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Acute exercise has been shown to provide beneficial effects on cognitive performance in young adult samples. More specifically, acute exercise has benefits for executive function (EF) which is an umbrella term for high-level cognitive processes necessary for goal-directed cognition and behaviors. These high-level processes are inhibitory control, planning, set shifting, and working memory (WM).

In the literature there seems to be a general trend around studies looking at EF and acute exercise. Previous research tends to focus on one component of EF, such as inhibitory control, with only a few empirical studies looking at set-shifting or WM. This focus is a limitation of the literature as expressed in a review by Ludyga, Gerber, Brand, Holsboer-Trachsler, and Pühse (2016). This limitation does not allow the extension of knowledge around the extent to which exercise impacts multiple EF measures.

Young adult samples are often utilized for exercise and EF research in the university setting. This setting is not only a centralized area from which to recruit the target sample, but the university draws people from various backgrounds which can better represent the population. The high demands of young adults in higher education, professional training, and work are areas in which higher demands of the EF system are needed. By understanding the relationship of exercise in higher education, we will be better equipped to expand our understanding of the impact that exercise can have on EF in this age group.

Therefore, the purpose of this study was to investigate the changes of EF after an acute bout of exercise in college-aged young adults (18-30) using a word recognition memory task, flanker task, and a WM task. The present study was part of a larger study regarding cognition and exercise. For this study, I hypothesized that exercise would beneficially affect RT and accuracy specific to each task. Results indicated that the variable time (pre, post) had a significant effect on reaction time (RT) for the flanker (congruent and incongruent trials) and the dot task. Regarding memory, there was a significant interaction effect for response accuracy. Results from this study show that condition (exercise, rest) did not have a significant effect on cognitive performance (RT, accuracy) for the memory task. Whereas, individuals improved their RT from pre-test to post-test for the dots and flanker tasks. These findings tell us that, regardless of certain measures utilized to test cognitive performance, condition (exercise, rest) had no effect on cognitive performance.

THE EFFECTS OF ACUTE AEROBIC EXERCISE ON COGNITION AMONG YOUNG ADULTS

by

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Approved by

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Committee Chair

To my wife,

for encouraging and supporting me through this journey.

APPROVAL PAGE

This thesis written by Ryan Anthony Stermer 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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CHAPTER I

INTRODUCTION

The relationship between exercise and cognition has been a prominent scientific research interest among scholars. Early exercise and cognition research focused on the effects of participation in physical education activities on reaction time, RT (Burpee & Stroll, 1936). In addition, scholars initially investigated specific cognitive abilities such as RT and speed of processing along with agility measures for major muscle groups as they related to certain sport skills (Beise & Peaseley, 1937). Since the 1930s, researchers have aimed to assess the paradigm differences of exercise such as chronic and acute exercise. A recent study described how chronic exercise had a positive effect on attentional networks in a young adult sample (Pérez, Padilla, Parmentier, & Andrés, 2014). The distinction between acute and chronic exercise is a key variable to consider when attempting to study exercise and cognition. Li, O'Connor, O'Dwyer, and Orr (2017) systematically reviewed the effect of both acute and chronic exercise on cognitive function in adolescents. The authors found that both exercise paradigms had favorable effects on cognitive function.

When considering the exercise and cognition literature, it is critical to understand how cognition has been operationalized. In an early definition, cognition was referred to as mental processes in which sensory input can be transformed, stored, recovered, and used to complete tasks like problem-solving (Neisser, 1967). Of particular interest in the exercise and cognition research is executive function (EF) which is a set of higher-order processes that has to do with the management of oneself and one's resource in order to achieve a certain goal. Scholars have defined EF as a construct that manages higher-order cognitive functions (Alvarez & Emory, 2006; Baddeley,1986) necessary for goal-directed and purposeful behaviors. Therefore, EF is used as an umbrella term for neurologically based skills involving mental control and self-regulation. The specific higher cognitive processes considered to be a part of EF consist of inhibitory control, planning, set-shifting, and working memory (WM) (Gilbert & Burgess, 2008). Although they reside under the term EF, each cognitive dimension is related but also distinct. Inhibitory control refers to the ability to voluntarily inhibit or regulate attentional or behavioral responses (Davis, Bruce, Snyder, & Nelson, 2003; Durston, Thomas, Yang, Ulug, Zimmerman, & Casey, 2002). Inhibitory control involves one's ability to stay focused on a specific and relevant stimulus in the presence of an irrelevant stimulus. A common measure of inhibitory control is the flanker task. Set-shifting is the degree to which one can shift attention between an old cognitive set or rule and a new one (Miyake, Friedman, Emerson, & Witzki, 2000). A common measure for set-shifting is the Wisconsin Card Sorting Test. Planning is the ability of thinking about activities to achieve a specific goal (Kramer, Hahn, Cohen, Banich, McAuley, Harrison, Chason, Vakil, Bardell, Boileau & Colcombe, 1999). A common measure for planning used in exercise literature is the Tower of London task (Chang, Chu, Chen, & Wang, 2011). WM is the ability to hold and manipulate information in the mind (Baddeley & Hitch, 1974) and is assessed in tasks where the participants are presented sequences of visual or verbal information and required to monitor and update the information in some way. Various measures such as the operation span task (OSPAN), reading span task (RSPAN), and n-back task have been used in scientific literature to measure WM.

More recently, because EF has been of interest in the exercise and cognition literature, researchers have conducted meta-analyses to understand the nature of the effect of exercise on cognition. Several meta-analyses have been published in order to provide a summary understanding of empirical research about exercise and EF. One meta-analysis provided findings of different exercises and how the exercise impacted cognition. Lambourne and Tomporowski (2010) found that acute bouts of cycling enhanced performance of EF both during and after exercise. Equally important, is that treadmill acute exercise elicited small improvements on EF after the completion of the exercise. The researchers' general finding from this review tell us that EF performance may be enhanced or weakened depending on when it is measured (before, during, after), the type of cognitive task, and the type of exercise. This literature depicts that cognitive task performance was impacted when assessed during an exercise condition, eliciting a mean effect of -0.14, whereas, performing cognitive tasks after an exercise improved performance by a mean effect of 0.20 (Lambourne & Tomporowski, 2010).

In addition, two other meta-analyses have provided work that supports (or "is consistent with") the results described in the former review. Chang and colleagues (2012) extended our knowledge when meta-analytically reviewing the acute exercise and cognition literature by incorporating different ages and by analyzing studies in three subsets of cognitive task administration (during exercise, immediately following exercise, and after a delayed timespan following exercise). Equally important, is that the authors looked at potential moderators such as exercise intensity, type of cognitive performance assessment, and participant fitness level. Like the previous review, Chang and colleagues found differential effects when cognitive performance was measured at various times. When cognition was measured during exercise results indicated a positive significant effect after 20 minutes of exercising. Also, results indicated that the largest positive effects were found in studies that measured cognition utilizing a 11-20 minute period of exercise and when cognition was performed within 15 minutes of completing the exercise. Furthermore, EF, attention, and crystalized intelligence measures showed significantly larger effects compared to other cognitive tasks such as information processing, memory, and RT. Regarding age differences, the authors found that most effects of exercise and cognition came from studies that tested young adults.

A recent review utilized similar methodologies as previous reviews regarding moderating variables (EF component, age, and fitness level) when looking at the relationship between acute exercise and cognition. Ludyga et al. (2016) found that studies of exercise and EF elicited greater effects in pre-adolescent children and older adults compared to young adults when RT was a dependent variable. Moreover, of the experimental studies compiled, exercise had small effects in time-dependent and accuracy measures of various EF tasks. This finding is consistent with previous reviews that also found small effects for EF measures (Chang et al., 2012). Additional examination of EF subcomponents did not reveal specific differences. However, the authors caution readers to understand that there tends to be more focus on certain EF components like inhibitory control compared to WM. Additionally, it is important to note that many studies only focus on one aspect of EF and therefore more research needs to look at multiple components of EF. Therefore, we need to look further into this relationship of exercise and cognition, specifically relating to EF.

Regarding beneficial effects of acute exercise on cognitive performance in young adult samples, there seems to be a general trend in many studies. In the extant literature, inhibitory control is commonly measured, but there are few studies looking at set-shifting or working memory. This limitation of studies only assessing one component of EF was expressed in the review by Ludyga and colleagues (2016). This is a critical shortcoming of the literature because our understanding of which aspects of EF are most improved by acute exercise is based only upon averages of effect sizes across studies. Given the myriad differences in study design, the interpretation of observed differences is unclear when it comes to identifying the specific variables that are driving the differences in effect sizes. Therefore, it is necessary to further our understanding around exercise and cognitive performance by assessing multiple aspects of EF in a single study. Since EF represents higher-order processing, it is crucial to understand how the benefits of exercise impact the various EF processes.

Although previous research has examined acute exercise and cognition of young adults utilizing a treadmill, few studies focus on comparing specific EF constructs such as WM and inhibition. By demonstrating sound evidence in this study, I hope to aid in the addition to knowledge around these constructs to better understand the impact that exercise has on the young adult population. The present study is part of a larger study regarding cognition and exercise which investigates the relation of individual differences such as, body mass index (BMI) to acute exercise effects on cognition and memory. For this study, the focus is on the RT and accuracy outcomes from the behavioral measures. I hypothesize that exercise will beneficially affect RT and accuracy specific to each task (flanker, dots, and memory task). Therefore, the aim of the investigation was to study the changes in EF and memory after acute aerobic exercise in college-aged young adults (18-30 years) using a word recognition memory task, flanker task, and a change detection task (dots task). Exercise was expected to beneficially affect RT and accuracy on each task (flanker, dot, memory), but the magnitude of the effects were expected to differ between the tasks. Partial eta squared was used to compare the ratio of variance between conditions.

