between acute aerobic exercise and cognitive performance. Importantly, several studies have indicated that acute resistance exercise can induce arousal via the same mechanisms that have been proposed to underlie an acute exercise and cognitive performance relationship, e.g., heart rate (Bloomer, 2005; Rezk, Marrache, Tinucci, Mion Jr, & Forjaz, 2006) and plasma catecholamines (French et al., 2007; Pullinen, Nicol, MacDonald, & Komi, 1999; Ramel, Wagner, & Elmadfa, 2004). Therefore, it is logical to expect resistance exercise to also provide benefits to cognition. Further, Chang and Etnier (in press) recently provided evidence that an acute bout of resistance exercise has a positive impact on automatic cognitive processes and on particular types of executive function in middle-aged adults.

Given that past acute exercise studies have focused exclusively on continuous exercise modalities, the relevance of resistance exercise to healthy lifestyles, the fact that resistance exercise impacts similar physiological systems (arousal and plasma concentrations of catecholamines), and the fact that benefits of resistance exercise on cognition have been found, it is important to further explore the effects of resistance exercise on cognitive performance.

A second limitation of the extant literature is that although potential mediators between exercise intensity and cognitive performance have been proposed, the approaches that have been used to statistically test these variables as mediators have not been sufficient. A frequently used approach to test the most commonly-proposed mediator (i.e., exercise-induced arousal) in the exercise-cognitive field is analysis of variance (ANOVA) (Aks, 1998; Allard, Brawley, Deakin, & Elliott, 1989; Cote, Salmela, & Papathanasopoulu, 1992; Davranche & Audiffren, 2004; Deary, Langan, Hepburn, & Frier, 1991; Delignieres, Brisswalter, & Legros, 1994; Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo, Nishihira, Hatta, Kaneda, Wasaka et al., 2004; McMorris, 1995; McMorris & Graydon, 1996a, 1996b, 1997a, 1997b; McMorris et al., 2003; Reilly & Smith, 1986; Salmela & Ndoye, 1986). A few studies have reported the results of simple regression analyses that test the ability of the mediator to predict cognitive performance (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Reilly & Smith, 1986). However, Baron and Kenny (1986) indicated that an ANOVA provides only a limited test of mediation and that a series of regression models are needed to appropriately test for mediation. To date, there is no published research in the acute exercise and cognition area in which mediation analysis has been undertaken to actually statistical test the mediation processes. Etnier (2007) further indicated that applying mediation analysis to test mediators is the next step to furthering our knowledge about the relationship.

In addition to the exercise modality and mediatonal questions, the issue of the effects of task specificity should be further addressed in understanding the relationship. Data collected by Arent and Landers (2003) led them to conclude that the linear facilitation might be more appropriate for explaining the exercise intensity-performance relationship for the components of a task that require more motor or peripheral processes. Whereas the inverted-U hypothesis might be appropriate for explaining the exercise intensity-performance relationship for the components of the task that require greater cognitive or central processes. Using fractionated reaction time, these results were recently confirmed for both simple and choice response time tasks (Chang, Etnier, & Barella, in press). Colcombe and Kramer (2003) further indicated that although chronic exercise facilitated four different types of cognitive functions (executive-control, controlled-processing, visuospatial, and speed), the greatest exercise effect was found on executive-control processes (effect size = 0.68), a type of higher cognitive function.

Executive-control processes, also known as executive function, are generally described as “higher level” or “meta” cognitive functions (Alvarez & Emory, 2006;

Baddeley, 1986; Salthouse, 2007). In the physical activity literature executive function is often described as behaviors involving planning, task coordination, initiation and stopping of behaviors, and processing of semantic information (Kramer et al., 1999). Although a positive relationship between chronic exercise and executive function has been found, to date most acute physical activity studies have examined the exercise intensity-performance relationship using reaction time tasks (Arcelin et al., 1997; Chmura et al., 1994; Davranche et al., 2005; Fleury & Brad, 1987; Hogervorst et al., 1996; McMorris, 1995; McMorris & Keen, 1994; McMorris et al., 2003; Travlos & Marisi, 1995) and visual recognition tasks (Bard & Fleury, 1978; Fleury et al., 1981). Only a few studies have examined the effect of acute exercise on executive function (Dietrich & Sparling, 2004; Hogervorst et al., 1996; Lichtman & Poser, 1983; Sibley, Etnier, & Le Masurier, 2006; Tomporowski et al., 2005). Therefore, the effects of acute exercise on executive function remain uncertain.

Summary

A substantial amount of research has been conducted to test the relationship between acute exercise and cognitive performance. This literature has been summarized using both narrative and meta-analytic techniques. The results generally indicate that a positive effect on cognitive performance is found when comparing submaximal exercise to rest or when examining dose-response relationships at several submaximal levels of exercise. However, most research studies have used an aerobic exercise condition and have not considered the potential for an acute bout of resistance exercise to evidence similar benefits. Given the importance of resistance exercise to health and that resistance exercise might benefit cognitive performance in a manner similar to aerobic exercise because both forms of exercise have an effect on arousal and on plasma catecholamines, further research examining the relationship between acute resistance exercise and cognition could play a vital role in the advancement of our knowledge. In addition, given that past studies have only used indirect approaches to test mediators, a secondary purpose of this study is to apply statistical techniques to actually test mediational processes. Lastly, most studies in the area of acute exercise and cognition have tested the effects on simple cognitive tasks. Thus, this study will extend the literature by including measures of executive function.

Purpose

The primary purpose of the present research is to explore the effect of acute resistance exercise intensity on cognitive function. More specially, the dose-response relationship between acute resistance exercise and cognition was examined via four different resistance exercise intensities (rest, 40%, 70% and 100% of 10-RM). A secondary purpose of this study is to use appropriate statistical techniques to test the role of heart rate and subjective arousal as mediators of the relationship between exercise intensity and cognitive performance.

Specific Research Questions and Hypothesis

The specific research questions and hypotheses are as follows:

1. *Research Question # 1.* What is the dose-response relationship between exercise intensity and exercise-induced arousal via heart rate (HR), ratings of perceived exertion (RPE), or subjective assessments of arousal (Felt arousal scale, FAS) and

mood (Feeling scale, FS)?

Hypothesis # 1. An acute bout of rest, 40%, 70% or 100% of 10 repetition maximal (10-RM) resistance exercise will result in increasing levels of arousal as assessed using HR, RPE, FS, and FAS. In addition, a linear dose-response relationship is anticipated.

2. *Research Question # 2.* What is the dose-response relationship between exercise intensity (rest, 40%, 70% or 100% of 10-RM resistance exercise) and cognitive performance?

   Hypothesis# 2. An acute bout of rest, 40%, 70% or 100% of 10-RM resistance exercise intensity will impact cognitive performance via assessments of Stroop Test and Paced Auditory Serial Addition Task (PASAT). In addition, either a linear or an inverted-U dose-response relationship is anticipated.

3. *Research Question # 3.* What is the dose-response relationship between exercise-induced arousal (as indexed by HR and FAS) and cognitive performance?

   Hypothesis# 3. Resistance exercise-induced arousal (as indexed by HR and FAS) will impact cognitive performance via assessments of Stroop Test and PASAT. In addition, either a linear an inverted-U dose-response relationship is anticipated.

4. *Research Question # 4.* Does arousal (as indexed by HR and FAS) mediate the relationship between exercise intensity and cognitive performance?

   Hypothesis# 4. HR and FAS are anticipated to be mediators of the relationship between exercise intensity and cognitive performance.

CHAPTER II

REVIEW OF THE LITERATURE

Cognition and Cognitive Decline

The term “cognition” comes from the Latin word *cognoscere* which means “to know”. The process of cognition or knowing is recognized as the cognitive processes which include the functions of perception, learning, remembering, reasoning, problem solving, decision making, and communicating (Herrmann et al., 2006). These cognitive functions not only occupy important roles for daily living, but also play a main component in health-related quality of life (Lox et al., 2006).

As important as its status is, however, cognitive ability declines with age. Surprisingly, the deterioration of cognitive ability is not found exclusively in the older population. In fact, in early adulthood, probably somewhere in the 20s, cognitive decline begins to appear (Salthouse, 2003, 2004). Salthouse (2003) indicates a similar age-related cognitive decline pattern in memory after the age of twenty. The memory function has been assessed by the Wechsler Memory Scale III using eight different criteria: immediate logical memory, delayed logical memory, immediate arbitrary pairs of words, delayed arbitrary pairs of words, immediate face recognition, delayed face recognition, immediate work recall, and delayed work recall. Although memory can be assessed in other ways, the results demonstrate strongly that age-related memory decline starts earlier than expected.

In addition to memory loss, Salthouse (2004) indicates that cognitive decline can also be found in speed (duration of comparing pairs of lines patterns) and reasoning (based on scores by Raven’s Progressive Matrices). Based upon the literature reviews, five important observations related to age-related cognitive decline are cited. First, vocabulary tests are the only measurement which improves with increasing age. The plateau is found to be in the mid-50’s. Secondly, correlations between age and speed, reasoning, and memory are found to be -0.47, -0.48, and -0.43 respectively which are considered to be moderate correlations. Lastly, although cognitive decline accelerates after the age of 50, age-related decline appears to begin at age 20.

Fortunately, research demonstrates that the rate of age-related cognitive decline varies across individuals (Albert et al., 1995). Rowe and Kahn (1997) indicates that people who experience better health and cognition as they age are identified as the “successful aging” group. Using a linear structural relations modeling technique, data indicates there are at least four potential endogenous model variables that predict cognitive change. These are education, strenuous activity, peak pulmonary expiratory flow rate, and self-efficacy (Albert et al., 1995).

Of particular interest is that physical activity is one of these factors. This is important because physical activity is a lifestyle behavior that can be modified. Physical activity has not only been shown to improve cardio-respiratory ability, health-related physical fitness, enjoyment, health-related quality-of-life but also to reduce the incidence of coronary heart disease, obesity, type-two diabetes and all causes of mortality (Kesaniemi et al., 2001; Pate et al., 1995). In addition, physical inactivity is associated with most of the major health problems that include heart disease, diabetes, osteoporosis, and negative psychological conditions such as depression and anxiety (U. S. Department of Health and Human Services, 1996).

Acute Physical Exercise and Cognition

Physical exercise is recognized as one of candidates in the improvement of cognitive performance and in the prevention of the deterioration of cognitive ability. In fact, the relationship between physical activity and cognitive performance is a main issue in both sport and exercise psychology fields. Although the results of the considerable amount of empirical studies have not yet been consistent, a positive relationship between physical exercise and cognitive performance has been reported in reviews using both narrative and meta-analytic techniques (Brisswalter et al., 2002; Colcombe & Kramer, 2003; Etnier et al., 1997; Hall et al., 2001; Heyn et al., 2004; McMorris & Graydon, 2000; Tomporowski, 2003)

Meta-Analytic Reviews

Findings from individual research studies are often conflicting and diverse which results in narrative reviewers categorizing studies as demonstrating positive effects, detrimental effects, both beneficial and deleterious effects, and no effects (Brisswalter et al., 2002; McMorris & Graydon, 2000; Tomporowski, 2003). These conflicting results make it very difficult for narrative reviewers to draw any conclusions from the extant literature.

In order to solve this problem, meta-analytic techniques have been used (Glass, 1977). Meta-analysis is a quantitative procedure which is used to quantify, integrate, analyze, and summarize numerical research results across many studies (Salazar, Petruzzello, Landers, Etnier, & Kubitz, 1993; Thomas & French, 1986). There are several advantages of using meta-analysis (Salazar et al., 1993; Thomas & French, 1986). First of all, the idea of meta-analysis is to collect all of the literature, both published and unpublished, or of a similar quality of literature, which reduces the bias of selecting research data subjectively by the reviewers. Secondly, meta-analysis makes it relatively easy to deal with a large number of studies and can establish a data bank of the topics under review. Thirdly, meta-analysis uses an objective system to code each studies' characteristics such as the independent and dependent variables. Fourth, meta-analysis uses a statistical tool to analyze and integrate the effects. Next, meta-analysis is able to provide the magnitude of the effect size relative to a particular moderator.

Although several meta-analytic reviews have examined the relationship between physical activity and cognition (Colcombe & Kramer, 2003; Etnier et al., 1997; Heyn et al., 2004), Etnier and her colleagues (1997) conducted the first meta-analysis which focused on both acute and chronic physical activity. Based upon her review, nearly 200 studies had been examined and 134 effect sizes were calculated. The overall effect of physical activity on cognition was 0.25 (SD = 0.6), and 0.29 (SD = 0.63) after adjustment, which was also significantly different from zero. The results suggested that physical activity had a benefit on cognitive performance by 0.25 standard deviation. Furthermore, the effect sizes for acute exercise, chronic exercise, study with cross-sectional designs, and mixed design were at 0.16 (n = 371), 0.33 (n = 358), 0.53 (n = 117), and 0.54 (n = 6), respectively. All of these effect sizes were significantly different from zero.

In terms of acute physical activity, several moderators had been identified. The top three largest effect sizes, based on sampling methods as a moderator, were random sampling (0.65), intact group (0.50) and random stratified (0.47) when compared to that of volunteer (0.13), not reported (0.13) and other (-0.08). Studies with four threats to internal validity demonstrated a larger effect (1.76) when compared to one, two, or three threats to internal validity (0.23, 0.21, and 0.13, respectively). In terms of cognitive test category, the top three effect sizes were studies that used motor skills (1.47), academic achievement (1.23) and a mixed bag of tests (1.20). Both of the largest effect sizes, in terms of the group's size,was found at 0.61 for a group with more than twenty people and the smaller group (between eleven to twenty people). Lastly, the effect size in a study with a mixed gender design (0.70) was better than only male (0.03) and only female (0.14) participants.

Performance At Rest Versus At Maximal Exercise Intensity

One of the parameters that has been used when addressing the relationship between acute physical activity and cognitive performance is a comparison of rest versus maximal exercise intensity conditions. In this protocol, most studies define maximal exercise intensity as conducting aerobic exercise until voluntary exhaustion, using either a bicycle ergometer (Bard & Fleury, 1978; Travlos & Marisi, 1995) or a treadmill (Chmura et al., 1994; Fleury et al., 1981). Since there are equivocal results between rest and maximal exercise intensity conditions, the following section will discuss these results of no effect, impairment, and mixed effect.

No effect. In an early study, Bard and Fleury (1978) had examined the effect of voluntary cycling to exhaustion on different components of visual capacity (visual search task, visual field task, and coincidence timing). The results indicated that, after maximal exercise, none of the visual performance measures changed significantly. Two series of experiments were conducted by Tomporowski et al. (1987). In the first study, 24 adults ran on a treadmill at 80% VO2max until exhaustion. A cognitive task, free recall memory, was taken by participants after the exercise. In the second study, 12 highly fit adults conducted a similar exercise and cognitive protocol as in experiment 1, and the results were further compared to the twelve adults from the first experiment. Data from both experiments showed no exercise effect on free-recall memory.

Similar to Tomporowski et al. (1987), Travlos and Marisi (1995) used a similar exercise protocol that examined the exercise effect on two different types of cognitive function. The results indicated there was no significant change on both the reaction time and random number-generation indexes after an acute strenuous exercise intervention. Upon further analysis, the study also stated that the fitness level might be independent of exercise and cognitive performance since there was no significant difference between the low or high fitness groups.

Fleury et al. (1981) assessed the effects of three different treadmill protocols (sprint condition, anaerobic running and endurance running) on visual detection tasks. The data showed that none of the exercise treatments impacted the visual detection task, and that fitness did not moderate the relationship. Using choice reaction time, Chmura et al. (1994) indicated that the maximal intensity exercise had a limited impact when compared to the rest condition. However, these authors used a dose-response design and were able to identify that faster reaction time was found at 75% VO2 max/Heart rate (164 beats/min condition), where the threshold of blood lactate and plasma adrenaline was reached.

Impairment effect. Unlike the afore-mentioned research, several studies found an impairment effect of acute maximal exercise on cognitive performance (Fery et al., 1997; Isaacs & Pohlman, 1991; McMorris, 1995; McMorris & Keen, 1994; Wrisberg & Herbert, 1976). Fery et al. (1997) recruited 13 healthy and fit college-aged males to perform a series of short-term memory tests with pedaling until exhaustion as an exercise protocol. In addition, two levels of task difficulty (4 consonant set vs. 7 consonant set) and two time points (a constant workload session/30% VO2max and a progressive workload session to exhaustion) were conducted in the experiment. The results indicated a negative effect of the progressive workload session on both measures of cognitive performances.

Isaacs and Pohlman (1991) used cycling to 100% VO2max as the exercise protocol and asked participants to complete a coincidence timing task at the highest intensity condition. Results showed an impairment in performance, but the impairment was small and transitory. Wrisberg and Herbert (1976) assigned participants to one of three test groups, 1) control condition, 2) local fatigue condition (three maximal static contractions with right shoulder horizontal flexors) or 3) general fatigue condition (treadmill running). The results indicated that both local fatigue and general fatigue conditions resulted in a transitory impairment on the coincidence timing performance.

Two studies conducted by McMorris's lab (McMorris, 1995; McMorris & Keen, 1994) examined the relationship using three exercise intensities as the exercise protocol: rest, 70% cycling maximal workout, and a 100% cycling maximal workout. The data showed that a significant decrease in performance was found between the 100% cycling maximal workout versus the other two conditions (McMorris & Keen, 1994).

Mixed effect. Using four different exercise protocols (anaerobic alactacid, anaerobic alactacid, sub-maximal aerobic, and maximal aerobic effort), Fleury and Bard (1987) indicated a significant improvement in sensory tasks in all four types of exercise conditions. There was also an improvement on sensory motor task performance that followed the progressive maximal and anaerobic alactacid efforts. However, after maximal aerobic exercise, there was a significant reduction in recall on the central vision task.

Gutin and DiGennaro's (1968) data examined the effect of exhaustion from running on an arithmetic accuracy and speed. Seventy-two participants were categorized into three groups depending upon their fitness level for the examination of the potential moderator within the relationship. The results indicated no significant difference in speed and an impairment in accuracy following the exhaustive exercise condition. Fitness did not moderate the effect. Hancock and McNaughton (1986)'s data demonstrated that, after conducting a treadmill run to anaerobic threshold within three minutes, symbol interpretation performance was impaired, but short-term memory and time estimation performance improved.

