ARM ERGOMETRY EXERCISE INTENSITY INTERACTION WITH MOTOR MEMORY

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DEDICATION

I dedicate this thesis to my parents, Jack Warner, Cynthia Warner, and D. Lynn Steinhiser, who have taught me to persevere through the stormy times of life and trudge on when the path may not have been quite clear.

"If for nothing else you can look someone straight in the eyes and say "But, I lived through it and it made me who I am today."" – Lian Thomas

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ABSTRACT

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Exercise interventions have demonstrated improvements in long-term declarative memory (Labban & Etnier, 2011; Potter & Keeling, 2005; Winter et al., 2006), and a smaller number of studies have produced the same benefit with procedural memory (Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen, 2012; Thomas et al., 2016). The purpose of this study was to determine if procedural memory was improved by either high or low-intensity arm ergometry exercise. Participants (N = 32) were assigned to control (CON), low-intensity (LOW), or high-intensity (HIGH) groups. Two motor tasks were investigated, fine and gross, utilizing three blocks of five trials at acquisition and one block of five trials at follow-up testing (one day and seven day). Repeated measures ANOVAs were executed. No significant effect was observed on fine or gross motor memory ($p > 0.05$). Many confounding variables existed to produce this outcome. Further research needs to be done to extrapolate a decisive conclusion.

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CHAPTER I
INTRODUCTION

Evidence exists that exercise can lower LDL, decrease triglycerides, reduce insulin resistance, and promote weight loss (Vuori, Lavie, & Blair, 2013). To gain strength, power, stamina, or generally be heart healthy, one should engage in exercise minimally 3 to 5 times a week (ACSM, 2014). All of these visible attributes are enhanced with exercise. The health improvements from exercise are not just physical. In the past few decades, a positive relationship between exercise and cognitive benefits has emerged.

Scientists are only beginning to scratch the surface when it comes to understanding the interaction of exercise with neuroscience in humans. It has been presented that physical activity can have a lasting impact on the brain as people enter the later stages of life (Colcombe & Kramer, 2003). Erickson et al. (2011) found that the hippocampus, the area of the brain primarily associated with memory, increases in size with voluntary exercise. Circuits that transfer information in the brain are not only created, but also strengthened with the intervention of exercise (Lardon & Polich, 1996). Exercise has been associated with higher levels of executive function (Hillman et al., 2014; Hillman, Snook, & Jerome, 2003; Law, Barnett, Yau, & Gray, 2014), greater concentration (Silva et al., 2015), and improved response time (McNerney & Radvansky, 2014). These positive changes to cognition are widespread and have been reported in

children (Hillman et al., 2014; Pesce, Crova, Cereatti, Casella, & Belluci, 2009; Silva et al., 2015), young adults (McNerney & Radvansky, 2014), older adults (Bakken et al., 2001; Larson et al., 2006) and in special populations such as those recovering from stroke (Globas et al., 2012; Nilsen et al., 2015).

A positive association emerges between exercise and memory when reviewing scientific literature (for a review, see Roig, Nordbrandt, Geertsen, & Nielsen, 2013). Memory contributes to whom a person becomes. The ability to recall positive images (Segal, Cotman, & Cahill, 2012), learn new vocabulary (Winter et al., 2006), recollect words (Labban & Etnier, 2011), and remember items (Coles & Tomporowski, 2008) is enhanced with exercise. It does not matter if one is young or old, or if the planned physical activity takes place early or late in the day, the effects from exercise have a predominantly positive influence on memory (Roig et al., 2013). While these findings have powerful implications, two limitations of the existing research exist. Studies mainly investigate short-term as opposed to long-term memory, and primarily declarative memory instead of procedural memory. Further investigation is required to understand the effect of exercise on long-term procedural memory better.

Short-term memory plays a role in task acquisition, specifically the initial learning of a motor memory (Maxwell, Masters, & Eves, 2003). However, the delayed recall of this memory is more influential in motor skill stability. Robertson (2009) established that the process of forming a memory has to undergo three steps: encoding, consolidation, and

retrieval. The encoding process takes place during the practice/acquisition stage of a motor function. Construction of the memory is the performance and behavior established with that task (Cahill, McGaugh, & Weinberger, 2001). Only when this task is successfully repeatable after a long-term time point is it considered consolidated, or learned. Kantak and Winstein (2012) defined the difference between learning and behavior as "learning (is) an internal process that is relatively permanent, and behavior or performance (is) an observable response" (p. 221). The behavior that is immediately shown may not always correlate with what is actually learned (Cahill et al., 2001). Retrieval happens when a memory is recalled and the action has to be executed again. The stability of this performance at a delayed time point determines the dissipation of the skill and whether it was consolidated to long-term memory. The ability to transfer the skill and perform it at a faster pace, or incorporate it into a more complex task, also demonstrates the status of solidification. Consolidation of the motor memory and its interaction with exercise is of interest in this study.

While exercise may improve both short-term (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Salas, Minakata, & Keleman, 2011) and long-term (McNerney & Radvansky, 2014; Roig, Skriver, Lundbye-Jensen, Kiens, & Neilsen, 2012) memory, the potential mechanisms responsible for each type of memory could be different. If viewed predominantly from a psychological perspective, increased arousal is often cited as an explanation for improved cognitive benefits including memory

(Lambourne & Tomporowski, 2010). Physiologically, this approach falls short of explaining how consolidation of memories, whether short or long-term, might be improved by exercise. Coles & Tomporowski (2008) saw that exercise did not increase memory performance rather it offset the decline in the encoding and consolidation process seen across exercisers and nonexercising counterparts. This suggests that exercise may not create an environment to facilitate short-term memories instead it may enhance consolidation of those memories. If this is the case, the influx of biomarkers related to exercise could be the potential mechanism these memories use to move from the fluid working (brief) memory to the solid long-term (permanent) memory. These mechanisms could be the reason why some studies only show an effect on long-term memory, but not on short-term memory (Coles & Tomporowski, 2008; Winter et al., 2006). It also could be why the intensity of exercise may be important when stimulating the neurophysiological effect.

Recently, blood borne biomarkers have been associated with memory. Exercise of varying intensities moderates memory (Chang, Lappan, Gapin, & Etnier, 2012). An increase in circulating brain-derived neurotrophic factor (BDNF) concentrations is seen during and following an acute bout of high-intensity exercise (Ferris, Williams, & Shen, 2007). Brain-derived neurotrophic factor has been shown to cross the blood brain barrier (BBB) and influence the growth of the hippocampus (Erickson et al., 2011) as well as increase neurogenesis (Phillips, Baktir, Srivatsan, & Salehi, 2014). A link has also been

made between hippocampal neurogenesis, learning, and memory (Leuner, Gould, & Shores, 2006). Memory was significantly increased when BDNF was directly injected into the rat hippocampal region (Alonso et al., 2002). Due to varying intervention conditions across multiple studies, research has not made a concrete positive association between BDNF and human memory (Goda et al., 2013). Even so, BDNF remains as a potential mechanism. In addition, lactate is a known intermediary expressed during exercise that can be moved across the BBB and used as energy in the brain (Brooks, Fahey, & Baldwin, 2005). A moderate, positive correlation (r = .57) between lactate and memory exists (Ferris, et al., 2007; Skriver et al., 2014). Utilizing lactate measurements is a much simpler way to distinguish if the essential exercise intensity is achieved to create neurological manipulation.

A limited amount of work has considered exercise's effect on procedural/motor memory. McNerney and Radvansky (2014) studied the influence of running sprints on procedural memory. They recruited 136 people and randomly placed participants in either a resting or an exercise group. Both groups performed a serial order task (SOT) where they responded to a stimulus on a computer screen and reacted by pushing a corresponding pre-defined key on the keyboard to the stimulus' location. As they acquired the motor task, response times were recorded to assess learning. In the rest group, this SOT was executed after being seated and performing Sudoku puzzles for 30 min. The exercise group did 2 min running sprints of unspecified distance followed by 3

min of rest and then performed the SOT. All participants returned 7 days after the first session to assess delayed, or long-term, memory. Response times were significantly faster after exercise than after rest at both immediate and delayed tests.

Roig et al. (2012) demonstrated that one session of high-intensity cycling for 20 min improved motor memory. Participants (N = 48) were randomly assigned to one of three different groups; exercise before task acquisition (BTA), exercise after task acquisition (ATA), and no exercise (CON). The groups were age and fitness matched and all performed a baseline visuomotor tracking task. The exercise groups performed 20 min of intense cycling either before or after a skill acquisition trial. CON rested in a bed for 20 min and then had the motor tracking practice trials. Retention was tested 1 hour, 24 hours, and 7 days after acquisition. No differences between groups were seen at baseline, but both BTA and ATA performed better than CON both 24 hours and 7 days after acquisition. Further, retention was greater for ATA than BTA after 7 days supporting that exercise during the consolidation period (as opposed to before task practice) has the greatest benefit for long term memory.

Based on the above results, there is a potential that exercise could lead to better acquisition of motor skills in populations with motor impairments. As previously shown, high-intensity exercise improves cognition (Hillman, et al., 2003; Winter et al., 2006), but a limitation is that high-intensity exercise would not be useful in a population unable to perform at this elevated level. The American College of Sports Medicine (ACSM)

recommends that elderly, or populations with contraindications to exercise, perform vigorous exercise only with a physician present (ACSM, 2014). This would make it extremely difficult for these individuals to experience the beneficial effects from exercise on memory if these benefits only occurred with high-intensity exercise. Narrowing the field down even more to an ever-growing population with motor impairments, such as stroke or Parkinson's disease patients, and vigorous exercise may not be possible at all.

While some studies have suggested high-intensity exercise has a stronger influence on memory than low-intensity exercise, at this point there are too few studies to make a conclusive argument. Demonstrating that motor performance can be influenced by exercise below high-intensity, Bakken et al. (2001) used low-moderate intensity exercise in an elderly group and revealed increased motor task performance. Winter et al. (2006) reported that high-intensity exercise led to greater improvements in memory than low-intensity exercise. However, closer inspection of their data reveals that no significant group differences emerged at either retention test, meaning no conclusion about the influence of intensity on long-term memory could be made. The only noticeable difference between groups was that during the acquisition phase, the high-intensity group reached peak level learning performance, meaning the point at which the task was considered learned, at an earlier time point and then plateaued. Additionally, Winter et al.'s (2006) results suggest that both low and high-intensity exercise resulted in increases in BDNF from baseline to post-intervention. With the current limited amount of

research (particularly with motor memory), it is unclear whether high-intensity exercise is necessary to invoke the memory benefits accounted for with exercise. Thus, the purpose of this study is to test the influence of high and low-intensity exercise on motor memory. It is hypothesized that both low and high-intensity exercise will result in improved performance in the retention and transfer phases on a fine and gross motor task as compared to nonexercising controls.

Statement of the Problem

Exercise has a positive influence on memory. Multiple studies have examined long-term memory and have found exercise increases delayed retention of the information (Labban & Etnier, 2011; McNerney & Radvansky, 2014; Quaney, Boyd, McDowd, Zahner, & He, 2009; Roig et al., 2012; Schmidt-Kassow et al., 2013; Segal, et al., 2012). This information, however, is predominantly declarative in nature (Labban & Etnier, 2011; McNerney & Radvansky, 2014; Schmidt-Kassow et al., 2013; Segal et al., 2012). Limited research exists on the influence exercise has on procedural memory (McNerney & Radvansky, 2014; Roig et al., 2012). The extent of previous testing on motor memory has demonstrated increased retention with high-intensity exercise, but no conclusive association has been made with low-intensity exercise. A need exists to determine whether low-intensity exercise can enhance motor memory similar to high-intensity exercise.

Null Hypotheses

The null hypotheses for this study are as follows:

- There will be no significant difference between exercise intensities on retaining the fine motor task.
- There will be no significant difference between exercise intensities on retaining the gross motor task.

Definition of Terms

Acquisition. The initial phase of a motor learning study during which the participant practices the motor task (Janelle, Kim, & Singer, 1995).

Acute Exercise. Performing a single bout of exercise.

Aerobic Exercise. Activities involving movement of the large muscle groups at a moderately vigorous level, leading to a sustained elevation in metabolic rate (Brehm, 2014).

Anaerobic Exercise. High-intensity exercise that utilizes energetic pathways that do not require the presence of oxygen (Brehm, 2014).

Arousal. Internal state of alertness or excitement (Schmidt & Lee, 2011).

Attention. A concept that describes limitations in the processing of information (Schmidt & Lee, 2011).

Body Mass Index (BMI). Relation of body mass to height. The calculation is body weight (kilograms) divided by height^2 (meters). (Brooks, et al., 2005).

Brain-derived Neurotrophic Factor (BDNF). Endogenous protein which influence neuronal creation, health, and survival (Ferris, et al., 2007)

Cerebellum. Area of the brain that aids in the regulation of movement (Brehm, 2014).

Consolidation. The process in which a memory becomes more stable over time.

Declarative Memory (a.k.a Explicit Memory). The memory of facts, events, times, places.

Encoding. Processing of the information and making clear associations between the task, goals, and movement outcomes (Kantak & Winstein, 2012).

Enhancement. The ability to increase proficiency over time without any practice. (Kantak & Winstein, 2011).

Executive Function. Processes that are in future-oriented behavior, such as planning, multi-tasking, setting priorities, and coping with distractions (Brehm, 2014).

Exercise Intensity. Rate of work produced; light intensity 30 to < 40% heart rate reserve (HRR), moderate-intensity 40 to 59% of HRR, and high (or vigorous) intensity at 60 to < 90% HRR, and > 89% HRR being near maximal exertion (ACSM, 2014).

Exercise Mode. The type of physical activity performed (Brehm, 2014).

Fitness Level. Assessment of cardiorespiratory physical fitness. Low < 24.4 ml/kg/min $V_{O_{2max}}$, Average 24.5 to 51.4 ml/kg/min $V_{O_{2max}}$, or Excellent > 51.5 ml/kg/min $V_{O_{2max}}$ (McArdle, Katch, & Katch, 2010).

Lactate. A metabolic compound that is released with exercise.

Learning effects. Effect of an intervention on relatively permanent changes in the performance of a motor skill (Schmidt & Lee, 2011).

Long-Term Memory. Permanent memory, retention of information over a delayed period of time (Roig et al., 2013).

Mediotemporal Lobe. Brain region that supports memory of facts, figures, and events (declarative memory).

Motor Cortical Area. Includes the striatum and the cerebellum. This brain region is associated with procedural memory (Robertson, 2009).

Motor Learning. A set of processes associated with practice or experience leading to relatively permanent changes in the capability for movement. (Schmidt & Lee, 2011).

Motor Memory (a.k.a. Procedural Memory). The memory for movement or motor information (Schmidt & Lee, 2011).

Neurogenesis. Formation of new neurons from stem cells or precursor cells (Brehm, 2014).

Neuroscience. Study of the brain and nervous system.

Oxygen consumption (V_{O_2}). The consumption rate of a certain volume of oxygen (O_2) (Brooks, et al., 2005).

Parietal Brain. Region of the brain most associated to goal-based processing.

Primary Motor Cortex (M1). Region of the brain most linked to movement-based processing.

Procedural Memory (a.k.a. Implicit Memory). Knowing how to do something.

Retention. A test of a practiced skill that a learner performs to assess learning following an interval of time after practice has ceased (Kantak & Winstein, 2012).

Retrieval. Assessing and recalling stored information. It is the only possible measure of memory (Kantak & Winstein, 2012).

Root Mean Square Error (RMSE). A measurement of error occurring in a continuous task. The measure is calculated by squaring the deviation from the desired performance at each time interval, then summing the squares, dividing by the number of samples, and finally taking the square root of that value (Schmidt & Lee, 2011).

Short-Term Memory (a.k.a. Working Memory). Temporary/brief recall of information. Center of activity of information processing system (Cox, 2012).

Transfer. A test in which a person performs a skill that is similar yet different from the skill that he or she has practiced (Kantak & Winstein, 2012).

Assumptions

This study was conducted with the following assumptions:

- All participants were truthful on all questionnaires about medical backgrounds.
- All participants performed the motor tasks to the best of their ability.
- All participants complied with the instruction to not practice the task outside of the experiment between the acquisition and retention/transfer phases.
- All participants followed procedures and did not exercise outside of the study between the acquisition trial and the first retention/transfer tests.

Limitations

This study was conducted with the identified limitations:

- The experimenter was not blind to experimental condition.
- The effect of preference and tolerance for specific exercise intensities has not been studied on motor memory and may have a potential influence on task performance.

- Retention trials were always presented before the transfer trials. The effect of practice before trial on transfer is unknown.
- Exercise history and dietary intake may influence results.

Significance of Study

Diagnoses of neurodegenerative diseases are increasing worldwide. The diseases predominantly affect movement patterns and progressively worsen over time. Symptoms, such as degradation in the ability to perform daily functional living tasks and fine motor skills, are incurable and do not typically respond to dopaminergic medications. One healthy population therapy that has received notoriety for neuroprotective tendencies is high intensity lower body exercise. Unfortunately, neurologically motor impaired populations are highly unlikely to be able to perform this form of exercise. They are in desperate need of alternative beneficial therapies to stop the degradation of, and possibly restore, both gross and fine motor memory. With the positive influence of low-intensity upper body exercise on motor memory, the potential exists to use this alternative therapy to help attenuate cognitive decline in those who are unable to perform high intensity lower body exercise.

CHAPTER II

REVIEW OF LITERATURE

Exercise, or physical activity, has been noted for years as a way to keep bodies physically healthy. The intervention does not discriminate by age, race, gender, disease state, or any other personal descriptive. The body reacts in several ways to initiation and continuation of physical activity. The cardiorespiratory system, which consists of the heart, lungs, and blood vessels, acutely, as well as sustainably, changes with exercise. The respiratory system increases ventilation to bring in more oxygen and disperse of carbon dioxide (McArdle, Katch, & Katch, 2010). The circulatory system facilitates a higher volume of blood distribution throughout the body (Shepherd, 1987). Heart rate, stroke volume, vessel diameter, blood pressure, and body temperature are all influenced by exercise (Shepherd, 1987). These variables allow for expedited blood transport and delivery to working muscles and throughout the remainder of the body. Participating in exercise over multiple days, weeks, months, and years changes the circulatory and respiratory system for the better (Warburton, Nicol, & Bredin, 2006). These changes in blood circulation, oxygen delivery, and cardiac output are associated with a better quality of living as well as a lower disease risk (Warburton et al., 2006).

More recent research suggests that the better quality of living and lower disease risk mentioned above is due to not only physical benefits, but neurological gains as well (Hillman, Erickson, & Kramer, 2008). Neurogenesis, vascular modifications, and exercise associated metabolic differences support beneficial change to the brain (Cotman, Berchtold, & Christie, 2007). Research is still in the infancy stage on exactly which parts of the brain are altered with exercise. A few regions have been noted to develop stronger electrical activity and even grow (Erickson et al., 2011). Most affected areas are sections of the limbic system (e.g., hippocampus, amygdala, basal ganglia, and motor areas) which control the emotional life of humans. Several neurological diseases reduce the neurons in the above-mentioned regions, which influences memory and motor function. A brain region that is stimulated by exercise is the Primary Motor Cortex (Singh & Staines, 2015). This is the principal area studied when it comes to movement. Another specific area is the hippocampus, which is a horseshoe structure predominantly controlling inhibition, spatial control, and memory (Scolville & Milner, 1957). Physical activity can increase hippocampal volume, which may translate into better cognitive function (Colcombe et al, 2003; Colcombe et al., 2006; Erickson et al., 2011; Olson, Eadie, Ernst, & Christie, 2006). Not only can hippocampal gray matter volume be manipulated through a physical fitness intervention, brain connectivity can be beneficially altered as well (Colcombe et al, 2004; Cotman & Berchtold, 2002; Voss et al, 2013). Scientists have yet to discover an unequivocal finding for other sections of the brain (Erickson, Leckie, & Weinstein, 2014; Morgan, Corrigan, & Baune, 2015).

Research demonstrates that there is a definite neurological impact, but the mechanism of the beneficial influence is still unknown.