CHAPTER II

REVIEW OF THE LITERATURE

Memory

The ability to encode, store, retain, and recall information or past experiences in the brain is known as memory. Essentially, memory is the summation of what we remember, and it allows us the capability to learn and adapt from former experiences. Memory is related to but also distinct from learning, which is the process of acquiring knowledge. Therefore, when we learn new things our memory provides sets of neural connections that allows for the storage and retrieval of learned information. The study of memory dates to Hermann Ebbinghaus (1885/1913 translation), who studied his own acquisition and forgetting of new information. William James (1890) later proposed the distinction between primary and secondary memory. Primary memory being the amount of information obtained relative to the conscious present, and secondary memory relating to the vast body of knowledge stored over a lifetime. Memory in the scientific literature has since been identified as three different types, short-term memory (STM), long-term memory (LTM), and working memory (WM).

STM and LTM have been studied across various disciplines. Researchers have discussed the distinction between the two and that they differ in both duration and capacity of stored information (Cowan, 2008). STM and LTM are different in duration where each memory system holds information over different spans of time. The difference between the two systems of memory can also be differentiated by a capacity difference in STM, which means that there is a limit to how many items can be held.

WM was introduced to describe the differences between information that was needed to fulfill near-term needs, and situations where information needed to be manipulated in some way to meet those near-term needs (Miller, Galantar, & Pribram, 1960). WM as its own construct became prevalent in the scientific research when Baddeley and Hitch (1974) introduced their model of WM. The authors define WM as a theoretical construct that refers to a system of mechanisms that allows humans to maintain task/goal-relevant information in the face of concurrent processing and/or distractions. WM incorporates its own unique constructs, thus setting it apart from other forms of memory. Baddeley and Hitch describe their model as consisting of three components. The most extensively investigated aspect of WM, and the first component in the model, is the phonological loop. This component has been thought to involve a sound or acoustic memory storage unit. The second component of WM is the visuospatial sketchpad. This component is less understood compared to the phonological loop. The authors describe the sketchpad as a general workspace or even blackboard for maintaining, holding, and retrieving visuospatial information. Additionally, there is some support that the sketchpad plays a part in planning and executing spatial tasks. The final component according to Baddeley and Hitch's 3-component model is the central executive. The central executive has been described as the most complex and least understood aspect of WM. This sub-component of WM manages all the information that is encoded by humans and divided into the specific component whether it be auditory or visual. Overall, WM acts as a theoretical construct that describes our ability to psychologically and neurologically assess the encoding, maintenance, and retrieval of information that is kept in the mind temporarily. The authors put forth the necessity of future research to focus on the visuospatial sketchpad and the central executive so that the scientific community can better understand the concept of WM. In 2000, Baddeley proposed a more up to date view of WM. Though his model did not dramatically change, Baddeley introduced the component called the episodic buffer. Baddeley described the episodic buffer as a limited capacity system. This system provides temporary storage of information held in various codes, which can combine information from the other subcomponents of the model (phonological loop and visuospatial sketchpad). Baddeley explained that conscious awareness is the principal mode of retrieval from the episodic buffer. This revised model differs from the original by focusing attention on the processes of integrating information compared to information being isolated in the respective subsystems. This allows for a more elaborate basis for looking at the complex aspects of executive control in WM.

Executive Function

Executive function (EF) has been extensively researched in many different fields. However, researchers are still trying to understand the many complexities. The intricacies of the brain have allowed researchers to pose enlightening questions to better understand how our brain works. Researchers' scholarly efforts have provided us knowledge in deciphering questions related to EF testing. Gilbert and Burgess (2008) describe current definitions of EF and how brain mapping techniques have been utilized to understand different neural structures in the brain. EF is described as the high-level cognitive processes necessary for goal-directed cognition and behaviors. The authors describe EF as an umbrella term for specific high-order cognitive processes such as planning, set shifting, inhibitory control, and WM. Neurological testing in humans and animals has provided foundational understandings of EF occurring in the frontal lobe specifically, the prefrontal cortex (PFC). The authors describe how breaking down the different neural regions of the PFC allows researchers the ability to gauge specificities in EF relating to the PFC regions. Studies have shown that the ventrolateral prefrontal cortex (VLPFC) is involved with the short-term maintenance of information. Research also shows that the dorsolateral prefrontal cortex (DLPFC) is implicated in the manipulation of information like dialing a number in reverse. Additionally, functional neuroimaging has suggested activation in the DLFPC when a measure such as the Stroop task is given. It has also been hypothesized that the DLPFC is involved with complex functioning like planning.

Exercise and Cognition

Many researchers have formulated studies to help understand the effect that exercise has on the brain. More specifically, scientific research has shown the impact of exercise on cognition. Sibley and Etnier (2003) meta-analytically reviewed the relationship between physical activity and cognition in children. The authors found an effect size of 0.32. Those results were similar (ES = 0.16) to another meta-analysis looking at the effects of physical activity on cognition across the life span (Etnier et al., 1997). These findings suggest that physical activity and/or exercise can be beneficial at all stages of life. More importantly, early intervention is preferable so that improvement and maintenance of cognitive function continue through adulthood. Equally important, is the relationship between exercise and memory. Stroth, Hille, Spitzer, and Reinhardt (2009) studied aerobic endurance exercise, memory, and affect in young adults. The authors found a significant increase in visuospatial memory performance and a significant increase in positive affect in the exercise experiment group compared to the control group. These findings not only aid in future research but demonstrate the positive implication of exercise as it relates to memory. In addition, exercise has also been researched with EF. Recall that EF allows people to plan, organize, and complete tasks that require higher ordered thinking and processing. Skills like inhibitory control are regularly tested in empirical research. There are several studies that have investigated inhibitory control (Alves et al., 2012; Barella et al., 2010; and Chang et al., 2012) and set-shifting (Coles & Tomporowski, 2008; Cordova et al., 2009; and Loprinzi & Kane, 2015), but there are fewer studies that have investigated WM. However, the empirical work that does look at WM (Chen et al., 2014) tends to be coupled with other aspects of EF. Therefore, studying multiple aspects of EF simultaneously will allow researchers to delve deeper into the question of how exercise can impact our higher-order functioning.

Empirical Studies

Sibley and Beilock (2007) conducted a study with young adults (N = 48; 31 males, 17 females). Pre-screening was performed during the first session. Following the first session, each participant performed two WM tasks and completed a graded exercise test to determine VO_{2max}. The exercise and control sessions were counterbalanced across participants, such that some participants performed the exercise first and some performed the control session first. One week later, at the same time of day, participants returned to the lab to perform a 30-minute self-paced bout of exercise on a treadmill. Each participant was instructed to keep his or her heart rate at 60%-80% of age predicted max HR. Immediately thereafter, each participant completed two valid measures of WM. The measures consisted of Operation Span (OSPAN) and Reading Span (RSPAN). Both WM tasks measure the ability to focus attention on a central task and execute its required demands while inhibiting irrelevant information. As previously described, the authors wanted to test the constructs based on individual differences, more specifically, testing to see if participants who score lower or higher during the baseline WM task would be more or less affected by an exercise condition. Based upon their performance at the pre-test, a quaternary split was conducted so that participants were placed into their respective WM quadrants for performance on OSPAN and RSPAN. The pre- and post- test measures along with the division of WM quadrants (low, middle-low, middle-high, high) allowed the authors to perform a 2 x 4 repeated-measures ANOVA. Interestingly, the authors found a significant increase in WM scores for participants whose baseline WM scores were in the lowest quartile. This novel study sheds light on the idea that acute exercise may have a more beneficial factor for people who generally have lower cognitive performance compared to regular or high cognitive performance individuals.

Identifying effects of exercise on executive processing, STM and LTM, Coles and Tomporowski (2008) studied the exercise-induced effects on cognitive performance across eighteen young adults (mean age = 22.2 years, s = 1.6). The authors hypothesized that short-term effects of acute exercise bouts would facilitate cognitive performance. The authors utilized the first session to gather participant information and for each participant to be familiarized with the cognitive tasks in the study. During all sessions, the first cognitive task was the immediate free-recall test. Thereafter, the following tasks were counterbalanced across participants, the switch task or Brown-Peterson task (STM). After the screening session, the order of conditions was counterbalanced among the participants. The experimental sessions included a 40-minute ergometer cycling acute exercise, a seated ergometer session, and a rest condition. Coles and Tomporowski tested the distributed-learning hypothesis by including two control conditions. The distributed-learning hypothesis predicts that individuals' cognitive performances would improve if given a rest period between cognitively challenging tasks. During the exercise condition, the workload (Watts) increased at a rate of 23 W per minute, and participants performed the exercise to exhaustion. Although the authors incorporated various cognitive tasks, there was no significant finding of exercise altering EF.

Investigating the impact of exercise on WM, Pontifex, Hillman, Fernhall, Thompson, and Valentini (2009) included aspects of executive control (EC) as it relates to the WM construct. Further, the authors extended the literature by comparing resistance exercise and aerobic exercise. A total of 21 young adults (12 men, 9 women; M=20.2 years) participated in the study. Day 1 consisted of the baseline testing that incorporated a PAR-Q to screen for health issues, instruments to gather height and weight, being fitted for a HR monitor, a VO_{2max}, and a 1-repetition max on several different exercises. Across days 2-4, participants completed the experimental sessions. Experimental sessions consisted of either resistance exercise (3 sets of 8-12 repetitions at 80% of their 1RM), aerobic exercise (30 min on a treadmill at a 60-70% VO_{2max}), or seated rest (served as the control condition). To measure WM, the Sternberg task was given before, immediately after, and 30 min after the experimental sessions. The findings showed a shorter RT latency on the Sternberg task immediately and 30-min after acute aerobic exercise, relative to the pretest. No effects on RT were found after resistance exercise or a seated rest.