McMorris and his colleagues conducted a series of experiments that used a cycling protocol and a soccer decision making test. Male soccer players, both experienced and inexperienced, were recruited in most of these studies. Generally, the exercise protocol was conducted in two different sessions. In the first session, the participants were instructed to ride a bicycle to assess maximal power output (MPO). In the second session, the participants were instructed to do a cognitive task at rest, exercise at 70% MPO, and then again at 100% MPO. In terms of the cognitive task, the researchers used questions related to soccer decision-making. Following the exercise session, the participant was asked to provide a vocal response in four different choices (pass, shoot, dribble, or run), and scores of speed and accuracy of choice were recorded for cognitive performance.

McMorris and Graydon (1996a) found a significant improvement in response speed for both the experienced and inexperienced soccer players following the exercise protocol. However, there was no significant difference in performance between the three exercise intensity conditions. To explain the lack of a dose-response effect, McMorris and Graydon suggested that since participants were performing at a high level of accuracy, a ceiling effect might have occurred making it difficult to observe dose-response effects.

In order to test this ceiling effect, McMorris and Graydon (1996b) conducted a second study in which they manipulated the task complexity, and two experimental designs were implemented in the research study. The first experiment replicated the previous study by McMorris and Graydon (1996a) and in the second experimental design the instructor gave these participants an additional verbal instruction that was related to either speed or accuracy. The results of both experiments indicated a significant improvement in response speed; however, no significant difference among the three intensity conditions in decision-making accuracy performance was found, regardless of the instruction provided.

Upon further examination of the exercise effect on speed, McMorris and Graydon

(1997a; 1997b) examined the relationship by manipulating task complexity using visual searching of either familiar (soccer game) and unfamiliar (non-game) scenarios. Similar to that of the decision-making speed, the visual searching speed showed a significant improvement in the 100% MPO condition over the other two exercise intensity conditions. In the second experiment (McMorris & Graydon, 1997b), four different tasks (speed of visual search, total speed of decision, speed of decision following ball detection, and accuracy of decision) were examined in the same exercise conditions. Although the results demonstrated a similar trend for speed measures, the accuracy of decision making also significantly improved which differed from their previous findings (McMorris & Graydon, 1996a, 1996b, 1997a, 1997b).

Lastly, McMorris et al. (2003) examined the relationship through the use of choice response time and concentration of adrenaline and noradrenaline during the three exercise conditions. The purpose of the study was to examine the effect on reaction time and movement time, and also to delineate the role of plasma catecholamine concentrations. The results showed that movement time during maximal exercise was significantly faster than in the other two conditions. In addition, the catecholamine concentrations were significant predictors of movement time but not of reaction time. The data demonstrated the role of the peripheral concentration of catecholamines on the central nervous system response.

Generally, the research studies conducted by McMorris and colleagues indicated that exercise at MPO facilitated the speed of decision making in soccer. In terms of accuracy of the soccer decision making test, only one study demonstrated that the accuracy of decision making test was positively affected by maximal exercise (McMorris & Graydon, 1997b).

Summary. Upon a closer narrative review of the studies which had examined "performance at rest versus at maximal exercise", many of the studies demonstrated conflicting results with studies reporting no effect, impairment effects, and mixed effects (a combination of improvement, impairment, and no effect) on cognitive performance after maximal intensity exercise. Potential moderators of the relationship included the fitness level of the participants, the participant's level of expertise, and task type. Generally speaking, although there were conflicting results, these research studies tended to demonstrate that maximal intensity exercise had a negative or a limited positive effect on cognitive performance.

Table 1

Summary Findings of Performance at Rest Versus at Maximal Exercise Intensity (A)

Status	Author (s)	n	Exercise protocol	Cognitive task (s)	Results
			No Effect		
A	Bard & Fleury (1978)	16	Cycling to exhaustion	Visual search task	No effect
				Visual field task	No effect
				Coincidence timing	No effect
A, C	Chmura, Nazar & Kaciuba-Ulscilko (1994)	22	Treadmill run ● Rest, 76%, and 100% VO_{2max} Blood sample ● Lactate, adrenaline and noradrenaline	Choice RT	No effect
A	Fleury, Bard, Jobin,	31	Treadmill run:	Letter detection	No effect

	& Carriere (1981)		● spring condition, anaerobic running, and endurance running Blood sample ● Lactate		
A	Tomporowski, Ellis, & Stephens (1987) Experiment 1	24	Treadmill run 50 min at 80% VO_{2max}	Free-recall memory	No effect
A	Tomporowski, Ellis, & Stephens (1987) Experiment 2	12	After Treadmill run	Free-recall memory	No effect
A	Travlos & Marisi (1995)	20	Cycling to Exhaustion	Choice RT Random number-generation indexes	No effect No effect

Impairment

A, B,C	Fery, Ferry, Vom Hofe, & Rieu (1997)	13	Cycling to exhaustion	Short term memory (4 consonant set) Short term memory (7 consonant set)	Impairment impairment
A	Isaacs & Pohlman (1991)	12	Cycling to 100% VO_{2max}	Coincidence timing	Impairment
A, C	McMorris (1995)		Rest, 75%, 100% MPO	Simple RT	Impairment
A, C	McMorris & Keen (1994)		Rest, 70%, 100% MPO	Simple RT	Impairment
A, C	Wrisberg & Herbert (1976)	24	Treadmill run to exhaustion	Coincidence timing	Impairment

Mixed Effect

A, B	Fleury & Bard (1987)	18	Running in treadmill until maximal aerobic efforts	Sensory task (peripheral threshold detection) Sensory motor task (coincidence-anticipation) Cognitive task (recall central vision)	Improvement Improvement Impairment
A	Gutin & Di Genaro (1968a)	72	Treadmill run to exhaustion	Arithmetic task (accuracy) Arithmetic task (speed)	Impairment No effect
A	Hancock & McNaughton (1986)	6	Treadmill run at anaerobic threshed	Short-term memory Time estimation Symbol Interpretation	Improvement Improvement Impairment
A, C	McMorris & Graydon (1996a)	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy) Soccer decision making test (speed)	No effect Improvement

A, C	McMorris & Graydon (1996b) Experiment 1	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1996b) Experiment 2	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1997a)	12	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1997b) Experiment 1	12	Rest, 70%, 100% MPO	Visual search in soccer	Speed at rest slowest

A, C	McMorris & Graydon (1997b) Experiment 2	12	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	Improvement
				Soccer decision making test (speed)	Improvement
A, C	McMorris, Myers, MacGillivary, Sexsmith, Fallowfield, Graydon, & Forster (1999)	9	Rest, Ta, 100% MPO Blood sample ● Lactate, adrenaline and noradrenaline	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris, Tallon, & Wiliams (2003)	9	Rest, 70%, 100% MPO Blood sample ● Lactate, adrenaline and noradrenaline	Choice response time task (reaction time)	No effect
				Choice response time task (movement time)	Improvement

Performance At Rest Versus At Single Sub-Maximal Exercise Intensity

The second approach that addressed the relationship between physical activity and cognitive performance used a comparison of rest versus a single sub-maximal exercise intensity condition. Based upon the existing literature, the results of the effect of acute physical exercise on cognitive performance also showed mixed results. Also from the previous literature reviews, the two different results, performance of improvement effect and mixed effect will be discussed here.

Improvement effect. Several research studies demonstrated the facilitation of cognitive performance following an acute bout exercise (Arcelin et al., 1997; Gondola, 1987; Lichtman & Poser, 1983; Tomporowski et al., 2005).

Arcelin et al. (1997) examined the effect of 60% VO_{2max} cycling exercise on achoice reaction time task. Cognitive tasks scores were collected at rest, after 3 minutes, and after 8 minutes of exercise. The results indicated that reaction time was not only significantly faster in the two exercise conditions, but was also faster than in the rest condition.

Gondola (1987) examined the relationship using a field-research approach. Twenty-one young women who participated in a 20 minute dance class were compared against sixteen women who did not exercise. The cognitive tasks involved tasks with alternate uses, remote response, and an obvious response. The results indicated that the exercise group had significantly better performance than the group without exercise. Although the data demonstrated a positive trend, undefined exercise intensity was a shortcoming of this study.

Lichtman and Poser (1983) looked at the effect of 45 minutes of jogging (at an unspecified intensity) and various other physical activities in one group and compared it to a hobby group that participated in either a painting or photography class. The results demonstrated that the exercise group showed a significant improvement in three of the Stroop Test scores, which implied that exercise had a benefit on both the automatic processes and conscious effort.

Recently, Tomporowski et al. (2005) used a more precise approach to examine the effect of aerobic exercise on response inhibition. The authors used the Paced Auditory Serial Addition Task (PASAT) which was used to measure information processing, attention, and concentration. In addition, the authors were involved in the effects of exercise or carbohydrate electrolytic on cognitive performance. In terms of treatment condition, each participant completed the PASAT in either drug-related conditions (baseline, drug, and drug plus exercise) or exercise-related conditions (baseline, placebo, and exercise only). The data indicated that after the exercise protocol (cycling for 40 min at 60% VO_{2max}) response inhibition showed an improvement. In the second experiment, participants were given one of three carbohydrate electrolyte drinks or a placebo drink, and then instructed to exercise (cycling for 120 minutes at 60% VO_{2max}) then the PASAT score was collected at the baseline and again after exercise. The results indicated a significant improvement in PASAT scores following exercise that was not moderated by any kind of drink. This demonstrated the positive exercise effect on working memory and attentional processes particularly.

Mixed effect. There were also a number of studies that reported ambiguous data for the effects of acute exercise on cognitive performance (Adam et al., 1997; Arcelin et al., 1998; Cian et al., 2001; Cian et al., 2000; Davranche et al., 2005, 2006; Dietrich & Sparling, 2004; Fery et al., 1997; Fleury & Brad, 1987; Heckler & Croce, 1992;

Hillman et al., 2003; Hogervorst et al., 1996; Marriott et al., 1993; Paas & Adam, 1991).

Adam et al. (1997) studied the relationship between physical activity and cognitive exercise. More specifically, they examined the effect based on Humphrey and Revelle's Dual Resource Theory. From the views of this dual resource theory, physical activity was expected to benefit sustained information transfer (SIT) tasks and was to have a negative effect on short term memory (STM) tasks. Twenty adults were recruited and told to conduct both tasks after exercise at 75% Wmax on a bicycle. The data collected supported the Dual Resource Theory in that performance on the SIT task was positively affected under the acute exercise intervention. However, no effect was found in the STM task.

In contrast to the Adam et al. (1997) study, Arcelin et al. (1998) examined the relationship based upon Sanders' cognitive-energetic model of human information processing. Three levels were described by Sanders' model: information processing level, executive control level and an energy pool level. Since information processing included several stages and was controlled by several factors and mechanisms, the effect of exercise could have influenced only a particular component of information processing rather than the overall system of information processing. In order to test this question, Arcelin and his colleagues (1998) looked at the effect of exercise on three different types of cognitive performances (signal intensity, stimulus-responses compatibility, and time uncertainty) at two different intensities of exercise. The data demonstrated that exercise only affected performance on time uncertainty, which indicated that moderate aerobic exercise benefited activation in the later (motor) stages of information processing rather than having an effect on general information processing.

Cian's series of research studies (2000; 2001) looked at this relationship using another approach. They not only examined the effect of prolonged exercise, but also tested the effects of thermal stress and dehydration on various cognitive performances. In the first experiment of the first study, Cian et al. (2000) compared the effect of running for two hours at 60% VO_{2max} to the effects of dehydration. The results indicated that, with a prolonged moderate exercise intensity, cognitive performance either demonstrated no effect or an impairment. Cian et al. (2001) further examined the issue by adding fluid ingestion. The results indicated a similar trend where both no effect and impairment results were found after running for two hours at 65% VO_{2max}. In addition, there was no beneficial effect of fluid ingestion on cognitive performance.

Similar to Arcelin et al. (1998), Davranche et al. (2005) demonstrated that exercise might benefit the later stages of information processing. Using running at 50% maximal aerobic output, Davranche and his colleagues looked at the relationship using two different levels of visual stimulus intensity (weak vs. strong stimulus) and fractionated reaction time on a choice reaction time task. According to their findings, exercise resulted in a faster reaction time regardless of signal intensity. However, when fractionated reaction time was examined, the results showed that exercise exerted a benefit on premotor time only in the strong stimulus condition which indicated that the effects were evident for central processing. In addition, exercise had a positive effect in both stimuli in terms of motor time.

In addition to a choice reaction time task, Davranche et al. (2006) used a similar exercise protocol and cognitive task (signal intensity) in assessing simple reaction time. The results were consistent with their past findings (Davranche et al., 2005) and indicated that exercise had a positive effect on motor time rather than pre-motor time.

Dietrich and Sparling (2004) conducted experiments that examined the effect of moderate exercise on cognitive ability using a neuropsychological test. Based upon the authors' views, most of the previous studies related to acute exercise and cognition used relatively simple tasks such as basic reaction time or visual recognition tasks, which did not evaluate changes in the higher cognitive abilities. Therefore, the Wisconsin Card Sorting Task (WCST), PASAT, Brief Kaufman Intelligence Test (K-BIT), and Peabody Picture Vocabulary Test (PPVT) were selected to examine these higher cognitive functions. In addition, relatively few studies looked at cognition during exercise, whereas most of the studies focused solely on cognition after exercise. Based upon the Transient Hypofrontality hypothesis, which postulated that the brain had a limited information processing capacity (Dietrich, 2003), temporary inhibition of this brain region during exercise might impair higher-cognitive functions. Twenty-four participants were recruited and selected to be in either the control group, running for 50 minutes at 70 to 80% heart rate maximum, or cycling for 50 minutes at 70 to 80% heart rate maximum. The WCST and K-BIT were assessed prior to and during the exercise sessions. The results indicated no significant difference on K-BIT among the three conditions but, the exercise groups (run and cycling) showed a significant impairment when compared to that of the control group. Since WCST was used to assess the function of some prefrontal cognitive processes such as working memory, sustained attention, and response inhibition, the effect during exercise showed a negative impact for prefrontal-dependent cognition. A second experiment was conducted in which only the running (65 minutes at 70-80% heart rate maximum) and the control groups were used and cognitive ability was assessed by PASAT and PPVT. On the PPVT, there was no significant difference between the two groups. However, exercise resulted in a significant impairment of performance on the PASAT. In conclusion, this research study was the first to show that during a bout of active exercise there was a negative effect on higher-cognitive functions. Therefore, further studies are needed to confirm this finding.

Two previously described studies that compared rest to maximal exercise also looked at submaximal levels of exercise. Fery et al. (1997) examined performance on a cognitive task at two levels of difficulty (4 consonant set vs. 7 consonant set) and at two measurement time points (a constant workload session/30% VO_{2max} and a progressive workload session to exhaustion). Their findings indicated that the submaximal constant workload had no effect on performance. However, Fleury and Bard (1987) found that submaximal exercise did exert a beneficial effect on peripheral processes but not on central processing.

Hillman et al. (2003) examined the relationship using different task and dependent variable assessments. They suggested that arousal induced by exercise might impact the central nervous system but at a level that was not evident in behavioral measures such as reaction time. Thus, Hillman and his colleagues examined the relationship between acute cardiovascular exercise and executive control function using both reaction time and event-related brain potentials. The results showed no relationship between acute exercise and behavioral reaction time. However, cardiovascular exercise did improve the speed of information processing as measured by both P300 amplitude and latency during an executive control task. These findings suggested that acute bouts of exercise did affect neuroelectric processes through the increased allocation of neuroelectric resources and changes in cognitive processing and stimulus classification speed.

Heckler and Croce (1992) looked at fitness and exercise duration as potential moderators. Eighteen female adults were categorized as either fit or unfit and were asked to perform mathematic computation trials (control vs. 20 min exercise vs. 40 min exercise) with three assessments post exercise (immediately, 5 minutes post exercise, and 15 minutes post exercise). The results indicated that following 20 minutes of exercise, there was a positive effect at the 15 minute post exercise assessment. However, following the 40 minute exercise protocol, the facilitation was only found in the fit group rather than in the unfit group.

Using more cognitive performance tests, Hogervorst et al. (1996) examined the effect of a 75% and 85% VO_{2max} on simple reaction time, choice reaction time, finger-tapping test and the Stroop Test in highly trained athletes. Their data demonstrated a positive effect of exercise for simple reaction time and for the Stroop Test. In addition, interference of the Stroop Test, which was indicative of a more complex task, was particularly improved after exercise.

Marriott et al. (1993) conducted a treadmill run of 45 minutes at 157 beat/min and used decision making in the soccer condition as the measure of cognitive performance. Their findings showed a positive effect on accuracy but a limited effect on speed.

Pass and Adam (1991) looked at the moderator through the use of four different protocols (rest, minimal load, interval exercise and endurance exercise) on both decision task and perception tasks. The data indicated that, with an increase in the physical workload, the decision task showed improvement whereas the perception task was reduced. However, with a decrease in the physical workload, reduced performance on the decision task and improved performance on the perception task was found. From these results, the author's concluded that task difficulty, task incentive, and motivation were the potential factors for the phenomena. In addition, one of the important findings from this study was that, although the minimal workload protocol had a higher heart rate response than in the rest condition, only the exercise condition showed the significant change. These results implied that substantial changes in physical exertion were needed to influence mental task performance.

Summary. Although there were conflicting results when using short term moderate intensity exercise protocols, most research supported or at least partially demonstrated a positive effect of submaximal exercise on cognitive performance. Clearly, one important moderator that might have influenced the results was exercise intensity. When using a moderate intensity exercise protocol (40% to 60% of the participant's $VO_{2\ max}$, maximal aerobic output, or maximal heart rate) with a duration from 20 to 60 minutes, most research supported either a positive effect (Arcelin et al., 1997; Gondola, 1987; Lichtman & Poser, 1983; Tomporowski et al., 2005) or a slight positive trend (Adam et al., 1997; Arcelin et al., 1998; Cian et al., 2001; Cian et al., 2000; Davranche et al., 2005, 2006; Dietrich, 2003; Fery et al., 1997; Fleury & Brad, 1987; Heckler & Croce, 1992; Herrmann et al., 2006; Hogervorst et al., 1996; Marriott et al., 1993; Paas & Adam, 1991) for the relationship between exercise and cognition.