Exercise and Neurological Biomarkers

The positive stimulation of exercise on the short and long term health of a person could be potentially due to the changes in blood circulation in particular brain regions. Exercise acts as a stressor on the body and with that comes an increase in blood flow. An increase in blood circulation brings with it a modification in the body's available biomarkers, such as catecholamines and trophic factors. Endorphins are known to elevate during and after exercise and bind to opioid receptors (Mastorakos, Pavlatou, Diamanti Kandarakis, & Chrousos, 2005). This helps to block the signal of discomfort and pain and tends to coincide with a feeling of euphoria (Dinas, Koutedakis, & Flouris, 2011). The rise in secretion can be seen with various exercise intensities, frequencies, and durations (Dinas et al., 2011).

Epinephrine, norepinephrine, serotonin, and dopamine are stress-altered catecholamines (Mastorakos et al. 2005). The biomarker levels stay elevated for short periods of time and then return to normal shortly after the exercise ceases. Norepinephrine and epinephrine are necessary to produce the increased muscular and cardiac stimulation associated with exercise. Serotonin and dopamine help with this as well, but are better known to bind to receptors in the central nervous system, in particular the brain. Dopamine plays a central role in motivation, reward and, specific emphasis in this study, motor function. The action of dopamine is what allows for smooth, controlled movements produced from the basal ganglia motor loop (Molina-Luna et al., 2009).

Pharmacological interventions have targeted dopamine replacement, or D-receptor activation, therapy in many neuron-degrading diseases. Since physical activity increases dopamine, this endorphin could be the potential mechanism responsible for the beneficial impact of exercise on certain neurological diseases. Further research needs to investigate how much dopamine is required to obtain the helpful effects from exercise. A general quantification theory (i.e. low, moderate, or high amount) could be initially formed by assessing what exercise intensity promotes the greatest cognitive neurological benefit.

Other potential mechanisms lie in what can cross the BBB and cause long term, sustainable positive effects. The BBB is a tightly woven mesh around the blood vessels of the brain creating a dense barricade to the brain cells. A very limited amount of substances can pass from the blood through this barrier to reach neurons. Dopamine cannot diffuse by itself through the BBB. This may be why it is a limited explanatory mechanism for the favorable effects of exercise on neurological regions and processes. Some neurotrophic factors, which assist with the health and survival of neurons, do have the ability to cross the BBB. One such element that has gained neuroscience research popularity is BDNF. Neurogenesis, the creation of new neurons, and neuroplasticity, the ability of the brain to adapt and form new connections, are stimulated by BDNF (Erickson et al., 2011; Phillips, et al., 2014). This chemical helps the brain rebuild itself. Exercise promotes new construction by increasing the amount of BDNF released into the blood stream that eventually reaches the brain (Phillips et al., 2014; Schmolesky, Webb, & Hansen, 2013). Higher aerobic fitness capacity (VO_{2max}) elicits larger changes in BDNF and is predictive of memory recognition accuracy (Whiteman et al., 2014).

Increases in BDNF and subsequent impact on neurogenesis and neurosynapsis could be why exercise helps cognition. Research still needs to assess how much of an increase in BDNF is needed for the full beneficial neurological effects of exercise. Similar to dopamine, general quantification can be examined through manipulating exercise intensity and measuring cognitive effect.

As with BDNF, lactate also has a similar increase with exercise intensity and duration. Schiffer et al. (2011) established that lactate regulates BDNF. Ferris, et al. (2007) identified a moderate correlation (r = .57) between BDNF and lactate. Lactate can cross the BBB and has an influence on receptor activation and other neurological biomarkers that can maneuver through the BBB (Newman, Korol, & Gold, 2011). Primary motor cortex excitability is positively impacted by introduction of lactate (Coco et al., 2010). This biomarker also correlates with better skill acquisition across various long-term time points (Skriver et al., 2014). Lactate is easier and less expensive to measure compared to the majority of other blood assays. With the simple ability to test for lactate, it would be possible to use this biomarker to determine the necessary exercise intensity for neurological advantage. As of this writing, no correlation has been made between blood lactate levels and motor memory impact. The goal would be to elicit the lowest amount of blood lactate possible to provide cognitive advancement. Lactate measurements could be then utilized to give specific exercise prescriptions for neurological enhancements.

Carried over from the discussion above, intensity of exercise could play a key role in deciding how much of a hormone is needed to elicit the desired cognitive effects

though the true mechanism may still be unknown. High intensity exercise produces a three-fold increase in BDNF concentration in the brain (Seifert et al., 2010). Moderate intensity exercise has also demonstrated a significantly marked increase in neurotrophic factors, though some varied results exist at this intensity (Ferris et al. 2007; Williams & Ferris, 2012).

Very few studies have been conducted to assess the difference that low intensity exercise creates in BDNF concentration (Skriver et al,. 2014). Previous research has assessed both the acute and long-term effects of exercise on BDNF levels. Many studies have concluded that an acute bout of exercise, as short as 20 min, can be effective in producing an increase in BDNF (for reviews, see Briken et al. 2016; Roig et al., 2013). Training studies, however, have reported inconsistent findings in changes in BDNF measurement from pre to post training. A significant beneficial change in concentrations on serum BDNF was reported from several exercise training studies provided by a meta-analysis (Dinoff et al., 2016).

In other studies, aerobic training did not elicit a greater influx of trophic factors from the first to last session over the multi-week training period (Briken et al., 2016; Schiffer et al., 2008; Williams & Ferris, 2012). This potentially leads to the conclusion that the training effect of exercise may not be what causes brain stimulation, but instead the single bout of exercise that impacts the brain's capabilities. A main moderating factor surfaces when reviewing studies assessing effects of exercise intensity on cognition though.

The different conclusions could be due to the variance and inconsistencies in intensity used as exercise interventions. While changes in BDNF levels due to physical activity are well studied, it is still unknown what minimal exercise intensity is needed to elicit favorable neurological affects. Since higher physical fitness is a protective measure against brain tissue loss and misfiring, it is necessary to determine the parameters of stimulation needed to maintain the proper neurological processes. It may be possible to obtain neuronal increase, or stave off degradation, with lower intensity stressors. The majority of the past research has utilized only moderate to high-energy expenditure interventions. The neuroprotective treatment parameters can become even more important when one is diagnosed with Parkinson's disease (PD) or has a Stroke. In these populations, moderate to high intensity exercise may not be possible due to physical, or even mental, limitations. Primarily for future purposes of utilizing exercise as a mentally therapeutic intervention in diseased populations, lower intensity exercise needs further experimental observation.

According to the Parkinson's Disease Foundation (2015), nearly 60,000 Americans are diagnosed with PD every year and an estimated 7 to 10 million people are living with PD worldwide. This currently incurable neurological disease manifests where dopamine producing neurons in the brain are slowly degraded. The cause of this cell death is unknown, but there is an age related correlation to the progression of the disease (Parkinson's Disease Foundation, 2015). Rigidity, postural instability, tremors, and slowness of movement are some of the main indications of PD that impact everyday living. Currently, medications enhancing dopamine uptake can be administered to treat

some of the symptoms related to the disease. The brain habituates to this form of medication and dosage adjustments are continuously needed throughout the progression of the disease (Parkinson's Study Group, 2004). It is often taken at the cost of incurring other ailments, such as hallucinations and chronic dizziness. For some patients, these ailments are intolerable and dopamine-assisting medication must be discontinued. A point also exists where a higher dosage is no longer productive and a different treatment option needs to be established.

Research is surfacing demonstrating an influence of exercise on PD related symptoms. Sasco, Paffenbarger, Gendre, and Wing (1992) observed that participating in sports, or practicing a moderate amount of exercise, led to a reduced risk of PD. This is not an uncommon finding when it comes to ascertaining the relationship exercise has with processes of the brain, even in the diseased brain. A decreased risk of dementia (Larson et al., 2006) and Alzheimer's has also been reported (Heyn, Abreu, & Ottenbacher, 2004) with the inclusion of physical activity in one's life. Even in those with mild cognitive impairment or no cognitive impairment at all, exercise has a positive effect on brain functioning (Segal, et al., 2012). As of this writing, no clear conclusion has been made as to how intense that exercise needs to be to elicit the activity's full effects on cognitive function. Subsequent sections of this chapter will present additional information relevant to understanding the association between exercise and cognition. Particularly, a lengthy discussion is included about the gap in literature of exercise intensity and long-term motor memory.

Exercise Mode and Cognition

Past research into the interaction of exercise and memory has provided some varied results (Roig et al., 2013). Several different parameters could lead to this discrepancy, one being the modality of exercise used. Elsais and Mohammad (2011) compared the physiological differences between treadmill running and cycling ergometry. Running provides significant increase in maximal oxygen uptake (V_{O2max}) and cycling affords greater minute ventilation (V_E). Stimulation of blood pressure and heart rate are significantly different between the two modes with cycling having lower values in both parameters (Kisan, Kisan, Anitha, & Chandrakala, 2012). Lactate reaction to different workloads is well reported and not significantly different between cycling and treadmill running (Dassonville et al., 1998). Incremental cycling ergometry or treadmill running elicit an increase in BDNF (Cho et al., 2012; Vega et al., 2006). The majority of past cognitive neurophysiological studies have utilized one, or both, modes as the exercise groups. Due to the above mentioned physiological differences, interpretation of exercise cognition study results should be carefully evaluated.

Running has been utilized as the intervention mode in cognitive studies several times, but has led to varied results. Lambourne and Tomporowski (2010) and Roig et al. (2013) reported an impaired performance on cognition when measured *during* running activity, but a significant cognitive advancement when assessed post-exercise. Breaking cognition down further, running helps facilitate stimulus detection (Fleury & Bard, 1987), computation of math (Heckler & Croce, 1993), recognition of incongruences (Litchman & Poser, 1983), and decision-making (Marriott, Reilly, & Miles, 1993). Learning can be

enhanced by incremental high intensity running (Winter et al., 2006). In contrast, object recognition is unaffected by jogging (Hopkins, Davis, Vantieghem, Whalen, & Bucci, 2012). Short term memory has shown negligible, (Tomporowski, Ellis, & Stephens, 1987) and even sometimes, negative effects (Dietrich & Sparling, 2004) from run performance. Most studies assessing the effects of exercise on long-term memory, declarative or procedural, have utilized other modes of exercise, particularly cycling. When having a participant run for the exercise session, the effect size on cognition is low, but positive (Lambourne & Tomporowski, 2010). Cycling produces an overall greater beneficial cognitive effect (Lambourne & Tomporowski, 2010).

The mode of cycling affords for a more stable exercise intervention with the ability to control workload more accurately. This mode allows for easier concurrent assessment of physiological and psychological variables due to less bodily movement. The majority of studies observing the effects of an acute bout of exercise on cognition have utilized a cycling ergometer or stationary bike. Executive function can be enhanced by cycling, independent of intensity utilized (Tsukamoto et al., 2016). When cycling to exhaustion, exercise has a beneficial impact on reaction time (Cote et al. 1992; Shanmugam & Narayanan, 1973; Sjoberg, 1977) and incongruence detection (Ferris et al., 2007).

Little to no effect of cycling on visual search has been detected (Bard & Fleury, 1978). Minimal favorable influence of riding a bicycle on attentional focus or task switching has been presented (Coles & Tomporowski, 2008; Tomporowski & Ganio, 2006). Coles and Tomporowski (2008) assessed cycling's effect on immediate and

delayed memory recall and found little to no difference, though this is an abnormal finding. Several studies have identified significantly helpful short-term memory gains from cycling, but most of the studies finding this utilized moderate to high intensity exercise (Davey, 1973; Griffin et al., 2011; Tomporowski, 2003).

Some contradictory evidence exists for short term memory, but a major methodological flaw could be the exercise intensity utilized for assessment. This same issue exists when observing long-term memory outcomes, but a stronger argument can be made for exercise's positive neurological impact (Coles & Tomporowski, 2008; Labban & Etnier, 2011; Mang, Snow, Campbell, Ross, & Boyd, 2014; Roig et al., 2012; Segal & Cahill, 2009; Statton, Encarnacion, Celnik, & Bastian, 2015). An in-depth look into the basis for the previous statement about methodological flaws will be provided in future paragraphs. Lambourne and Tomporowski (2010) and Roig et al. (2013) provided reviews of the influence of exercise on cognition incorporating several of the above studies, but neither analysis included upper body exercise interventions. This exclusion could be due to the minimum number of arm ergometry and cognition studies executed.

Lower limb movement degrades fastest in neurological degenerative diseases (Obeso et al. 2010; Poewe, 2006). Mobility is the highest reported effector of daily living activities (r = -.74; Salter, Cutter, Tyry, Marrie, & Vollmer, 2010). Due to the progressive loss of lower body function, an analysis on how upper body exercise impacts cognition needs to be established. At submaximal workloads, upper and lower body exercise provide the same cardiac output, though this is achieved through different mechanisms. Upper body exercise requires a lower stroke volume, but higher heart rate

when compared to lower body exercise (Clausen, 1976; Pendergast, 1989). Circulating blood has a shorter distance to travel to provide active upper body muscles with necessary nutrients. Upper body activity requires little use of the muscle pump in the legs to return blood to the heart (Shepherd, 1987).

When maximal intensities are utilized for upper body exercise, $V_{O_{2max}}$ values are significantly lesser than lower body exercise (Pendergast, 1989). Heart rate is 30-35% higher in upper body exercise when compared to lower body exercise at maximal intensity (Miles, Cox, & Bomze, 1989). A similar lactate response is recorded in submaximal arm ergometry when compared to treadmill running and cycle ergometry (Dassonville et al., 1998). In the same comparison, maximal efforts significantly increase blood lactate levels for arm ergometry indifferent of collection site (Dassonville et al., 1998). An elevated response in BDNF is recorded with incremental upper body exercise just as it is with running or cycling (Seifert et al., 2010). Arguably most important, arm ergometry provides an option for exercise with less lower body fatigue. Lower body fatigue presents as a less efficient muscular contraction and instability (Nardone, Tarantola, Galante, & Schieppati, 1998). Leg fatigue can play a major role in a person's ability to walk, let alone learn, or relearn, lower body motor tasks. Cycling and running have been known to cause lower body fatigue and loss of equilibrium (Nardone et al., 1998). In diseased populations, particularly those with stroke or lower body movement disorders, upper body exercise provides a safe and feasible option for increasing energy expenditure. Very limited research has been done into assessing the effects of upper body exercise on cognition.

The studies presented below advise on more functional movement impact because cognitive, particularly memory, assessments utilizing arm ergometry have rarely been performed. The investigative groups of Bronas, Treat-Jacobson, and Leon (2011), Briken et al. (2014), and Zwierska et al. (2006) all established that upper limb aerobic exercise allowed for greater walking distance comparative to lower limb aerobic exercise, or control groups. Leg ergometry lead to higher postural sway than arm ergometry (Hill, Pereira, Talbot, Oxford, & Price, 2015). Range of motion and motor control were positively impacted by upper body repetitive exercise (Diserens et al., 2007). In one of the only upper body exercise neurophysiological studies currently available, arm ergometer exercise training provided for an improvement in verbal learning and focus shifting over nonexercising controls (Briken et al., 2014). Most notable information is arm ergometry afforded for a positive influence on delayed word recall, or long term declarative memory (Briken et al., 2014). These cognitive increases were observed after multiple weeks of training with two to three sessions per week. The exercise intensity is identified as 120-130% of aerobic threshold, but the determination of aerobic threshold was not described. No comparison of cognitive effect was made between different exercise intensities on the arm ergometer. Pre and post-acute exercise session cognitive measurements were not completed. More research needs to be performed to continue the progress in closing the information gap on whether upper body exercise can be utilized as neurological therapy. Further assessment needs to be performed to discover the impact an acute bout of arm ergometry has on cognition, specifically motor memory. The specific prescription of exercise intensity for neurological gains still needs to be addressed.

Exercise Intensity and Cognition

As briefly discussed in the paragraphs above, the intensity of exercise can have high degree in variance of effects on the body, both physiologically and neurologically. Blood volume transportation, oxygen delivery, and biochemical stimulation all change when the intensity of exercise is manipulated. Exercise intensity has varied across neurological studies, but due to bodily system arousal, high intensity exercise has gained the most notoriety for cognitive improvement. In children, reaction time is decreased after an acute bout of high intensity aerobic exercise (Maltais et al., 2016). Complex memories seem to be beneficially impacted by high intensity sprints, but simple word pair recall is potentially not altered by this exercise (McNerney & Radvansky, 2014).

In agreeance with Draper, McMorris, and Parker (2010), a lack of definitive parameters to exercise intensity in cognitive research studies exists. The majority of the high intensity studies state that the power output is self-paced or prescribed by a rating of perceived exertion. Without controlling the workload, or doing accurate measurements with either lactate or V_{O_2}, it is possible that the participants may be working out at a level too low to elicit necessary hormonal or mechanistic responses though the exercise may feel intense. Research that has better controlled the workload has demonstrated an acute bout of vigorous intensity exercise allows for better image consolidation (Segal, et al., 2012). This beneficial influence of exercise is indifferent whether the individual is healthy or neurologically impaired (Segal et al., 2012).

Taking a look at a step down in workload, moderate intensity cycling improves reaction time (Yanagisawa et al., 2009). Attention and inhibition is promoted in

adolescents with an acute bout of exercise of moderate intensity (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Hillman et al., 2014). Again, the majority of these studies that utilized moderate intensity as the intervention, allowed participants to interpret what "moderate" meant. Even with this self-paced description, paragraph recall can be beneficially influenced (Labban & Etnier, 2011) and an increased vocabulary recall is observed with concurrent moderately low intensity exercise and learning (Schmidt-Kassow et al., 2013).

Though only a few studies have been executed, moderate and vigorous intensity have both been utilized as intervention specifics to assess the impact exercise has on long term memory, declarative and procedural. Intermittent vigorous cycling exercise elicits an enhanced ability to perform better at a novel visuomotor tracking task (Roig et al., 2012). McNerney and Radvansky (2014) reported faster motor movement, recorded as reaction time, to a screen stimulus before or after moderate intensity exercise. Even neurologically impaired patients who have suffered from a stroke saw a significant increase in procedural memory, specifically serial reaction time, with moderate intensity aerobic exercise (Quaney et al., 2009). Little doubt remains that physical activity has an influence in a beneficial way across various cognitive functions, but only a few of those studies have looked at long-term memory effects. Any of the procedural memory research has looked at the impact of exercise on memory of fine motor skills that leaves a gap in the literature for memory of gross motor skills. A deeper discussion on what long-term memory studies have been performed, methodological weaknesses and findings is found below. Appendix A also contains a table highlighting the results of the studies

summarized below to provide a snapshot of the influence of exercise on memory formation.

Long-Term Memory and Exercise Studies

Long-term memory is formed by the creation, or strengthening, of neural circuits (Fuster, 1997). Explicit and implicit memories both fall under this category. Declarative memory is often also termed explicit memory. This is the memory of facts, figures, names, and events that can be consciously recalled after a period of time. When interpreting the influence of exercise on declarative memory, the type of memory being assessed is important. The exercise intervention happening before, during, or after learning is also important.

Acquisition is when the memory is first formed and still in working memory. This form of memory is imperative and is always changing, but it typically lasts less than a minute before degrading or decidedly consolidating to an arguably more important long-term memory. The memory then passes from the encoding stage to consolidation. The consolidation phase can last anywhere from 1 min up to 24 hrs. Previous studies have determined that sleep is extremely impactful on this consolidation phase and why assessing long-term memory after a sleep cycle is necessary (Bernardi et al., 2016; Walker & Stickgold, 2004; Walker, Stickgold, Alsop, Gaab, & Schlaug, 2005). Exercise is now emerging to be just as impactful as sleep on long-term memory.

Declarative (Explicit) Memory

Similar to findings with other forms of cognition, an acute bout of exercise can have an effect on long-term memory, specifically in the form of paragraph recall (Labban

& Etnier, 2011). With a self-determined moderate intensity bout of cycling for 30 min, paragraph recall can be beneficially influenced when exercising before learning. A moderate intensity (*M* RPE = 13.4) exercise bout boosts participant performance and allows more story items to be recalled. This stimulation could potentially be due to the heightened arousal of the person's circulatory system during encoding. An increased amount of biomarkers, an enhanced amount of circulating blood, and elevated blood oxygen levels influence the memory areas of the brain at moderate intensity without affecting working memory in a dual task function. The self-determined workload could leave the results up to interpretation though since no definitive recording of intensity was reported in the study.