Li and colleagues (2014) investigated the effect of acute aerobic exercise on WM while also measuring neural brain activity through functional magnetic resonance imaging (fMRI). The conditions consisted of a 30-minute acute session at a moderate intensity (60%-70% estimated maximal HR) and a control condition of 20 minutes of seated rest. Within 15 minutes of the exercise or control condition, participants performed the N-back task while undergoing a MRI scan. The authors hypothesized that aerobic exercise would improve WM as measured by the N-back task and change neural activity associated with WM. Even though there was a lack of behavioral measures affected by exercise, it did have an impact on activations of brain regions that reflect an improvement of EF.

Researching differential effects of acute exercise on EF, Weng, Pierce, Darling, and Voss (2015) implemented two experimental sessions to measure within-subject conditions of exercise modality and EF tasks. A total of 26 young adults were utilized in this study. Participants in the study were counterbalanced among exercise conditions. The exercise conditions consisted of an active 30-minute moderate intensity bout of aerobic cycling or a passive motor driven cycling ergometer which was meant to represent a low intensity workout. EF was measured based on two subcomponents, WM and inhibition. In order to measure WM, the authors utilized a modified facial n-back task, whereas, inhibition was measured by the flanker task. The authors hypothesized that cognitive improvements would come after active exercise rather than passive exercise. Results showed that the active exercise condition slightly improved WM performance during the facial n-back task, specifically, the 2-back condition. In terms of inhibition, active aerobic exercise did not significantly affect performance for incongruent trials on the flanker task. On the other hand, there was a decrease in performance from pre-test to post-test during the passive exercise condition.

Wang and colleagues (2015) assessed EF by using the Wisconsin Card Sorting Task (WCST). The authors assessed 27 young adults across two different groups. The adults were randomly assigned to either an exercise (30-minute single bout of exercise at moderate intensity) condition or a 30-minute reading control condition. EF was measured by implementing the WCST right before and after the assigned condition. The authors found no significant effects, suggesting that acute exercise failed to demonstrate an effect on EF. Consequently, the authors attempted to reproduce the same study but with a middle-aged adult sample. The second study was used to act as a control for potential ceiling effects in young adult ages. After replicating study 1 on middle-aged adults, the authors found similar effects. Results from study 2 indicated that acute exercise had no significant effect on EF in a middle-aged adult sample.

Utilizing a higher education classroom setting, Ludyga, Gerber, Brand, Pühse, and Colledge (2018) examined the effects of acute aerobic exercise on EF. The sample consisted of 51 young adults (M_{age} = 21) on a university campus. Each participant completed a 20-minute bout of moderate intensity running or read an article while seated. Participants were counterbalanced across conditions. The two experimental sessions were separated by one week. After the completion of the experimental or control condition each participant completed the free-recall task, followed by the n-back and flanker task. The order of EF task presentation was counterbalanced across participants. The free-recall task is used to study STM and LTM, the n-back assesses WM, and the flanker task assesses inhibitory control. Therefore, this study utilized three factors or subsets of EF. Ludyga and colleagues found that a moderate run compared to an inactive control positively influenced inhibitory control, STM, and LTM. However, aerobic exercise posited no influence on WM.

Meta-Analyses

McMorris, Sproule, Turner, and Hale (2011) compared the effect of acute, moderate intensity exercise on two distinct factors of performance in memory tasks, specifically, speed and accuracy. A total of 24 empirical articles were included in this analysis that incorporated 14 different WM tasks, such as operation span (OSPAN), reading span (RSPAN), the paced auditory serial addition task (PASAT), and the Sternberg task. In order to investigate the effects of moderate intensity exercise on WM, meta-analytic methods were utilized to focus on effect sizes rather than probability. The authors hypothesized that moderate intensity exercise would portray beneficial effects on response time in WM tasks and show different effect sizes between response time and accuracy. The authors calculated the effect-size as Cohen's d and Hedge's g. Overall, the results supported the authors' hypothesis. Moderate intensity exercise did have a large beneficial effect on response time in WM tasks. In addition, there were no significant differences between the exercise durations, fitness level, gender, or age.

Utilizing meta-analytic techniques, Lambourne and Tomporowski (2010) reviewed studies that focused on acute exercise and cognitive performance. The inclusion criteria consisted of the study being: performed on healthy adults, using repeated-measures, and using a within-subject design, and the study had to be in English. Twenty-one studies were included to analyze measure of cognition before and during exercise, while 29 studies were included to analyze pre- and post-exercise cognitive measures. The authors were focused on five different hypotheses. First, the effects of exercise on cognition were predicted to be contingent on the exercise intensity and duration of the exercise. Second, the timing of the cognitive task was expected to have an influence. Specifically, where larger effects were seen during exercise with a gradual decrease as the exercise was completed. Third, the exercise mode was expected to depict a differential effect size. The authors predicted a smaller effect during exercise on a treadmill compared to exercise on a cycling ergometer. Next, the authors hypothesized that specific cognitive tasks that measure speed, decision-making, and executive processing would result in larger effect sizes than tasks requiring memory encoding and retrieval. Some of the cognitive tasks used included PASAT, Stroop task, visual search, RT, choice response time (CRT), finger tapping, and the flanker task. Lastly, studies that included a resting control condition were hypothesized to portray smaller effect sizes compared to pre- and post- exercise measurement designs. A multiple regression model was used to determine the effect of moderating variables during exercise. Three moderators had an independent relation to the effect size. Negative effects were found during the first 20 minutes of exercise and positive effects were found after the first 20 minutes of exercise. The exercise modality showed statistical differences between exercise modes. The effect size for studies that incorporated a treadmill was negative, whereas, the cycling mode was positive. Lastly, effect sizes were dependent on the type of task where positive effects were found for studies that used a visual search and negative effects were found for studies that incorporated processing speed and perceptual tasks. An additional model was used to assess design and timing of the cognitive assessment. Large negative effects were found in studies without a control group that measured cognitive performance during the first 20 minutes of exercise compared to studies with a control group. In addition, a large positive effect was found with testing cognition after 20 minutes of exercise. Task type and exercise dictated the interaction where processing speed during a steady-state exercise was positive but then negative when exercise focused on fatigue. Similarly, the authors used a multiple regression model to look at the moderating effects after exercise. Overall, acute exercise indicated a small but significant improvement in cognitive task performance after a bout of exercise. Task type also portrayed a small effect for tasks that measured processing tasks ($\Delta = .18$) compared to memory tasks ($\Delta = .30$). Lastly, larger effects were found in studies that did not include a control condition.

Chang, Labban, Gapin, and Etnier (2012) provided a meta-analysis on the effects of a single session of exercise on cognitive performance. The authors used broad inclusion criterion to gather empirical studies on cognitive performance and exercise. This approach differed from the meta-analysis performed by Lambourne and Tomporowski in that the aim was to provide a more comprehensive review of the literature which allowed the Chang and colleagues to test for additional moderators. More specifically, Chang and colleagues incorporated various moderators to gauge the effectiveness of exercise on cognitive performance. It was hypothesized that exercise would have a small but beneficial effect on cognitive task performance after the single session of exercise. Additionally, the authors hypothesized that a negative effect would be seen in cognitive performance during the exercise session. For the purpose of this meta-analysis the authors included studies that incorporated exercise on a single day. Cognitive performance domains were included based on information regarding processing, attention, expertise, memory, and EF. Seventy-nine studies and 1034 effect sizes were included. The 79 studies incorporated a wide range of participants (2072 total) including children (5-20 years), adults (30-60 years), and older adults (>60 years). In order to measure effect sizes, Cohen's d was utilized.

Exercise intensity did not moderate the relationship of the cognitive task administration during a session of exercise. The moderating variable time impacted effects on cognitive performance. If the test was administered during the first ten minutes of the exercise session, there was a negligible effect. Whereas, administering the cognitive test 11-20 minutes during the exercise resulted in negative effects and administration after 20 minutes of exercise resulted in positive effects, all while still performing the exercise session. Regarding cognitive task type, only tasks that were categorized as an EF task had a significantly larger effect than other cognitive task types. Fitness levels moderated the effects such that positive effects were found for higher fit individuals and negative effects were found for moderate and low fit individuals.

Next, the authors calculated effect sizes of the moderators when the cognitive task was performed immediately following the exercise. Very light exercise intensity showed positive effect sizes that were differed from zero, whereas, moderate and maximal intensities were not significantly different from zero. The cognitive tasks that showed significant effects were tasks that measured crystallized intelligence, attention, and EFs. In addition, the three tasks were not significantly different from one another. Fitness levels also had a significant moderating effect such that people who were deemed high fit or low fit achieved positive significant effects in response to acute exercise as compared to moderately fit people who showed no significant effects.

Additionally, moderating effects were analyzed to study the influence of exercise and cognitive performance with a delay after the exercise session. Light intensity varied from all other levels where light exercise had negative effects on cognitive performance with a delayed administration of the test. On the other hand, all other intensity levels showed positive effects that differed from zero.

Lastly, cognitive tasks that aim to measure memory are important to understand moving forward in the research. The authors found that cognitive tasks measuring memory immediately following exercise and after a delay, yielded no significant difference from zero. Additionally, there was a difference in moderating effects regarding memory tasks. Positive effects were found for measures of visual STM, negative effects were found for sequential memory, and non-significant effects for verbal WM. These findings help researchers understand the impact of different cognitive tasks specific to memory and exercise. Overall, most effects came from studies that specifically tested young adults and studies that did not incorporate a particular theoretical framework.