Table 2

Summary Findings of Performance at Rest Versus at Single Sub-Maximal Exercise Intensity (B)

Status	Author (s)	n	Exercise protocol	Cognitive task (s)	Results
			Improvement		
B	Arcelin, Brisswalter, & Deligierres (1997)	22	Cycling at 0%, 60% VO_{2max} Choice	Choice discrimination	Improvement
B	Gondola (1987)	21	Aerobic dance 20 min	Alternate uses	Improvement
				Remote response	Improvement
				Obvious response	Improvement
B	Lichtman and Poser (1983)	10	Aerobic run of 45 min	Stroop Test (word)	Improvement
				Stroop Test (color)	Improvement
				Stroop Test (color-word)	Improvement
B	Tomporowski,	9	Cycling 40 min at 60% VO_{2max}	The Paced Auditory Serial Addition	Improvement

	Armstrong, & Kane (2005) Experiment 1			Test (PASAT)	
B	Tomporowski, Armstrong, & Kane (2005) Experiment 2	8	Cycling 120 min at 60% VO_{2max}	The Paced Auditory Serial Addition Test (PASAT)	Improvement
			Mixed Effect		
B	Adam, Teeken, Ypelaar, Verstappen, & Paas (1997)	20	Cycling 40 min at submaximal loads	Sustained information transfer (SIT) Short term memory TM (STM)	Improvement No effect
B	Arcelin, Delignieres, & Brisswalter (1998)	22	During Cycling 30 min at 60% VO_{2max}	Signal intensity (two levels) Stimulus-responses compatibility	No effect No effect

				(two levels)	Improvement
				Time uncertainty (two levels)	
B	Cian, Barraud, Melin, & Raphel (2001)	7	After Running 2 h at 65% VO_{2max}	Choice reaction time	No effect
				Tracking	No effect
				Perceptual discrimination	Impaired RT
				STM	Impairment
				Free-recall memory	No effect
B			Following hydration	Choice reaction time	No effect
				Tracking	No effect
				Perceptual discrimination	Impaired RT
				STM	facilitated
				Free-recall memory	NO effect
B	Cian, Koulmannn, Barraud, Raphel, Jimenez, & Melin	8	After Running 2 h at 60% VO_{2max} to dehydration	Choice reaction time	No effect
				Tracking	Impairment
				Perceptual discrimination	Impaired RT

	(2000)			STM	Impairment
				LTM	No effect
B			Following hydration and arm exercise	Choice reaction time	No effect
				Tracking	Impairment
				Perceptual discrimination	No effect
				STM	No effect
				Free-recall memory	Impairment
B	Davranche, Burle, Audiffren, & Hasbroucq (2005)	12	Cycling at 50% maximal aerobic output	Two level signal intensity (choice reaction time task)	
				● Reaction time	Improvement
				● Premotor time	Improvement/no effect
				● Motor time	Improvement
B	Davranche, Burle, Audiffren, &	12	Cycling at 50% maximal aerobic output	Two level signal intensity (simple reaction time task)	

	Hasbroucq (2006)			● Reaction time ● Premotor time ● Motor time	Improvement no effect Improvement
B	Dietrich & Sparling (2004) Experiment 1	16	Run 50 minutes at 70 to 80% maximum heart rate (HR maximum) Cycling 50 minutes at 70 to 80% HR maximum	Wisconsin Card Sorting Task (WCST) Brief Kaufman Intelligent Test (K-BIT)	Impairment No effect
B	Dietrich & Sparling (2004) Experiment 2	8	Run 65 minutes at 70 to 80% maximum heart rate (HR maximum)	Paced Auditory Serial Addition Task (PASAT) Peabody Picture Vocabulary Test (PPVT-III)	Impairment No effect
A, B,C	Fery, Ferry, Vom Hofe, & Rieu (1997)	13	30% VO_{2max}	Short term memory (4 consonant set) Short term memory (7 consonant set)	No effect impairment

A, B	Fleury & Bard (1987)	18	An aerobic alactacid run And anaerobic lactacid run	Sensory task (peripheral threshold detection)	Improvement
			A sub-maximal aerobic effort	Sensory motor task (coincidence-anticipation)	Improvement
				Cognitive task (recall central vision)	Impairment
B	Heckler & Croce (1992)	18	Treadmill runs of 20, 40 min at 55% VO_{2max}	Mathematics computations	Improvement for fit women
B	Hillman, Snook, & Jerome (2003)	20	Running 30 minutes at 83.5% maximal heart rate	Erickson flankers task of event-related potential (ERP)	
				● P300 Amplitude	Improvement
				● P300 Latency	Improvement
				● Reaction time	No effect
B	Hogervorst, Riedel, Jeukendrup, & Jolles (1996)	15	Cycling 60 min at 75–85% VO_{2max}	Simple reaction time	Improvement
				Choice reaction time	No effect
				Finger tapping	No effect

				Stroop Test	Improvement
B	Marriott, Reilly, & Miles (1993)	16	Treadmill runs of 45, 90 min at 157 betas min_1	Decision making in soccer (accuracy)	Improvement
				Decision making in soccer (speed)	No effect
B	Paas and Adam (1991)	16	Cycling 40 min (two protocols)	Decision task	Improvement
				Perception task	Impairment and Improvement

Performance At Several Different Exercise Intensities

The third approach in addressing the relationship between physical activity and cognitive performance is to examine performance at several different exercise intensities. Unlike using one sub-maximal or maximal exercise intensity, this type of research examines the relationship using two or more exercise intensity conditions. The purpose of these studies is to not only demonstrate the effect of exercise on cognitive function, but also to depict the dose-response trend of this relationship. In addition, the change of arousal level is recognized as a possible mechanism within this dose-response relationship. Here, the literature reviews will be discussed as demonstrating a linear relationship, a U-shaped relationship, no effect, or mixed findings.

Linear facilitation. Aks (1998) indicated that higher sub-maximal exercise intensity (85% work load) with cycling yielded a better visual searching task than in the low exercise intensity (65% work load). The data implied that both short exercise durations had a positive effect on visual search in speed, frequency of error and slope. In addition, with an increase in exercise intensity, a greater benefit was found.

Tenebaum et al. (1993) recruited 118 handball players to examine the relationship. The cognitive performance used was complex decision making related to specific handball situations and was rated and scored by a panel of experts. Using the different cognitive performance approaches and regardless of level of handball playing experience, a better decision making performance was found at the higher exercise level than at the lower exercise condition. The experiment protocol was later replicated and modified by McMorris's lab, where most of research demonstrated a positive exercise effect on decision-making speed rather than on accuracy (McMorris & Graydon, 2000).

U-shaped relationship. Recently, Arent and Landers (2003) conducted a study by examining the arousal-performance relationship using a causal design. College-aged participants (*n*=104) were randomly assigned into one of eight arousal levels and performed a simple reaction time task. Arousal levels were manipulated by asking participants to ride a bicycle ergometer at one of eight arousal levels between 20% to 90% heart rate reserve (HRR). Results showed that arousal was related to both reaction time and response time in a quadratic trend as hypothesized via the inverted-U hypothesis. However, results for movement time supported the drive theory in that movement time improved linearly with increased levels of arousal. According to the authors, the low task complexity was the reason behind the linear arousal-performance relationship for the movement time. A complementary explanation was that, unlike reaction time measurements, movement time measures were essentially devoid of any cognitive elements. This suggested that the inverted-U hypothesis was appropriate for explaining the arousal-performance relationship for the components of the task that required greater cognitive or central processes; while the drive theory explained the arousal-performance relationship for the components of the task that required more motor or peripheral processes.

Brisswalter et al. (1995) also found an inverted-U dose-response trend. Participants were instructed to pedal at seven different rates of their MPO. Within the exercise protocol, simple reaction time was used to assess cognitive performance. Results indicated that the fastest reaction time was found for pedaling rates at 50 revolutions/minute and the longest reaction time was found for pedaling rates at 80 revolutions/minute.

Chmura et al. (1994) recruited 22 male soccer players who were instructed to take a choice reaction time task while performing an incremental cycling protocol. In addition, lactate, adrenaline and noradrenaline were collected from blood samples to determine exercise intensity. The data demonstrated an inverted-U dose-response relationship not only between reaction time and incremental exercise, but also between reaction time and the plasma catecholamine levels. The study also further indicated that the best reaction time performance was found at an intensity of 75% VO_{2max} where it exceeded the blood lactate and plasma adrenaline threshold. Based upon these findings, the levels of lactate and plasma adrenaline were supported as possible mechanisms that influenced the dose-response curve.

Reilly and Smith (1986) used a similar cycling protocol as Brisswalter et al. (1995), where the exercise intensity was set at rest, 25%, 40%, 55%, and 85% VO_{2max}. The pursuit rotor task was conducted twice at four and six minutes intervals after the participants reached the target cycling intensity. The results supported an inverted-U dose-response relationship with the best score found at the moderate work intensity of 38% VO_{2max}.

Both studies by Levitt and Gutin (1971) and Salmela and Ndoye (1986) used heart rate as the exercise intensity index and choice reaction time as the cognitive performance assessment. Both studies showed an inverted-U dose-response curve between choice reaction time and different intensities of heart rate. In addition, the increase in performance was found at heart rates from rest to 145 beat/min which was later recognized as 70% of the maximal heart rate. Unlike other research, Salmela and Ndoye applied the Easterbrook's cue utilization theory of attention as a potential hypothesis to explain the relationship.

Salmela and Ndoye (1986) performed a duplicate study that examined the relationship using cycling to exhaustion and five different choice reaction time tasks, again, their data indicated no significant exercise effect on cognition.

Mixed relationship. A number of studies also reported ambiguous data that did not support either a linear or an inverted-U relationship between exercise intensity and cognitive performance.

Allard, Brawely, Deakin, and Elliot (1989) conducted two experiments that examined the relationship. In the first study, 30 undergraduate students conducted a visual search task in three exercise intensity conditions (rest, 30% maximal workload, 60% workload). The results indicated that the participants performed better following both intensities of exercise. The authors believed there were two potential explanations for the positive effect of exercise on the cognitive response. First, exercise facilitated the neuromuscular system which allowed a participant to move faster rather than through the use of the attentional system. Another explanation was that exercise benefited some process which occurred before the automatic process of the visual task. In order to test the second hypothesis, Posner and Boies (1971)'s experimental design was used. They created a simple letter matching task that divided a participant's attention into preparation and encoding phases. Here, the preparation phase was linked to a general readiness to process information, and the encoding phase occurred once a participant had some information as to what was expected. The data demonstrated a difference in the effects of exercise on the preparation phase and the encoding phase which did not speed up information processing, and only showed up in the preparation phase.

Similar to Arcelin et al. (1998) who studied the relationship based on Sander's cognitive-energetic model, Davranche and Audiffren (2004) examined the effect of two exercise intensities (20% and 50% maximal aerobic power versus rest conditions) using the Critical Flicker Fusion Test with manipulated signal quality, stimulus-response compatibility, and time uncertainty. The results showed that both exercise conditions resulted in better performance than at the pre-test. In addition, there was a linear relationship between the increase in exercise intensity and reaction time. However, in terms of signal quality, stimulus-response compatibility, and time uncertainty, no significant interactions were observed. In conclusion, the authors stated that moderate exercise improved cognition. Upon further examination using fractionated reaction time, Davranche and his colleagues hypothesized that exercise had a positive effect on motor time rather than pre-motor time (Davranche et al., 2005, 2006).

Delignieres, Brisswalter, and Legros (1994) set an exercise intensity protocol with 20%, 40%, 60% and 80% maximal aerobic power. Each participant was instructed to conduct two types of choice response time tasks one minute after each exercise intensity condition. In addition, participants were recruited by other criteria which divided them into two groups. One group was participants who had professional fencing experience which was indicative of the ability for rapid response task, and the other group was comprised of participants without this but with a similar fitness level. The data showed a significant linear improvement at the 40%, 60% and 80% maximal aerobic power for those participants with the fencing experience. However, for the second group of participants without professional experience, a significant amount of deterioration in the cognitive response was found at the 40%, 60% and 80% maximal aerobic power conditions. This research suggested that expertise relative to a particular cognitive task moderated the relationship between exercise intensity and cognitive performance.

Kamijo and his colleagues conducted two research studies that examined the dose-response relationship (Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo, Nishihira, Hatta, Kaneda, Wasaka et al., 2004). The exercise protocol in both studies were conditions of rest, cycling to low intensity, medium, and high intensity. However, in addition to using a choice reaction time task, event-related potential (ERP), and contingent negative variation (CNV) were also assessed to further examine information processing. Generally, although no significant difference was found in terms of premotor time assessment (i.e., the behavioral measure), the amplitude of the Go P300, No-go P300, and CNV demonstrated a dose-response relationship. In contrast to previous studies (Allard et al., 1989; Arcelin et al., 1998; Davranche & Audiffren, 2004; Davranche et al., 2005, 2006) which indicated that exercise only benefited the later components of information processing, Kamjio and his colleagues' data revealed that exercise influenced both the perceptual and central processes, although it did not show up in the behavioral assessment.

McGlynn, Laughlin, and Bender (1977) examined the relationship during progressive treadmill runs. The results demonstrated that a significant improvement in speed on a discrimination task was found following an increase in exercise speed and grade. In addition, the fastest speed of performance was found in the higher exercise intensities and speed was reduced after termination of the exercise. However, in terms of accuracy, no effects were found. Using a similar exercise protocol, McGlynn, Laughlin, and Rowe (1979) reexamined the relationship using accuracy and speed on visual discrimination at four different exercise intensities. The data showed no significant difference in accuracy during exercise; however, the speed was significantly faster at the highest intensity level when compared to other the exercise conditions. Thus, in these studies better scores were only found at the highest exercise intensities.

Sjoberg, Ohlsson, and Dornic (1975) looked at the relationship between exercise and cognition using two different mental tasks, short-term memory and paired-associate memory at rest, 25%, 50%, and 75% maximal working capacity. Although the results indicated a facilitation effect on short-term memory, there was no exercise effect on paired-associated memory. In a further research study with a similar exercise protocol, Sjoberg (1980) was unable to replicate these findings. The author used three different mental tasks, short-term memory, paired-associate memory, and mathematical computation, at rest, 25%, 50%, and 75% maximal working capacity. The data showed no significant difference in performance on the mental task as a function of the four exercise conditions.

Additional research demonstrating this mixed effect comes from a series of studies published by McMorris's laboratory which have been described previously. In these studies, there were three different exercise intensity conditions used: rest, 70% maximal power output, and 100% maximal power output. In addition, the participants were people with or without professional soccer experience who were instructed to conduct a soccer decision-making task. Generally, McMorris and his colleagues indicated that exercise induced a central nervous system arousal which increased the central nervous system resources for cognitive performance. However, in terms of accuracy of decision-making task, none of these studies showed a significant difference among the three exercise intensities.

No effect. Although most of the studies indicated a linear facilitation, inverted-U or mixed relationship between incremental exercise and cognitive performance, one study demonstrated no effect (Cote et al., 1992).

Summary. Most research studies demonstrated that moderate exercise intensity was either linearly related to or showed an inverted-U relationship with certain specific cognitive tasks. In addition, the change of arousal level was recognized as a possible mechanism within this dose-response relationship.

Table 3

Summary Findings of Performance at Several Different Exercise Intensities (C)

Status	Author (s)	n	Exercise protocol	Cognitive task (s)	Results
			Facilitation		
C	Aks (1998)	18	Cycling aerobically, anaerobically	Visual search	Facilitation
C	Tenenbaum, Yuval, Elbaz, Gar-Eli, & Weinberg (1993)	118	During Treadmill run of moderate and high speed	Decision making in handball	Facilitation
			U-Shaped Facilitation		

C	Arent & Landers (2003)	104	Cycling at eight exercise intensity level	Simple reaction time	U-shaped facilitation
C	Brisswalter, Durand, Delignieres, & Legros (1995)	18	Cycling at progressively faster rates	Simple reaction time	U-shaped facilitation
A, C	Chmura, Nazar, & Kaciuba-Ulscilko (1994)	22	Cycling at progressively greater load Blood sample ● Lactate, adrenaline and noradrenaline	Choice reaction time	U-shaped facilitation
C	Levitt & Gutin (1971)	20	Treadmill run at progressively higher HR	Choice reaction time	U-shaped facilitation
C	Reilly & Smith (1986)	10	During Cycling at 0, 25, 40, 55, 85 VO_{2max}	Pursuit rotor	U-shaped facilitation

C	Salmela & Ndoye (1986)	10	During Cycling at progressively higher HR	Choice reaction time	U-shaped facilitation
			No Effect		
C	Cote, Salmela, & Papthanasopoloulu (1992)	17	Cycling at progressively higher HR	Five types of Choice reaction time task	No effect
			Mixed Effect		
C	Allard, Brawley, Deakin, & Elliot (1989)	30	Cycling at 0%, 30%, 60% VO_{2max}	Visual search	Facilitation

	Experiment 1				
C	Allard, Brawley, Deakin, & Elliot (1989)	8	Cycling at 30%, 70% VO_{2max}	Letter matching	No effect
	Experiment 2				
C	Davranche & Audiffren (2004)	16	Cycling at 20%, 50% of maximal aerobic power	Choice reaction time	Facilitation
				Signal quality	No effect
				Stimulus-response	No effect
				Compatibility	No effect
				Time uncertainty	No effect
C	Delignieres, Brisswalter, & Legros (1994)	40	Cycling at 20%, 40%, 60%, 80% VO_{2max}	Choice RT	Facilitation for experts; impairment for novices
A, B, C	Fery, Ferry, Vom Hofe, & Rieu (1997	13	Cycling to exhaustion	Short term memory (4 consonant set)	Impairment impairment

				Short term memory (7 consonant set)	
C	Gutin & DiGennaro (1968b)	55	Rest, Step-ups 1, and 5 min	Mathematics computations	Facilitation for fit
C	Kamijo, Nishihira, Hatta, Kaneda, Wasaka, Kida, & Kuroiwa (2004)	12	Cycling at rest, low, medium and high intensity	Contingent negative variation (CNV) amplitude	U-shaped facilitation
				Premotor time	
C	Kamijo, Mishihira, Hatta, Kaneda, Kida, Higashiura, & Kuroiwa (2004)	12	Cycling at rest, low, medium and high intensity	Go P300 of ERP	
				● Amplitude	U-shaped facilitation
				● Latency	No effect
				No-go P300 of ERP amplitude	U-shaped facilitation
				● Amplitude	No effect
				● Latency	No effect
				Premotor time	