Whether the exercise is implemented before or after learning, both timings have a supportive impact on sentence memory, either recalling the text or the situation described (McNerney & Radvansky, 2014). A self-paced vigorous intensity exercise session helps with accuracy and lowering error rate when it comes to sentence memorization. Not only can this benefit be observed in those that exercise prior to memorizing, but in those that exercise after learning as well. The importance of this study demonstrates that exercising during the acquisition phase *or* the consolidation phase can both have an influence on declarative memory. This is specific to memorization of sentences though and not single word pairs. Complex memories seem to be beneficially impacted by physical activity, but simple word pair recall is potentially not altered by exercise, irrelevant of whether the exercise is done pre or post learning (McNerney & Radvansky, 2014).

The effect of an acute bout of exercise on the brain to better consolidate images is indifferent of whether the individual is healthy and neurologically impaired (Segal, et al., 2012). Mild cognitively impaired or healthy individuals who exercise outperform sedentary counterparts on explicit memory. Specifically designated (70% V_{O2max}) vigorous intensity cycling exercise allows for better verbal free recall of images. Those that have mental impairment could potentially see a twofold cognitive improvement from doing exercise (Segal, et al., 2012). This provides evidence that not only does exercise neurologically help healthy individuals, but those with malfunctioning brains as well. This is promising for those that have been diagnosed with brain diseases. Unfortunately, the intensity of exercise may be physically unachievable and the exercise mode may be problematic for someone with limited leg function.

One of the only documented memory studies utilizing lower intensity exercise implied that it could be advantageous for increasing vocabulary recall (Schmidt-Kassow et al., 2013). The exercise session was done *during* the acquisition phase and intensity was self-assessed to be low to moderate. This could leave room for variance in physiological reactions when the participant could in fact have been at a higher intensity than requested. The concurrent learning and exercise could lead to different theories on why the intervention worked, such as arousal during encoding. Even though the exercise bout was done during the encoding process, there is an impact of utilizing a lower intensity exercise session. This demonstrates that it may not be necessary to use only moderate or vigorous intensity exercise to get long-term memory benefits. The simultaneous activity during learning may have increased biomarkers, such as BDNF,

enough to elicit stimulation to the hippocampus to influence declarative memory. Schmidt-Kassow et al. (2013) also utilized the same parameters for an exercise session prior to learning and found no effect. An unknown effect of low intensity exercise post learning exists as the experimental design by Schmidt-Kassow et al. (2013) did not incorporate this. It is also unknown if the motor cortex or cerebellum would be impacted enough to specifically influence motor memory.

As described in the studies above, acute bouts of exercise executed before or after learning prove to be beneficial for declarative memory. The favorable effect of exercise on explicit memory can be seen across both vigorous and moderate intensities, but it cannot be determined if low intensity exercise performed during the consolidation phase would have an impact. Cycling and running can be utilized as modes for improving this form of long-term memory, but upper body exercise has not been utilized. These are all areas that need to be investigated in future studies. Declarative memory is important, but past qualitative studies have recognized that procedural memory is even more imperative to daily functioning (Salter et al., 2010). A hole in the scientific knowledge exists to this day as to the influence various intensities of exercise has on implicit, or motor, memory.

Procedural (Implicit) Memory

Implicit memory, also known as procedural memory, is the ability to know *how* to do something. It is the unconscious, automatic motor memory of skills. These skills can be everything from daily living activities to surgical skills and anything in between. Moderate intensity exercise (60% $V_{O_{2max}}$) imposes a significant positive effect on *learning* fine motor laparoscopic skills, but not necessarily retaining the skill (Chartrand

et al., 2014). The ability to learn motor skills faster is a valid finding, but the retention of those skills is even more important. McNerney and Radvansky (2014) not only assessed declarative memory as discussed above, but also took on assessing the effect of vigorous intensity running on retention of procedural memory. In the serial order task, reaction time is measured to a stimulus on a screen that requires a motor response. Both exercising before and exercising after allow for faster reaction time to a stimulus. This exercise enhanced movement pattern can be maintained over an extended period of time and solidify learning. These findings are specific to a fine motor task with high visual input. Even though both pre and post exercising can enhance motor learning, high intensity running may not be a viable solution for those with lower body motor degradation.

Procedural memory is typically assessed with reaction time or by error rate defined by distance from target, as in a visuomotor tracking task. A 20 min session of intermittent vigorous cycling exercise elicits an enhanced ability to perform better at a novel visuomotor tracking task (Roig et al., 2012). In the short-term (1 hr) exercising prior to acquisition or during consolidation does not affect retention of the motor task. Looking at time points further out (24 hr and 7 days) from acquisition though, a definite cognitive impact can be seen of exercise on learning the fine motor task. Exercising *after* learning has a more critical long-term influence on skill retention than exercising before learning. Roig et al. (2012) stated that the "workload was determined based on the results obtained in the graded exercise test," but they did not specify exactly what percentage of maximal power, heart rate, or lactate workload was correlated to (p. e44594). Even though the setup of the task was rudimentary, Roig et al. (2012) were able to assess the

previously unknown impact of exercise on motor memory. The memory benefit could potentially be caused by the elevated neurotransmitters in the motor cortex area as well as the hippocampal region of the brain. Without blood analysis and imaging, this is only a theory. The cycling mode of exercise utilized is more controlled and generalizable to a population with motor deficits. Insufficiently reporting the specific intensity used in the protocol is unacceptable. This is essential to determine the true prescription that can be employed for motor memory influence. Finally, the specific motor task was fine motor and still highly visually dependent. Enhancing gross motor learning by means of exercise is still unexplored in the area of brain therapy.

The investigation that Roig et al. (2012) performed prompted Thomas et al. (2016) to explore the comparison between lower moderate (45% V_{O2max}) and high (90% $V0_{2max}$) intensity cycling exercise post motor learning. Thomas et al. (2016) followed suit with previous research and utilized a fine motor visually dependent motor learning paradigm. This was a great step in the right direction with investigation into less intense physical activity though still not low intensity. The discovery is important that both high and moderate intensity cycling have a beneficial influence on a visual tracking task long term. Unfortunately, high intensity, which may not be possible for some populations, had the biggest impact on motor memory consolidation at both 1 and 7-day retention tests. Providing evidence that moderate intensity can be neurologically helpful is still useful for future mechanistic and therapeutic research. In contrast though, Snow et al. (2016) utilized moderate intensity (60% V_{O2max}) exercise as an intervention for a continuous tracking task as well and found no significant differences at retention one day after

acquisition. This provides conflicting information as to whether a lower exercise intensity is a worthwhile alternative. Still needing to be further addressed is how *gross* motor memory is impacted by exercise intensities that would be viable for impaired populations. Upper body, instead of lower body, exercise still needs to be assessed as a potential mode to support the limbic system.

This study has three healthy population aims: to determine the effect that varying intensities of exercise have on motor memory, to understand the impact exercise has specifically on gross motor memory, and diagnose if arm ergometry exercise is a feasible neurological therapy. The long-term implication of this research line is to determine if a population that is neurologically impaired can experience the same benefits. Brain regions associated with motor memory have already shown beneficial stimulation through exercise in those that have detrimental malfunctions of the brain (Quaney et al., 2009). Patients who have suffered from a stroke saw a significant increase in procedural memory with moderate intensity aerobic exercise training (Quaney et al., 2009). Cycling sessions at 70% of $V_{O_{2max}}$ aid in faster reaction times and lift force responses. This was seen after an 8-week training intervention. The influence of aerobic exercise on the diseased brain is established, but far more work is necessary to understand the intricacies of this benefit. A lower level of intensity still needs to be assessed. Further down the road, acute bouts as well as training studies need to be carried out in diseased populations to understand the cognitive impact of exercise.

Studies have established vigorous and moderate intensity exercise is useful to enhance motor memory, but there is no comparison to low intensity exercise and in

certain cases discrepancies or limited information about how intensity is defined. Incidentally, all of the above studies utilized lower body exercise. It is clear that memory, even specifically motor memory, is affected by exercise, but the unknown still remains as to exactly how intense that exercise needs to be to achieve beneficial neuronal effects, and if that benefit persists with upper body exercise. From this advancement in knowledge, next steps can be taken to look more into what mechanism is activated at the most brain beneficial intensity. Dialing in the intensity and discovering if upper body exercise is cognitively useful will help create a stronger platform for neurological prescription.

CHAPTER III

METHODS

Participants

In the present study, 32 healthy men and women, ages 21-37 years old, were recruited from Denton, TX and the surrounding area to assess the influence of arm ergometry exercise intensity on motor memory. Potential participants were excluded if they answered "yes" to any questions in the Physical Activity Readiness Questionnaire (PAR-Q) form, had a Body Mass Index (BMI) above 29 m/kg^2 or were pregnant. Self-reported history of psychological or neurological disorders, or current use of prescription psychiatric medications, nicotine, or recreational drugs that potentially affect focus or attention also resulted in exclusion from the study. Participants previously diagnosed with oculomotor dysfunction (i.e., eye movement or tracking problems) were excluded from the study. Participants were randomly assigned to either a low-intensity ergometry (LOW), high-intensity ergometry (HIGH), or no exercise (CON) group, while ensuring each group was matched for age, most recent grade point average (GPA), BMI, and aerobic fitness level ($V_{O_2}max$). All procedures were approved by the Texas Woman's University (Denton, TX) Institutional Review Board and all participants provided written informed consent prior to beginning the study.

Procedures

For a detailed overview of the experiment, see Table 1. Participants visited the lab a total of four times over a 9-day period with a total time commitment of 2.5 hr. On

the first visit, each participant completed the Physical Activity Readiness Questionnaire (see Appendix B), medical history (see Appendix C), and informed consent forms (see Appendix D). Participants also filled out a handedness assessment questionnaire (see Appendix E). A maximal oxygen consumption (VO_2max) test on an arm ergometer was performed to assess aerobic fitness. After a minimal time period of 48 hr, each participant returned to the lab for Visit 2. This session consisted of a motor skill acquisition phase, and an intervention, either rest or exercise, phase. Each participant returned to the lab for a separate retention and transfer test on each return trip that was twenty-four hours after and 7 days after the acquisition phase. These tests assessed the amount of motor memory retained.

Table 1

Study Timetable and Phases

Time Lapsed		Subjects: N = 32
Day 1		Informed Consent, PAR-Q, Medical History Questionnaire, Handedness Assessment
		Progressive Ergometry Test (VO_2max Test)
		Randomization into experimental group
Day 2	>=48 hours after VO_2max test	Motor Skill Acquisition Randomized Order Gross Motor (Three blocks of five trials) Fine Motor (Three blocks of five trials)
	Directly after motor skill acquisition	Intervention: *Control*: no exercise for 20 min; *Exercise*: low-intensity = 20 min 35% VO_2max; **or** high-intensity = 2 min 35% VO_2max + (3 x (3 min 85% VO_2max + 2 min 35% VO_2max)) + 3 min 35% VO_2max)
	Post intervention phase (30 min after motor skill acquisition)	Drink 8 oz. water
Day 3	24 hours after motor skill acquisition	Randomized Order: Retention Gross Motor 1 (Five trials) Retention and Transfer Fine Motor 1 (Five trials each)
Day 4	Seven days after motor skill acquisition	Randomized Order: Retention Gross Motor 7 (Five trials) Retention and Transfer Fine Motor 7 (Five trials each)

Aerobic Fitness Assessment

The testing room was kept between 21-23 °C. Upon arrival to the lab, participants were briefed on the procedures of the VO_2max test. Next, the investigator cleaned and abraded the skin and placed 10 electrodes on the participant's chest and torso to track

heart rate (HR) and cardiac rhythm during rest and exercising portions of the test. The participant sat in front of the arm ergometer (Monark Exercise, 881E, Vansbro, Sweden) while the investigator adjusted the desk and grip position to fit properly. The arms had a slight flexion at the elbow joint when fully extended horizontally. Feet were placed flat on the floor and no waist or torso restraints were utilized. At this time, the Borg 15-point rating of perceived exertion (RPE) scale (Borg, 1970) was explained.

The investigator had each participant sit comfortably in a chair and assist in securing a mask tightly to the face. The mask with a Hans Rudolph two way valve was then connected to a hose leading to a metabolic cart (Parvo Medics TrueOne 2400 Metabolic Measurement System). The 12 leads were connected to a stress test ECG recorder (Quinton Q-Stress Q40). While at rest, 5 min of expired respiratory gases, minute ventilation data (V_E), carbon dioxide production (V_{CO_2}), oxygen consumption (V_{O_2}), respiration exchange ratio (RER), and HR data were collected. Systolic (SBP) and Diastolic (DBP) blood pressure (BP) were obtained with a sphygmomanometer and stethoscope placed on the upper dominant arm during this rest time.

The progressive exercise test only occurred if normal resting values for BP, VO_2, and RER were recorded during this collection period. The American College of Sports Medicine (2014) recommends normal BP to be SBP < 120 mmHg and DBP < 90 mmHg. In a rested state, absolute V_{O_2} should be approximately .25 L/min and RER approximately .85 (Brooks, et al., 2005). Resting data collected from the participant was close to the recommended values to proceed with the max test. The ECG recordings were free from artifact and had a regular rhythm with no abnormal conduction recordings

to begin the progressive test (Ehrman, Gordon, Visich, & Keteyian, 2009). If the necessary values were not observed after an additional 5 min, the participant was dismissed for the day and asked to return at another time.

Once normal resting values were observed, the V_{O_2}max test began with the first crank stroke. A crank rate of 70 rpm was held while workload started out at 30 W. For each stage, HR was collected every min, V_{O_2}, V_{CO_2}, V_E, and RER were captured continuously. Blood lactate was evaluated at 1:45 min through an earlobe prick capillary sample created by a disposal lancet (Accu-check Safe-T-Pro Plus, Roche Diagnostics, Switzerland). The blood was evaluated with a portable lactate analyzer for venous blood lactate concentration (Lactate Scout Pro, Sports Resource Group, Hawthorne, NY). Rate of perceived exertion was requested at 2:00 min into each stage before progressing to the next stage with a 20 W increase in workload (i.e. progress test every 2 min with workload increase of 20 W). The same data collection steps above were repeated for each 2 min stage. Verbal encouragement was given throughout the test for the participant to go as long as possible and to achieve maximal effort. The test continued until exhaustion was reached, or the participant could no longer hold the pedal rate above 55 rpm. Final blood lactate was collected at 5 min post exercise.

Maximal oxygen consumption from a graded exercise test is classically defined as an increase in workload producing no further increase in V_{O_2} uptake (Brooks, et al., 2005). If this was not ascertainable, the following criteria was used: RER $\geq$ 1.1, lactate $\geq$ 8.0 mmol, attainment of age predicted maximal HR (ACSM, 2014) to determine if V_{O_2} max was reached. The desired intensity for subsequent exercise interventions was

determined by correlating designated % V_{O_2}max with workload (watts) from the progressive test.

Motor Tasks

Fine motor learning was assessed with a visuomotor task similar to what was previously utilized by Roig et al. (2012). The pursuit rotor tracking (PRT) task was used as the novel fine motor skill to measure the accumulation of motor memory. It is a perceptual motor task performed on a touch screen tablet (Microsoft Surface Pro 3, Redman, WA) where the participant uses a stylus to follow a moving target around a circular path at a defined speed. A work station was setup at a desk with a comfortable desk chair and the tablet on top of the desk. The tablet was located 4 in from the edge of the desk and the chair was centered directly on it. The participant held the stylus in the dominant hand as determined by the handedness questionnaire and was instructed not to let the elbow touch the desk during trials (see Appendix B). When participants had the stylus correctly on top of the target, it changed color from dark red to bright red to provide augmented feedback about desired performance. Time on target was the main output metric with mean deviation from target center as a second metric recorded. For this study, the valid and reliable (Piper, 2011) Psychology Experiment Building Language (PEBL; Mueller, 2012) version of the task was administered.

The acquisition of the fine motor task consisted of three blocks of five trials resulting in 15 total trials. Each trial was 30 s work by manually following the target moving at 90 degrees per second (dps) with 15 s rest after each trial. No rest break was

taken between blocks. The breakdown of initial learning was 7.5 min skill practice, 3.75 min rest, totaling 11.25 min.

Dynamically balancing on a stabilometer (Lafayette Instruments Company, 16030, Lafayette, IN) was used as the novel gross motor skill to measure the accumulation of motor memory. The stabilometer is a wooden platform lifted from the ground by two free rotating center located axis points. Specific computerized recordings of spatial-temporal parameters were outputted from the device every second the participant was in balance. The maximum angular position change allowed is 15° on either side. Each trial was averaged and then plotted for further analysis. Root mean square error (RMSE) was the main output metric recorded. Previous studies have validated the data captured by equipment and software. (Shea & Wulf, 1999; Wulf, McNevin, & Shea, 2001).

Participants received one initial balancing trial with verbal directions and feedback for familiarization to the task. The acquisition period consisted of three blocks of five trials resulting in 30 total trials. Each trial was 30 s long with a 15 s rest period. A total of 15 trials were completed. The breakdown of initial learning was 7.5 min skill practice and 3.75 min rest (Total time = 11.25 min).

In accordance with Kimble and Bilodeau (1949), the work and rest period of the motor learning task have to each be taken into consideration. A 2:1 work-to-rest ratio has been confirmed as the most beneficial for learning a motor task (Plutchik & Petti, 1964). Based on this information, trials in the present study were set at 30 s each with a 15 s rest

between trials. A pilot study with two participants was conducted to ensure all trials were fully achievable and steps could be replicated.

Intervention Phase

Upon arrival to the lab for the second visit, all participants received verbal instructions for the dynamic balancing task and visuomotor task. The motor tasks were performed in random order to accommodate for any learning cross-over and fatigue effect between tasks. Participants completed the acquisition phase for both the novel fine motor and gross motor tasks.

Thomas et al. (2016) proposed that timing of exercise following motor learning plays an important role in memory consolidation and retention. Per the results of the 2016 study, exercise promotes the best ability to retain motor skills when the physical activity is completed between 20 to 60 min post skill acquisition. The methodological setup of the current study allowed for the exercise to be completed within 20 to 30 min after learning which falls within the parameters of the above finding.

At the start of the intervention phase, the investigator assisted the participant with putting on a HR monitor (Polar, FT1, Lake Success, NY). Each participant was seated at the arm ergometer (Monark Exercise, 881E, Vansbro, Sweden). Participants in CON were allowed to read, but were not allowed to sleep or use electronic devices. For the exercise groups, the results from each individual progressive test completed on Day 1 was utilized to set the desired exercise intensity workload. The LOW participants performed arm ergometry at 70 rpm for 20 min with the workload set at 35% V_{O_2}max. The participants in HIGH performed a high intensity interval training protocol. Each

subject performed arm ergometry at 70 rpms for 3 min low-intensity (35% V_{O_2}max) to warm up then did three sets of the following intervals in a row: 3 min high-intensity (85% V_{O_2}max) + 2 min low-intensity (35% V_{O_2}max). A cool down period of two min low-intensity (35% V_{O_2}max) finished off the treatment for HIGH. For all groups during the intervention, venous blood lactate concentration (BL) was obtained three times through an earlobe prick capillary sample generated by a disposal lancet (Accu-check Safe-T-Pro Plus, Roche Diagnostics, Switzerland). Lactate has previously been moderately correlated (r = .57) with brain derived neurotrophic factor (Ferris, et al., 2007) and is highly involved in neurological biomarkers crossing the blood brain barrier (Bergerson, 2015; Newman, et al., 2011). The blood was analyzed with a portable lactate analyzer (Lactate Scout Pro, Sports Resource Group, Hawthorne, NY) at Minute 16 and 20. An additional sample was taken at 5 min post exercise. Participant HR was recorded at every minute throughout the session.

Once the participant completed the intervention phase, 8 oz of water was given for ingestion to replenish any potential fluid lost during the previous time period. Prior to leaving the lab, participants were instructed not to engage in exercise for the next 24 hr.