Empirical research has shown that exercise can be used to improve memory. Roig, Nordbrandt, Geertsen, and Nielsen (2013) aimed to meta-analytically review the current literature on exercise and human memory. Studies were categorized by the measure of long-term memory and short-term memory. In each given category, the studies were also categorized into groups of acute interventions and long-term interventions. In order to examine differential aspects that could impact the effects of acute exercise on memory the authors grouped studies depending on time of information encoding, exercise intensity, and duration of the exercise. Long-term exercise interventions were grouped depending on the intensity of the exercise, duration of the exercise itself, and the exercise program length. Lastly, the authors grouped studies based on additional moderating factors such as age and fitness level. The final count of studies incorporated was 41 (29 acute exercise, 19 long-term exercise). Overall, researchers found that acute exercise has a moderate to large effect on long-term memory and moderate effects on short-term memory. In contrast, long-term exercise did not show an effect on long-term memory and only produced small effects on short-term memory.

There is a vast amount of research that investigates the relationship between exercise and EFs. Ludyga et al. (2016) meta-analytically reviewed the relationship between exercise and EF as well as additional factors such as age and aerobic fitness levels. The authors selected studies based on criteria such as changes of EF after moderate aerobic exercise, the use of time and accuracy of EF measures, the use of counterbalanced and or randomized study designs, and comparison of an exercise and control group. The authors' first sub-group analysis inspected effects of aerobic exercise on different EF measures. These measures consisted of inhibitory control, shifting, and WM. The researchers' second analysis focused on how age impacted the relationship as a moderating variable. Ludyga and colleagues implemented a third subgroup analysis, which investigated participants' fitness level as a moderating variable between exercise and EF. Fitness was measured based on VO_2max and categorized as low-fit, average-fit, and high-fit.

The authors found that there was a small effect of moderate aerobic exercise on timing measures (g=.35) and accuracy in EF tasks (g=.22). Regarding age, the authors found that preadolescent children and older adults benefit most from aerobic exercise. Comparatively, young adults (g=.20) showed small improvements of time-dependent EF measures after acute exercise. Fitness levels were also assessed as a possible moderating variable of EF and exercise. According to the authors, EF and exercise did not different between different levels of fitness. Overall, authors found that age does have a moderating impact, in that preadolescent children and older adults perform better on EF tasks after moderate exercise.

Therefore, this study aimed to investigate the changes in EF and memory after acute aerobic exercise in college-aged young adults (18-30 years) to see if cognitive performance differed from past literature.

CHAPTER III

METHODS

Participants

Participants (n= 30) for this study included students (22 females, 8 males) between 18 and 30 years of age from the University of North Carolina at Greensboro (UNCG) campus. In order to recruit this sample, flyers were posted, the study was verbally explained to Kinesiology undergraduates in various classes, and word of mouth was used. Participants were first screened by telephone or email to verify age and physical ability to exercise. All inclusion criteria were discussed with the participant. Inclusion criteria consisted of participants being between the ages of 18-30 years old at the time of testing and being physically capable to perform the exercise in the study. The latter was confirmed by the participant completing the Physical Activity Readiness Questionnaire (PAR-Q) and the cardiovascular section of the Health History and Demographics Questionnaire (vision, neurological conditions, and native language) through the online Qualtrics survey software (Qualtrics, 2019).Participants had to have normal or corrected-to-normal vision based on the minimal 20/20 standard in order to complete the computer tasks. In addition, participants had to be free of any neurological conditions that would otherwise limit them from completing the cognitive tasks. Lastly, English had to be the native language of all participants.

Procedures

Day 1

Participants were provided a detailed explanation of the purpose of the study, any possible risks from participating in the study, and allowed to ask questions once the explanation was given. Before obtaining informed consent, participants acknowledged the potential risks, and that they were under no obligation to participate in the study, and that at any time they could withdraw without penalty. After completing the informed consent paperwork, each participant completed several surveys utilizing the Qualtrics survey software. The questionnaires consisted of a Health History and Demographics questionnaire, the Physical Activity Readiness Questionnaire (PAR-Q), and the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003). Next, the participants completed the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; Weschler, 2011) which is a tool to measure level of intelligence. This measure was administered by a trained lab member in paper-pencil format. There was no specific score that needed to be met on the WASI-II to be included in the study. The scores were utilized for future statistical analyses to see if level of intelligence acted as a moderating variable. Following the WASI-II, each participant was directed towards the computer where a practice phase was completed by each participant. This practice phase consisted of a shortened version of the entire battery of computerized cognitive tasks which included 4 words on the memory encoding phase (15 seconds), 8 words on the memory test phase (25 seconds), and 52 trials on the flanker task (1 minute 5 seconds), and 32 trials for the dot task (2 minutes 30 seconds). The purpose of having a practice phase was to allow the participant to get an understanding of each task and what was expected of them to complete the task. This portion was solely to get the participants acquainted with the tasks and no data was collected for these practice trials. In addition, each participant was given an identification number. This number was put in place not only for confidentiality purposes but also acted as guideline for specific cognitive tasks such as the dots task and memory testing phase. If a participant received an odd ID number then they would use a left button click to indicate when they saw a color change (right button click for no color change) in the dots task and a left button click when recognizing an old word (right click for new word). If a participant received an even ID number then they would use a right button click to indicate when they saw a color change (left button click for no color change) in the dots task and a right button click when recognizing an old word (left click for new word).

Next, the participant completed a graded exercise test (GXT). Before the test began, the participant was provided an orientation to the equipment for aerobic fitness testing (i.e., mouth apparatus, nose clip, treadmill). Additionally, before starting the GXT a Polar heart rate monitor was attached to each participant just under their sternum. This device allowed us to record the resting and max HR. After the introduction of the equipment, the GXT was performed to assess aerobic capacity (VO_2max). This aerobic assessment was based on a modified version of the Balke treadmill protocol. The general procedures for GXT of cardiorespiratory fitness are as follows. The exercise test began with a 3 min warm-up. During the first minute, a comfortable speed was established between the experimenter and the participant. Since the participant was hooked up to a

VO_2max headset non-verbal signals were utilized. An index finger pointing up meant to increase the speed, index finger down meant decrease the speed, and a thumbs up was indicated for the comfortable speed in which the test was administered. After, the 3-minute warm-up and establishment of a comfortable speed, the gradient was increased to level 2.5 on the treadmill. Gradient levels on a treadmill are predetermined and programmed within the unit. An increase in gradient level means that the base of the treadmill would move to an inclined position dependent upon the level picked on the equipment dashboard. Heart rate (HR) was monitored every 2 minutes to verify steady-state. Once the fixed duration of 2 minutes passed, workload increased by adjusting the gradient. If the participant's HR was not greater than or equal to 185 bpm, workload increased after the 2-minute stage of the previous workload level. Workload gradient levels were, 4 min is 2.5, 6 min is 5/6, 8 min is 7.5/8.5, 10 min is 10/11, 12 min is 12.5/13.5, and 14-20 min will be set at 15. The exercise test was stopped if participants indicated they needed to stop based on volitional exhaustion or if the trained experimenter noticed physical fatigue manifestations in the participant. When the GXT was conducted, one trained CPR certified experimenter was present. While performing the GXT, HR was continuously recorded. In addition, participants' ratings of perceived exertion (RPE), feeling state (FS), and the felt arousal scale (FAS) were assessed every 2-minutes by having the participant point to a laminated paper with each scale. To measure RPE, Borg's RPE scale ranging from 6 (no exertion at all) to 20 (maximal exertion) was used (Borg, 1998). FS is an affective valence scale ranging from -5 (very bad) to +5 (very good) (Hardy & Rejeski, 1989). The FAS measures perceived activation and ranges from

1 (low arousal) to 6 (high arousal) (Svebak & Murgatroyd, 1985). Following the completion of the exercise test, attainment of performance of VO_2max was confirmed by participants reaching 3 of 4 criteria including VO_2Plat (<2.0ml/kg/min increase despite increase in workload), RER (>1.1), RPE (≥1.7), and HR (≥ 185 bpm). Testing on day 1 in the lab took approximately 2 hours. Those who met all inclusion criteria were invited to participate in two additional days of testing. Lastly, each participant was asked to not participate in exercise or physical activity on day 2 and day 3 of testing. This allowed us the best possible chance for gathering reliable data on how rest or exercise can impact cognition.

Day 2-3

This study utilized a within-subject randomized counterbalanced design. Each participant was given a rest day and an aerobic exercise day that were separated by a minimum of two days. In addition, each participant was scheduled either at the exact same time of day on days 2 and 3 or within a two-hour time gap of time on days 2 and 3. Each day the participant was given a brief overview of the planned experimental session including an orientation of the equipment and procedures used that day. Following the initial discussion, participants put on a Polar HR monitor and completed a practice phase that was the same as the practice phase on day 1. Following the practice, initial testing acted as a baseline cognitive measurement. Following each cognitive task, baseline HR, FAS, FS, and Time were recorded. After, participants performed a 30-minute aerobic exercise or seated rest dependent on the order given. Every two minutes the following items were recorded, speed, incline, HR, RPE, FAS, and FS. Following the exercise, another round of cognitive tasks was administered to assess memory (recognition memory task), WM (change detection task), and inhibitory control (flanker task). Following each post-test, HR, FAS, FS, and Time were recorded. Throughout each day, participants were allowed to ask questions pertaining to any part of the procedure. These sessions lasted about 2 hours.