C	McGlynn, Laughlin, & Bender (1977)	14	Treadmill run at progressively faster speed	Visual discrimination (speed) Visual discrimination (accuracy)	Facilitation No effect
C	McGlynn, Laughlin, & Rowe (1979)	15	Treadmill run at progressively faster speed	Visual discrimination	Facilitation at highest speed
A, C	McMorris & Keen (1994)		Rest, 70%, 100% MPO	Simple reaction time	Impairment
A, C	McMorris (1995)		Rest, 75%, 100% MPO	Simple reaction time	Impairment
A, C	Wrisberg and Herbert (1976)	24	Treadmill run to exhaustion	Coincidence timing	Impairment
A, C	McMorris & Graydon (1996a)	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy) Soccer decision making test (speed)	No effect Improvement

A, C	McMorris & Graydon (1996b) Experiment 1	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1996b) Experiment 2	20	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1997a)	12	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	No effect
				Soccer decision making test (speed)	Improvement
A, C	McMorris & Graydon (1997b) Experiment 1	12	Rest, 70%, 100% MPO	Visual search in soccer	Speed at rest slowest
A, C	McMorris & Graydon (1997b) Experiment 2	12	Rest, 70%, 100% MPO	Soccer decision making test (accuracy)	Improvement
				Soccer decision making test (speed)	Improvement

A, C	McMorris, Myers, MacGillivary, Sexsmith, Fallowfield, Graydon, & Forster (1999)	9	Rest, Ta, 100% MPO Blood sample ● Lactate, adrenaline and noradrenaline	Soccer decision making test (accuracy) Soccer decision making test (speed)	No effect Improvement
A, C	McMorris, Tallon, & Wiliams (2003)	9	Rest, 70%, 100% MPO Blood sample ● Lactate, adrenaline and noradrenaline	Choice response time task (reaction time) Choice response time task (movement time)	No effect Improvement
C	Sjoberg (1980)	48	During Cycling at 0%, 25%, 50%, 75% VO_{2max}	Short-term memory Paired-associate memory After Mathematical computation	No effect No effect Impairment of low fit
C	Sjoberg, Ohlsson, & Dornic (1975)	48	During Cycling at 0%, 25%, 50%, 75% VO_{2max}	Short-term memory Paired-associate memory	Facilitation No effect

Exercise and Executive Function

In addition to the exercise modality question, the issue of the task specificity of the effects was further addressed to examine the relationship between acute exercise and cognition. Colcombe and Kramer (2003) studied the relationship between chronic exercise and cognitive function using a meta-analytic approach. They categorized the cognitive tasks as representing four different types of cognitive functions: 1) executive-control, 2) controlled-processing, 3) visuospatial, and 4) speed. The authors indicated that chronic exercise facilitated all levels of cognitive function. However, chronic exercise demonstrated the greatest effect on executive processes (effect size = 0.68), a type of higher cognitive function, when compared to other types of cognition. Although this general finding had been well supported, further research was designed to examine the particular type of executive function that showed a greater sensitivity to the effects of acute exercise. Executive function encompasses a wide variety of cognitive abilities such as working memory, response inhibition, attention capacity, self-regulation, behavioral sequencing, cognitive flexibility, planning, and organization of behavior (Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000).

Importantly, in the existing acute exercise literature, most studies have examined the arousal-performance relationship using only a simple or choice reaction time task (Arcelin et al., 1997; Chmura et al., 1994; Davranche et al., 2005; Fleury & Brad, 1987; Hogervorst et al., 1996; McMorris, 1995; McMorris & Keen, 1994; McMorris et al., 2003; Travlos & Marisi, 1995) and/or visual recognition tasks (Bard & Fleury, 1978; Fleury et al., 1981). To date, only a few studies have looked at the effect of acute exercise on executive function (Dietrich & Sparling, 2004; Hogervorst et al., 1996; Lichtman & Poser, 1983; Sibley et al., 2006; Tomporowski et al., 2005). The few studies that assessed the effects of acute exercise on executive function used a variety of tasks including the Stroop Test, Trail Making Test, WCST, and PASAT.

Hogervorst et al. (1996) examined the effect of cycling at 75% and 85% VO_{2max} on cognitive function using both reaction time and Stroop Tests. Results indicated a positive effect of exercise on both simple reaction time and on speed of processing as measured by the Stroop Test. In addition, results from the Stroop Test showed that interference was particularly improved after exercise. Similar results using the Stroop Test were also found when the participant either jogged for 45 minutes (Lichtman & Poser, 1983) or when the participant conducted a 20-minute moderate exercise regimen (Sibley et al., 2006).

Recently, Tomporowski et al. (2005) examined the effect of aerobic exercise on executive function as assessed using the PASAT. The results demonstrated that after cycling for 40 min at 60% VO_{2max}, performance in response inhibition was improved when compared to a control group. In their second experiment, participants were given one of three carbohydrate electrolyte drinks or a placebo drink, and then instructed to cycle for 120 minutes at 60% VO_{2max}. The results also indicated a significant improvement in PASAT scores regardless of any kind of drink, which demonstrated the positive exercise effect on working memory and attentional processes in particular.

Although all of these tasks assessed executive function, the relative importance of particular components of executive function was variable across these tasks making it difficult to clearly understand which executive functions were most sensitive to the effects of acute exercise. Therefore, it is very important to further examine the relationship between acute exercise and executive functions using multiple assessments.

Mechanisms Associated with Acute Exercise and Cognition

Although the results have been inconsistent, past literature reviews generally conclude that there is a positive relationship between acute exercise and cognition when using moderate exercise intensity (Tomporowski, 2003). Arousal is the most commonly cited potential mechanism for the explanation of the relationship between acute exercise and cognitive performance. According to Gill (2000), arousal had been defined as the general state of activation and is referred to as the intensity dimension of behaviors. Increased arousal is typically associated with increases in heart rate, respiration, and sweat response (Gill, 2000; Weinberg & Gould, 2003). It is also associated with the amount of resources available to the central nervous system (McMorris et al., 1999). The following discussion will focus on the dose-response relationship between acute physical activity and cognition and on the proposed underlying mechanisms.

Drive Theory

Drive theory, as revised by Spence and Spence (1996), describes a positive linear relationship between arousal and performance. Performance is predicted to increase linearly as the level of arousal increases. Based upon this theory, since increasing exercise results in increased arousal levels, performance is expected to improve with increasing exercise. As mentioned in the past section, in fact, a considerable amount of literature has demonstrated a linear facilitation effect of incremental exercise on cognitive performance (Aks, 1998; Allard et al., 1989; McGlynn et al., 1977; Tenenbaum et al., 1993), which supports drive theory. However, it has also been suggested that this relationship is influenced by the level of difficulty of the task and by the participant's dominant (or automatic) response set. That means that a positive linear relationship between arousal and performance is only expected when a participant is familiar with a certain skill-set so that the dominant response for that participant had been the correct response. In contrast, poor performance is expected during the execution of complex or unlearned skills under conditions of high arousal because the dominant response for these tasks is an incorrect response.

Inverted-U Hypothesis

The inverted-U hypothesis, originally described in research by Yerkes and Dodson (1908), provides an alternative explanation of the relationship between arousal and performance. Yerkes and Dodson developed their hypothesis based upon research in which they examined the ability of mice to learn a choice-discrimination task under three differing levels of arousal, which were achieved using electric shock. The results revealed that moderate arousal levels produced the best performance. However, performance declined as the level of arousal moved above or below this moderate level. In the 1970s, researchers began to examine the inverted-U hypothesis as an explanation of the relationship between arousal and sport performance. For example, Martens and Landers (1970) tested the hypothesis on junior high school boys who performed a tracking task at three levels of stress which yielded three arousal levels. The results showed that boys who performed the task under moderately stressful conditions did better than those who performed the low or highly stressful situations. Subsequently, similar results for performance were found in studies of Little League baseball players, high school basketball players, and female collegiate basketball payers(Klavora, 1977). In all of these studies, the authors concluded that their findings demonstrated support for the inverted-U hypothesis.

Similar to the drive theory, considerable research has supported the inverted-U relationship between acute exercise and cognitive performance (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Levitt & Gutin, 1971; Reilly & Smith, 1986; Salmela & Ndoye, 1986). Attempts to provide mechanistic explanations of this relationship focused on Easterbrook's cue utilization theory of attention and on the plasma catecholamine hypothesis.

Easterbrook's Theory of Attention

Salmela and Ndoye (1986) found an inverted-U dose- response when they used exercise as a stressor on a five-choice reaction time task. Based on their views, Easterbrook's theoretical approach of attention and stress provided a useful framework to explain the relationship. According to Easterbrook's theory of attention, increased arousal and state anxiety influenced behavior through changes in attention and concentration. Specifically, an increase in arousal following a stressor (i.e., exercise) is predicted to lead to a loss of attentional flexibility whereby the individual tends to narrow his attention too much and to be unable to scan for task-relevant cues. In contrast, low arousal increases attentional flexibility whereby the individual tends to focus too broadly on task-irrelevant cues. Although the theory had been useful for explaining the U-shaped relationship between incremental exercise and cognitive performance that is sometimes observed, this theory did not provide for an explanation of the linear facilitative effects and the mixed effects that were often observed.

Plasma Catecholamine Hypothesis

Chmura et al. (1994) examined the relationship from another angle. They recruited 22 male soccer players who were instructed to take a choice reaction time task while performing an incremental cycling exercise protocol. In addition, lactate, adrenaline and noradrenaline were collected from blood samples to determine the exercise intensity. The results indicated that an inverted-U dose-response is found, not only between incremental exercise and reaction time, but also between plasma catecholamines and reaction time. Moreover, the optimal cognitive response is found at 75% $VO_{2\ max}$, which significantly exceeded the blood lactate and plasma adrenaline thresholds. However, further increases in work load resulted in a rapid deterioration of cognitive performance.

Using three exercise intensities (rest, adrenaline threshold, and maximum power output) on a soccer decision-making task and the concentration of plasma catecholamines (adrenaline, noradrenalin, and lactate), McMorris and his colleagues indicated that both the adrenaline threshold and maximum power output condition had a significantly better speed performance than is observed in the rest condition. These results supported the conclusion of Cooper (1973) and Chmura et al.(1994) that exercise induced a change in the central nervous system arousal levels. In addition to the soccer decision-making task, McMorris et al. (2003) examined the relationship using choice response time and concentration of adrenaline and noradrenaline during three exercise conditions. The purpose of the research is to examine the role of plasma catecholamine concentration in the effect on reaction time and movement time. The results indicated that the movement time during maximal exercise is significantly faster than in the other two conditions. In addition, the catecholamine concentration is significant in predicting movement time and not reaction time. These studies demonstrated the role of peripheral concentrations of catecholamines in the central nervous system response.

Mediation Analysis Approach

Although these potential mediators (i.e., exercise-induced heart rate, plasma catecholamine level) between exercise intensity and cognitive performance have been proposed, the various approaches to test these mediators have not been concerned.

Generally, approaches to test mediators in the exercise-cognitive field have included either via analysis of variance (ANOVA) (Aks, 1998; Allard et al., 1989; Cote et al., 1992; Davranche & Audiffren, 2004; Deary et al., 1991; Delignieres et al., 1994; Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo, Nishihira, Hatta, Kaneda, Wasaka et al., 2004; McMorris, 1995; McMorris & Graydon, 1996a, 1996b, 1997a, 1997b; McMorris et al., 2003; Reilly & Smith, 1986; Salmela & Ndoye, 1986) or single regression analyses between mediators and cognitive performance (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Reilly & Smith, 1986). However, Baron and Kenny (1986) indicated that an ANOVA provides only a limited assessment of a mediation hypothesis whereas a series of regression models are necessary for testing mediation. In order to test for mediation, a series of regression analyses must be conducted (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). To date, although experimental designs or single regression analysis have been used for testing mediators in the field, there are no published studies that have used mediation analysis to actually test for these mediation processes (Etnier, 2007). Etnier (2007) further indicated that applying mediation analysis to test mediators is the next step to further our knowledge in the examination of this relationship.

The statistical approach described by Kenny and colleagues (Baron & Kenny, 1986; Judd & Kenny, 1981) is one of the most widely used methods to assess mediation. Based upon their description, the relationship that exists among the independent variable, the mediator and the dependent variables can be expressed briefly by a single mediator model (see Figure 1). In addition, three regression equations were included in the simple mediator model as follows:

In the model, the symbol "c" is the estimate of the total effect of X (independent variable) on Y (dependent variable) without consideration of other variables. The regression model of the equations can be expressed as $Y = i_1 + cX + e_1$, where i_1 and e_1 represent, respectively, intercepts and unexplained/ error variability. The symbol "a" is the estimate of the effect of X on M (mediator), and the symbol "b" and "c'"are the estimated effects of M on Y, and the X on Y when adjusting for M. The regression equations of these effect (a, b, c') can be expressed by $M = i_3 + aX + e_3$ and $Y = i_2 + c'X + bM + e_2$, where i_2 and i_3 represent intercepts and e_2 and e_3 represent error. In addition, the product of "a" and" b" is known as the mediated or indirect effect, which can also be represented as c – c' (MacKinnon, 2008).

Based upon the research from Baron and Kenny (1986), in order to test the mediator, four steps should be conducted to establish mediation and they are described as follows:

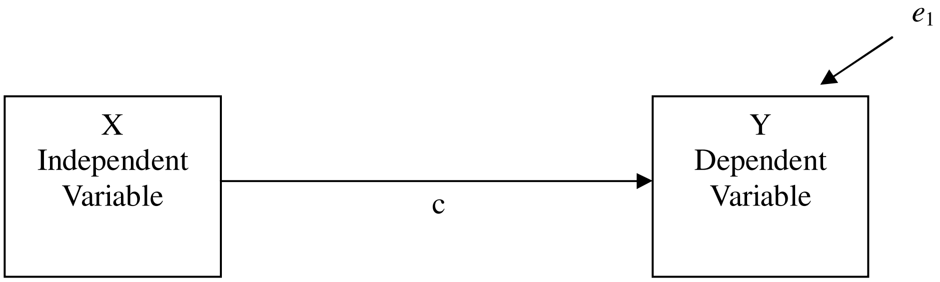
1. The total effect (c) of X on Y must be significant.
2. The effect of X (a) on M must be significant.
3. The effect of M (b) on Y controlled for X must be significant.
4. The direct effect (c') of X on Y adjusted for M must be non-significant.

If all four criteria are met, then the model can be represented as full/complete mediation between X and Y. However, if, in Step 4, the c' has a significant effect, which indicates X is a significant predictor to Y, then the model can be represented as a partial mediation between X and Y.

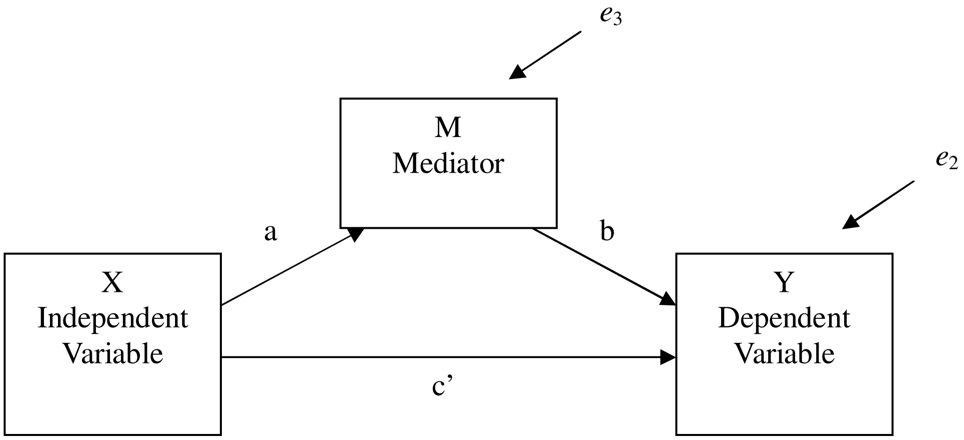
Summary

Based upon the previously cited literature, arousal has been recognized as the most popular potential mechanism for the explanation of the relationship between acute aerobic exercise and cognitive performance. In addition, based on the studies of incremental exercise on cognitive performance, although the results were in conflict, most of the research stated there is either a linear facilitation effect as would have been predicted by the Drive Theory (Aks, 1998; Arent & Landers, 2003; McGlynn et al., 1977; Tenenbaum et al., 1993) or an inverted-U facilitation effect (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Levitt & Gutin, 1971; Reilly & Smith, 1986; Salmela & Ndoye, 1986) as predicted by the inverted-U hypothesis. Easterbrook's Cue Utilization Theory of Attention (Salmela & Ndoye, 1986) and the Plasma Catecholamine

Hypothesis (Chmura et al., 1994) have also been proposed to explain the dose-relationship and imply the potential mediators between acute exercise and cognitive performance. However, to date, none of the published research in the exercise-cognitive field has used the appropriate statistical techniques to test the mediator directly.



$$Y = i_1 + cX + e_1$$



$$M = i_3 + aX + e_3$$
$$Y = i_2 + c'X + bM + e_2$$

Figure 1. Single mediator model with path diagram and equations for the regression model.

Resistance Exercise and Cognition

Health-Related Benefit of Resistance Training

Resistance exercise involves the voluntary activation of specific skeletal muscles against some form of external resistance, provided by body mass, free weights, or a variety of exercise equipment including machines, springs, elastic bands, or manual resistance (Winett & Carpinelli, 2001). According to the definition of health-related physical fitness which includes five criteria (cardiovascular ability, muscular strength, muscular endurance, flexibility and body composition), resistance exercise was a form of exercise that benefited at least three components of health-related physical fitness (Buckworth & Dishman, 2002). In addition, the American College of Sports Medicine (ACSM) began to include resistance training as a recommendation in their guidelines as of 1990 (American College of Sports Medicine, 1990). Resistance exercise not only increases muscular strength and muscular endurance but also exerts an indirect impact on a person's activities of daily living (ADLs). In addition, resistance exercise has also been found to benefit health-related diseases such as osteoporosis, low back pain, hypotension, diabetes, and blood lipids (Kraemer, Ratamess et al., 2002; Winett & Carpinelli, 2001).