Retention and Transfer Phase

A retention and transfer test was administered at 24 hr and 7 days after the skill acquisition. The retention test consisted of five trials identical to the conditions during acquisition for both fine and gross motor tasks. The tasks were randomly ordered. Post-retention trials on both follow-up days, a transfer test was administered for the PRT task. The target rotation speed was increased to 150 dps, up from the previous 90 dps during

acquisition and retention. This test was designed to assess the stability and the adaptability of fine motor memory.

Data Analyses

The DataLab 2000 Interface© output files from the stabilometer and The PEBL output files from the PRT were converted from text to data files in Excel and then imported into SPSS, version 22 (SPSS Inc., Chicago, IL) for analysis. The RMSE was calculated for the gross motor task. The TOT and the mean difference in pixels (MDP) between the cursor and target were the dependent variables assessed for the fine motor task. Note that lower scores on MDP indicate less error occurring as the participant stayed closer to the target even if the stylus was not directly on it.

Baseline measures of aerobic fitness (VO_2max), academic aptitude (GPA), and weight management (BMI) were analyzed using a multivariate analysis of variance (MANOVA) to ensure no initial differences existed between groups. If significant differences were revealed, then these variables became covariates in subsequent analyses. Separate one-way analyses of variance (ANOVA) were used to determine differences between groups on serum blood lactate concentration, rate of perceived exertion, and heart rate response generated during the intervention sessions.

Separate 3 (Group) x 3 (Block) repeated measures ANOVAs were used on RMSE, TOT, and MDP with repeated measures on Block for acquisition data for the two learning tasks. Similarly, separate 3 (Group) x 2 (Test: 24-hr retention, 7-day retention) repeated measures ANOVAs were used on RMSE, TOT, and MDP with repeated measures on Test to assess differences in learning of the two tasks. All significant main

effects and interactions in the ANOVAs were followed up with Sidak *post-hoc* tests to determine the source of the differences. Levene's test was used to check for equality of variance on all MANOVAs and ANOVAs. Additionally, in any case where sphericity was violated, Greenhouse-Geisser corrections were applied. The alpha level for all tests was set at .05.

CHAPTER IV

RESULTS

Participant Demographics

A total of 32 participants (age 21-37 years old) were randomly assigned to a control (CON), low-intensity (LOW), or high-intensity (HIGH) exercise group and completed this 9-day study (CON: $n = 11$; LOW: $n = 11$; HIGH: $n = 10$). Gender was predominantly female in all groups (CON: $m = 4$, $f = 7$; LOW: $m = 3$, $f = 8$; HIGH: $m = 4$, $f = 6$). Mean GPA, BMI, and V O_2max were compared between groups and are displayed in Table 2. No significant differences between groups were revealed in any demographic data, $\Lambda_{Wilk's} = .718$, $F(4, 8) = 1.17$, $p = .334$.

Table 2

Mean Values ± Standard Deviations of Demographics Compared between Groups.

	CON	LOW	HIGH	F-ratio	p-value
Age (years)	25.1 ± 5.0	24.4 ± 2.9	25.5 ± 5.6	0.17	.848
BMI (kg/m^2)	25.7 ± 3.1	22.5 ± 2.3	23.8 ± 3.7	2.98	.067
GPA	3.3 ± 0.4	3.1 ± 0.5	3.3 ± 0.4	0.99	.385
VO_2max (ml/kg/min)	20.5 ± 5.2	21.1 ± 5.1	20.9 ± 5.0	0.04	.958

Physiological Response to Exercise

Means and standard deviations for peak lactate levels, peak heart rate, and RPE during exercise for each group can be found in Table 3. A one-way ANOVA revealed a main effect of group on lactate concentration, $F(2, 29) = 25.80$, $p < .001$. Sidak *post-hoc* procedures indicated lactate measurement following exercise for HIGH was significantly higher than both CON ($p < .001$) and LOW ($p < .001$). Groups CON and LOW were not significantly different from each other ($p = .424$). A main effect of group on peak heart rate was discovered through performing a one-way ANOVA, $F(2, 29) = 57.94$, $p < .001$. Sidak *post-hoc* measures revealed all groups were significantly different with CON having a peak heart rate significantly lower than LOW ($p = .003$) and LOW having a significantly lower heart rate than HIGH ($p < .001$). Participant's RPE was compared between groups with a one-way ANOVA where a significant main effect of group was observed, $F (2, 29) = 123.15$, $p < .001$. Group CON reported an average perceived exertion of 6 ± 0, which is equivalent to "very, very light" activity on the Borg Rating of Perceived Exertion Scale. Group LOW reported an average rating of 10 ± 2 ("fairly light"), and HIGH described an average rating of 15 ± 2 ("hard"). When comparing RPE between groups, CON was significantly less than LOW ($p < .001$) and LOW was significantly less than HIGH ($p < .001$).

Table 3

Mean Values ± Standard Deviations of Physiological Responses to Exercise Compared between Groups.

	Control	Low	High	*F*-ratio	*p*-value
Peak Lactate Level (mmol/L)	1.7 ± .5	2.5 ± .6	5.8 ± 2.3	25.80	<.001
Peak Heart Rate (bpm)	85 ± 12	110 ± 15.5	158 ± 19.2	57.94	<.001
Rating of Perceived Exertion	6 ± 0	10 ± 2	15 ± 2	123.15	<.001

Motor Skill Performance and Learning

Fine Motor Task

Acquisition. Figure 1 and Figure 2 visually represent TOT and mean difference in pixels (MDP) respectively for all groups during acquisition. All groups improved on the fine motor task similarly across blocks with regard to TOT. The main effect for block was significant, $F(2, 58) = 50.11$, $p < .001$, $\eta_p^2 = .63$. Block 1 had significantly less time on target than Block 2 ($p < .001$) and Block 3 ($p < .001$), but Block 2 and Block 3 were not significantly different from each other ($p = .229$). The main effect for group was not significant, $F(1, 29) = 2.76$, $p = .08$, nor was the group x block interaction, $F(4, 58) = .63$, $p = .65$.

A repeated measures ANOVA was conducted for mean difference in pixels from target during the fine motor task. A significant main effect of block existed for this dependent variable, $F(2, 28) = 28.247$, $p < .001$, $\eta_p^2 = .669$. Follow-up analysis was performed and Block 1 was significantly higher than Block 2 ($p < .001$) and Block 3 ($p < .001$), but Block 2 was not significantly higher than Block 3 ($p = .502$). The main effect of group was not significant, $F(2, 29) = 1.63$, $p = .21$, but the group x block interaction was significant, $F(4, 58) = 4.84$, $p = .008$, $\eta_p^2 = .25$. This interaction was further analyzed with Sidak *post-hoc* analysis. Group LOW performed significantly better in Block 2 ($p = .008$) and Block 3 ($p = .004$) compared to Block 1. Similarly, HIGH performed significantly better in Block 2 ($p < .001$) and Block 3 ($p < .001$) compared to Block 1. Both LOW and HIGH did not differ in performance between Block 2 and Block 3. Group CON did not perform significantly better across blocks ($p > .05$).

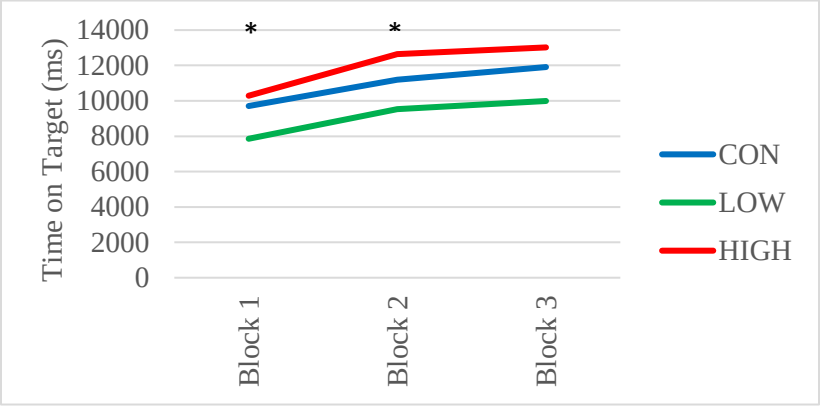

Figure 1. Mean time on target of the fine motor task for CON, LOW, and HIGH groups during acquisition (* indicates significantly different from each other).

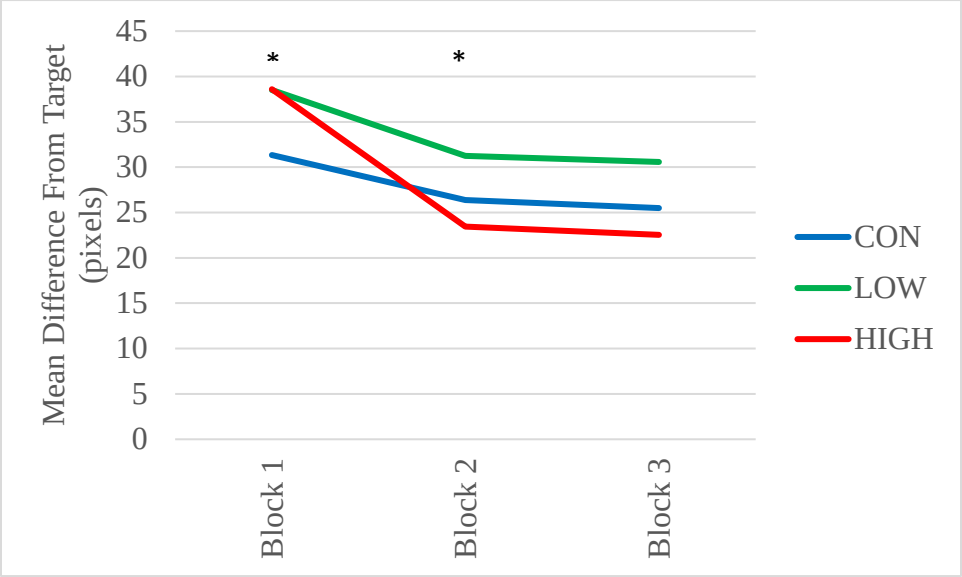

Figure 2. Mean difference in pixels of the fine motor task for CON, LOW, and HIGH groups during acquisition (*indicates significantly different from each other).

Retention. When comparing time on target for groups at post-intervention retention, a repeated measures ANOVA was executed and no significant test effect was observed, $F(1, 29) = 1.79$, $p = .191$, nor a group effect established, $F(1, 29) = 2.13$, $p = .137$. The test x group interaction was also not significant either, $F(2, 29) = .67$, $p = .521$. The same analysis was performed for mean difference in pixels for retention of the fine motor task. No significant test effect was revealed, $F(2, 29) = .03$, $p = .875$. No significant group effect was ascertained, $F(1, 29) = 2.03$, $p = .149$, and the test x group interaction was not significant, $F(2, 29) = .02$, $p = .979$. These results are displayed in Figures 3 and 4 respectively.

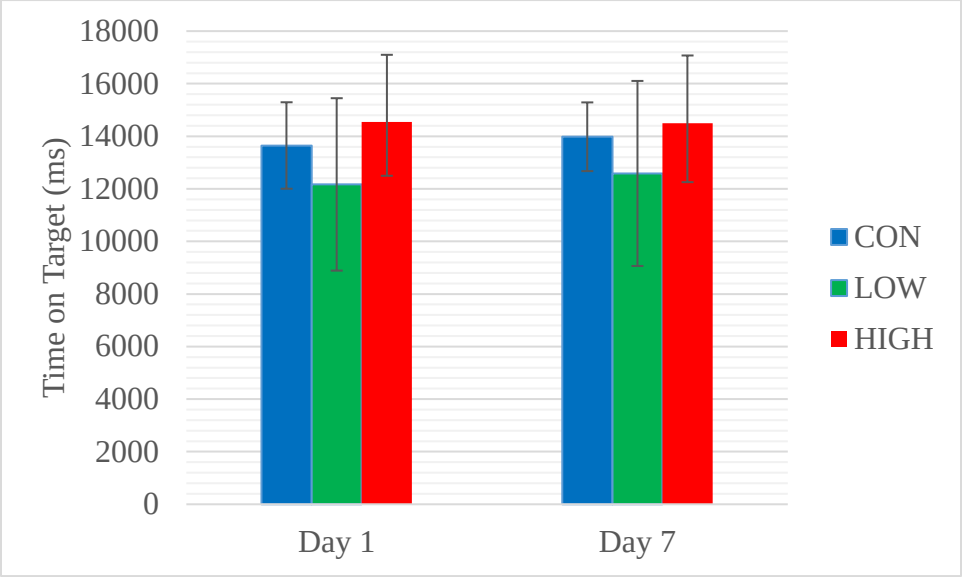

Figure 3. Mean time on target of the fine motor task for CON, LOW, and HIGH groups compared at retention on Day 1 and Day 7.

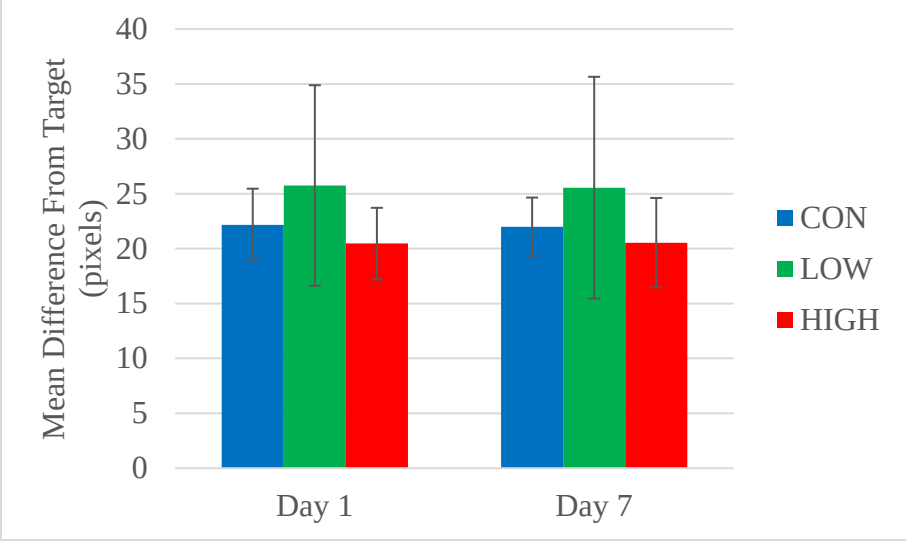

Figure 4. Mean difference in pixels of the fine motor task for CON, LOW, and HIGH intensity groups comparing retention at Day 1 and Day 7.

Transfer. A repeated measures ANOVA was utilized to assess the effects of exercise intensity on skill transfer of the fine motor task in terms of TOT. A significant test effect was observed between Day 1 and Day 7, $F(1, 29) = 24.31$, $p < .001$, $\eta_p^2 = .456$, but no group effect was observed, $F(1, 29) = 2.10$, $p = .141$. The test x group interaction was also not significant, $F(2, 29) = .03$, $p = .973$. All groups had a significantly higher TOT on Day 7 than on Day 1 as seen in Figure 5. Figure 6 represents skill transfer of the fine motor task measured through MDP. A repeated measures ANOVA was performed. A significant test effect was revealed, $F(1, 29) = 27.87$, $p < .001$, $\eta_p^2 = .490$. Further analysis exhibited a significantly lower MDP on Day 1 transfer compared to Day 7 transfer, but no difference between groups, $F(1,29) = 1.43$, $p = .255$. The test x group interaction was also not significant, $F(2, 29) = 1.70$, $p = .201$.

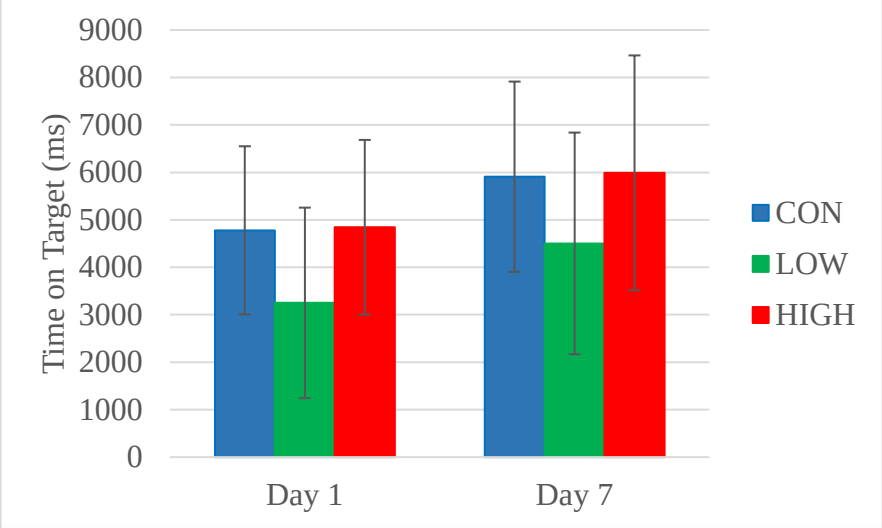

Figure 5. Transfer mean time on target of the fine motor task for CON, LOW, and HIGH intensity groups compared at retention Day 1 and Day 7.

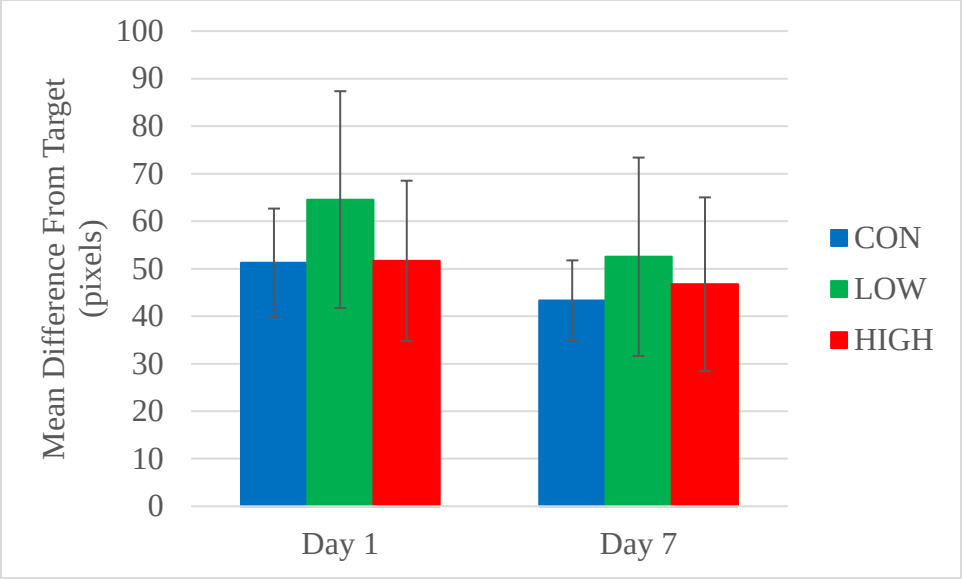

Figure 6. Mean difference in pixels of the fine motor task for CON, LOW, and HIGH intensity groups compared at transfer Day 1 and Day 7.

Gross Motor Task

Acquisition. The gross motor task performance was assessed through a repeated measures ANOVA of the variable RMSE. The change in performance during acquisition of the task can be visually distinguished in Figure 7. A significant positive change in performance across blocks was revealed, $F(2, 58) = 64.03$, $p < .001$, $\eta_p^2 = .688$. Sidak *post-hoc* procedures indicated each block had lower error than the preceding block (p's < .05). No significant difference was exposed between groups during acquisition, $F(1, 29) = .94$, $p = .403$, and the group x block interaction was also not significant, $F(4, 58) = 2.46$, $p = .074$.