Experimental Conditions

The aerobic exercise protocol consisted of 20-minutes of running on a treadmill at 70% of max heart rate (HR max is based on maximum HR achieved following completion of the GXT test on day 1). Accommodations were made if the participant appeared to struggle maintaining a continuous run for the entirety of the exercise bout. Accommodations included an increase of incline and a decrease of treadmill speed, short slow walking breaks, or cessation of the exercise bout at the request of the participant or if it was visibly apparent that the participant was in distress. Also, there was a 5-minute warm up prior to the exercise condition and a 5-minute cool down after the exercise making the total exercise protocol 30-minutes. This exercise protocol has been used in empirical research (Tomporowski, 2003; Sibley & Beilock, 2007) and has been shown to elicit changes in brain function and task performance.

The rest condition consisted of the participants sitting on a chair, remaining quiet, and watching an educational video for 30 minutes. HR was also recorded using a Polar HR monitor during all interventions to estimate intensity.

Cognitive Tasks

Participants completed several cognitive tasks presented on a computer screen. All stimuli in the tasks were presented at an approximate distance of 1 meter using PsychoPy stimulus presentation software (Pierce, 2009; www.psychopy.org). Participants were instructed to respond with a thumb pressure response pad. Task instructions and encouragement were emphasized for all cognitive tasks before and after each task block (i.e., "It is important that you respond as accurately as possible…") with secondary instructions pertaining to speed. This was to help participants stay within the allotted response window (i.e., "but we also want you to respond quickly so please make sure you respond before the next set of stimuli appears on the screen.") Before testing, participants were given practice trials to control for potential practice effects.

The word recognition task (memory task) required participants to memorize a list of 30 words during the study phase and then perform a delayed recognition test (i.e., 30 words from the study phase intermixed and randomly presented with 30 new words) by responding if it was an old word or a new word. Sets of 360 words were collected from the MRC Psycholinguistic Database (Coltheart, 1981b). Word selection was based on the number of letters (3-6), written frequency (2-60; Kucrea and Francis, 1982), concreteness (500-700), familiarity (300-600), and age of acquisition. Words selected were equivalent in terms of the word selection criteria as previously listed and were randomly assigned to four non-overlapping word lists. The four lists were used to make sure there was no learning effect of the words between pre- and post-test for the experimental day and the control day. The word stimuli consisted of 3 cm tall capitalized white Arial font on a black background for a duration of 100 ms with a 1200 ms inter-stimulus interval. The stimuli representation was consistent throughout the learning phase and testing phase. Participants were asked to memorize the initial 30 words during the study phase without a response. The participants were presented each word once during the study phase. The memory encoding phase took 2 minutes 15 seconds. After a delay (the WM task was performed), participants completed the memory test phase (60 words) and responded as accurately as possible by pressing the correct button on the thumb response pad. The memory test phase took 3 minutes 30 seconds. The WM task (dot task; see Figure 1) had an encoding phase and recognition phase. The encoding phase consisted of an arrow directing the participant's attention to the left or right side (200 ms) of the screen. Then the arrow disappeared and only a fixation crosshair was present in the middle of the screen for 500 ms. Afterwards, the memory array appeared – this consisted of several colored dots displayed in random locations on the monitor for a short period (150 ms). Then a delay or retention phase (850 ms) occurred in between the encoding and recognition phase with no dots on the screen. During the recognition phase (2000 ms), the dots reappeared, and participants responded with a button press indicating if any of the dots for the attended half (indicated by the arrow) had changed in color from the encoding phase. Upon the button press indicating the participant's response (or after 2000 msec had passed), there was a 1000 ms intertrial interval before the next trial was displayed on the screen. Each dots task took about 6 minutes 15 seconds (total dots task time = 18 minutes 45 seconds). Overall, 80 trials were completed. In 40 trials, there was a color change while in 40 trials there was not a color change. In each group of 40 trials, there were 20 trials in which the participant focused on the left side and 20 trials on the right side. Within each group of 20 trial, there were 5 trials each for with 2 dots, 3 dots, 4 dots, and 5 dots. Among these variations, each were equiprobable.

For the final cognitive task, participants completed a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). They were instructed to respond to the direction of the centrally presented target (3 cm tall white arrow on a black background) surrounded by either congruent (e.g., <<<<< or >>>>>) or incongruent (e.g., <<><< or >><>>) flanking non-targets. A total of 108 trials were presented randomly for 100 ms on the screen with equal congruency and directionality. Additionally, the inter-stimulus interval consisted of three varying time spans (1000 ms, 1200 ms, 1400 ms). The reason for alternating timespans was to minimize learning and anticipation effects. The learning effect was corrected by the "jitter" of timespans (Kao et al., 2017). Each flanker task took 2 minutes 10 seconds (total flanker task time = 2 minutes 20 seconds). Completion of the cognitive tasks in total took about 28 minutes 50 seconds.

Lastly, a diagram of procedures was provided (see figure 2).

Statistical Analysis

The analytical methods were conducted utilizing an alpha level of p=.05. The measures of RT and accuracy were evaluated for each cognitive task utilizing a 2 (Condition: Exercise, Rest) x 2 (Time: Pre, Post) repeated-measures analysis of variance. Lastly, partial eta-squared was presented as a measure of effect size for significant ANOVAs. Descriptive statistics were presented for FS, FAS, and RPE.

CHAPTER IV

RESULTS

Participants in this study consisted of 22 females and 8 males with an average of 22.38 years old *(SD*= 1.41*)*. According to the results of day 1 testing, participants' average maximal HR (VO_{2max} HR) was 187.23 bpm (*SD*= 11.83*)*. In addition, the HR recorded during the VO_{2max} test was used to calculate 70% of the HR max. The average HR collected during the exercise condition was 127.07 bpm (*SD*=11.48*)* which equates to 67.87% of HR max. IPAQ scores were also calculated. Participants responded that they completed moderate physical activities in the garden/yard on an average of 1.8 days *(SD*=1.90*)* and for an average of 41.7 minutes *(SD*= 66.73*)*. Participants were also asked how many days and for how long they performed moderate physical activities inside their home. Participants responded that they completed moderate physical activities inside their homes on an average of 2.5 days *(SD*= 1.89*)* and spent an average of 59 minutes *(SD*= 68.98*)* completing the tasks. In addition, participants averaged 1.5 days *(SD*= 1.98*)* of moderate physical activities during leisure time (i.e., running, bicycling, etc.) and averaged 25.4 minutes *(SD*= 43.89*)*. Regarding vigorous physical activity, participants averaged 1.9 days *(SD*= 2.02*)* of vigorous physical activity for leisure time and averaged 42.5 min *(SD*= 53.45*)* of vigorous physical activity. Lastly, participants on average would spend 6.9 hours *(SD*= 3.88*)* of sitting during the weekday and 7.3 hours *(SD*= 3.67*)* of sitting during the weekend.

Descriptive statistics were provided for HR and affect of the conditions. From the data displayed in Figure 3, one can see there was a difference in HR between the conditions with the average HR during exercise *(M= 127.07 bpm, SD= 11.48)* higher than that observed during the control condition (*M=76.53 bpm, SD=1.50)*. In Figure 4, we see that participants perceived exertion ratings increase around the transition from warm-up to the moderate exercise. Participants' RPE scores averaged 10.58 *(SD= 1.37)* which according to the Borg's RPE scale represents a fairly light exercise. Comparatively, participants responded with an average RPE score of 6.44 *(SD=0.04)* during the rest condition. Also, the felt arousal scores show that the arousal state of participants was higher during exercise than during rest (see Figure 5). FAS average rating for the exercise condition was 2.62 *(SD= 0.24)* and 1.48 *(SD=0.11)* for the rest condition. Lastly, from Figure 6 one can see that participants tended to feel slightly worse when performing the exercise *(M= 3.27, SD= 0.24)* condition compared to the rest condition *(M= 3.38, SD= 0.11)*.

No main effects were found for RT during the memory task as a function of condition, $F(1, 29) = 0.00$, $p>.05$, or time, $F(1, 29) = 1.56$, $p>.05$. There was no significant interaction between condition and time on the memory task, $F(1,29) = 0.07$, $p>.05$. For response accuracy, no main effects were found for condition, $F(1,29) = 0.35$, $p>.05$, or time, $F(1, 29) = 0.31$, $p>.05$. However, there was an effect for the interaction between condition and time, $F(1, 29) = 5.16$, $p=.03$, $\eta_p^2= 0.15$. Response accuracy is the number of correct hits plus number of correct rejects divided by 60 (total number of words for memory recognition phase). The results are depicted in Figure 7. The data shows us that response accuracy for the memory task increased after a bout of acute aerobic exercise, while response accuracy decreased after a bout of rest.

Regarding cognitive outcomes, time (pre, post) had a significant main effect on the RT for congruent stimuli during the flanker task, $F(1, 29) = 11.23$ $p=.002$, $\eta_p^2 = 0.28$ (see Figure 8). There was no main effect for condition (exercise, rest), $F(1, 29) = 0.32$, $p>.05$, or interaction effect, $F(1, 29) = 0.35$, $p>.05$, on RT during congruent trials. Response accuracy for congruent trials portrayed no effect from condition, $F(1, 29) = 0.00$, $p>.05$, time, $F(1, 29) = 0.40$, $p>.05$, or the interaction, $F(1, 29) = 0.39$, $p>.05$. In addition, similar findings were also seen for the incongruent flanker task. The variable time had a main effect for RT during the incongruent trials, $F(1, 29) = 12.77$, $p=.001$, $\eta_p^2 = 0.31$ (see Figure 9). On the other hand, there was no effect from the condition (exercise, rest), $F(1, 29) = 0.05$, $p>.05$, or the interaction, $F(1, 29) = 0.75$, $p>.05$. Lastly, no effects for response accuracy on incongruent flanker trials were found for condition, $F(1, 29) = 0.03$, $p>.05$, time, $F(1, 29) = 3.63$, $p>.05$, or their interaction, $F(1, 29) = 0.42$, $p>.05$.