Osteoporosis is related to bone mineral density which has been defined as the amount of bone mineral per measured area of bone. It has been suggested that the better the bone mineral density, the better the chances of preventing osteoporosis and fractures (Winett & Carpinelli, 2001). Studies have showen that resistance training provides a better effect than does repetitive low-intensity activities such as walking. Furthermore, Kerr, Morton, Dick and Prince (1996) examined the effect of resistance exercise on bone mineral density by comparing 8 - 10 repetition maximum (RM) to 20 - 25 RM. The results revealed that fewer repetitions with a heaver load proved to be more beneficial for increasing bone density than more repetitions with a lighter load.

Back pain had is the most common Workers' Compensation claim in the United States (Winett & Carpinelli, 2001). Mooney, Kron, Rummerfield, and Holmes (1995) indicated that a strip-mining operation reduced the number of incidents of back injury after conducting one set of lower back resistance training exercises once a week. Equally encouraging, one set of lower back exercises performed once or twice a week was also effective as a resistance exercise dose for increasing lumbar vertebrae bone mineral density (Pollock, 1992).

In addition, resistance exercise has also proven to benefit insulin resistance, glucose intolerance, abnormal lipoprotein-lipid profiles and hypertension via the reduction of central obesity (Depres, 1997). Based upon the above-mentioned findings, researchers have called for resistance training to be recognized as a critical form of exercise for improving the human lifespan rather than being viewed as a secondary option for maintaining physical fitness (Winett & Carpinelli, 2001).

Prescription of Resistance Training for Healthy Populations

Based upon their review, Hass, Feigenbaum and Franklin (2001) concluded there are at least three components that should be considered for making an appropriate resistance exercise prescription: number of repetitions, number of sets, and the frequency of training. The number of repetitions was prescribed based upon the participant's specific goal. In order to increase muscular strength, heavier weight with fewer repetitions was recommended. Whereas, in order to enhance muscular endurance, a lighter weight with a greater number of repetitions was used. In general, 8 to 12 repetitions per set has been suggested for increasing muscular strength and endurance as well as muscle hypertrophy. Unlike the number of repetitions, the optimal number of sets has not been reported in the literature. Recently, guidelines from the American College of Sport Medicine(Kraemer, Adams et al., 2002), American Heart Association (Fletcher et al., 1996), and American Association of Cardiovascular and Pulmonary Rehabilitation (Williams et al., 2007) indicated that the number of sets should depend upon the participant's fitness level. In the traditional resistance exercise prescription, at least three sets of 6 to 12 repetitions per exercise performance was recommended. Lastly, the frequency of training per week is another important component of the resistance exercise prescription. It has been suggested that 2 days which elicit 80 to 90% of strength benefits allows for more time for recuperation and is less time consuming and, therefore, more likely to be adhered to.

Resistance Exercise and Cognition

Although resistance exercise has been recognized as important from a health perspective, previous studies testing the effects of either acute or chronic exercise on cognition concentrated mainly on continuous exercise modalities such as jogging or cycling (Etnier et al., 1997; Tomporowski, 2003). Panton, Graves, Pollock, Hagberg, and Chen (1990) examined the effect of six months of aerobic and resistance exercise on fractionated reaction and speed of movement. However, unlike their initial expectations, neither aerobic exercise or strength training resulted in a significant difference in reaction time or speed of movement.

Using a similar exercise design as that of Panton et al. (1990), Ozkaya et al. (2005), in contrast, had data which indicated that both 9-weeks of aerobic exercise and 9-weeks of strength training benefited cognitive performance using neuroelectronic assessment. Both strength and aerobic groups displayed a better effect when compared to the control group. In addition, latencies of P2 and N2 components were decreased significantly and the amplitude of N1P2, P2N2, and N2P2 components increased significantly in the strength training group when compared to the aerobic training group. These results demonstrates that strength training facilitates early sensory processing and cognitive function in this population.

Possible Mechanisms Associated with Resistance Exercise and Cognition

As mentioned in the past section, arousal has been the most popular potential mechanism proposed to explain the relationship between acute aerobic exercise and cognitive performance. In addition, most studies testing the effects of incremental exercise on cognition supported either a linear facilitation (Aks, 1998; Allard et al., 1989; McGlynn et al., 1977; Tenenbaum et al., 1993) or an inverted-U facilitation effect (Arent & Landers, 2003; Brisswalter et al., 1995; Chmura et al., 1994; Levitt & Gutin, 1971; Reilly & Smith, 1986; Salmela & Ndoye, 1986).

It could be likely that resistance exercise might also impact cognitive performance in a fashion similar to that observed with aerobic exercise. This is because resistance exercise impacts many of the same potential mechanisms that are affected by aerobic exercise.

Several studies have shown that acute resistance exercise induces arousal as assessed via heart rate (Bloomer, 2005; Rezk et al., 2006) and plasma catecholamines (French et al., 2007; Pullinen et al., 1999; Ramel, Wagner, & Elmadfa, 2007).

Bloomer (2005) looked at the difference in energy expenditure between a resistance exercise session and an aerobic exercise session. Ten healthy trained men were asked to conduct both resistance and aerobic exercises with crossover design. In the resistance exercise condition, participants were instructed to perform a free-weight squatting at 70% of 1 RM for 30 minutes. In the aerobic exercise condition, participants were instructed to conduct aerobic exercise at 70% of VO_{2max} for 30 minute on a cycle ergometer. VO_{2max}, kilocalories, heart rate, and rating of perceived exertion (RPE) data were recorded. The results indicated that cycling resulted in a greater total VO_2 and kilocalories when compared against the strength exercise protocol. However, resistance exercise resulted in greater RPE and nearly identical heart rates when compared to aerobic exercise. Other studies also demonstrated an increase in heart rate above baseline after a bout of resistance exercise (Ballor, Becque, & Katch, 1987; Katch, Freedson, & Jones, 1985).

Arent, Landers, Matt, and Etnier (2005) examined the dose-response relationship between resistance exercise and affect using heart rate, RPE, and salivary cortisol as exercise intensity indicators. Based upon their results, 40%, 70% and 100% of predetermined 10 repetition maximal (10 RM) for 10 repetitions with 3 sets were recognized as low, moderate and high intensity bouts of exercise. In addition, resistance exercise as well as aerobic exercise demonstrated a curvilinear dose-response effect on affect.

In addition to heart rate, plasma concentrations of catecholamines, noradrenaline, and adrenaline, potential mechanisms of aerobic exercise and cognition, have also been shown to increase during anaerobic exercise (Galbo, 1986). Ramel et al. (2007) looked at the effect of a resistance protocol that was comprised of ten exercises at 75% of 1 RM on 10 exercise/muscle groups on noradrenaline concentration, neutrophil counts, plasma antioxidants, and lipid oxidation. Their results indicated that noradrenaline concentrations which were associated with higher plasma antioxidant concentrations increased after sub-maximal resistance exercise.

Summary

Resistance exercise is an important exercise modality, it plays a central role in the exercise guidelines (American College of Sports Medicine, 1990), and shares a similar physiological response to that of aerobic exercise. However, to date, only a few research studies have focused on acute resistance exercise and cognition. Therefore, it is important to explore the effects of an acute bout of resistance exercise on cognitive performance to further understand the relationship.

Summary of the Literature Review

A substantial amount of research has been conducted to test the relationship between acute exercise and cognitive performance. This literature has been summarized using both narrative and meta-analytic techniques. The results generally indicate that a positive effect on cognitive performance is found when comparing submaximal exercise to rest or when examining dose-response relationships at several submaximal levels of exercise. However, most research studies have used an aerobic exercise condition and have not considered the potential for an acute bout of resistance exercise to evidence similar benefits. Given the importance of resistance exercise to health and that resistance exercise might benefit cognitive performance in a manner similar to aerobic exercise because both forms of exercise have an effect on arousal and on plasma catecholamines, further research examining the relationship between acute resistance exercise and cognition could play a vital role in the advancement of our knowledge. In addition, given that past studies have only used indirect approaches to test mediators, a secondary purpose of this study is to apply statistical techniques to actually test mediational processes. Lastly, most studies in the area of acute exercise and cognition have tested the effects on simple cognitive tasks. Thus, this study will extend the literature by including measures of executive function.

CHAPTER III

METHODOLOGY

Participants Description and Selection

Participants (*M* = 25.95 years, *SD* = 3.20) of different genders and ethnic backgrounds were recruited by flyers posted at the University of North Carolina at Greensboro. A demographic questionnaire included variables such as height, weight, age, gender, and ethnicity. The Aerobics Center Longitudinal Study Physical Activity Questionnaire was used to identify the participant's habitual physical activities. Inclusion criteria were assessed using the Physical Activity Readiness Questionnaire (PARQ) to insure that it was safe for the participant to perform this series of resistance exercises. The PARQ consists of seven questions regarding the presence of conditions that would contraindicate exercise, and participants were only included if they answer "NO" to all of the questions. This approach follows the ACSM guidelines (American College of Sports Medicine, 2007).

When participants meets the inclusion criteria, participants were stratified by sex and then randomly assigned into either the control reading group (control), or one of three different resistance exercise intensity groups (40%, 70%, and 100% of 10-RM). Each group included at least sixteen participants. The number of participants was based on a power analysis using a 2 x 4 mixed design with the effect size estimated from a previous study testing the effects of resistance exercise on cognitive performance in middle-aged adults (effect size f = 0.27) (Chang & Etnier, 2008), power = 0.8 and alpha at .05. The protocol was approved by the University of North Carolina at Greensboro Committee for Institutional Review, and the participants were offered the opportunity to give their informed written consent prior to participation.

Resistance Exercise Intervention

Hass et al. (2001) indicated several components that should be considered when designing a resistance exercise intervention: number of repetitions, number of sets, and frequency of training. In addition, the amount of weight, the rest interval between sets, and the order of exercise should also be considered (Hesson, 2003). Because the present research will focus on an acute resistance exercise bout, the amount of weight/load, number of repetitions, number of sets, muscle groups, and the rest interval between sets were particularly considered.

The goal of the present study was to establish the dose-response effect of resistance exercise intensity on cognition. Because no previous study has tested this relationship in the resistance exercise-cognition field, the resistance exercise protocol was selected based on the protocol used by Arent et al. (2005) who examined dose-response relationships between resistance exercise and affect using intensities at 40%, 70% and 100% of 10-RM. These intensities were confirmed by indicators including HR, RPE, and salivary cortisol to represent low, moderate and high exercise intensities, respectively. 10-RM means the participant can lift the load 10 repetitions before exhaustion. The use of 10 repetitions for the conditions is consistent with the 8 to 12 repetitions per set suggested for increasing muscular strength and endurance as well as muscle hypertrophy by ACSM guidelines.

The resistance exercise session of the present protocol included two sets of 10 repetitions for each of six muscle groups: bench presses, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left). The rest period between sets and between exercises was set at two to four minutes.

Measures

Heart Rate

For each participant, heart rate (HR) was monitored by short-range radio telemetry devices (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland) during the entire treatment session. The heart rate monitor consists of an elastic band that is strapped around the chest to hold a rubber pad (that contains the HR measuring device with the transmitter) in place just below the sternum, and a wristband receiver. The participants' HR is displayed on the face of the wristband receiver. Data from the HR monitor was recorded at 1-minute intervals. Seven HR related variables (HR_{peak}, HR_{average}, HR_{Stroop}, $HR_{\text{Stroop difference}}$, HR_{PASAT}, $HR_{\text{PASAT difference}}$, and FAS) were included. HR_{peak} represents the highest HR attained during the treatment session. HR_{average} represents the average HR attained during the treatment session. HR_{Stroop} represents the HR recording that was taken immediately before performance of the Stroop Test. $HR_{\text{Stroop difference}}$ represents the HR difference between HR_{Stroop} and pre-test HR. HR_{PASAT} represents the HR recording that was taken immediately before performance of the PASAT. $HR_{\text{PASAT difference}}$ represents the HR difference between HR_{PASAT} and pre-test HR.

Ratings of Perceived Exertion (RPE)

Ratings of Perceived Exertion (RPE), developed by Borg (1982), provide a subjective rating of each individual's perception of effort during exercise. The original Borg scale has a range from 6 to 20 RPE. From 6 to 11 is recognized as "very, very light to fairly light" which is also presented as the range for warm-up and cool-down; from 12 to 13 is recognized as "somewhat hard" and can be presented as approximately 60% maximal HR; and, finally, from 16 to 20 is recognized as "hard to very hard" which is presented as approximately 90% maximal HR (Pollock, Wilmore, & Fox, 1984).

Feeling Scale (FS) and Felt Arousal Scale (FAS)

The Feeling Scale (FS) and the Felt Arousal Scale (FAS) are subjective self-report single-item scales used to assess the valence and intensity of arousal, respectively (Hardy & Rejeski, 1989; Svebak & Murgatroyd, 1985). The FS ranges from -5 (very bad) to +5 (very good) with 0 (neutral) as the midpoint. The FAS is a 6- point scale measuring perceived activation that ranges from 1 (low arousal) to 6 (high arousal). The two scales were applied to assess immediate feelings of pleasure and displeasure, and change of self-reported activation relative to the acute resistance exercise. These self-reports are beneficial to identity the role of potential confounders such as anxiety induced by resistance exercise.

Stroop Test

The Stoop Test (Stroop, 1935), also referred to as the Color Naming Task, is used to assess information processing speed, executive abilities, selective attention, and the ability to inhibit habitual responses (Pachana, Thompson, Marcopulos, & Yoash-Gantz, 2004). Typically, a participant is required to name the color in at least three conditions. In the Stroop Word condition (SW), participants see the color names written in black ink, and are asked to read the word aloud. In the Stroop Color condition (SC), participants see a rectangle printed in one of four colors of ink and are instructed to verbally identify the color of the ink. In the Stroop Color-Word condition (SCW), participants see a color name printed in a different color ink (such as the word RED printed in green ink) and are instructed to verbally identify the color of the ink. The test-retest reliability of the Stroop Test is approximately 0.84 (Siegrist, 1997).

Paced Auditory Serial Addition Task (PASAT)

The PASAT (Gronwall, 1977) has been widely used to measure information processing, attention and concentration (Deary et al., 1991). The test required participant to listen to a series of 60 digit numbers from an audio tape and then to verbally provide the sum of the two numbers. In other words, each participant adds the most recently heard number to the number immediately preceding it and then provides the sum orally. The number series is provided by an auditory tape with increasing rates of speed (2.4, 2.0, 1.6, and 1.2 s per digit). The correct responses for each series as well as the average correct responses were analyzed. Cronbach's alpha for the four PASAT trials has been reported as 0.96 (Egan, 1988).

Procedures

Participants were requested to come to the Sport and Exercise Psychology Laboratory at University of North Carolina at Greensboro for two separate testing sessions. The two sessions had to be within the same two-week period but at least 48 hours apart. Participants were instructed not to drink caffeinated beverages before or during the sessions. During session one, the participant was invited to the laboratory and presented with a brief introduction to the study by the investigator. The participant also filled out the consent form, demographic questionnaire, PARQ, and The Aerobics Center Longitudinal Study Physical Activity Questionnaire. The PARQ was used for determining their inclusion or exclusion in the proposed study. After confirming the criteria for the inclusion and exclusion, participants were stratified by sex, and then randomly assigned into a control group (rest; watching resistance exercise related video) or one of three different resistance exercise intensity groups (40%, 70%, or 100% of 10-RM). Then, the investigator recorded the participant's baseline arousal level by assessing resting HR after sitting quietly in a comfortable chair in a dimly lit room for 15 minutes. A Polar Heart Rate Monitor was used to measure HR. Then, FAS and FS were assessed.

After examining the baseline HR, FS, and FAS, each participant was asked to complete the PASAT and Stroop Test for baseline data. Then, each participant's 10-RM for each of the six exercises (bench press, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left)) was determined. The determination of 10-RM resistance exercise was based on a protocol used by Baechle, Earle, and Wathen (2000), and the process was described as follows:

1. Participants performed a stretching routine as a warm-up. Fourteen static stretching movements were selected as a stretching routine based on recommendations from Hesson (2003). Participants were instructed to assume a stretch position for 10 seconds. The duration of the stretch routine was approximately 5 minutes.
2. After the warm up, participants were instructed on how to perform the resistance exercises.

3. The participants were instructed to lift progressively heavier weights to determine the 10-RM.
4. Target weight was determined as the maximum weight that a participant was able to lift 10 times in good form.
5. 2 to 4 minutes was allowed between attempts in order to ensure adequate recovery.
6. The participant repeated the same process for each of the six exercises (bench press, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left).

During session two, participants' baseline arousal was assessed using the same process as was used in session one. This served as the pre-test measure of arousal. After collecting the pre-test arousal level from HR, FAS, and FS, the participants performed the Stroop Test and the PASAT in order as pre-test cognitive performance scores.

Next, participants performed their assigned treatment condition. In the exercise groups, participants performed two sets of 10 repetitions for each of the six exercises at either 40%, 70% or 100% of 10-RM. Participants in the control group were asked to watching resistance exercise related video for a similar amount of time to the resistance exercise (determined through pilot testing). HR, RPE, FS, and FAS were recorded before, during, and immediately after the treatment conditions. Then, the cognitive tests were conducted again as a post-test cognitive performance score after the treatment. Session one took approximately fifty minutes, and session two took approximately one hour.

Data Analysis and Statistical Interpretation

This was a randomized controlled trial with two independent variables: Group (rest, 40%, 70% or 100% of 10-RM resistance exercise) and Time (pre-test vs. post-test).

Group is a between-subjects variable and time is a within-subjects variable. The dependent variables were HR_{peak}, $HR_{average}$, HR_{Stroop}, $HR_{Stroop\ difference}$, HR_{PASAT}, $HR_{PASAT\ differemce}$, FAS, RPE, performance on the three conditions of the Stroop Test, and four individual trials and average performance on the PASAT.

Prior to conducting the analyses and to assist with choosing the appropriate analysis, one-way analysis of variance (ANOVA) was computed for demographic variables, habitual physical activity, baseline measures of HR, FAS and FS, and baseline measures of cognitive performance (SW, SC, SCW, four trials and average performance of PASAT).