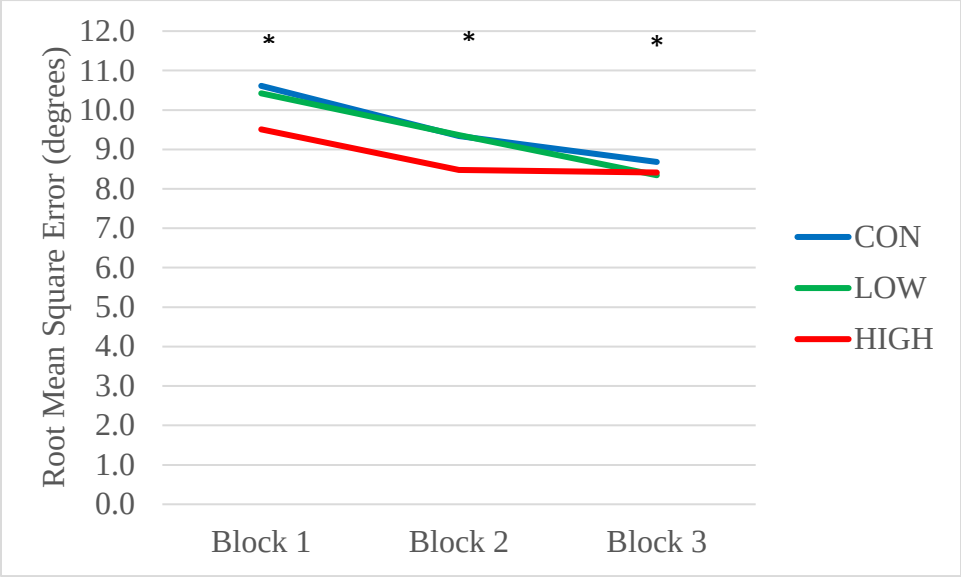

Figure 7. Root mean square error for the gross motor task for CON, LOW, and HIGH intensity groups during acquisition (*indicates significantly different from each other).

Retention. Day 1 and Day 7 retention points of RMSE were assessed with a repeated measures ANOVA. Figure 8 visually compares the each group's RMSE performance across retention time points. A main effect of test was present, $F(1, 29) = 9.10$, $p = .005$, $\eta_p^2 = .239$, with RMSE being lower on Day 7 than Day 1. No significant difference between groups was detected, $F(2, 29) = .32$, $p = .729$, and the group x test interaction was not significant, $F(2, 29) = 1.65$, $p = .210$.

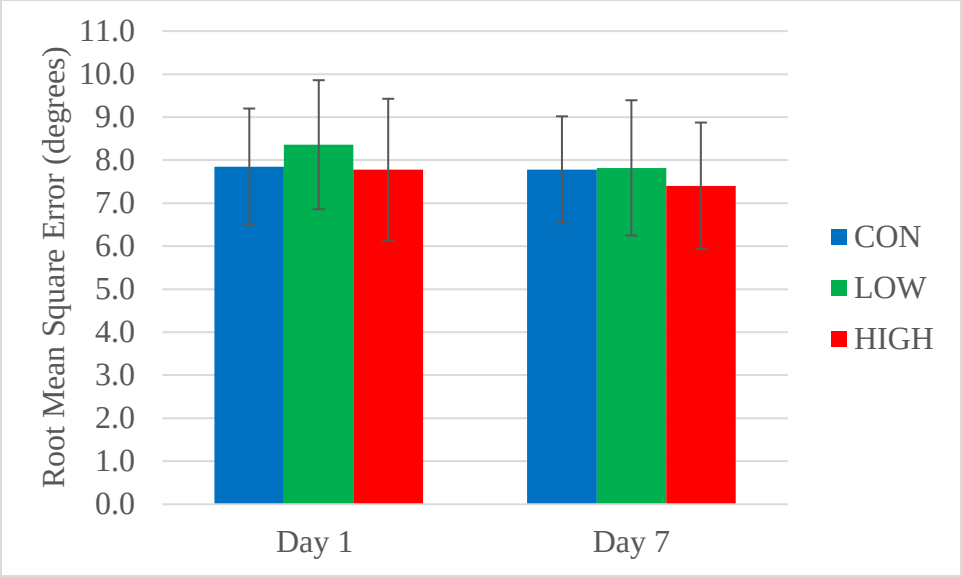

Figure 8. Root mean square error of the gross motor task for CON, LOW, and HIGH intensity groups comparing retention at Day 1 and Day 7.

CHAPTER V
DISCUSSION

Previous literature has suggested that exercise has a positive influence on long-term memory, particularly declarative memory (Labban & Etnier, 2011; McNerney & Radvansky, 2014; Schmidt-Kassow et al., 2013; Segal et al., 2012). A smaller number of studies have demonstrated a benefit of exercise on procedural (i.e., motor) memory as well, but the majority of the interventions utilized high-intensity exercise (McNerney & Radvansky, 2014; Roig et al., 2012). All of these long-term memory studies utilized lower body exercise as the mode to increase heart rate, oxygen consumption, and biomarker availability. The task used in these previously mentioned studies was also exclusively fine motor and typically a single degree of freedom task. Extremely limited research has been completed looking at the influence of low-intensity exercise on long-term procedural memory. The use of arm ergometry as the exercise mode has been studied even less. No studies have looked at the influence exercise has on gross motor memory retention, nor complex tasks.

The purpose of this study was to determine if high or low-intensity exercise using arm ergometry would have a beneficial impact on fine and gross motor memory. The hypotheses for this study were as follows:

1. High-intensity exercise would improve retention of both motor tasks when compared to low-intensity exercise and non-exercising controls.
2. Low-intensity exercise would beneficially impact motor memory more than no exercise at all.

These hypotheses were not supported by the results of this study, but the null finding should not necessarily be interpreted as meaning exercise with arm ergometry does not influence motor memory. This discussion will address possible interpretations of the null findings, and address certain study limitations.

Many parameters in this study have only briefly been researched in the past, if at all. Moderate and high-intensity exercise have been utilized several times in previous studies to show a beneficial impact on motor memory (Maltais et al., 2016; McNerney & Radvansky, 2014; Roig et al., 2012), but low-intensity has not received as much attention (for reviews see Lambourne & Tomporowski, 2010; Roig et. al, 2013). Fine motor memory has been investigated in combination with exercise interventions (Chartrand et al., 2014; Mang, Snow, Wadden, Campbell, & Boyd, 2016; Roig et al., 2012; Thomas et al., 2016), but as of this writing, no studies have viewed the impact on gross motor memory. Lower body exercise, predominantly cycling, has been utilized as the effective mode to change motor memory (Lambourne & Tomporowski, 2010; Roig et. al, 2013), but arm ergometry has not been explored. For this study, a healthy population was examined and the results suggest that doing low-intensity upper body exercise after

learning a novel fine motor task and a novel gross motor task does not impact the retention of those tasks. In fact, neither high-intensity nor low-intensity exercise had an effect on either motor task. All groups did learn and retain the tasks better across time, and were even able to perform the task at a faster speed, but neither exercising group outperformed the nonexercise group.

Arm ergometry, or upper body exercise, has only previously been studied once with its impact on memory (Briken et al., 2014). Even then, the study was a training study and did not assess an acute bout of upper body exercise. Briken et al. (2014) found an improvement in word recall, but the current study was not able to create similar results in motor memory. This finding could be due to a variety of reasons. When looking at the physiological changes caused by upper body exercise, the differences when compared to lower body exercise could potentially explain the divergent findings. Though arm ergometry can cause the same amount of lactate to be released into the blood stream, V_{O_2} is lower with upper body exercise (Pendergast, 1989). Higher V_{O_2} elicits stronger changes in biomarkers (e.g. serum BDNF) that help with cognition (Whiteman et al., 2014). It may be that a higher delivery of oxygen is needed for the exercise session to be impactful on motor memory. The muscle pump of the larger muscles of the body are also underutilized in upper body exercise which may be an important part of releasing neuronal staving biomarkers (Shepherd, 1987). The differing natural changes that happen for arm ergometry may have led to the different results achieved in the present study. It

may be that arm ergometry does not elicit enough physiological reaction and lower body exercise may be what is needed for the brain changes to occur.

Arm ergometry is also a novel exercise to most individuals. Even though the participants in this study did have an introductory session on the arm ergometer during their graded exercise test, the intervention of upper body exercise was still not likely a familiar mode for most. Roig et al. (2012) found that exercising after learning, during the consolidation period, had a much greater influence on retention of the movement. The present study implemented this same theory, but it may have actually been detrimental. Due to the exercise mode being novel to majority of the participants, it could have led to interference of consolidating the motor tasks. The participants may have had to concentrate harder on performing the exercise session, limiting available resources for the use of memory consolidation. Additionally, unless coming from a background of having repetitive upper body exercise movement, such as swimming or rowing, most people's arm muscles are not used to maintaining physical activity for 20 continuous min. It could be that the unfamiliarity of doing upper body exercise led to both physical and mental fatigue during the consolidation period. It may have been better to do the exercise prior to learning the motor tasks or utilizing lower body exercise to prevent either of these hindrances.

Even though the order of the motor tasks was counterbalanced to prevent order effects, the learning of two tasks as opposed to one task may have promoted interference

of the consolidation of one or both motor tasks. Extensive research in motor learning suggests that when learning multiple tasks at once, it is more effective to perform the tasks in a random order (i.e., intermixing practice of the two tasks randomly), than it is to perform them in a blocked order (i.e., complete all practice with one task, then switch to another; Lee & Simon, 2004; Shea & Morgan, 1979). The action plan reconstruction hypothesis (Lee & Magill, 1985) suggests that random practice benefits learning by requiring participants to access and generate a motor solution each time a task switch happens. With blocked practice, this only occurs on the first trial of practice. It is possible that the use of blocked practice diminished learning in this study, but random practice did not seem like a practical solution with the current research question. More importantly, the blocked practice of the second task may have inhibited the immediate consolidation of memory related to the first task due to an immediate shift to learning something else.

Another variation between this and previous studies is the type of motor tasks used. Previous research had only utilized one simple fine motor task. Roig et al. (2012) utilized a task that had movement of a joystick to track a dot on the screen. Thomas et al. (2016) and Skriver et al. (2014) utilized this same fine motor movement. Mang et al. (2016) assessed the effects with a visual tracking task that utilized moving a mouse to follow a target with the non-dominant hand. The fine motor task utilized in the current study was a visuo-motor tracking task akin to those implemented in these previous

studies. However, it did differ in terms of movement complexity as measured by the number of available degrees of freedom.

Previous studies contained the fine motor task to one joint moving in only one plane (i.e., single degree of freedom). Roig et al. (2012), Skriver et al. (2014) and Thomas et al. (2016), had participants learn a visuomotor tracking task that only utilized wrist extension and flexion. All other joints of the arm were held stationary in a rigid apparatus. Mang et al. (2016) also constructed a rig that held the movement to one joint and a decreased amount of degrees of freedom. The fine motor task implemented in the current study allowed for movement of the shoulder, elbow, wrist, and even fingers. The degrees of freedom that needed to be controlled by the motor system were exponentially higher, meaning a more complex motor program would be needed to execute the task. On a similar note, the gross motor task involved controlling and stabilizing the whole body while balancing on the stability platform.

With both tasks being far more complex than those in previous studies on exercise and motor memory, it raises the question of whether the benefit of exercise on motor memory transfers to complex tasks. More motor units would need to be activated, controlled, and most importantly coordinated to learn and consolidate these tasks. The demand of coordinating multiple joints and muscles with multiple degrees of freedom may be too demanding to see a benefit from a single bout of low intensity upper body exercise during consolidation. Future work should take a nuanced approach to

investigating whether the benefit of exercise on motor memory exists with the development of more complex motor memories.

Even with all of the above methodological constraints on the study, the debatable findings could simply be due to a lack of statistical power in the study. The sample size was small with predominantly female participants majoring in kinesiology. A larger sample size may have allowed for different findings that may have lined up with previous studies that had more adequately powered designs. The present findings would be hard to generalize without taking on a larger sample and a more diverse sample population.

Conclusions

Taking the results as is would lead one to believe that low intensity upper body exercise has no impact on motor memory. This would be an improper conclusion. A null finding should not be interpreted as the independent variable(s) having no influence on the dependent variables. Rather, it simply indicates a failure to detect a cause and effect relationship between the independent and dependent variables from the way this study was completed. Even though the findings are limited, methodology to use in future studies can be taken away from this study. Upper body exercise was a useful mode that all participants were able to perform. It was easy to control the workload and take blood for serum blood lactate measurements. Though a little scary at first to some, the gross motor task of balancing on a stabilometer was exciting and intriguing to majority of the participants. All participants were able to execute and learn the task. The output metrics

were easy to analyze and would be a useful task for future research. In general, the most important conclusion from this study is that further research is necessary to further understand the influence of exercise on motor memory. Recommendations for future research are outlined below.

Recommendation for Future Research

The limitations to this study allow for a long line of future research to happen. Most importantly, future research should consider assessing each of the variables manipulated in this study in isolation. By manipulating exercise intensity, task complexity, the number of tasks, and exercise modality, it is difficult to identify which factor(s) may have contributed to the null finding. Future work should consider a multiple experiment approach addressing each factor independently. This particular study tried to manipulate too many variables at once which may have led to no significant outcome.

A study investigating the difference that lower body and upper body high intensity exercise would have on a simple fine motor task would be one suggestion. Since majority of previous research has used lower body exercise, the novel variable would be to use upper body exercise. Following suit with previous positive research, maintaining the use of a simple fine motor task and high intensity exercise would be advantageous. It would be the specific recommendation of these authors to compare arm ergometry to leg ergometry instead of utilizing running as the lower body intervention. This is due to the controllability of the movement, the specific designation of the

workload, and the ability to more readily take measurements, such as blood draws and blood pressure.

A second recommendation would be to look further into specifically controlling the workload of lower body exercise then observe the effects on a simple fine motor task. This has been touched on in past research, but the workload of the exercise was subjective by utilizing perceived exertion with the exception of Snow et al. (2016). If one would use cycling ergometry and dial in the intensity of the exercise by power, then a truer outcome can be extrapolated as to the effect intensity has on the fine motor task. Taking control of the intervention a step further and measuring serum blood lactate levels would give an additional parameter to make sure the intensity is creating an increase in blood biomarkers. Again, utilizing an exercise mode and motor task that has been previously studied will allow for better, more definitive findings.

The complexity of the task would be a further variable that could be assessed. Utilizing a standard exercise mode, such as cycling, and a previously researched intensity, such as high intensity, would be useful. The variable that would change in this study would be the complexity of a fine motor task. Past research has used a single degree of freedom, single-joint fine motor movement to evaluate the effect on the dependent variable. Holding everything the same with the exercise intervention, but comparing a multi-joint task to a single-joint task would be interesting to see if the conclusions would be similar.

A final parameter that could be investigated would be looking at the effect exercise has on fine motor *and* gross motor memory. Holding the mode, intensity, and task complexity the same for the intervention would be key to determining the differences. This study would be most useful if the previous suggestion demonstrates that a more complex task shows the same benefit as a simple task. Gross motor tasks are rarely simple movements, so this would be difficult to study with a single degree of freedom task.

Each of these variables could potentially have an impact in their own right on the outcome of the study. Putting them all together in one study led to inconclusive evidence of the effect exercise has on motor memory. Future research should tease each one out and investigate the impact on motor memory.

REFERENCES

American College of Sports Medicine. (2014). *ACSM's guidelines for exercise testing and prescription.* (9th ed.). Philadelphia: Lippincott, Williams, & Wilkins.

Alonso, M., Vianna, M, Depino, A., Mello E Souza, T., Pereria, P., & Szapiro, G. (2002). BDNF-triggered events in the rat hippocampus are required for both short- and long-term memory formation. *Hippocampus. 12*, 551-560. doi: 10.1002/hipo/10035

Bakken, R., Carey, J., Fabio, R., Erlandson, T., Hake, J., & Intihar, T. (2001). Effect of aerobic exercise on tracking performance in elderly people: a pilot study. *Physical Therapy. 81*, 1870-1879.

Bard, C., & Fleury, M. (1978). Influence of imposed metabolic fatigue on visual capacity components. *Perceptual and Motor Skills, 47*(3 suppl), 1283-1287.

Bergersen, L. H. (2015). Lactate transport and signaling in the brain: potential therapeutic targets and roles in body–brain interaction. *Journal of Cerebral Blood Flow & Metabolism*, *35*(2), 176-185.

Bernardi, G., Cecchetti, L., Siclari, F., Buchmann, A., Yu, X., Handjaras, G., … Tononi, G. (2016). Sleep reverts changes in human gray and white matter caused by wake-

dependent training. *Neuroimage, 129,* 367-377. doi: 10.1016/j.neuroimage.2016.01.020.

Borg G. (1970). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Brehm, B. (2014). *Psychology of health and fitness*. Philadelphia: F.A. Davis Company.

Briken, S., Gold, S., Patra, S., Vettorazzi, E., Harbs, D., Tallner, A., Ketels, G., Schulz, K., & Heesen, C. (2014). Effects of exercise on fitness and cognition in progressive MS: a randomized, controlled pilot trial. *Multiple Sclerosis Journal. 20*, 382-390.

Briken, S., Rosenkranz, S., Keminer, O., Patra, S., Ketels, G., Heesen, C., Hellweg, R., Pless, O., Schulz, K., & Gold, S. (2016). Effects of exercise on Irisin, BDNF and IL-6 serum levels in patients with progressive multiple sclerosis. *Journal of Neuroimmunology*. 299. doi: 10.1016/j.jneuroim.2016.08.007.

Bronas, G., Treat-Jacobson, D., & Leon, A. (2011). Comparison of the effect of upper body-ergometry aerobic training vs treadmill training on central cardiorespiratory improvement and walking distance in patients with claudication. *Journal of Vascular Surgery, 53*, 1557-64. doi: 10.1016/j.jvs.2011.01.077.

Brooks, G., Fahey, T., & Baldwin, K. (2005). *Exercise physiology: human bioenergetics and its applications.* (4th ed). New York:McGraw-Hill.

Budde, H., Voelcker-Rehage, C., Pietrabyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*. 219-223. doi: 10.1016/j.neulet.2008.06.024.

Cahill, L., McGaugh, J., & Weinberger, N. (2001). The neurobiology of learning and memory: some reminders to remember. *Trends in Neuroscience, 24*, 578-581.

Chang, Y., Lappan, J., Gapin, J., & Etnier, L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brian Research, 1453,* 87-101. doi: 10.1016/j.brainres.2012.02.068

Chapman, L. & Chapman, J. (1987). The measurement of handedness. *Brain and Cognition, 6*, 175-183.

Chartrand, G., Kaneva, P., Kolozsvari, N., Li, C., Petrucci, A., Mutter, A., … Vassiliou, M. (2014). The effects of acute aerobic exercise on the acquisition and retention of laparoscopic skills. *Surgical Endoscopy, 29*. 10.1007/s00464-014-3691-7.

Cho, H., Kim, J., Kim, S., Hee Son, Y., Lee, N. & Jung, S. (2012). The concentrations of serum, plasma and platelet BDNF are all increased by treadmill VO_2max performance in healthy college men. *Neuroscience Letters, 519,* 78-83. 10.1016/j.neulet.2012.05.025.

Clausen, J. (1976). Circulatory adjustments to dynamic exercise and effect of physical training in normal subjects and in patients with coronary artery disease. *Progress in Cardiovascular Disease, 18,* 459-495.

Coco, M., Alagona, G., Rapisarda, G., Costanzo, E., Calogero, R., Perciavalle, V., & Perciavalle, V. (2010). Elevated blood lactate is associated with increased motor cortex excitability. *Somatosensory & Motor Research,* 27, 1 - 8. doi:10.3109/08990220903471765

Colcombe, S., Erickson, K., Raz, N., Webb, A., Cohen, N., McAuley, E., & Kramer, A. (2003). Aerobic fitness reduces brain tissue loss in aging humans. *Journals of Gerontology: Series A, Biological Sciences and Medical Sciences Gerontological Society of America, 58,* 176-80.

Colcombe, S., Erickson, K., Scalf, P., Kim, J., Prakash, R., McAuley, E., Elavsky, S., Marquez, D., Hu, L., & Kramer, A. (2006). Aerobic exercise training increases brain volume in aging humans. *Journals of Gerontology: Series A, Biological Sciences and Medical Sciences Gerontological Society of America, 61,* 1166-70.

Colcombe, S. & Kramer, A. (2003). Fitness Effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14,* 125-130.

Colcombe, S., Kramer, A., Erickson, K., Scalf, P., McAuley, E., Cohen, N., Webb, A., Jerome, G., Marquez, D., & Elavsky, S. (2004). Cardiovascular fitness,

cortical plasticity, and aging. *Proceedings of the National Academy of Sciences, 101*, 3316-3321. doi:10.1073/pnas.0400266101

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

Cote, J., Salmela, J., & Papthansopoloulu, K. (1992). Effects of progressive exercise on attentional focus. *Perceptual and Motor Skills, 73*, 351–354.