Cognitive outcome for the dots task RT illustrated statistically significant effects only for time, $F(1,29) = 94.61$, $p=.00$, $\eta_p^2 = 0.77$. Participants illustrated an improved RT from the first round of the cognitive task to the second round for both conditions (see Figure 10). No main effect was found for condition, $F(1,29) = 1.039$, $p>.05$. Likewise, the interaction between condition and time did not reach statistical significance, $F(1,29) = 0.01$, $p>.05$. Similar to the flanker task response accuracy, no main effect was found for condition, $F(1, 29) = 0.67$, $p>.05$, time $F(1, 29) = 0.10$, $p>.05$, or the interaction of condition by time, $F(1, 29) = 0.37$, $p>.05$ for response accuracy on the dot task.

CHAPTER V

DISCUSSION

The purpose of this study was to examine the changes in EF and memory after acute aerobic exercise in college-aged young adults (18-30) using a word recognition memory task, flanker task, and a working memory (WM) task. It was hypothesized that exercise would beneficially affect RT and accuracy specific to each task (flanker, dot, and memory task). Our results revealed the condition (exercise, rest) did not have a statistically significant effect on RT or response accuracy for EF and memory tasks, whereas, the variable time (pre-test, post-test) did have a statistically significant effect on RT across flanker task trials and the dot task. In addition, there was a significant interaction effect of condition (exercise, rest) by time (pre-test, post-test) for response accuracy on the word recognition memory task. Improvement on memory recognition accuracy from pre-test to post-test was greater for the exercise condition compared to the rest condition. Aside from the interaction effect on memory recognition accuracy in this study, exercise did not have a significant effect on RT performance.

The current findings on memory performance in this study are similar to a study done by Labban and Etnier (2011). Researchers in the study found that acute moderate intensity exercise positively affected LTM. In addition, meta-analytic review of cardiovascular exercise on human memory supports the findings in the previous study and in the current study. Overall, acute exercise had small to moderate effects on LTM. Although, findings from the current study are consistent with past memory literature there is one main difference. Memory in this study was measured using a recognition task. Researchers have utilized both memory recall and recognition in their methodologies but only found significant effects on memory recall (Etnier, Labban, Piepmeier, Davis, Henning, 2014). This significant finding for memory recognition in the current study is a new finding in the literature. In addition, the memory task in this study utilized a different amount of words presented to the participants. The current study tested participants on recognizing old words (30) and new words (30), bringing the test phase to a total of 60 words. Previous research utilized a 15 word to 30 word testing ratio (Etnier et. al, 2014).

Regarding the flanker task, only the variable time (pre-, post-) had a significant effect on RT for both the congruent and incongruent trials. No significant effect was found for condition (exercise, rest) in either RT or response accuracy. According to the findings of this study, RT improved significantly from pre-test to post-test, regardless of the condition, suggesting a learning effect from pre-test to post-test. The learning effect is when cognitive test scores increase as the number of repetitions increase. Researchers found that as the number of test repetitions increased, so did the speed and accuracy on cognitive tasks (Tao, Yang, Liu, 2019). Interestingly, the same study found different effects for speed and accuracy, where speed improvements were higher compared to improvements on accuracy. Results from the current study partly coincide with the findings of the former. For the flanker task (congruent and incongruent), time (pre-test, post-test) had a significant effect on RT but no significant improvement for accuracy. Although, the findings around accuracy do not match, it is suggested from previous research that the learning effect has a greater impact on RT (Tao et. al., 2019). The learning effect in this study stems from the variable time, which consisted of 2 repetitions (pre-test, post-test) of the cognitive tasks.

Similar to inhibition, WM performance was not impacted by a bout of acute exercise. This finding aligns with Ludyga et al. (2018), who found that WM performance did not change between exercise and rest conditions on RT in WM tasks. These findings conflict with results from McMorris, Sroule, Turner, and Hale (2011), who found that exercise had a positive significant effect on RT in WM tasks. Even though we did not find significant effects from condition (exercise, rest), there was a significant effect of time (pre-test, post-test) on RT in the WM task. This finding is similar to the inhibitory control component in this study in that RT was impacted significantly from pre-test to post-test and not by condition (exercise, rest).

Potential limitations should be considered when interpreting the results of this study. First, it is possible that the length of cognitive tasks resulted in a too long a delay from cessation of the condition to completion of the computerized tasks. The exercise-induced benefits may have depleted over time as the participants were completing the tasks. Chang et al., (2012) meta-analytically reviewed the research on acute exercise and cognitive performance. They found that the timing of task administration was a moderating variable. Effects sizes were significant and positive when administering the cognitive task 1-15 minutes after exercise cessation but were insignificant when waiting longer than 15 minutes to administer the task (Chang et. al, 2012). In the current study, the total amount of time on tasks was approximately 28 minutes ± a couple of minutes to run the code for the next task. The memory encoding phase was a short task, whereas, the dot task had 3 testing periods and took longer to complete. Based on previous research, performance on the two tasks (memory and dots) should have been positively affected by the exercise condition. While effects were evident for memory, there were no significant effects for dots or flankers (two measures of EF). In addition, a limitation to consider is the time of day in which participants completed the acute exercise session. Previous researchers have found a significant positive effect on cognitive performance when participants performed an acute exercise session in the morning compared to afternoon or evening exercise sessions which illustrated a negligible effect (Chang et. al, 2012). In this study, each testing session took place in the afternoon or evening. The time of day for completing exercise sessions adds to the possibility of why exercise did not have a more beneficial impact on cognitive performance. Lastly, not knowing the entire mechanistic understanding of how acute exercise impacts the various components within WM limits our interpretation of significant effects.

In conclusion, this study demonstrated a significant learning effect on EF tasks and an interaction effect on memory. This initial study adds to the growing body of literature around acute exercise and cognition by assessing multiple EF components. Researchers should continue to explore the effect of acute bouts of exercise on cognition. One possible direction for future studies is to look at individual factors such as BMI to see if those who tend to be overweight are impacted more by exercise compared to healthy average BMI people. Previous research shows that being overweight is associated with decreased cognitive functioning (Li, Dai, Jackson, & Zhang, 2008). One study looked at the impact of exercise on cognition for overweight children. Researchers found that both exercise groups (20-min, 40-min) showed increased cognitive performance compared to a rest group (Mahoney, 2005). Since WM is a complex EF component studies should aim to look at intricacies of WM such as, the phonological loop and visuospatial sketchpad. This should be done in order to assess measures that will most effectively capture the scope of each, which in turn will give us a better understanding of WM.

Recommendations for future replication on this study should aim include an equal amount of male and female participants so that we can see if sex is a moderating factor. In addition, future replication should not accept VO_2 max results that do not meet the confidence criteria. By improving this aspect researchers can have a more accurately calculated HR range for moderate intensity exercise.

Figure 1. Visual for Dots Task

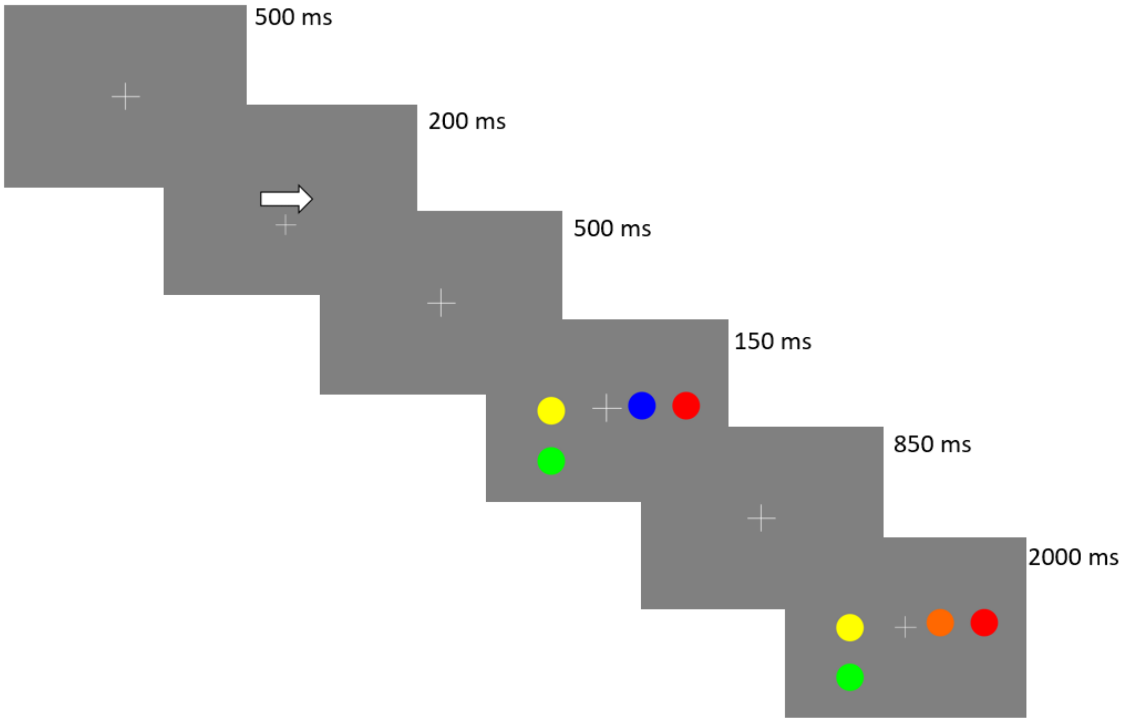


Figure 2. Diagram of Procedures

Diagram of Procedures								
Memory Encode phase (Pre-test)	Dots Task x3 (Pre-test)	Memory Recognition Phase (Pre-test)	Flanker Task (Pre-test)	Condition (exercise or rest)	Memory Encode phase (Post-test)	Dots Task x3 (Post-test)	Memory Recognition phase (Post-test)	Flanker Task (Post-test)
HR, FS, FAS	HR, FS, FAS	HR, FS, FAS	HR, FS, FAS	HR, RPE, FS, FAS every 2 minutes	HR, FS, FAS	HR, FS, FAS	HR, FS, FAS	HR, FS, FAS