1. *Hypothesis # 1.* An acute bout of rest, 40%, 70% or 100% of 10 repetition maximal (10-RM) resistance exercise will result in increasing levels of arousal as assessed using HR, RPE, FS, and FAS. In addition, a linear dose-response relationship is anticipated.

Regression analysis was computed to describe the dose-response relationship between exercise intensity and the exercise-induced arousal variables of HR_{peak}, $HR_{average}$, HR_{Stroop}, $HR_{Stroop\ difference}$, HR_{PASAT}, $HR_{PASAT\ difference}$, FAS, FS, and RPE.

2. *Hypothesis# 2.* An acute bout of rest, 40%, 70% or 100% of 10-RM resistance exercise intensity will impact cognitive performance via assessments of Stroop Test and PASAT. In addition, either a linear or an inverted-U dose-response relationship is anticipated.

In order to examine the dose-response relationship among the four exercise intensity groups and the change in cognitive performance from pre-test to post-test, regression analysis was applied. Difference scores between post-test and pre-test were used as main outcome variables for cognitive performance. Exercise intensity served as the predictor. Separate regression analyses were computed for SW, SC, SCW, Trial 1, Trial 2, Trial 3, Trial 4, and average PASAT performance.

3. *Hypothesis# 3*. Measures of arousal (HR, RPE, and FAS) will impact cognitive performance. In addition, either a linear or an inverted-U dose-response relationship is anticipated.

In the area of exercise and cognition, one of most widely used approaches to indirectly test the role of exercise-induced arousal as a mediator is to use regression analysis to test the relationship between exercise-induced arousal and cognitive performance. To allow for comparisons to this literature, simple regression analysis was performed to examine the dose-response relationship between exercise-induced arousal and cognitive performance. Here, exercise-induced arousal was indexed by HR_{peak}, $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, $\text{HR}_{\text{Stroop difference}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, and FAS. Cognitive performance was defined as the difference scores between post-test and pre-test on SW, SC, SCW, Trial 1, Trial 2, Trial 3, Trial 4, and average performance of PASAT.

4. *Hypothesis# 4*. HR, RPE, and FAS are predicted to be mediators of the relationship between exercise intensity and cognitive performance.

In order to examine the meditational processes directly, a series of regression analyses are recommended (MacKinnon et al., 2002). Therefore, mediation analysis was performed to test the seven potential mediators by HR_{peak}, $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, $\text{HR}_{\text{Stroop difference}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, and FAS between exercise intensity and cognitive performance via assessments of Stroop Test and performance of PASAT.

To testing for mediation, four regression analyses should be conducted and they have to satisfy the following conditions (Baron & Kenny, 1986). X, M, and Y represent the independent variable, potential mediator, and dependent variable respectively.

1. The total effect (c) of X on Y must be significant.
2. The effect of X (a) on M must be significant.
3. The effect of M (b) on Y controlled for X must be significant.
4. The direct effect (c') of X on Y adjusted for M must be non-significant.

If all four criteria are met, then the model can be represented as full/complete mediation between X and Y. However, if, in Step 4, the c' has a significant effect, which indicates X is a significant predictor of Y, then the model can be described as a partial mediation between X and Y.

An alpha of .05 was used as the level of statistical significance for all statistical analyses conducted by SPSS 11.0.

CHAPTER IV

RESULTS

Three participants failed to complete all of the cognitive assessments and were eliminated from the analyses. This left 16 participants in the control, 40% 10-RM, and 70% 10-RM groups, and 17 participants in the 100% 10-RM group.

Table 4 includes the descriptive statistic of the participants. One-way ANOVA revealed that there were no significant differences ($p > .05$) among the four groups in age, $F(3, 61) = 0.08$; height, $F(3, 61) = 0.27$; weight, $F(3, 61) = 0.84$; physical activity, $F(3, 59) = 1.71$; or body mass index, $F(3, 61) = 1.08$. Further, there were no significant differences ($p > .05$) among the four groups in baseline measures of HR, $F(3, 61) = 2.49$; FAS, $F(3, 61) = 1.27$; FS, $F(3, 61) = 0.13$; Stroop Word performance, $F(3, 61) = 0.41$; Stroop Color performance, $F(3, 61) = 0.65$; Stroop Color Word performance, $F(3, 61) = 1.94$; Trial 1 of PASAT, $F(3, 61) = 0.48$; Trial 2 of PASAT, $F(3, 61) = 0.33$; Trial 3 of PASAT, $F(3, 61) = 0.70$; Trial 4 of PASAT, $F(3, 61) = 0.19$; or Average performance of PASAT, $F(3, 61) = 0.35$.

Table 4

Means and Standard Deviation for Participant Descriptive and Baseline Data

	Exercise Intensity				
Variable	Control (M = 8; F = 8) M (SD)	40% 10 RM (M = 8; F = 8) M (SD)	70% 10 RM (M = 8; F = 8) M (SD)	100% 10 RM (M = 9; F = 8) M (SD)	Total (N = 65) M (SD)
Descriptive data					
Age (yr)	26.00 (3.41)	25.88 (3.67)	25.69 (3.38)	26.24 (2.59)	25.95 (3.20)
Height (cm)	170.08 (11.19)	171.12 (12.00)	168.33 (8.16)	168.92 (5.92)	169.60 (9.41)
Weight (kg)	72.41 (18.12)	68.43 (19.20)	63.78 (12.00)	70.63 (14.84)	68.84 (16.21)
ACLSPAQ (MET-hr/week)	28.40 (15.96)	34.48 (20.69)	32.13 (24.68)	20.40 (10.59)	28.76 (19.02)
BMI (kg/m^2)	24.78 (4.54)	23.13 (5.34)	22.41 (3.34)	24.64 4(.50)	23.76 (4.50)
Baseline	76.13	68.13	69.38	73.06	71.69

HR (bpm)	(7.83)	(10.01)	(7.48)	(11.00)	(9.55)
Baseline	2.72	2.27	2.41	2.67	2.52
FAS	(0.45)	(0.72)	(0.46)	(0.52)	(0.56)
Baseline	2.50	2.56	2.78	2.47	2.58
FS	(1.51)	(1.50)	(1.49)	(1.66)	(1.51)
Baseline cognitive performance					
Stroop Word	18.67	19.92	20.30	19.86	19.69
	(3.75)	(3.22)	(3.76)	(6.15)	(4.34)
Stroop Color	23.87	26.17	25.71	24.97	25.18
	(5.27)	(3.84)	(4.73)	(5.87)	(4.96)
Stroop Color	34.18	37.02	40.21	37.73	37.29
Word	(6.34)	(6.01)	(7.70)	(8.16)	(7.28)
Trial 1 of	43.63	45.25	41.19	42.53	43.14
PASAT	(11.24)	(8.99)	(10.08)	(9.32)	(9.82)
Trial 2 of	39. 25	39.88	37.94	36.47	38.35
PASAT	(13.01)	(9.89)	(9.38)	(10.29)	(10.56)
Trial 3 of	36.44	35.06	31.50	34.18	34.29
PASAT	(11.14)	(10.40)	(11.18)	(6.63)	(9.90)
Trial 4 of	25.38	23.56	23.75	23.59	24.06
PASAT	(9.75)	(9.77)	(6.18)	(6.30)	(8.01)

Average of PASAT	36.17 (10.59)	35.94 (8.63)	33.59 (8.29)	34.19 (6.67)	34.96 (8.50)

Note. M = Male; F = Female; ACLSPAQ = the aerobics center longitudinal study physical activity questionnaire; BMI = body mass index, Baseline HR = baseline heart rate; Baseline FAS = Baseline Felt arousal scale; Baseline FS = baseline feeling scale.

Hypothesis # 1

Arousal as a Function of Exercise Intensity

Means and standard deviations as a function of treatment group are presented in Table 5. Regression analyses revealed that with the exception of scores on the FS, there were significant linear relationships between exercise intensity and exercise-induced arousal measures in $HR_{\text{peak,}}$ HR_{average}, HR_{Stroop}, $HR_{\text{Stroop difference,}}$ HR_{PASAT}, $HR_{\text{PASAT difference}}$, RPE, and FAS. F’s (1, 62) > 22.30, R2 = 30% to 93%, p’s < .05. In addition, with the exception of scores on the FS, significant bivariate correlations were observed between exercise intensity and exercise-induced arousal measures, and among these arousal measures. The Pearson correlations for the relationships between exercise intensity and the measures of arousal are presented in Table 6.

Table 5

Means and Standard Deviations for the Effects of Exercise Intensity on the Measures of Arousal at the Post-Test

Variable	Exercise Intensity				Total
	Control	40% 10 RM	70% 10 RM	100% 10 RM	
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
HR_{peak}	81.59 (12.35)	99.67 (10.05)	121.50 (14.44)	142.64 (19.06)	111.55 (27.44)
$\text{HR}_{\text{average}}$	80.50 (10.65)	94.37 (9.25)	116.31 (13.72)	135.74 (19.27)	106.96 (25.48)
$\text{HR}_{\text{Stroop}}$	81.06 (11.78)	94.00 (8.17)	116.12 (14.40)	134.71 (18.95)	106.91 (25.23)
$\text{HR}_{\text{Stroop difference}}$	2.47 (12.80)	24.21 (8.40)	48.06 (13.53)	61.12 (20.04)	34.20 (27.20)
HR_{PASAT}	80.69 (9.72)	81.29 (8.59)	90.38 (13.56)	102.40 (17.63)	89.00 (15.58)
$\text{HR}_{\text{PASAT difference}}$	2.10 (6.12)	11.50 (6.51)	22.31 (9.87)	28.80 (14.62)	16.30 (14.37)
RPE	5.06 (0.24)	12.30 (1.25)	17.72 (0.82)	19.56 (0.51)	13.65 (5.84)
FAS	2.76 (0.43)	3.40 (0.47)	3.94 (0.40)	4.85 (0.42)	3.75 (0.89)
FS	1.65 (1.50)	2.00 (1.77)	2.38 (1.67)	2.59 (1.23)	2.15 (1.55)

Note. HR_{peak} = peak heart rate (bpm); $\text{HR}_{\text{average}}$ = average heart rate (bpm); $\text{HR}_{\text{Stroop}}$ = heart rate that was taken immediately before performance of the Stroop Test (bpm); $\text{HR}_{\text{Stroop difference}}$ = heart rate difference from $\text{HR}_{\text{Stroop}}$ and pre-test heart rate (bpm); HR_{PASAT} = heart rate that was taken immediately before performance of the PASAT (bpm); $\text{HR}_{\text{PASAT difference}}$ = heart rate difference from HR_{PASAT} and pre-test heart rate (bpm); RPE = rating of perceived exertion; FAS = Felt arousal scale; FS = feeling scale.

Table 6

Pearson Correlations for the Effects of Exercise Intensity on the Measures of Arousal at the Post-Test

Measure	1	2	3	4	5	6	7	8	9	10
1. Exercise Intensity	_ _									
2. HR_{peak}	0.86**	_ _								
3. $\text{HR}_{\text{average}}$	0.84**	0.99**	_ _							
4. $\text{HR}_{\text{Stroop}}$	0.84**	0.98**	0.99**	_ _						
5. $\text{HR}_{\text{Stroop difference}}$	0.85**	0.90**	0.91**	0.92**	_ _					
6. HR_{PASAT}	0.55*	0.73**	0.74**	0.74**	0.51**	_ _				
7. $\text{HR}_{\text{PASAT difference}}$	0.73**	0.80**	0.79**	0.79**	0.83**	0.76**	_ _			
8. RPE	0.96**	0.81**	0.79**	0.78**	0.84**	0.48**	0.72**	_ _		
9. FAS	0.86**	0.77**	0.77**	0.76**	0.76**	0.54**	0.69**	0.83**	_ _	
10. FS	0.24	0.26*	0.23	0.23	0.23	0.14	1.67	0.23	0.23	_ _

Note. HR_{peak} = peak heart rate (bpm); $\text{HR}_{\text{average}}$ = average heart rate (bpm); $\text{HR}_{\text{Stroop}}$ = heart rate that was taken immediately before performance of the Stroop Test (bpm); $\text{HR}_{\text{Stroop difference}}$ = heart rate difference from $\text{HR}_{\text{Stroop}}$ and pre-test heart rate (bpm); HR_{PASAT} = heart rate that was taken immediately before performance of the PASAT (bpm); $\text{HR}_{\text{PASAT difference}}$ = heart rate difference from HR_{PASAT} and pre-test heart rate (bpm); RPE = rating of perceived exertion; FAS = Felt arousal scale; FS = feeling scale.

*p < .05, ** p < .01.

Hypothesis# 2

Stroop Test as a Function of Exercise Intensity

Means and standard deviations at the pre-test and post-test as a function of treatment group and difference scores between post-test and pre-test are presented in Table 7. Regression analysis revealed a significant linear trend for the relationship between exercise intensity and SC performance, $F(1, 62) = 3.72$, $p < .05$, R^2=11%. Although SW performance did not reach significance, it revealed a close linear trend between performance and exercise intensity, and accounted for 5.4% of the variance in performance, $F(1, 63) = 3.61$, $p = 0.06$. A significant quadratic trend was observed for the relationship between exercise intensity and SCW performance, $F(1, 62) = 7.34$, $p < .001$, R^2=19%. These performance curves illustrate in Figure 2.

PASAT as a Function of Exercise Intensity

Means and standard deviations at pre-test and post-test as a function of treatment group and difference scores between post-test and pre-test are presented in Table 8. Exercise intensity did not significantly predict performance on Trial 1, $F(1, 63) = 1.37$, $p = 0.25$. However, significant quadratic trends were observed for Trials 2, 3, 4, and for average performance of PASAT , *F*'s (1, 62) > 7.06, *p*'s < .01. These results accounted for 19%, 23%, 35%, and 39% of the variance in performance, respectively. These performance curves illustrate in Figure 3.

Table 7

Descriptive Data and Difference Scores for the Stroop Test Measures Relative to Exercise Intensity

	Exercise Intensity											
	Control			40% 10 RM			70% 10 RM			100% 10 RM		
	Pre-test	Post-test		Pre-test	Post-test		Pre-test	Post-test		Pre-test	Post-test	
Stroop Test	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS
SW	17.70 (3.21)	17.31 (2.91)	-0.39	19.65 (2.49)	18.28 (2.50)	-1.37	19.37 (3.42)	18.79 (3.06)	-0.58	18.80 (3.42)	17.09 (3.10)	-1.71
SC	21.32 (4.63)	21.17 (4.09)	-0.15	23.94 (3.65)	22.87 (2.98)	-1.07	23.93 (4.02)	23.22 (4.25)	-0.71	21.89 (3.23)	20.13 (3.25)	-1.76
SCW	28.53 (5.62)	28.40 (5.55)	-0.13	33.54 (4.45)	29.94 (5.50)	-3.6	33.71 (4.90)	30.84 (4.43)	-2.87	32.18 (5.80)	29.13 (4.88)	-3.05

Note. Values for the Stroop Tests measures are in msec, thus a negative mean value is indicative of an improvement in performance from pre-test to post-test; SW= Stroop word; SC = Stroop color; SCW = Stroop color-word; DS = the difference between post-test and pre-test scores.

Table 8

Descriptive Data and Difference Scores for the PASAT Measures Relative to Exercise Intensity

	Exercise Intensity											
	Control			40% 10 RM			70% 10 RM			100% 10 RM		
	Pre-test	Post-test		Pre-test	Post-test		Pre-test	Post-test		Pre-test	Post-test	
PASAT	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS	M (SD)	M (SD)	DS
Trial 1	50.25 (9.23)	51.94 (8.96)	1.69	51.75 (8.09)	53.06 (6.77)	1.31	49.88 (8.90)	53.56 (7.46)	3.68	52.18 (6.10)	55.00 (4.18)	2.82
Trial 2	47.06 (10.51)	47.69 (10.59)	0.63	46.81 (9.92)	48.88 (8.87)	2.07	43.81 (9.47)	49.56 (9.51)	5.75	46.00 (9.21)	49.51 (8.74)	3.51
Trial 3	43.13 (13.48)	41.88 (13.92)	-1.25	42.06 (11.39)	44.38 (10.09)	2.32	37.63 (10.90)	42.56 (9.85)	4.93	39.82 (8.13)	43.35 (10.49)	3.53
Trial 4	32.75 (10.69)	30.50 (10.71)	-2.25	29.06 (10.30)	34.31 (10.00)	5.25	26.19 (7.32)	32.56 (9.03)	6.37	28.41 (8.01)	33.05 (9.60)	4.64
Average	43.30 (10.55)	43.00 (10.44)	-0.30	42.42 (9.33)	45.16 (8.25)	2.74	39.37 (8.24)	44.56 (8.31)	5.19	41.60 (6.99)	46.50 (5.95)	4.90

Note. Values for the PASAT measures are the number of correct responses, thus a higher mean value is indicative of an improvement in performance from pre-test to post-test; DS = difference mean scores between post-test and pre-test.