Cotman, C. & Berchtold, N. (2002). Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends in Neuroscience, 25*, 295-301.

Cotman, C., Berchtold, N., & Christie, L. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends in Neuroscience, 30*, 464-72

Cox, R. (2012) *Sport psychology.* (7th ed). New York, NY: McGraw-Hill.

Dassonville, J., Beillot, J., Lessard, Y., Jan, J., Andre, A., …Care, F. (1998). Blood lactate concentrations during exercise: effect of sampling site and exercise mode. *Journal of Sports Medicine and Physical Fitness, 38,* 39-46.

Davey, C. P. (1973). Physical exertion and mental performance. *Ergonomics, 16,* 595e599.

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

Dinas, P., Koutedakis, Y., & Flouris, A. (2011). Effects of exercise and physical activity on depression. *Irish Journal of Medical Science, 180,* 319-25. doi:10.1007/s11845-010-0633-9.

Dinoff, A., Herrmann, N., Swardfager, W., Liu, C., Sherman, C., Chan, S., & Lanctôt, K. (2016). The effect of exercise training on resting concentrations of peripheral Brain-Derived Neurotrophic Factor (BDNF): A meta-analysis. *PLoS ONE, 11,* e0163037. https://doi.org/10.1371/journal.pone.0163037

Diserens, N., Perret, S., Chatelain, S., Bashir, D., Ruegg, P., Vuadens, F., & Vingerhoets, K. (2007). The effect of repetitive arm cycling on post stroke spasticity and motor control: repetitive arm cycling and spasticity. *Jounral of Neurological Sciences, 253,* 18-24. doi: 10.1016/j.jns.2006.10.021

Draper, S., McMorris, T., & Parker, J. (2010). Effect of acute exercise of differing intensities on simple and choice reaction and movement times. *Psychology of Sport and Exercise, 11,* 536-541. doi:10.1016/j.psychsport.2010.05.003

Ehrman, J., Gordon, P., Visich, P., & Keteyian, S. (2009). *Clinical exercise physiology*. (2nd ed.) Champaign, IL: Human Kinetics.

Elsais, W. & Mohammad, W. (2011). Effect of different exercise modes on cardiovascular responses in male runners. *World Journal of Sports Sciences, 5,* 191-196.

Erickson, K., Leckie, R. & Weinstein, A. (2014). Physical activity, fitness, and gray matter volume. *Neurobiology of Aging, 35*, S20 - S28

Erickson, K., Voss, M., Prakash, R., Basak, C., Szabo, A., Chaddock, L., Kim, J., Heo, S., Alves, H., White, S., Wojcicki, T., Mailey, E., Vieira, V., Martin, S., Pence, B., Woods, J., McAuley, E., & Kramer, A. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of National Academy of Science, 108*, 3017-3022.

Ferris, L., Williams, J., & Shen, C. (2007). The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function. *Medicine and Science in Sports Exercise, 39*, 728-734.

Fleury, M. & Bard, C. (1987). Effects of different types of physical activity on the performance of perceptual tasks in peripheral and central vision and coincident timing. *Ergonomics, 30*. 945-58. doi:10.1080/00140138708969790.

Fuster, J. (1997). Network memory. *Trends in Neurosciences. 20*. 451-9. 10.1016/S0166-2236(97)01128-4

Globas, C., Becker, C., Cerny, J., Lam, J., Lindemann, U., Forrester, L., Macko, R., & Luft, A. (2012). Chronic stroke survivors benefits from high intensity aerobic treadmill exercise: a randomized control trial. *Neurorehabilitation Neural Repair, 26*, 85-95. doi: 10.1177/1545968311418675.

Goda, A., Ohgi, S., Kinpara, K., Shigemori, K., Fukuda, K., & Schneider, E. (2013). Changes in serum BDNF levels associated with moderate-intensity exercise in healthy young Japanese men. *Springer Plus, 2*, 678.

Griffin, É., Mullally, S., & Foley, C., Warmington, S., O'Mara, S., & Kelly, A. (2011). Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology & Behavior, 104*. 934-41. doi:10.1016/j.physbeh.2011.06.005.

Heckler, B. & Croce, R. (1993). Effects of time of posttest after two durations of exercise on speed and accuracy of addition and subtraction by fit and less-fit women.. *Perceptual and Motor Skills, 75*. 1059-65. 10.2466/PMS.75.8.1059-1065.

Heyn, P., Abreu, B., & Ottenbacher, K. (2004). The effects of exercise training on elderly persons with cognitive impairment and dementia: A meta-analysis1. *Archives of Physical Medicine and Rehabilitation, 85*, 1694-704. doi:10.1016/j.apmr.2004.03.019.

Hill, M., Pereira, C., Talbot, C., Oxford, S., & Price, M. (2015). The effects of acute arm crank ergometry and cycle ergometry on postural sway and attentional demands during quiet bipedal standing. *Experimental Brain Research, 233*, 1801-910.1007/s00221-015-4252-6.

Hillman, C., Erickson, K., & Kramer, A. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9,* 58–65.

Hillman, C., Pontifex, M., Castelli, D., Khan, N., Raine, L., Scudder, M., …Kamijo, K. (2014). Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics, 134,* 1063-1071.

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

Hopkins, M., Davis, F., Vantieghem, M., Whalen, P., & Bucci, D. (2012). Differential effects of acute and regular physical exercise on cognition and affect. *Neuroscience, 215*. 59-68. doi:10.1016/j.neuroscience.2012.04.056.

Janelle, C., Kim, J., & Singer, R. (1995). Subject-controlled performance feedback and learning of a closed motor skill. *Perceptual and Motor Skills, 81,* 627-634.

Kantak, S. & Winstein, C. (2012). Learning-performance distinction and memory processes for motor skills: a focused review and perspective. *Behavioral Brain Research, 228,* 219-231.

Kimble, G. & Bilodeau. (1949). A further analysis of variables in cyclical motor learning. *Journal of Experimental Psychology, 39,* 332-337.

Kisan, R., Kisan, S., Anitha, O., & Chandrakala, D. (2012). Treadmill and Bicycle Ergometer Exercise: Cardiovascular Response comparison. *Global Journal of Medical Research, 12,* 5.

Labban, J. & Etnier, J. (2011). Effects of acute exercise on long-term memory. *Research Quarterly for Exercise and Sport, 82,* 712-721.

Lambourne, K. & Tomporowski, P. (2010) The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. *Brain Research, 1341*, 12-24.

Lardon, M., & Piloch, J. (1996). EEG Changes from long-term physical exercise. *Biological Psychology, 44,* 19-30.

Larson, E., Wang, L., Bowen, J., McCormick, W., Teri, L., Crane, P., & Kukull, W. (2006). Exercise is associated with reduced risk for incident dementia among persons 65 years of age or older. *Annals of Internal Medicine, 144*, 73-81.

Law, L., Barnett, F., Yau, M., & Gray, M. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. *Ageing Research Reviews, 15*, 61-75. doi: 10.1016/j.arr.2014.02.008

Lee, T. & Magill, R. (1985). Can forgetting facilitate skill acquisition? In: Goodman D, Wilberg RB, Franks IM, editors. *Differing perspectives in motor learning, memory, and control*. Amsterdam: Elsevier. 3–22.

Lee, T. & Simon, D. (2004). Contextual interference. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice*. London: Routledge. 29–44.

Leuner, B., Gould, E., Shores, T. (2006). Is there a link between adult neurogenesis and learning? *Hippocampus, 16,* 216-224.

Lichtman, S. & Poser, E. (1983). The effects of exercise on mood and cognitive functioning. *Journal of Psychosomatic Research, 27*. 43-52. 10.1016/0022-3999(83)90108-3.

Maltais, D., Gane, C., Dufour, S., Wyss, D., Bouyer, L., McFadyen, B. … Voisin, J. (2016). Acute physical exercise affects cognitive functioning in children with cerebral palsy. *Pediatric Exercise Science, 28*. 304-311. 10.1123/pes.2015-01-10.

Mang, C., Snow, N., Campbell, K., Ross, C., & Boyd, L. (2014). A single bout of high-intensity aerobic exercise facilitates response to paired associative stimulation and promotes sequence-specific implicit motor learning. *Journal of Applied Physiology, 117*(11), 1325-1336.

Mang, C., Snow, N., Wadden, K., Campbell, K., & Boyd, L. (2016). High-Intensity aerobic exercise enhances motor memory retrieval. *Medicine & Science in Sports & Exercise, 48*. 1. doi:10.1249/MSS.0000000000001040.

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

Mastorakos, G., Pavlatou, M., Diamanti Kandarakis, E., & Chrousos, G. (2005). Exercise and the stress system. *Hormones, 4*, 73-89.

Maxwell, J., Masters, R., & Eves, F. (2003). The role of working memory in motor learning and performance. *Consciousness and Cognition, 12*, 376-402. doi: 10.1016/S1053-8100(03)00005-9

McArdle, W., Katch, F., & Katch, V. (2010). *Exercise physiology: nutrition, energy, and human performance*. Riverwoods, IL: Lippincott, Williams & Wilkins.

McNerney, M. & Radvansky, G. (2014). Mind racing: the influence of exercise on long-term memory consolidation. *Memory, 14*, 1-12.

Miles, D., Cox, M., & Bomze, J. (1989). Cardiovascular responses to upper body exercise in normals and cardiac patients. *Medicine and Science in Sports and Exercise, 21*. S126-31. 10.1249/00005768-198910001-00003.

Molina-Luna, K., Pekanovic, A., Röhrich, S., Hertler, B., Schubring-Giese, M., Rioult-Pedotti, M-S., & Luft, A. (2009) Dopamine in motor cortex is necessary for skill

learning and synaptic plasticity. *PLoS ONE, 4,* e7082. doi:10.1371/journal.pone.0007082

Morgan, J., Corrigan, F., & Baune, B. (2015). Effects of physical exercise on central nervous system functions: a review of brain region specific adaptations. *Journal of Molecular Psychiatry, 3,* 3. https://doi.org/10.1186/s40303-015-0010-8

Mueller, S. (2014). *The PEBL manual: programming and usage guide for the Psychology Experiment Building Language*.

Nardone, A., Tarantola, J., Galante, M., & Schieppati, M. (1998). Time course of stabilometric changes after a strenuous treadmill exercise. *Archives of Physical Medicine and Rehabilitation, 79,* 920-924.

Newman, L., Korol, D., & Gold, P. (2011). Lactate produced by glycogenolysis in astrocytes regulates memory processing. *PLoS One, 6,* e28427. doi: 10.1371/journal.pone.0028427

Nilsen, D., Gillen, G., Geller, D., Hreha, K., Osei, E., & Saleem, G. (2015). Effectiveness of interventions to improve occupational performance of people with motor impairments after stroke: an evidence-based review. *American Journal of Occupational Therapy, 69,* 6901180030p1-6901180030p9. doi: 10.5014/ajot.2015.011965.

Obeso, J., Rodriguez-Oroz, M., Goetz, C., Marin, C., Kordower, J., Rodriguez, M., ... & Halliday, G. (2010). Missing pieces in the Parkinson's disease puzzle. *Nature Medicine, 16*, 653-661.

Olson, A., Eadie, B., Ernst, C. & Christie, B. (2006). Environmental enrichment and voluntary exercise massively increase neurogenesis in the adult hippocampus via dissociable pathways. *Hippocampus. 16*, 250-60.

Parkinson's Study Group. (2004). Levodopa and the progression of Parkinson's disease. *New England Journal of Medicine. 351*, 2498-508.

Pendergast, D. (1989). Cardiovascular, respiratory, and metabolic responses to upper body exercise. *Medicine and Science in Sports and Exercise, 21*, S121-S125.

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

Phillips, C., Baktir, M., Srivatsan, M., & Salehi, A. (2014). Neuroprotective effects of physical activity on the brain: a closer look at trophic factor signaling. *Frontiers in Cellular Neuroscience, 20*, 170. doi: 10.3389/fncel.2014.00170

Piper, B. (2011). Age, handedness, and sex contribute to fine motor behavior in children. *Journal of Neuroscience Methods, 195*, 88-91.

Plutchik, R. & Petti, R. (1964). Rate of learning on a pursuit rotor task at a constant work-rest ratio with varying work and rest period. *Perceptual and Motor Skills, 19*, 227-231.

Poewe, W. (2006). The natural history of Parkinson's disease. *Journal of Neurology, 253*, vii2-vii6.

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

Potter, D. & Keeling, D. (2005). Effects of moderate exercise and circadian rhythms on human memory. *Journal of Sport and Exercise Psychology, 27*, 117-125

Quaney, B., Boyd, L., McDowd, J., Zahner, L., & He, J. (2009). Aerobic exercise improves cognition and motor function poststroke. *Neural Rehabilitation and Neural Repair, 23*, 879-885. doi: 10.1177/1545968309338193

Robertson, E. (2009). From creation to consolidation: a novel framework for memory processing. *PLoS Biology, 7*, 19.

Roig, M., Nordbrandt, S., Geertsen, S., & Neilsen, J. (2013). The effects of cardiovascular exercise on human memory: a review with meta-analysis. *Neuroscience and Biobehavioral Reviews, 37*, 1645-1666. 10.1016/j.neubiorev.2013.06.012

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., & Neilsen, J. (2012). A single bout of exercise improves motor memory. *PLoS One, 7*, e44594. 10.1371/journal.pone.0044594

Salas, C., Minakata, K., & Keleman, W. (2011). Walking before study enhances free recall but not judgement-of-learning magnitude. *Journal of Cognitive Psychology, 23*, 507-513.

Salter, A., Cutter, G., Tyry, T., Marrie, R., & Vollmer, T. (2010). Impact of loss of mobility on instrumental activities of daily living and socioeconomic status in patients with MS. *Current Medical Research and Opinion, 26*, 493-500.

Sasco, A., Paffenbarger, R., Gendre, I., & Wing, A. (1992). The role of physical exercise in the occurrence of Parkinson's disease. *Archives of Neurobiology*, 49, 360-365.

Schiffer, T. Schulte, S., Hollmann, W., Bloch, W., & Strüder, H. (2008). Effects of strength and endurance training on Brain-Derived Neurotrophic Factor and Insulin-like Growth Factor 1 in humans. *Hormone and Metabolic Research, 41*. 250-4. doi:10.1055/s-0028-1093322.

Schiffer, T., Schulte, S., Sperlich, B., Achtzehn, S., Fricke, H., & Strüder, H. (2011). Lactate infusion at rest increases BDNF blood concentration in humans. *Neuroscience Letters, 488*, 234-237. doi: 10.1016/j.neulet.2010.11.035.

Schmidt, R.A., & Lee, T. (2011). *Motor control and learning* (5th ed.). Champaign, IL: Human Kinetics.

Schmidt-Kassow, M., Deusser, M., Thiel, C., Otterbein, S., Montag, C., Reuter, M., Banzer, W., & Kaiser, J. (2013). Physical exercise during encoding improves vocabulary learning in young female adults: a neuroendocrinological study. *PLoS ONE, 8,* e64172. https://doi.org/10.1371/journal.pone.0064172

Schmolesky, M., Webb, D., & Hansen, R. (2013). The effects of aerobic exercise intensity and duration on levels of brain-derived neurotrophic factor in healthy men. *Journal of Sports Science & Medicine*, *12*, 502–511.

Scolville, W. & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal Neuropsychiatry Clinical Neuroscience, 12*, 103-13.

Segal, S. & Cahill, L. (2009). Endogenous noradrenergic activation and memory for emotional material in men and women. *Psychoneuroendocrinology*, *34*, 1263–1271.

Segal, S., Cotman, C., & Cahill, L. (2012). Exercise-induced noradrenergic activation enhances memory consolidation in both normal aging and patients with amnestic mild cognitive impairment. *Journal of Alzheimer's disease, 32*, 1011-1018.

Seifert, T., Brassard, P., Wissenberg, M., Rasmussen, P., Nordby, P., Stallknecht, B., ...Secher, N. (2010). Endurance training enhances BDNF release from the human

brain. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology Impact Factors, 298,* R372–377. doi: 10.1152/ajpregu.00525.2009

Shanmugam, T. & Narayanan, S. (1973). Effect of bicycle ergometer work on arousal. *Indian Journal of Experimental Psychology, 7,* 1-9.

Shea, C. & Morgan, R. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning & Memory, 5,* 179–187.

Shea, C. & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science, 18*(4), 553-571.

Shepherd, J. (1987). Circulatory response to exercise in health. *Circulation, 76,* VI3-10.

Silva, A., Prado, S., Scardovelli, T., Boschi, S., Campos, L., & Frere, A. (2015). Measurement of the effect of physical exercise on concentration of individuals with ADHD. *PLoS One, 10,* e0122119. doi: 10.1371/journal.pone.0122119

Singh, A. & Staines, W. (2015). The effects of acute aerobic exercise on the primary motor cortex. *Journal of Motor Behavior*, 47, 328-39. doi:10.1080/00222895.2014.983450.

Sjoberg, H. (1977). Interaction of task difficulty, activation and work load. *Journal of Human Stress, 3,* 33- 38.

Skriver, K., Roig, M., Lundbye-Jensen, J., Pingel, J., Helge, J., Kiens, B., & Nielsen, J. (2014). Acute exercise improves motor memory: exploring potential biomarkers. *Neurobiology of Learning and Memory, 116*, 46-58.

Snow, N., Mang, C., Roig, M., McDonnell, M., Campbell, K., & Boyd, L. (2016). The effect of an acute bout of moderate-intensity aerobic exercise on motor learning of a continuous tracking task. *PLoS ONE, 11*, 1-16. doi:10.1371/journal. pone.0150039

Statton, M., Encarnacion, M., Celnik, P., & Bastian, A. (2015). A single bout of moderate aerobic exercise improves motor skill acquisition. *PLoS ONE, 10*, e0141393. doi:10.1371/journal.pone.0141393

Thomas, R., Johnsen, L., Geertsen, S., Christiansen, L., Ritz, C., Roig, M., & Lundbye-Jensen, J. (2016). Acute exercise and motor memory consolidation: the role of exercise intensity. *PLoS ONE, 11*, 1-16. doi:10.1371/journal.pone.0159589

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112,* 297e394.

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

Tomporowski, P. & Ganio, M. (2006). Short-term effects of aerobic exercise on executive processing, memory, and emotional reactivity. *International Journal of Sport and Exercise Psychology, 4*. 57-72. doi:10.1080/1612197X.2006.9671784.

Tsukamoto, H., Suga, T., Takenaka, S., Tanaka, D., Takeuchi, T., Hamaoka, T., ... & Hashimoto, T. (2016). Greater impact of acute high-intensity interval exercise on post-exercise executive function compared to moderate-intensity continuous exercise. *Physiology & Behavior*, *155*, 224-230.

Vega, S., Strüder, H., Wahrmann, B., Schmidt, A., Bloch, W., & Hollmann, W. (2006). Acute BDNF and cortisol response to low intensity exercise and following ramp incremental exercise to exhaustion in humans. *Brain Research*, 1121. 59-65. 10.1016/j.brainres.2006.08.105.

Voss, M., Erickson, K., Prakash, R., Chaddock, L., Kim, J., Alves, H., … Kramer, A. (2013). Neurobiological markers of exercise-related brain plasticity in older adults. *Brain, Behavior, and Immunity*, 28, 90-9. doi: 10.1016/j.bbi.2012.10.021.

Vuori, I., Lavie, C., & Blair, S. (2013). Physical activity promotion in the health care system. *Mayo Clinic Proceedings, 88*, 1446-1461. doi:10.1016/j.mayocp.2013.08.020

Walker, M. & Stickgold, R. (2014). Sleep-dependent learning and memory consolidation. *Neuron, 44*, 121-133.

Walker, M., Stickgold, R., Alsop, D., Gaab, N., & Schlaug, G. (2005). Sleep-dependent motor memory plasticity in the human brain. *Neuroscience, 133*, 911-7.

Warburton, D., Nicol, C., & Bredin, S. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*, 801-809. doi: 10.1503/cmaj.05135

Whiteman, A., Young, D., He, X., Chen, T., Wagenaar, R., Stern, C., & Schon, K. (2014). Interaction between serum BDNF and aerobic fitness predicts recognition memory in healthy young adults. *Behavioral Brain Research, 259*, 302-312. doi: 10.1016/j.bbr.2013.11.023.