Figure 3. Mean Heart Rate

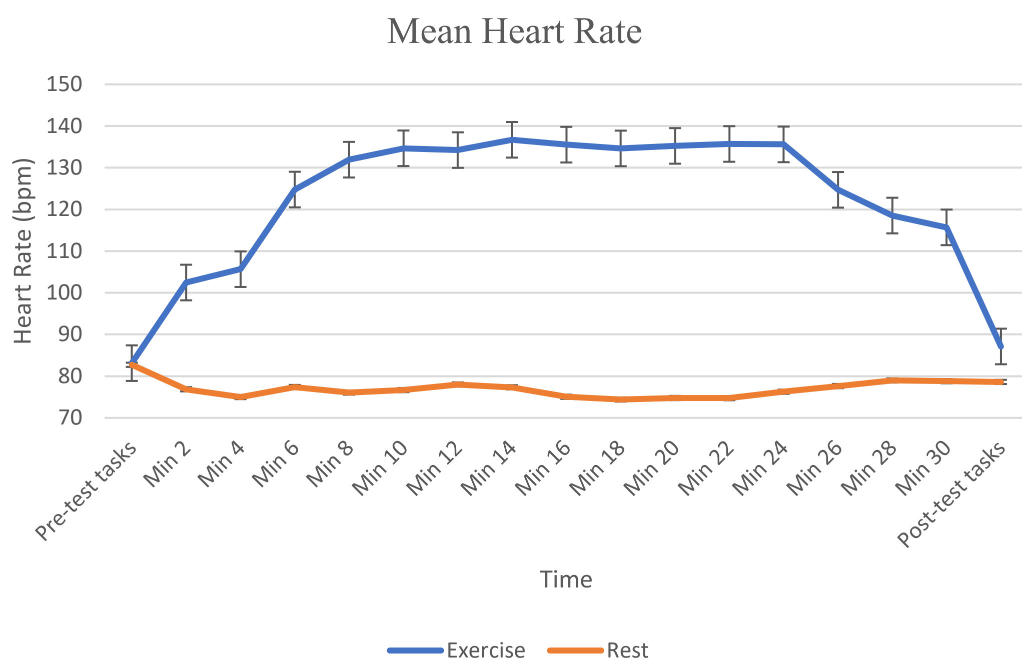


Figure 4. Ratings of Perceived Exertion

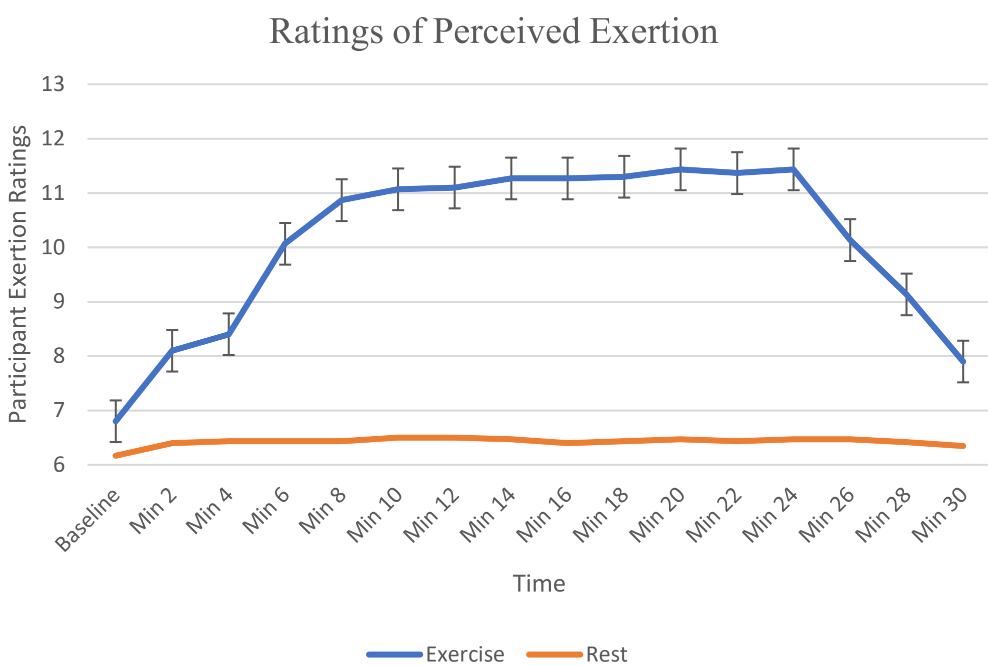


Figure 5. Felt Arousal Scale Scores

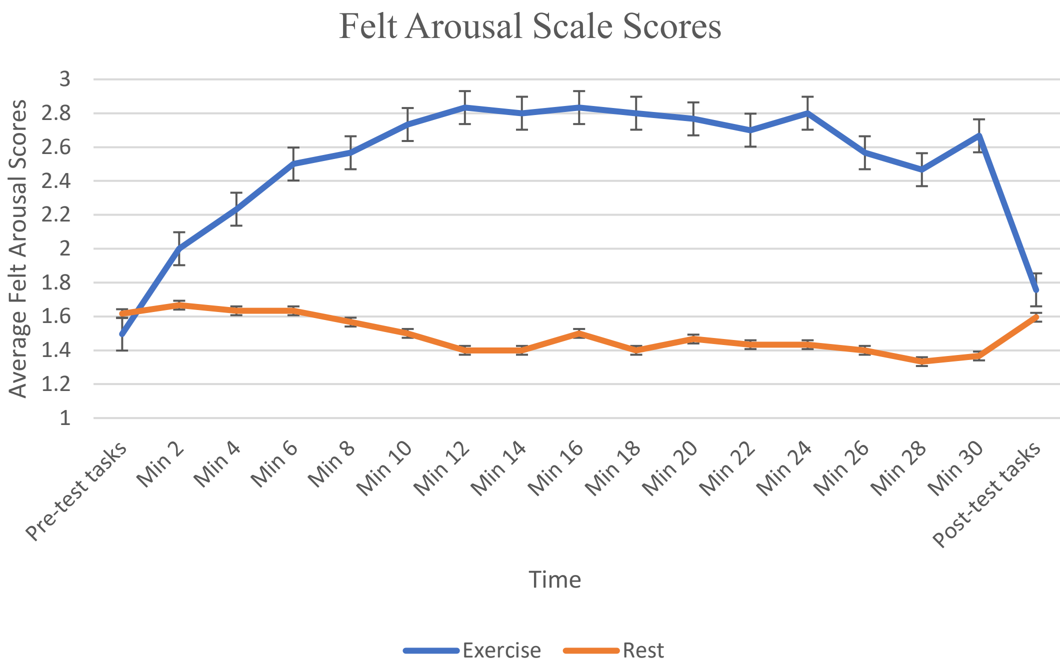


Figure 6. Feeling State Scores

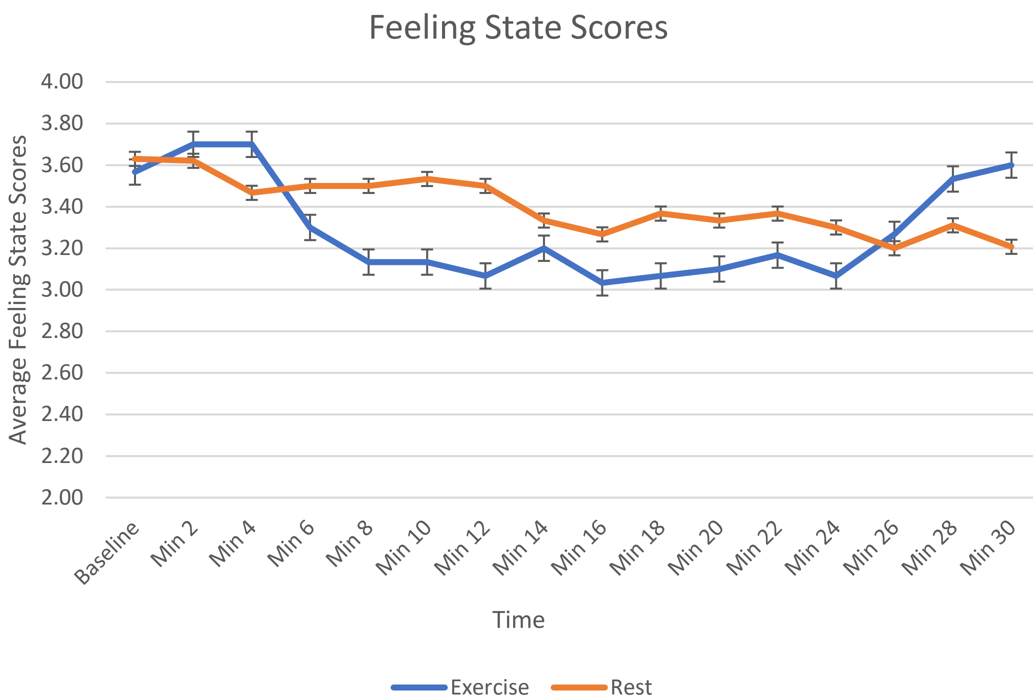


Figure 7. Response Accuracy for Memory Task