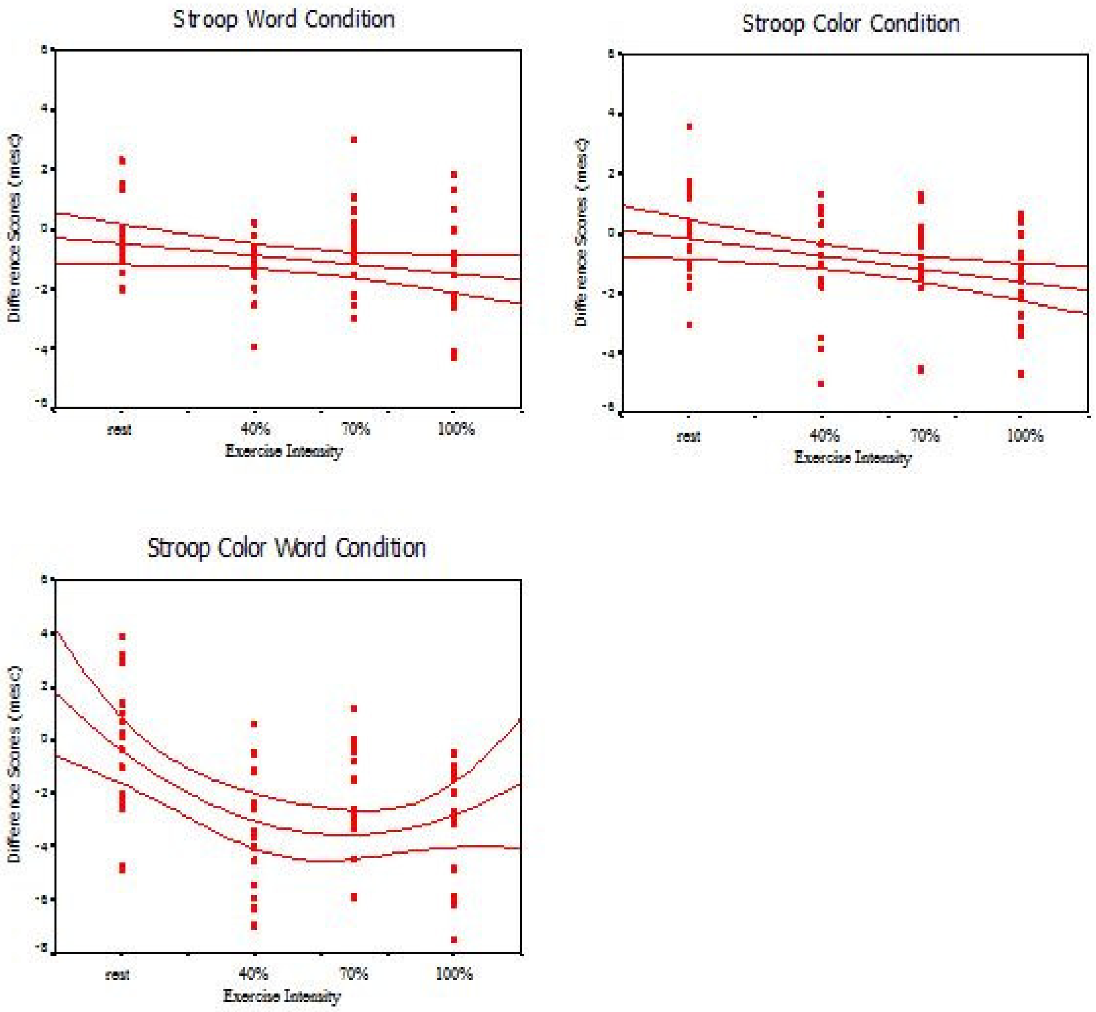


Figure 2. Stroop Test performance as a function exercise intensity on Stroop Word, Stroop Color, and Stroop Color-Word conditions. Values for the Stroop Tests are in msec, thus a lower score is indicative of better performance. The x-axis represents the exercise intensity group (rest, 40%, 70%, and 100% 10-RM).

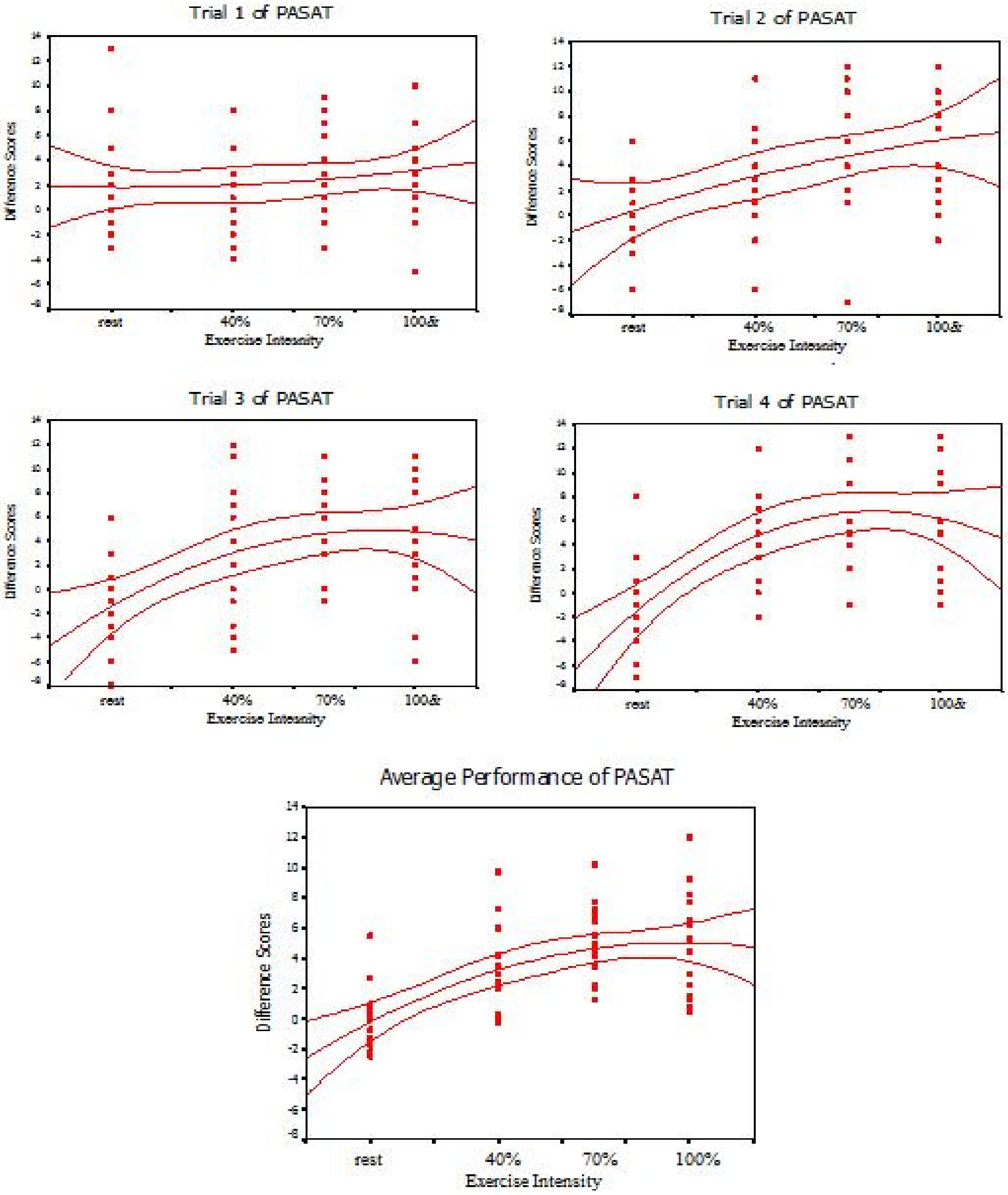


Figure 3. PASAT performance as a function of exercise intensity on Trial 1, Trial 2, Trial 3, Trial 4, and average performance conditions. Values for the PASAT are correct scores, thus higher positive scores are indicative of better performance. The x-axis represents the exercise intensity group (control, 40%, 70%, and 100% 10-RM).

Hypothesis# 3

Stroop Test as a Function of Exercise-induced Arousal

Exercise-induced arousal measures include HR $_{\text{peak}}$, HR $_{\text{average}}$, HR $_{\text{Stroop}}$, HR $_{\text{Stroop difference}}$, HR $_{\text{PASAT}}$, HR $_{\text{PASAT difference}}$, and FAS.

In terms of using peak HR as a predictor, a quadratic trend in SCW performance, $F(1, 62) = 6.05$, $p < .01$, $R^2 = 16\%$ was found. However, peak HR was not a significant predictor of performance in the SW and SC conditions.

In terms of using average HR as a predictor, a quadratic trend in SCW performance, $F(1, 62) = 5.04$, $p < .001$, $R^2 = 14\%$ was found. However, average HR was not a significant predictor of performance in the SW and SC conditions.

In terms of using HR $_{\text{Stoop}}$ as a predictor, a quadratic trend in SCW performance, $F(1, 62) = 6.16$, $p < .001$, $R^2 = 17\%$ was found. However, HR $_{\text{Stoop}}$ was not a significant predictor of performance in the SW and SC conditions.

In terms of using HR $_{\text{Stoop difference}}$ as a predictor, a quadratic trend in SCW performance, $F(1, 62) = 6.55$, $p < .001$, $R^2 = 18\%$ was found. However, HR $_{\text{Stoop difference}}$ was not a significant predictor of performance in the SW and SC conditions.

When using FAS as a predictor, regression analysis revealed a significant linear trend for SC performance, $F(1, 63) = 3.71$, $p < .05$, and a quadratic trend for SCW performance, $F(1, 62) = 3.76$, $p < .01$. These results accounted for 11% of the variance in both performances. FAS was not a significant predictor of performance in the SW condition.

PASAT as Function of Exercise-induced Arousal

In terms of using peak HR as a predictor, regression analysis revealed a significant quadratic trend for Trial 2, Trial 3, Trial 4, and average performance on the PASAT, *F*'s (1, 62) > 4.48, *p*'s < .01. These results accounted for 12% to 27% of the variance in performance.

In terms of using average HR as a predictor, regression analysis revealed a significant quadratic trend for Trial 2, Trial 3, Trial 4, and average performance on the PASAT, *F*'s (1, 62) > 3.94, *p*'s < .05. These results accounted for 11% to 25% of the variance in performance.

In terms of using HR_{PASAT} as a predictor, regression analysis revealed there is no any significant trend for any of the PASAT scores.

In terms of using $HR_{PASAT\ difference}$ as a predictor, regression analysis revealed a significant quadratic trend for Trial 3, Trial 4, and average performance on the PASAT, *F*'s (1, 62) > 5.18, *p*'s < .01. These results accounted for 15% to 24% of the variance in performance.

When using FAS as a predictor, regression analysis revealed a significant quadratic trend for Trial 2, Trial 3, Trial 4, and average performance, *F*'s (1, 62) > 6.06, *p*'s < .001. These results accounted for 16% to 34% of the variance in performance.

Hypothesis# 4

To test the role of exercise-induced arousal as a mediator of the relationship between exercise intensity and cognitive performance, four steps were conducted as per the guidelines of Baron and Kenny (1986) . For the Stroop task, analyses were only performed for SC and SCW conditions based on their significant relationship with exercise-induced arousal. For the PASAT, average performance was selected to represent the overall effect of PASAT. Therefore, X, M, and Y here represent the independent variable (exercise intensity), potential mediators (HR_{peak}, $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, $\text{HR}_{\text{Stroop difference}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, and FAS), and dependent variable respectively (SC, SCW, and average PASAT performance).

Step 1. The total effect (c) of X on Y must be significant.

Step 2. The effect of X (a) on M must be significant.

Step 3. The effect of M (b) on Y controlled for X must be significant.

Step 4. The direct effect (c') of X on Y adjusted for M must be non-significant.

Mediation Analysis between Stroop Test and Exercise Intensity

Regression analysis revealed that exercise intensity did have a significant impact on both SC and SCW performance, thus satisfying step 1 (see results for Hypothesis 1). Results also indicated that exercise intensity was a significant predictor of HR_{peak}, $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, $\text{HR}_{\text{Stroop difference}}$, and FAS on SCW, thus satisfying step 2 (see results for Hypothesis 2). However, regression analysis indicated that when using HR_{peak} to predict cognitive performance while simultaneously considering exercise intensity,HR?? did not significantly predict either SC or SCW (step 3, b). B, standard error, beta, t, and R^2 for peak HR are presented in Table 9 for SC and SCW. Therefore, results indicated that peak HR was not a significant mediating variable in the relationship between exercise intensity and performance.

Equivalent results were found when running $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, and FAS as mediators (see Table 10, Table 11, and Table 13) of the relationship between exercise intensity and performance in the SC and SCW conditions.

$\text{HR}_{\text{Stroop difference}}$ is the only significant mediator that was found in the mediation analysis. The significant mediation was found only in the SCW and not in the SC condition (see Table 12).

Because exercise-induced arousal variables were highly correlated with exercise intensity ($r > 0.70$), which indicates a high shared variance and may result in multi-collinearity issues in the regression analysis, we then conducted collinearity diagnostics using the condition index. Blesley, Kuh & Welsch (1980) suggest that the condition index should be less than 30 to insure that multi-collinearity is not a serious concern. The observed values of the condition index were from 9.38 to 18.83 suggesting that multi-collinearity is not a serious concern in these analyses.

Mediation Analysis between PASAT and Exercise Intensity

The test of arousal as a mediator of the relationship between exercise intensity and performance on the PASAT also satisfied step 1 (see results for Hypothesis 1) and step 2 (see results for Hypothesis 2). However, when testing HR_{peak}, $\text{HR}_{\text{average}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, and FAS as mediators (step 3, b), these were not found to be significant predictors when exercise intensity was controlled for. Therefore, results indicate that HR_{peak}, $\text{HR}_{\text{average}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, and FAS are not mediating variables in the relationship between exercise intensity and average performance on the PASAT.

For these analyses, the values of the condition index were from 7.2 to 18.83, which indicated that multi-collinearity is relatively. B, standard error, beta, t, and R^2 for HR_{peak},

$HR_{average}$, HR_{PASAT}, $HR_{PASAT\ difference}$, and FAS are presented in Tables 14 to 18.

Table 9

Summary of Results for the Meditation Analysis Testing Peak Heart Rate as a Mediator of the Relationship between Exercise Intensity and Stroop Test Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
			Stroop color condition (SC)				
Step 1 (c)	EI	SC	-0.47	0.17	-0.32	-2.69**	0.09
Step 2 (a)	EI	HR_{peak}	20.49	1.56	0.86	13.16***	0.74
Step 3 (b)	HR_{peak}	SC	0.02	0.01	0.31	1.36	0.10
Step 4 (c’)	EI		-0.85	0.33	-0.59	-2.57*	
			Stroop color-word condition (SCW)				
Step 1 (c)	EI	SCW	-0.78	0.30	-0.31	-2.61*	0.08
Step 2 (a)	EI	HR_{peak}	20.49	1.56	0.86	13.16***	0.74
Step 3 (b)	HR_{peak}	SCW	-0.03	0.02	-0.31	-1.36	0.10
Step 4 (c’)	EI		-0.11	0.57	-0.05	-0.20	

Note. DV = dependent variable; EI = exercise intensity; HR_{peak} = peak heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 10

Summary of Results for the Meditation Analysis Testing Average Heart Rate as a Mediator of the Relationship between Exercise Intensity and Stroop Test Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
			Stroop color condition (SC)				
Step 1 (c)	EI	SC	-0.47	0.17	-0.32	-2.69**	0.09
Step 2 (a)	EI	HR	18.73	1.50	0.84	12.46***	0.70
Step 3 (b)	HR	SC	0.02	0.01	0.29	1.29	0.10
Step 4 (c')	EI		-0.81	0.32	-0.56	-2.54*	
			Stroop color-word condition (SCW)				
Step 1 (c)	EI	SCW	-0.78	0.30	-0.31	-2.61*	0.08
Step 2 (a)	EI	HR	18.73	1.50	0.84	12.46***	0.70
Step 3 (b)	HR	SCW	-0.03	0.03	-0.28	-1.26	0.09
Step 4 (c')	EI		-0.19	0.55	-0.08	-0.35	

Note. DV = dependent variable; EI = exercise intensity; HR = average heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 11

Summary of Results for the Meditation Analysis Testing HR $_{\text{Stroop}}$ *as a Mediator of the Relationship between Exercise Intensity and Stroop Test Performance*

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
			Stroop color condition (SC)				
Step 1 (c)	EI	SC	-0.47	0.17	-0.32	-2.69**	0.09
Step 2 (a)	EI	HR $_{\text{Stroop}}$	18.24	1.53	0.84	11.93***	0.69
Step 3 (b)	HR $_{\text{Stroop}}$	SC	0.02	0.01	0.37	1.73	0.12
Step 4 (c')	EI		-0.91	0.31	-0.63	-2.93**	
			Stroop color-word condition (SCW)				
Step 1 (c)	EI	SCW	-0.78	0.30	-0.31	-2.61*	0.08
Step 2 (a)	EI	HR $_{\text{Stroop}}$	18.24	1.53	0.84	11.93***	0.69
Step 3 (b)	HR $_{\text{Stroop}}$	SCW	-0.04	0.02	-0.36	-1.66	0.12
Step 4 (c')	EI		-0.06	0.53	-0.03	-0.12	

Note. DV = dependent variable; EI = exercise intensity; HR $_{\text{Stroop}}$ = heart rate that was taken immediately before the performance of Stroop Test; R^2= adjusted R square.

$*p < .05$, $** p < .01$, $*** p < .001$.

Table 12

Summary of Results for the Meditation Analysis Testing $\text{HR}_{\text{Stroop difference}}$ *as a Mediator of the Relationship between Exercise Intensity and Stroop Test Performance*

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
			Stroop color condition (SC)				
Step 1 (c)	EI	SC	-0.47	0.17	-0.32	-2.69**	0.09
Step 2 (a)	EI	$\text{HR}_{\text{Stroop difference}}$	19.96	1.59	0.84	12.56***	0.71
Step 3 (b)	$\text{HR}_{\text{Stroop difference}}$	SC	0.01	0.01	0.24	1.06	0.09
Step 4 (c')	EI		-0.76	0.33	-0.52	-2.31*	
			Stroop color-word condition (SCW)				
Step 1 (c)	EI	SCW	-0.78	0.30	-0.31	-2.61*	0.08
Step 2 (a)	EI	$\text{HR}_{\text{Stroop difference}}$	19.96	1.59	0.84	12.56***	0.71
Step 3 (b)	$\text{HR}_{\text{Stroop difference}}$	SCW	-0.05	0.02	-0.46	-2.06*	0.14
Step 4 (c')	EI		0.15	0.55	0.06	0.28	

Note. DV = dependent variable; EI = exercise intensity; $\text{HR}_{\text{Stroop difference}}$ HR = heart rate difference from $\text{HR}_{\text{Stroop}}$ and pre-test heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 13

Summary of Results for the Meditation Analysis Testing FAS as a Mediator of the Relationship between Exercise Intensity and Stroop Test Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
			Stroop color condition (SC)				
Step 1 (c)	EI	SC	-0.47	0.17	-0.32	-2.69**	0.09
Step 2 (a)	EI	FAS	0.68	0.05	0.88	14.33***	0.76
Step 3 (b)	FAS	SC	-0.35	0.46	-0.19	-0.76	0.08
Step 4 (c')	EI		-0.23	0.35	-0.16	-0.64	
			Stroop color-word condition (SCW)				
Step 1 (c)	EI	SCW	-0.78	0.30	-0.31	-2.61*	0.08
Step 2 (a)	EI	FAS	0.68	0.05	0.88	14.33***	0.76
Step 3 (b)	FAS	SCW	-0.32	0.80	-0.10	-0.40	0.08
Step 4 (c')	EI		-0.56	-.62	-0.23	-0.91	

Note. DV = dependent variable; EI = exercise intensity; FAS = Felt arousal scale.