Williams, J. & Ferris, L. (2012). Effects of endurance exercise training on brain-derived neurotrophic factor. *Journal of Exercise Physiology Online, 15*. 11-17.

Winter, B., Breitenstein, C., Mooren, F., Voelker, K., Fobker, M., Lechtermann, A., … Knecht, S. (2006). High impact running improves learning. *Neurobiology of Learning and Memory, 87*, 597-609. doi: 10.1016/j.nlm.2006.11.003

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology: Section A*, *54*(4), 1143-1154.

Yanagisawa, H., Dan, I., Tsuzuki, D., Kato, M., Okamoto, M., Kyutoku, Y., & Soya, H. (2009). Acute moderate exercise elicits increased dorsolateral prefrontal

activation and improves cognitive performance with Stroop test. *NeuroImage, 50*. 1702-10. 10.1016/j.neuroimage.2009.12.023.

Zwierska, I., Walker, R., Choksy, S., Male, J., Pockley, G., & Saxton, J. (2006). Upper- vs lower-limb aerobic exercise rehabilitation in patients with symptomatic peripheral arterial disease: A randomized controlled trial. *Journal of Vascular Surgery, 42*. 1122-30. 10.1016/j.jvs.2005.08.021.

APPENDIX A

Snapshot of the Influence of Exercise on Memory Formation

Snapshot of the Influence of Exercise on Memory Formation

Authors/Year	Exercise Mode	Exercise Intensity	Type of Memory	Cognitive Findings
Labban, J. & Etnier, J. (2011).	cycling	Moderate (75% HR_{max})	Long-term memory - paragraph recall	Exercising prior to learning paragraphs beneficially influences recall.
McNerney, M. W. & Radvansky, G. (2014).	running	high (sprints)	Procedural memory - serial order task (response time), Declarative memory - paired associate memory task (word pair recall), Declarative memory - sentence memory task (text and situation recall)	Exercise prior to encoding (before learning) helps procedural memory and sentence memory, but not paired associate learning.
McNerney, M. W. & Radvansky, G. (2014).	running	high (sprints)	Procedural memory - serial order task (response time), Declarative memory - paired associate memory task (word pair recall), Declarative memory - sentence memory task (text and situation recall)	Exercise during consolidation (post learning) helps procedural memory and sentence memory, but not paired associate learning.
Roig, M., et al. (2012).	cycling	vigorous (lactate after exercise 12.72-13.14 mmol)	Procedural memory - visuomotor tracking task	Improved motor learning through an optimization of motor memory at delayed time points, not immediate. Exercising post learning critically effects long-term retention of the motor movement, though pre

				learning exercise does have an effect, just not as much.
Schmidt-Kassow, M., et al. (2013)	cycling	Low-Moderate	Declarative memory - Vocabulary Recall	Light to moderate physical activity during encoding improved vocab learning. Serum BDNF was not significantly correlated with vocab learning.
Segal, S., et al. (2012).	cycling	70% VO_{2max}	Long term memory - image free recall	A single bout of post-learning exercise enhances memory in both cognitively impaired and healthy adults over sedentary controls. The impact was significantly greater on the cognitively impaired than healthy individuals.
Quarney, B., et al. (2009).	cycling	70% HR_{max}	Procedural Memory - Serial Reaction Time Task (SRTT); Conditional learning ability - Predictive grip force modulation (PGMF)	Following lower extremity bicycle exercise, chronic stroke survivors in the aerobic exercise group significantly improved motor learning at the end 8 weeks of aerobic training.

APPENDIX B

Physical Activity Readiness Questionnaire

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Name _____ Date _____

Purpose: For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable.

Directions: Please read each question below. Answer each question with a yes or no. If the answer "yes" to any question, please explain fully the extent of the problem.

yes	no	1.	Has your doctor ever said you have heart trouble?
yes	no	2.	Do you frequently suffer from pains in your chest?
yes	no	3	Do you often feel faint or have spells of severe dizziness?
yes	no	4	Has a doctor ever said your blood pressure was too high?
yes	no	5.	Has a doctor ever told you that you have bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
yes	no	6.	Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
yes	no	7.	Are you over age 65 and not accustomed to vigorous exercise?

APPENDIX C

Personal History Questionnaire

Self-Administered Pre-exercise Medical History Form

Name _____ Date _____

PAST HISTORY

(Have you ever bad?)	Yes	No	Explain:
Rheumatic fever	( )	( )	
Heart murmur	( )	( )	
High blood pressure	( )	( )	
Any heart trouble	( )	( )	
Disease of arteries	( )	( )	
Varicose veins	( )	( )	
Lung disease	( )	( )	
Injuries to back	( )	( )	
Epilepsy	( )	( )	

Operations(explain)_____
_____
_____

Other
_____

PRESENT SYMPTOMS REVIEW

(Have you ever bad?)	Yes	No	Explain:
Chest pain	( )	( )	
Chest pain when exercising or under emotional stress	( )	( )	
Shortness of breath	( )	( )	
Asthma	( )	( )	
Irregular or rapid heartbeat	( )	( )	
Cough on exertion	( )	( )	
Fainting or dizziness	( )	( )	
Weakness or numbness of an arm or leg	( )	( )	
Balance problem while walking or standing	( )	( )	
Coughing of blood	( )	( )	
Back pain	( )	( )	
Swollen, stiff or painful joints	( )	( )	

Do you regularly awaken at night to urinate?	( )	( )
Allergies to drugs	( )	( )

Other_____
_____

FAMILY HISTORY

(Have any of your relatives bad?)	Yes	No	Explain:
Heart attack	( )	( )	
High blood pressure	( )	( )	
Too much cholesterol	( )	( )	
Diabetes	( )	( )	
Congenital heart disease	( )	( )	
Heart operations	( )	( )	

Other_____
_____

PERSONAL QUESTIONNAIRE

Please take a few minutes to complete this questionnaire. Your identity will remain confidential.

A. PERSONAL INFORMATION AND HISTORY

1. Name

   Street

   City State Zip

   Phone

2. Date of birth

3. Weight

4. Height

5. Do you take ADHD medication? Yes / no

6. Do you take anti-depressants or anti-anxiety medications? Yes / no

7. Do you take vitamin supplements? Yes / no

8. Do you drink alcoholic beverages? Yes / no

   If yes, how many drinks per week?

Beer (12oz) _____

Wine (5 oz glass) _____

Hard Liquor (1 .5 oz) _____

9. Do you consume caffeine? Yes / no Did you consume caffeine today? Yes / no If yes, how long prior to this session did you consume caffeine? _____

B. RISK FACTORS

1. Smoking Yes No

Do you smoke? ( ) ( )

Cigarettes ( ) ( ) How many? How many years?

Cigar ( ) ( ) How many? How many years?

Pipe ( ) ( ) How many times/day? _____ Years?

How old were you when you started?_____

If you stopped, how old were you? How long did you smoke?

C. EXERCISE

Do you engage recreational sports or physical activity? _____ What? _____

How often? _____

How far do you think you walk each day? _____

Is your occupation: Sedentary ( ) Moderately Active ( ) Active ( ) Heavy work ( )

Do you have discomfort, shortness of breath, or pain with moderate exercise?

If yes explain: _____

Were you a high school or college athlete? _____ Explain: _____

Have you ever had an exercise stress test? Yes/ No

if yes, when? _____ Any problems? ___

APPENDIX D

Informed Consent

INFORMED CONSENT

1. Study Title: Exercise Intensity Interaction with Motor Memory.

2. Performance Site: Pioneer Hall Exercise Physiology Laboratory (PH 112)
Texas Woman's University
Denton, TX 76204

3. Investigators: The following investigators are available for questions about this study,

4. M-F, 8:00 a.m.-4:30 p.m.

Principal Investigator: **Kristen Codish, B.S.** **940.898.2672**
Advisor: **Kevin Becker, PhD** **940.898.2592**

4. Purpose of the Study: In this study, we will examine the effect of two different intensities of exercise on the retention of motor memory.

5. You will be randomly assigned into one of three groups. Group one will not exercise after the acquisition trials. Group two will exercise at low intensity after the acquisition trials. Group three will exercise at high intensity after the acquisition trials. An equal number of males and females will be assigned to each group.

6. Total Time Commitment: You will be asked to commit approximately 2.5 hours of your time for this study over 9 days (4 days of actual testing).

7. Study Procedures:
Visit 1
You will report to the Exercise Physiology Laboratory (Pioneer Hall 112) for initial intake and to complete the physical activity readiness questionnaire, medical history, and informed consent forms. You will also fill out a handedness assessment questionnaire. You will be briefed on the procedures of doing a maximal oxygen consumption ($V_{O_{2max}}$) test on an arm cycle ergometer. A female or male investigator will be available if you feel more comfortable being prepped by the same gender. A small private room will be made available for preparation if increased privacy is needed. The investigator will clean and abrade the skin and place ten electrodes on your chest and torso to record a 12-lead

electrocardiograph (ECG). This will track heart rate (HR) and cardiac rhythm during rest and exercise portions of the test. The investigator will then have you sit comfortably in a chair and assist you in securing a mask tightly to your face. You will then be hooked up to a metabolic cart and stress test ECG recorder to collect 5 minutes of resting HR, V_{O_2} and respiration exchange ratio (RER) measurements. Blood pressure (BP) will be measured during this time as well. The test will occur if normal resting values are recorded during this collection period. After 5 minutes, you will sit in front of the arm ergometer (Monark Exercise, 881E, Vansbro, Sweden) while the investigator adjusts the desk height and grip position to fit properly. The crank axle will be adjusted to shoulder height. The arms have a slight flexion at the elbow joint when fully extended horizontally. Feet are placed flat on the floor and no waist or torso restraints are utilized. The V_{O_2}max test will begin with the first crank stroke. A crank rate of 70 rpm will be held while workload starts out at 30W. For each stage, HR will be collected every min, V_{O_2}, V_{CO_2}, V_E, and RER will be captured continuously. Blood lactate will be evaluated at 1:45 min through an earlobe prick capillary sample created by a disposal lancet (Accu-check Safe-T-Pro Plus, Roche Diagnostics, Switzerland). The blood will be evaluated with a portable lactate analyzer for venous blood lactate concentration (Lactate Scout Pro, Sports Resource Group, Hawthorne, NY). Rate of perceived exertion will be requested at 2:00 min into each stage before progressing to the next stage with a 20W increase in workload (i.e. progress test every 2 min with workload increase of 20W). The same data collection steps above will be repeated for each two min stage. Verbal encouragement will be given throughout the test for you to go as long as possible and to achieve maximal effort. The test continues until exhaustion is reached, or you can no longer hold the pedal rate above 55rpm. A cool down session will be recommended. Final blood lactate will be collected at five min post exercise. The total time commitment on this day is approximately 60 minutes.

Prior to Visit 2, you will be randomly assigned to either a no exercise group, a low-intensity exercise group (30-40% $V_{O_{2max}}$), or a high-intensity exercise group (80-85% $V_{O_{2max}}$).

Visit 2 (minimally 48 hours after VO_{2max} test):
Visit 2 will consist of a motor skill acquisition phase and an exercise/rest phase. For the fine motor skill acquisition phase, you will be seated at a work station and will practice a pursuit rotor tracking task on a Windows Surface Pro (tablet computer) on the top of the desk. This task involves using a stylus to track a target travelling around a circular path at a rate of 30 degrees per second on the touch screen. The investigator will give verbal instructions on how to complete the pursuit rotor task. The acquisition period will consist of three blocks of five trials

(15 trials total). Each trial will be 30 seconds long, with 15 seconds rest in between trials. 11.25 min total will be spent on this fine motor acquisition period.

Dynamically balancing on a stabilometer (Lafayette Instruments Company, 16030, Lafayette, IN) will be used as the novel gross motor skill to measure the accumulation of motor memory. The stabilometer is a wooden platform lifted from the ground by two free rotating center located axis points. Specific computerized recordings of spatial-temporal parameters will be outputted from the device every second you are in balance. You will receive one initial balancing trial with verbal directions for familiarization to the task. The acquisition period will consist of three blocks of five trials resulting in 15 total trials. Each trial will be 30 s long with a 15 s rest period. 11.25 min total will be spent on this gross motor acquisition period. The motor tasks will be performed in random order to accommodate for any learning cross-over and fatigue effect between tasks. You will then proceed to the exercise/rest phase of the visit.

At the start of the exercise/rest phase, the primary investigator will assist you with putting on a heart rate monitor. A male or female investigator will be present to assist if same gender is requested. If you are in one of the two exercise conditions, you will then be seated at the arm cycle ergometer. If in the no exercise group, you will lay in a supine position in a bed. The no exercise group will remain in this position for 20 minutes. If in the low intensity exercise group, you will cycle at 70 rpm for 20 minutes with the workload set at 30-40% $V_{O_{2max}}$. The workload will be determined by correlating V_{O_2} with power from day one testing and determining % $V_{O_{2max}}$ desired for the exercise session. If in the high intensity group, you will cycle at 70 rpms for 3 minutes at low intensity (30-40% $V_{O_{2max}}$) then do 3 sets of the following intervals in a row: 3 minutes at high intensity (80-85% $V_{O_{2max}}$) + 2 minutes at low intensity (30-40% $V_{O_{2max}}$). A cool down period of 2 minutes at low intensity (30-40% $V_{O_{2max}}$) will finish off the treatment. For all groups, blood lactate will be evaluated with an earlobe prick at minutes 6, 11, 16 and 20 since lactate has previously been correlated with motor memory. HR will be recorded at every minute throughout the test.

Once you have completed the exercise/rest session, you will be asked to drink 8oz of water to replenish any potential fluid lost during the previous time period. You will not be able to engage in exercise outside of the experiment until after Visit 3. Total time commitment on this day is approximately 60 minutes.

Visit 3 (24 hours after completion of the acquisition trial):
Visit 3 will consist of a retention and transfer test to assess the amount of motor memory retained. A sleep questionnaire will be filled out at this time to assess the

length and quality of sleep had during this in between period. Prior to each test, the investigator will repeat the same verbal instructions given prior to the acquisition trials. Just as before, you will follow a target on the touch screen with a stylus in your dominant hand and balance dynamically on a stabilometer. The retention test will consist of five trials that are identical to the conditions during acquisition. The transfer test will consist of five trials of the same task, but with varying the speed of rotation in the tracking task and closing the eyes in the balance task. This test is designed to assess the stability and the adaptability of the motor memory. Each test will take 4.5 min each (5 trials x 30 sec motor task with 15 sec rest in between). The participant will spend approximately 15 min total in the lab for this session.

Visit 4 (7 days after completion of the acquisition trial):
Experimental conditions on this visit will be identical to visit 3. Again, the investigator will give verbal instructions on how to complete the pursuit rotor task. Just as before, you will follow a target on the touch screen with a stylus in your dominant hand and balance dynamically on a stabilometer. The retention test will consist of five trials that are identical to the conditions during acquisition. The transfer test will consist of five trials of the same task, but with varying the speed of rotation in the tracking task and closing the eyes in the balance task. Each test will take 4.5 min each (5 trials x 30 sec motor task with 15 sec rest in between). Total time spent will be approximately 15 min in the lab for this session.

8. Benefits: You will receive the results from the VO_{2max} test. If interested, you will be sent information about the study results.

9. Risks/Discomforts:

RISK	STEPS TO MINIMIZE RISK
Abnormal Blood Pressure	A pre-screening of blood pressure and medical history will be done before any participation in physical activity. If abnormal prior to test, the student will not be allowed to participate. According to the American College of Sports Medicine guidelines for exercise testing, blood pressures will be monitored during the maximal cycle test and exercise sessions. If blood pressure exceeds 260/115 mm Hg, systolic blood pressure falls more than 20 mm Hg, or signs of lightheadedness develop, the test will be terminated.
RISK	STEPS TO MINIMIZE RISK
Muscle Fatigue or Soreness	All participants will be continuously monitored for signs of muscular fatigue. If the participant does not appear capable of maintaining adequate coordination, testing will be terminated. To minimize the risk of muscle soreness, participants will be asked to stretch prior to and following all exercise sessions.
RISK	STEPS TO MINIMIZE RISK
Discomfort and Fatigue	Discomfort and fatigue may occur during the testing and exercise bouts. To ensure safety, trained professionals will be on hand to monitor the participant's heart rate and discomfort during these sessions. To alleviate possible discomfort, the participant will be asked for any uneasiness during the exercise period and every effort will be made to help the participant relax. The participant may also dismiss themselves from the study at any time due to discomfort.

RISK	STEPS TO MINIMIZE RISK
Fainting	Lightheadedness will be monitored for during activity. Participants will be seated in a comfortable stable chair during testing and on a cycle during exercise. Trained professionals will be monitoring the participants during all sessions. If the participant feels nauseous or faint, the participant will be encouraged to perform cool-down exercises. The participant will also be asked to lie down on the floor with feet elevated to alleviate these symptoms.
RISK	STEPS TO MINIMIZE RISK
Bruising	The risk of bruising resulting from the earlobe prick is minimal due to this procedure being performed by trained personnel. Universal precautions will be used during all earlobe prick procedures. To minimize bruising, pressure will be applied to the site for approximately fifteen seconds after each blood sampling.
RISK	STEPS TO MINIMIZE RISK
Loss of Confidentiality	Confidentiality will be protected to the extent that is allowed by law. It is possible that there might be a loss of participant confidentiality in emails, other internet communications and data stored offline. There is a potential risk of loss of confidentiality in all email, downloading, and internet transactions. Persons not associated with the study will have no access to the folders (soft or hard copies).

RISK	STEPS TO MINIMIZE RISK
Skin irritation due to ECG preparation	The surface of the chest will be prepared by roughing the skin in 10 specified areas with a piece of gauze and alcohol in order to optimize adhesion and conduction of the electrodes. The preparation for the ECG may cause slight discomfort in the areas of electrode placement, which may sting slightly, similar to a rug burn, but the discomfort should subside within two days.
RISK	STEPS TO MINIMIZE RISK
Heart attack, stroke and death	Serious risks like heart attack, stroke, and death are possible, however these risks are extremely rare during submaximal exercise intensities. All technicians will be certified in CPR and AED (automated external defibrillators). If the participant is at high risk of these serious cardiovascular events, the participant will not be admitted into the study. Signs and symptoms for high risk include, but are not limited to ECG abnormalities; pain or discomfort in the chest, neck, jaw, arms, or other areas that may result from ischemia; shortness of breath at rest or with mild exertion; dizziness or loss of consciousness; dyspnea (abnormally uncomfortable awareness of breathing); ankle edema; palpitations or tachycardia (forceful or rapid beating of heart); known heart murmur; or unusual fatigue or shortness of breath with usual activities. If it is suspected that serious risks are occurring, emergency medical help will be called immediately. Every effort will be made to minimize the risks inherent to exercise through preliminary examination and observations during testing by trained personnel according to the American College of Sports Medicine guidelines for testing procedures. In addition, an AED is available in the exercise physiology laboratory (PH 116).

RISK	STEPS TO MINIMIZE RISK
Infection	The risk of infection resulting from blood draws is minimal due to this procedure being performed by trained personnel. Universal precautions will be used during all blood draw procedures. Sites for blood draws will be cleaned with alcohol immediately prior to each earlobe prick. Each new lancet that is opened will be disposed of in biohazard boxes immediately after use. Additionally, oral infection resulting from breathing through a mouthpiece is minimal. All mouthpieces and nose clips will be sterilized prior to use and handled with gloves.
RISK	STEPS TO MINIMIZE RISK
Latex allergy	The investigator will wear gloves during all exercise testing. Prior to each test, the participant will be asked if he/she is allergic to latex. If the investigator is informed that the participant is allergic to latex, another type of glove will be used.
RISK	STEPS TO MINIMIZE RISK
Mask discomfort	During procedures that require the collection of gases, the participant will be expected to wear and breathe through a mask. The mask may be uncomfortable. To minimize discomfort, proper sizing of the mask will be made for each participant. The participant will be informed the mask can be removed at any time the discomfort exceeds an individually determined acceptable level.