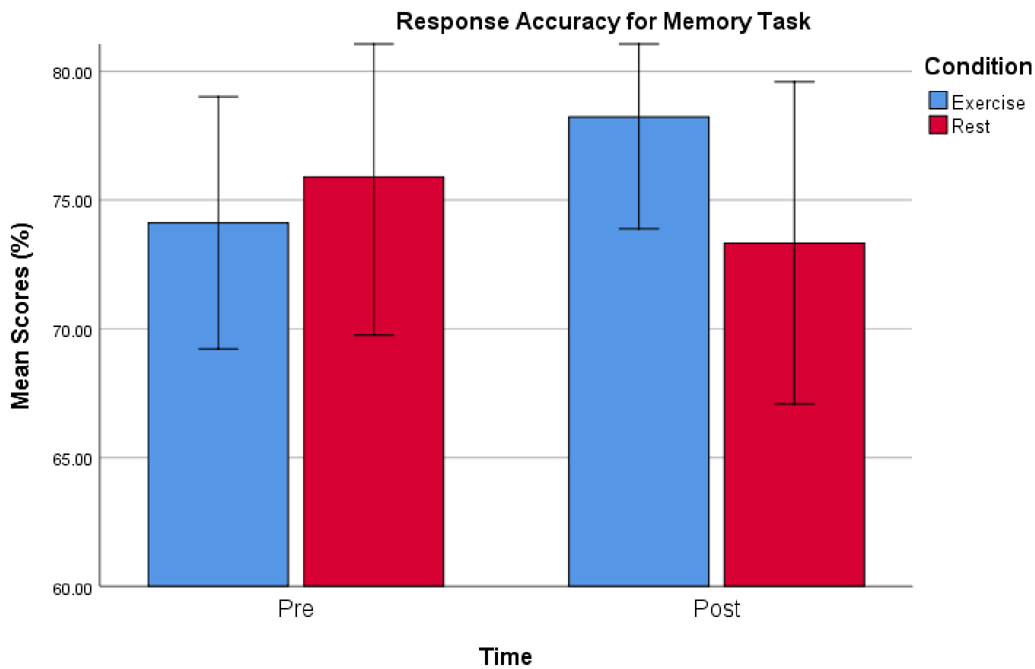


Figure 8. Flanker Task RT (Congruent Trials)

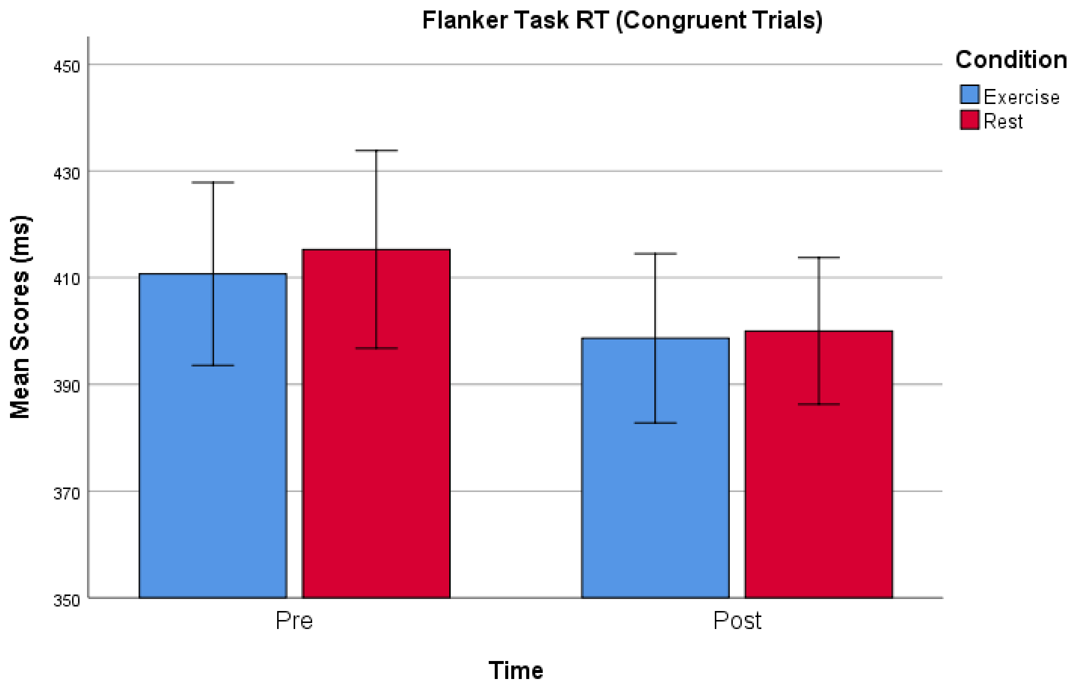


Figure 9. Flanker Task RT (Incongruent Trials)

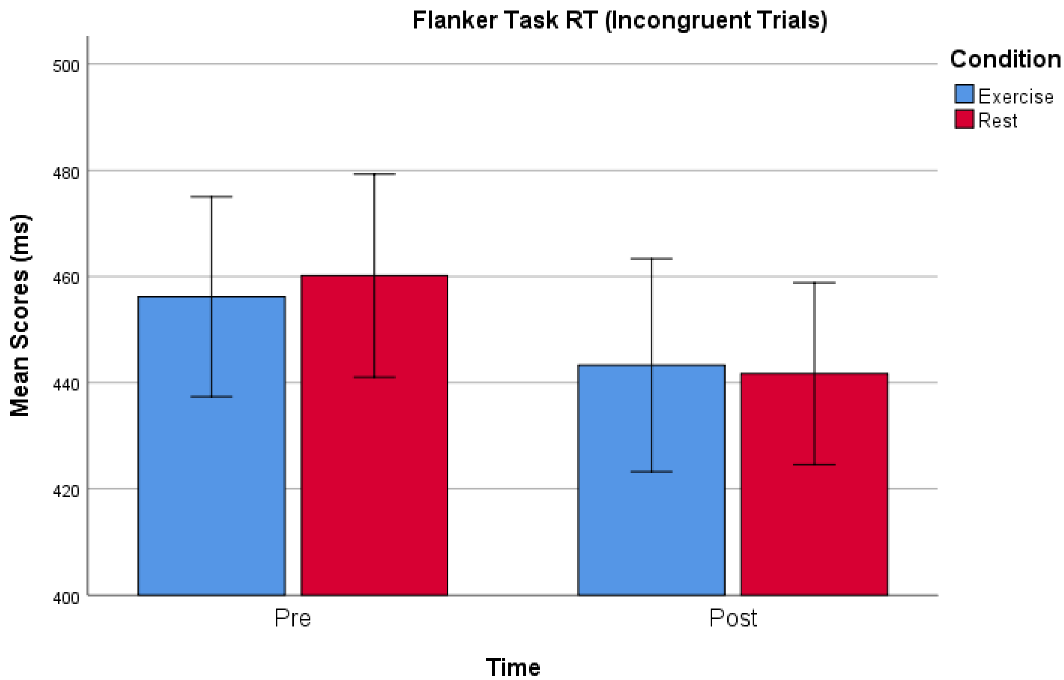
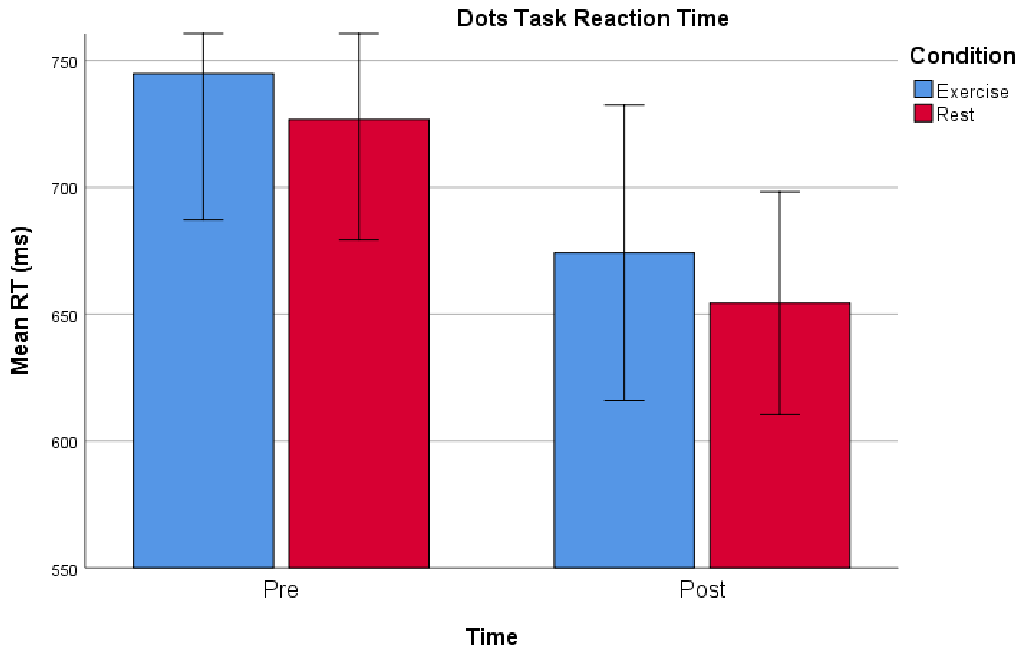


Figure 10. Dots Task Reaction Time



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