*p < .05, ** p < .01, *** p < .001; R^2= adjusted R square.

Table 14

Summary of Results for the Meditation Analysis Testing Peak Heart Rate as a Mediator of the Relationship between Exercise Intensity and PASAT Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
Step 1 (c)	EI	Average	1.74	0.30	0.59	5.78***	0.34
Step 2 (a)	EI	HR_{peak}	20.49	1.56	0.86	13.16***	0.74
Step 3 (b)	HR	Average	0.00	0.03	0.01	0.06	0.32
Step 4 (c')	EI		1.71	0.59	0.58	2.90***	

Note. Average = average performance of PASAT; DV = dependent variable; EI = exercise intensity; HR_{peak} = peak heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 15

Summary of Results for the Meditation Analysis Testing Average Heart Rate as a Mediator of the Relationship between Exercise Intensity and PASAT Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
Step 1 (c)	EI	Average	1.74	0.30	0.59	5.78***	0.34
Step 2 (a)	EI	HR	18.73	1.50	0.84	12.46***	0.70
Step 3 (b)	HR	Average	-0.00	0.03	-0.03	-0.14	0.33
Step 4 (c’)	EI		1.82	0.57	0.61	3.20***	

Note. Average = average performance of PASAT; DV = dependent variable; EI = exercise intensity; HR = average heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 16

Summary of Results for the Meditation Analysis Testing HR $_{PASAT}$ as a Mediator of the Relationship between Exercise Intensity and PASAT Performance

			Unstandardized coefficients		*Standardized coefficients*		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
Step 1 (c)	EI	Average	1.74	0.30	0.59	5.78***	0.34
Step 2 (a)	EI	HR $_{PASAT}$	7.36	1.44	0.55	5.13***	0.29
Step 3 (b)	HR	Average	-0.05	0.03	-0.22	-1.83	0.36
Step 4 (c’)	EI		2.11	0.36	0.71	5.90***	

Note. Average = average performance of PASAT; DV = dependent variable; EI = exercise intensity; HR $_{PASAT}$ = heart rate that was taken immediately before performance of PASAT; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 17

Summary of Results for the Meditation Analysis Testing $HR_{PASAT\ difference}$ *as a Mediator of the Relationship between Exercise Intensity and PASAT Performance*

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
Step 1 (c)	EI	Average	1.74	0.30	0.59	5.78***	0.34
Step 2 (a)	EI	$HR_{PASAT\ difference}$	9.08	1.08	0.73	8.40***	0.52
Step 3 (b)	$HR_{PASAT\ difference}$	Average	0.04	0.04	0.11	0.70	0.30
Step 4 (c’)	EI		1.73	0.45	0.58	3.84***	

Note. Average = average performance of PASAT; DV = dependent variable; EI = exercise intensity; $HR_{PASAT\ diff\ ,}$ = heart rate difference from HR_{PASAT} and pre-test heart rate; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

Table 18

Summary of Results for the Meditation Analysis Testing FAS as a Mediator of the Relationship between Exercise Intensity and PASAT Performance

			Unstandardized coefficients		Standardized coefficients		
Step	Predictor	DV	B	Standard Error	Beta	t	R^2
Step 1 (c)	EI	Average	1.74	0.30	0.59	5.78***	0.34
Step 2 (a)	EI	FAS	0.68	0.05	0.88	14.33***	0.76
Step 3 (b)	FAS	Average	0.78	0.80	0.20	0.97	0.34
Step 4 (c')	EI		1.22	0.63	0.41	1.95	

Note. Average = average performance of PASAT; DV = dependent variable; EI = exercise intensity; FAS = Felt arousal scale; R^2= adjusted R square.

*p < .05, ** p < .01, *** p < .001.

CHAPTER V

DISCUSSION

The purpose of this study was to examine the dose-response relationship between resistance exercise intensity and cognitive function on two types of cognitive tasks. A secondary purpose was to examine the role of the arousal response as a contributing mediator to cognitive function changes following different intensity levels of resistance exercise.

Using the 10-RM as a standard, the intensity of the resistance exercise was manipulated. With the exception of FS, exercise-induced arousal as indexed by HR_{peak}, $HR_{average}$, HR_{Stroop}, $HR_{Stroop\ difference}$, HR_{PASAT}, $HR_{PASAT\ difference}$, RPE, and FAS revealed significant differences among the four exercise intensity groups as anticipated. In addition, arousal variables revealed linear trends where the greatest values were seen in the 100% 10-RM group, followed by the 70% 10-RM group, then the 40% 10-RM group, and finally the control group. This finding indicates that an appropriate manipulation of resistance exercise intensity was used. The finding is also consistent with previous research which has used this protocol to create varying resistance exercise intensities (Arent et al., 2005). Importantly, FS did not differ between treatments suggesting that negative feelings or anxiety cannot explain the differences in cognitive performance between the groups.

The Stroop Test is one of the most widely used neuropsychological assessments for the measurement of cognitive functions and it assesses both basic information processing speed and executive function. For example, performance on the SW and SC conditions is used as a measure of speed of basic information processing and performance on the SCW condition is used as a measure of executive functions such as inhibition, selective attention, and shifting ability (Miyake et al., 2000; Pachana et al., 2004). The present results indicated that resistance exercise has benefits for both speed of information processing and the executive functions necessary to perform the SCW (Hogervorst et al., 1996; Lichtman & Poser, 1983; Sibley et al., 2006). Furthermore, the results extend the research by examining the dose-response effect on the Stroop Test relative to exercise intensity.

The present findings indicated that in terms of basic speed of information processing, performance improved linearly with increasing exercise intensity. This supports the past literature which noted a positive linear relationship between exercise intensity and speed of performance when a participant is familiar with the required skill-set or the dominant response for that participant is being tested (Adam et al., 1997; Aks, 1998; Allard et al., 1989; McGlynn et al., 1977; McMorris & Graydon, 2000; Tenenbaum et al., 1993).

On the other hand, an inverted-U relationship was found for the relationship between exercise intensity and both SCW and PASAT performance. As mentioned, the SCW indexes the executive functions of inhibition, selective attention and shifting. The cognitive demands of the PASAT include an active maintenance and control of task-relevant information and the cognitive operations involved in working memory

(Gonzalez et al., 2006), divided attention (Kinsella, 1998), and information processing capacity (Shucard et al., 2004). The present results indicated that there is a positive effect of acute resistance exercise on executive functions as assessed using both the SCW and the PASAT. Furthermore, the results extend research by demonstrating that there is an inverted-U relationship between executive function and increasing exercise intensity. Interestingly, with increasing difficulty in the PASAT trials, the inverted-U trend relationship became increasingly stronger (see Figure 3) suggesting the role of task difficulty on this relationship. This inverted-U relationship is consistent with previous literature using relatively complex cognitive assessments (i.e., choice reaction time) (Chmura et al., 1994; Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo, Nishihira, Hatta, Kaneda, Wasaka et al., 2004; Reilly & Smith, 1986; Salmela & Ndoye, 1986).

The inverted-U trends are consistent with Easterbrook's theory of attention, which suggests that low and high arousal lead to less attentional flexibility. Recently, Kamkjo et al.(2004) further confirmed the role of attention using event-related potentials, and indicated that moderate exercise intensity induced significantly larger P300 amplitude (an indicator of the amount of attentional resource demands for a specific task) than control, small, and high exercise intensity conditions.

In terms of implied mediators, when using traditional simple regression analysis, the present results indicated that arousal related indexes (HR_{peak}, $HR_{average}$, HR_{Stroop}, $HR_{Stroop\ difference}$, HR_{PASAT}, $HR_{PASAT\ difference}$, and FAS) are significantly related to executive function perforamnce (SCW and PASAT). In addition, these indexes are all revealed quadratic fashion on executive function performance which accounted for 9% to 40% of the variance in performance, and the nature of the relationships was consistent with the dose-response relationships between exercise intensity and cognitive performance. Surprisingly, when using the appropriate analysis to actually test mediational processes as recommended by researchers (Baron & Kenny, 1986; Etnier, 2007; MacKinnon et al., 2002), only $\text{HR}_{\text{Stroop difference}}$ was identified as a significant mediator of the relationship between exercise intensity and cognitive performance. Neither HR_{peak}, $\text{HR}_{\text{average}}$, $\text{HR}_{\text{Stroop}}$, HR_{PASAT}, $\text{HR}_{\text{PASAT difference}}$, nor FAS were established as mediators of the relationship between exercise intensity and cognitive performance. These results are important because dose-response trends of the present research indicated similar results as previous literature in that there were significant relationships among these measures and cognitive function assessment; however the mediation analysis indicates that these variables do not consistently *explain* the relationship between exercise intensity and cognition.

An unpublished dissertation conducted by Sibley (2004) was the first research to apply the mediation analysis approach in the area of exercise and cognition. Based upon his results, exercise-induced HR was not found to be a significant mediation variable, which corresponds with the present finding. Therefore, these findings imply that exercise-induced arousal do not able to appropriately explain the mediational relationship between exercise intensity and cognitive performance.

However, Sibley also called for caution about the unavoidable multi-collinearity issue that might reduce the statistical power for the regression analysis. Similar to Sibley, in the present research, the strong relationship between exercise intensity and the measures of arousal raises concern over multicollinearity. However, this was not deemed to limit the mediational analyses here because the condition indexes were relative low.

Although much further research is needed, these findings fail to support HR related indexes as mediators of the relationship between exercise intensity and cognitive performance. This suggests that other potential mediators of the relationship should be considered in future research. For example, Chmura et al.(1994) and McMorris and Graydon (2000) manipulated work load and found that physiological measures such as blood lactate, plasma adrenaline, and plasma noradrenaline were significantly related to cognitive performance, which implies the potential mediating roles of these physiological variables. However, these authors did not statistically test for mediation and so it remains unclear as to whether or not these variables actually explain the relationship.

Strengths and Limitations

The present research had several strengths. First, it is the one of few empirical studies to examine the benefit of resistance exercise on cognitive ability. In addition, this is the first study to assess the dose-response effect of resistance exercise intensity on different types of cognitive abilities. Third, the present research targets not only basic information processing, but also executive function. Lastly, it is only the second study in which mediation analysis has been used to directly examine the mediation effect rather than using an indirect approach.

As a final consideration, limitations of our study should be addressed. First, although there is no significant difference in physical activity levels or resistance exercise experience among the groups, most of the participants had little resistance exercise experience. Clearly, this might influence the participants exercise-induced HR and subjective reports of RPE and FAS.. Thus, the results of this study might not generalize to participants who are more experienced with resistance exercise. That being said, we did not observe any differences in the FS as a function of the exercise condition, suggesting that participants did not experience anxiety in response to the exercise. Second, the present study identified only HR-related variables and FAS as indexes for exercise-induced arousal and the status of other arousal-related indexes are unknown. Therefore, other exercise-induced measures of arousal might serve as mediators of the relationship between exercise intensity and cognitive performance. Lastly, given that the sample in this study consisted of persons from 18 to 31 years of age with college or higher education levels, caution is urged in generalizing these findings to other populations.

Summary

The present findings indicate that a 30-minute bout of resistance exercise has a positive impact on cognitive function. Specifically, the present findings indicate that there is a significant linear trend for exercise intensity and information processing speed. On the other hand, a significant quadratic trend for exercise intensity was found on measures that assess inhibition, working memory and attentional flexibility. Based upon the results of this study, it is possible to create exercise prescriptions for populations who would like to improve short-term cognitive performance using resistance exercise. Lastly, the present research suggests that heart rate and subjective measures of arousal do not adequately explain the relationship between exercise intensity and cognitive performance.

Future Directions

Based upon these findings, suggestions for further research in this area are warranted. First, given that this is the first published study in which the dose-response effects of acute bouts of resistance exercise on cognition have been tested, further studies should be conducted to insure that these results are replicable. Once the dose-response is further confirmed, the results will be useful for identifying the optimal intensity at which acute exercise benefits cognitive performance so that mechanisms can be tested. Second, given that both cognitive performance and physical capacity begin to decline in young middle-age (Salthouse, 2003), future research should assess whether or not the dose-response effect can be generalized to other populations such as middle-aged and older adult populations. Lastly, given that various potential mediators between exercise intensity and cognition have been proposed, actually testing the mediational processes with mediation analysis is recommended for future research.

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APPENDIX A.
CONSENT FORM

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
CONSENT TO ACT AS A HUMAN PARTICIPANT: Long Form

Project Title: Acute Effects of Localized Resistance Exercise on Cognitive Performance among Older Adults

Project Director: Yu-Kai Chang

Participant's Name: _________________

PURPOSE OF THIS STUDY IS TO:

The purpose of this study is to explore the effect of acute resistance exercise on executive function. More specially, the dose-response relationship between acute resistance exercise and cognition will be examined via four different resistance exercise intensities (reading/0%, 40%, 70% and 100% of 10 repetition maximum (RM)). Executive cognitive ability will be assessed via both the Paced Auditory Serial Addition Task (PASAT) and the Stroop Test.

PROCEDURE OF THIS STUDY IS:

The experimental design consists of two different sessions, and you will be requested to come to the Sport and Exercise Psychology Laboratory at University of North Carolina at Greensboro on two separate days. The two separate sessions will be held within a one week period but separated by at least 48 hours. During session one, you will be invited to the laboratory and presented with a brief introduction of the study by the investigator. You will also be asked fill out the consent form and questionnaires. Physical Activity Readiness Questionnaire will be used to insure that you meet safety criteria for exercise participation (according to the American College of Sports Medicine). After confirming that you meet inclusion criteria, you will be fitted with a Polar Heart Rate Monitor, you will be instructed to complete a trait anxiety questionnaire, and you will be given practice trials on the cognitive tests. You will then be asked to perform two cognitive tests, and will be assigned into a control group or one of three different resistance exercise intensity groups. Next, the investigator will record your baseline physical arousal level by assessing heart rate (HR), ratings of perceived exertion (RPE), and self-reported arousal and mood after sitting quietly in a comfortable chair in a dimly lit room for 15 minutes.

The amount of weight that you can lift 10 times, which also recognized as 10 repetition maximum (10 RM), will be determined for 6 muscle groups (bench press, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left)). The determination of 10 RM resistance exercise is based on a protocol used by Baechle, Earle, and Wathen (2000), and the process is described as follows:

7. Participants will perform a stretching routine as a warm-up consisting of 14 static stretching movements. Participants will be instructed to assume a stretch position for 10 seconds. The duration of the stretch routine will be approximately 5 minutes.
8. After warm up, participants will be instructed as to how to perform the resistance exercises.
9. The participant will be instructed to lift progressively heavier weights to determine the 10 RM.
10. Target weight is determined as the maximum weight that a participant is able to lift 10 times in good form.
11. 2 to 4 minutes will be allowed between attempts in order to ensure adequate recovery.
12. The participant will repeat the same process for each of the six exercises (bench press, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left)).

During Session Two, baseline HR will be assessed in the same fashion as in Session One. You will then be asked to perform two cognitive performance tests.

Participants in the exercise groups will perform two sets of 10 lifts with each of the six exercises (bench press, rowing (right), rowing (left), lateral raise, arm curl (right), and arm curl (left)) at your assigned load. Participants in the control group will be asked to read about resistance exercise for a similar amount of time to the resistance exercise. Following the exercise or watching a resistance exercise related program, the cognitive tests and arousal assessments will be conducted again. Session One's protocol will take approximately fifty minutes whereas the Session Two protocol will take approximately one hour.

All of the procedures with either a resistance exercise or a cognitive test will be conducted in the laboratory. The lab setting is prepared to handle any emergency during the resistance training. First of all, health status will be confirmed following the inclusion criteria. Moreover, the telephone, CPR, and emergency map are available in the lab and known by the principle investigator. Finally, you may stop any exercise or cognitive task during the procedure, if you feel any discomfort.

The results of the proposed research will offer further information regarding the dose-relationship between resistance exercise and executive cognitive performance, and this may provide important benefits for society for offering evidence of the benefits of an alternative approach to exercise to increase cognition.

Confidentiality will be maintained by using numerical identifiers on all hard copies of data. Data from this study will be identified by a numerical identification code. Results will be presented only in aggregate form or in a form that is only linked to the numerical code. Hard copies of data will be stored in a locked office located in the exercise and sport psychology laboratory at UNCG. Hard copies of data will be destroyed by shredder when the research has been published. Electronic databases will be maintained indefinitely, but will not contain any personal identifiers.

RISKS AND DISCOMFORTS:

There are only minimal risks that include muscle fatigue/soreness and dizziness after the exercise.

POTENTIAL BENEFITS:

There is no compensation for your volunteer status; however, your participation will help us to gain a further understanding of the relationship between exercise and human cognitive function

COMPENSATION/TREATMENT FOR INJURY:

There is no compensation for any physical or psychological events that may result from your participation. Please contact Mr. Eric Allen at (336) 256-1482 if you sustain any research-related injuries.

By signing this consent form, you agree that you understand the procedures and any risks and benefits involved in this research. You are free to refuse to participate or to withdraw your consent to participate in this research at any time without penalty or prejudice; your participation is entirely voluntary. Your privacy will be protected because you will not be identified by name as a participant in this project.

The University of North Carolina at Greensboro Institutional Review Board, which insures that research involving people follows federal regulations, has approved the research and this consent form. Questions regarding your rights as a participant in this project can be answered by calling Mr. Eric Allen at (336) 256-1482. Questions regarding the research itself will be answered by Dr. Jennifer Etnier at (336) 334-3037. Any new information that develops during the project will be provided to you if the information might affect your willingness to continue participation in the project.

By signing this form, you are affirming that you are 18 years of age or older and are agreeing to participate in the project described to you by Yu Kai Chang.

_____________________________________ _______________

Participant's Signature* Date