RISK	STEPS TO MINIMIZE RISK
Embarrassment	During the ECG electrode placement, and measurement of body composition, height and weight the participant may feel embarrassed. To minimize embarrassment, participants will have the option to have measurements taken by a male or female research team member. Additionally, to ensure privacy ECG preparations, height and weight measurements will be conducted in a small private room located in the exercise physiology laboratory (PH 112).

In addition to the risks listed above, you may experience a previously unknown risk or side effect.

10. Injury/Illness: The researchers will try to prevent any problem that could happen because of this research. You should let the researchers know at once if there is a problem and they will help you. However, TWU does not provide medical services or financial assistance for injuries that might happen because you are taking part in this research.

11. Right to Refuse: You may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which you might otherwise be entitled.

12. Privacy: Your identity will remain confidential unless disclosure is required by law. In other words, data will be kept confidential unless release is legally compelled. All data collected will be handled only by the investigators and kept in a secure location. Results of the study may be published using group means only and names or identifying information will not be included in the publication. Five years after the completion of the study, all information with personal identifiers will be shredded.

13. Financial Information: There is no cost to you, nor is there any compensation for participating in the study.

14. You will be given a copy of this signed and dated consent form to keep. If you have any questions about the research study you should ask the researchers; their phone numbers are at the top of this form. If you have questions about your rights as a participant in this research or the way this study has been conducted, you may contact the Texas Woman's University Office of Research and Sponsored Programs at 940-898-3378 or via e-mail at IRB@twu.edu.

15. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have any questions about subjects' rights or other concerns, I can contact the Institutional Review Board at irb@twu.edu. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

_____ _____
Participant's Signature Date

*If you would like to know the results of this study tell us where you want them to be sent:

Email: _____
or
Address:

_____

_____

APPENDIX E

Handedness Assessment

Handedness Assessment

Which hand would you self-describe as your dominant hand?
____ Strongly Right _____Strongly Left _____No Preference Between Right or Left

Please circle below which hand you ordinarily use for each activity.
With which hand do you:

Draw?	1. Left	2. Right	3. Either
Write?	1. Left	2. Right	3. Either
Use a bottle opener?	1. Left	2. Right	3. Either
Throw a snowball to hit a tree?	1. Left	2. Right	3. Either
Use a hammer?	1. Left	2. Right	3. Either
Use a toothbrush?	1. Left	2. Right	3. Either
Use a screwdriver?	1. Left	2. Right	3. Either
Use an eraser on paper?	1. Left	2. Right	3. Either
Use a tennis racquet?	1. Left	2. Right	3. Either
Use scissors?	1. Left	2. Right	3. Either
Hold a match when striking it?	1. Left	2. Right	3. Either
Stir a can of paint?	1. Left	2. Right	3. Either
On which shoulder do you rest a bat before swinging?	1. Left	2. Right	3. Either

Chapman & Chapman (1987). The measurement of handedness. *Brain and Cognition. 6*, 175-183.

Participant ID _____

APPENDIX F

Complete Data Set

Subject	DominantHand	Weight	Height	BMI	Age	GPA	Alcohol	PhysicallyActive	Occupation	SchoolAthlete	BPRest
TH170105	Right	170.2	88.6	29.8	22	3.27	2	1	1	2	139/66
TH170106	Right	182.9	90.9	27.1	22	3.4	2	1	2	1	138/68
TH170107	Right	154.9	65.5	27.2	24	2.8	2	2	1	1	112/60
TH170111	Right	162.6	65.9	26.6	23	3.2	1	1	2	1	104/60
TH170115	Right	170.2	81.8	28.2	21	3.1	2	2	1	2	114/70
TH170119	Right	162.6	81.8	30	37	4	1	2	2	1	120/80
TH170121	Right	177	74	22.7	25	3.95	1	1	2	1	122/78
TH170123	Right	130	64	22.3	22	3.4	1	1	3	1	114/58
TH170125	Right	135	64	23.2	21	3.2	1	1	2	2	122/76
TH170129	Right	174	71	24.4	29	2.98	1	1	3	1	122/76
TH170133	Left	141.5	69	21	30	3.4	2	1	3	2	132/78
TH170103	Right	190.5	84.5	23.2	30	3.75	1	1	2	2	98/62
TH170104	Right	177.8	63.6	20.1	22	3.4	1	1	3	1	104/62
TH170109	Right	105	63	18.6	25	2.6	1	1	2	1	118/70
TH170110	Right	154.9	57.3	23.8	25	2	1	1	1	1	110/66
TH170112	Right	180.3	79.5	24.4	27	2.8	1	1	2	1	122/88
TH170118	Right	177.8	88.6	26.5	27	3.2	1	1	2	1	132/70
TH170122	Right	135	66	21.8	21	3.7	1	1	1	2	108/64
TH170124	Right	110	62	20.1	22	3.4	1	2	3	2	114/69
TH170127	Right	145	66	23.4	23	3.3	1	1	1	2	124/76
TH170131	Right	125	63	21.5	25	2.7	2	1	2	1	108/58
TH170134	Right	133	62	24.3	21	3.2	2	1	3	2	118/80
TH170101	Right	176	76	24.5	37	3.8	1	1	2	1	102/64
TH170102	Right	175.3	80.9	26.1	34	3.6	1	1	1	1	124/84
TH170113	Right	162.6	62.7	24.1	23	3	2	1	3	1	106/64
TH170114	Left	170.2	59.1	20.4	24	3.2	2	1		1	110/70
TH170116	Right	165.1	59.1	21.1	21	3.01	1	2	1	1	114/60
TH170120	Right	160	81.8	31.9	27	2.45	1	1	2	1	98/62
TH170126	Right	119	66	19.2	21	3.8	2	1	3	2	116/78
TH170128	Right	145	63	25.7	22	3.2	1	1	2	1	118/70
TH170130	Right	168	71	23.4	23	3.6	2	1	3	1	114/58
TH170132	Right	138	67	21.6	23	3.5	2	1	3	1	112/62

Subject	Highest Inter Lactate	Highest Inter HR	Inter RPE	Pre Sleep Quantity	Pre Sleep Quality	Pre Feeling Rested
TH170105	1.2	73	6	3	5	1
TH170106	1	71	6	8	4	5
TH170107	1.7	93	6	5	5	6
TH170111	2.5	89	6	9	5	4
TH170115	2.1	105	6	5	5	5
TH170119	1.5	82	6	8	6	7
TH170121	1.7	84	6	5	5	5
TH170123	0.9	66	6	5	6	6
TH170125	1.9	91	6	6	6	5
TH170129	2.4	101	6	8	6	6
TH170133	1.2	88	6	7	6	4
TH170103	2.6	96	12	5	4	6
TH170104	2.2	106	11	9	5	6
TH170109	4	146	11	7	5	5
TH170110	1.8	115	10	5	5	4
TH170112	2.1	87	11	7	4	4
TH170118	2.9	99	8	6	5	5
TH170122	2.2	106	9	6	4	3
TH170124	2.4	121	10	5	4	4
TH170127	2.1	104	10	6	5	5
TH170131	2.3	115	11	5	3	1
TH170134	2.7	115	7	5	5	5
TH170101	10.9	183	15	7	5	6
TH170102	3.8	129	14	7	5	5
TH170113	3.9	146	15	3	4	1
TH170114	6.3	169	15	4	5	5
TH170116	6.2	172	17	11	6	6
TH170120	8.3	167	13	7	6	5
TH170126	5.3	163	13	3	2	2
TH170128	5.8	180	16	7	6	6
TH170130	3.7	147	13	5	7	4
TH170132	3.7	132	18	6	5	5

Subject	Post Sleep Quantity	Post Sleep Quality	Post Feeling Rested	PRAcqMeanTOT1	PRAcqMeanTOT2
TH170105	6	5	4	8993.6	8341.8
TH170106	8	4	5	11405.4	13030.4
TH170107	7	7	5	11280.4	12253.8
TH170111	9	6	4	8115	8696.8
TH170115	5	5	5	9316.2	10820.8
TH170119	5	5	6	11380.4	13107.2
TH170121	5	6	6	8469.2	11425.2
TH170123	8	7	6	8927.2	11388.2
TH170125	8	6	6	10671.6	12872.2
TH170129	7	6	6	9274.8	9737.2
TH170133	7	5	6	8941.8	11377.4
TH170103	3	2	4	12862.4	13836.6
TH170104	5	3	4	8014.2	11090
TH170109	8	6	6	12417.6	15227.4
TH170110	6	4	5	8467.2	10543.8
TH170112	7	5	5	5203.4	5469
TH170118	7	6	6	2727	3059
TH170122	7	6	4	6451.8	6703.8
TH170124	6	4	4	7575	10087.4
TH170127	7	5	5	10013.2	11627.2
TH170131	1	3	1	2691.2	4918.2
TH170134	5	5	6	9988.6	12305.4
TH170101	6	5	5	11217.2	12850.6
TH170102	6	6	6	16079.8	17566.8
TH170113	1	3	1	11590	14150.2
TH170114	5	4	4	11612.6	15053.2
TH170116	9	5	5	3165.4	5080.6
TH170120	5	6	5	11193.6	13625.4
TH170126	12	7	7	9317.8	10530.6
TH170128	10	7	7	8451.8	12303.6
TH170130	6	7	4	10773.2	13213
TH170132	8	6	5	9481.6	12124.4

Subject	PRAcqMeanTOT3	PRRetMeanTOT1	PRTranMeanTOT1	PRRetMeanTOT7	PRTranMeanTOT7
TH170105	11295.8	10595.8	2977	11443.4	2691.4
TH170106	12640.8	13798	4910.4	13695.6	6886
TH170107	12197.2	13724	2871.6	13618.8	4281.4
TH170111	11212.8	14243	6879	12902.2	6503.4
TH170115	9378.4	11550.8	1571.8	13922.6	4120.8
TH170119	13443.4	14981.6	6956.4	15210.8	7811.4
TH170121	13196.2	13051.6	5303.2	15202	5437.6
TH170123	12459.8	14962.2	6416.8	14456.2	6950.4
TH170125	12866.2	16122.4	5972.2	15428.8	8740.6
TH170129	10355.8	14766.4	4729.2	15358.2	7986.4
TH170133	11963.6	12338.2	3978.4	12553.8	3579.2
TH170103	14800.8	16115.2	6740.2	16437	9163.4
TH170104	11819	14054.2	5089.2	15037.6	4887
TH170109	14782.8	16565.4	4492.4	16665	5897.2
TH170110	8271	11012.4	139.2	12131	4104.4
TH170112	5365.8	9910.8	1667.2	9500.8	2511
TH170118	3467.2	5551.8	731	5438	499.8
TH170122	12577.8	13009.6	3674.4	12642.6	3988.6
TH170124	10144.4	11560.8	3838.6	12249.6	5855.4
TH170127	12113.8	13297	4448.8	15297.2	6215
TH170131	6573.8	8618.8	1613.4	8704.4	2157.6
TH170134	9988.6	14151	3311.2	14332.2	4251
TH170101	14099.8	12704.8	5666.6	14560.2	4621.6
TH170102	17105.2	17779.2	5916.4	18155.4	8775.4
TH170113	14311.2	15063.8	7108	16584.8	8897
TH170114	15290.6	16329.4	5764.4	16311	5348.2
TH170116	5083.2	10292.8	820.4	9933.2	1399.6
TH170120	13063.4	13539	6465.4	13565.4	8140.8
TH170126	13156.8	14828	3929.2	14058.2	5807.8
TH170128	10668	14351	3113.6	13238.6	3760.2
TH170130	13955.8	15053.2	4648.8	13818.4	8189.6
TH170132	13471	15477.4	4994.2	14682.2	4955

Subject	PRAcqMeanErr1	PRAcqMeanErr2	PRAcqMeanErr3	PRRetMeanErr1	PRTranMeanErr1	PRRetMeanErr7
TH170105	31.5835	30.23288	25.05058	26.0896	58.97544	24.7207
TH170106	28.1541	23.13572	24.28334	23.00538	56.4637	22.0685
TH170107	27.89658	25.3487	24.3903	22.1382	63.21442	22.89872
TH170111	33.97622	31.51814	26.77362	21.20432	41.231	23.1468
TH170115	33.28652	32.6501	39.28676	28.75974	74.13076	24.0149
TH170119	27.19598	21.87546	21.75302	19.07138	36.85804	18.61546
TH170121	33.05808	25.41078	22.30174	22.2429	44.5557	18.74258
TH170123	34.74632	25.15906	23.29316	19.90536	43.43132	19.8716
TH170125	29.9529	21.90104	22.21006	17.17568	40.51506	18.51156
TH170129	31.38448	28.41966	27.22238	20.154	49.46826	25.96696
TH170133	33.45006	24.5911	23.82686	24.15708	54.94112	23.46322
TH170103	23.98054	20.64338	19.3233	17.45564	37.99528	17.28894
TH170104	41.57606	25.94308	24.69532	20.26194	44.23566	18.89552
TH170109	25.85146	18.908	19.97234	16.87234	51.57302	16.15426
TH170110	34.82532	25.8083	28.98032	25.46734	82.26006	22.7912
TH170112	47.91394	45.8737	55.33646	35.1842	84.98108	45.8468
TH170118	55.30188	55.08846	55.27828	47.92232	112.79758	42.7367
TH170122	35.92408	33.6507	22.9448	21.96906	53.86592	22.87896
TH170124	36.60958	28.69884	27.46578	24.737	60.60178	24.25296
TH170127	29.3567	24.21326	23.94648	21.43018	44.2765	18.8428
TH170131	63.30626	40.89878	35.21546	30.54138	80.65612	30.70954
TH170134	28.925	23.95254	23.1481	21.43454	56.6603	20.72766
TH170101	42.63598	22.85752	20.15684	23.27678	46.7292	20.38822
TH170102	18.21396	15.23686	16.44754	15.24118	40.70446	14.08612
TH170113	47.82754	20.1047	19.52516	21.0501	38.5093	16.19108
TH170114	39.82686	18.69686	18.32754	17.30584	43.56356	17.80276
TH170116	54.22994	41.16204	39.85658	26.82072	96.1968	28.15334
TH170120	30.31398	21.91388	21.9866	20.73462	40.89076	21.81584
TH170126	31.5528	25.69302	21.50944	19.31506	53.80548	20.9309
TH170128	41.57448	23.63486	25.3393	20.41162	57.69284	21.28438
TH170130	27.65284	21.9781	20.52842	18.2242	52.77138	25.04038
TH170132	52.08834	23.1522	21.69364	22.23456	45.64602	19.75082

Subject	PRTranMeanErr7	SMAcqMeanTIB1	SMAcqMeanTIB2	SMAcqMeanTIB3	SMRetMeanTIB1	SMRetMeanTIB7
TH170105	58.04698	3.8932	7.1408	2.927	4.2472	4.8252
TH170106	41.92764	2.3332	7.4118	5.167	6.0402	5.993
TH170107	49.15372	1.395	8.57	3.0188	3.733	3.311
TH170111	43.60154	4.0822	5.3634	6.01	4.879	5.7196
TH170115	52.62172	1.934	9.0704	4.015	3.3728	3.5392
TH170119	34.84524	2.4482	7.2014	4.0918	4.6774	6.3584
TH170121	41.52302	5.3412	7.0826	3.0582	5.829	5.8788
TH170123	36.85784	3.3816	7.5396	6.7704	7.95	8.2738
TH170125	31.22436	2.3646	7.1666	4.6918	6.2044	5.0748
TH170129	35.63814	3.534	6.1676	5.1638	8.2232	9.0488
TH170133	50.73718	2.5172	8.2244	5.327	7.9248	7.1134
TH170103	30.60486	4.3102	9.2222	7.4618	8.5854	7.5286
TH170104	41.57284	3.9046	6.04	6.1844	4.4638	5.5632
TH170109	38.2209	3.866	6.1384	9.2788	7.0796	6.9232
TH170110	47.41856	1.2094	10.301	3.6062	2.8318	3.2002
TH170112	64.69088	1.3592	6.7338	3.6202	3.2982	4.6406
TH170118	105.32268	3.3944	5.9444	3.9886	4.5432	3.9378
TH170122	46.85926	2.2688	8.8744	6.3124	6.7734	6.7802
TH170124	45.67034	2.8038	6.9362	4.0162	5.053	6.2694
TH170127	38.72394	2.7408	7.006	4.4658	4.0416	4.8304
TH170131	69.97756	3.263	8.5424	4.2008	3.3856	5.0042
TH170134	48.6339	3.747	6.03	6.2288	8.483	9.2636
TH170101	47.74978	3.6146	7.6592	3.749	4.784	5.9666
TH170102	29.1788	4.7954	5.6958	6.0024	6.5444	8.1732
TH170113	31.99158	4.7954	5.6958	6.0024	5.819	8.5178
TH170114	43.40404	4.2126	7.1678	4.38	5.5714	6.1192
TH170116	82.42036	3.6174	6.0958	5.8628	6.6486	6.5472
TH170120	34.42554	3.3942	5.7406	4.2234	4.892	5.9152
TH170126	41.76258	1.8756	8.3368	2.2856	3.3254	3.322
TH170128	76.74098	4.1784	6.5984	7.7786	8.6294	7.6912
TH170130	36.58902	2.322	8.523	1.8338	3.3844	3.7886
TH170132	43.1125	9.4514	4.858	8.044	10.5754	7.22

Subject	HRRest	RERRest	VO2Rest	TimeFinish	PowerFinish	LactateFinish	HRFinish	LactatePost	BPPost	HRPost
TH170105	68	0.89	0.27	9:00	60	6.2	161	12.5	114/54	101
TH170106	51	0.94	0.37	17:00	100	7.4	160	10.7	148/78	99
TH170107	67	0.86	0.22	6:00	40	8.2	186	7	130/64	92
TH170111	88	0.93	0.29	8:00	50	7.7	195	8.1	98/56	108
TH170115	86	0.85	0.2	7:00	50	5.2	173	6.9	112/68	108
TH170119	84	0.87	0.33	8:00	50	5.3	169	7.5	114/80	90
TH170121	67	0.85	0.28	12:00	80	7.1	153	8	110/70	70
TH170123	64	0.8	0.29	8:00	60	10.5	181	10.5	110/58	102
TH170125	94	0.81	0.23	6:30	50	5.1	158	8.7	108/78	123
TH170129	70	0.97	0.31	8:00	60	10.6	167	7.8	114/70	88
TH170133	68	0.96	0.31	6:00	50	11.8	172	13.1	164/70	94
TH170103	59	0.83	0.24	9:00	100	5.1	144	9.2	124/80	79
TH170104	80	0.99	0.26	6:00	40	5.7	154	8.1	106/64	83
TH170109	69	0.84	0.21	4:00	30	3.3	170	8.1	116/58	101
TH170110	72	0.88	0.19	6:00	50	5.1	167	5.8	102/54	98
TH170112	60	0.98	0.19	14:00	80	11.1	171	12.3	94/70	88
TH170118	62	0.87	0.32	11:00	70	9.5	167	14.3	120/74	94
TH170122	79	0.83	0.26	6:00	50	7	184	9	98/48	108
TH170124	69	0.85	0.23	6:00	50	8.8	183	9.9	112/70	88
TH170127	76	0.92	0.27	10:00	70	14.1	176	11.6	112/60	109
TH170131	64	0.77	0.22	7:00	50	7.3	158	7.6	104/56	84
TH170134	97	0.8	0.36	6:00	50	7.4	179	10.2	112/66	103
TH170101	64	0.8	0.22	11:00	60	7.8	130	11.6	118/68	104
TH170102	55	0.92	0.23	16:00	90	6.2	176	10.1	128/80	88
TH170113	66	0.88	0.23	8:00	50	7.7	156	9.8	110/56	93
TH170114	76	0.82	0.24	7:00	50	5.3	153	5.3	108/70	84
TH170116	77	0.87	0.16	5:00	55	4.6	152	4	108/58	78
TH170120	64	0.72	0.18	8:00	60	7.5	148	9.2	92/52	97
TH170126	70	0.84	0.22	6:00	50	9.9	155	11.3	122/68	100
TH170128	74	0.97	0.28	6:00	50	9	153	9.5	118/66	96
TH170130	70	0.83	0.35	10:00	80	5.8	150	6.1	114/58	80
TH170132	82	0.82	0.26	9:00	60	6.1	154	8.8	102/56	102

Subject	VO2Max	Power35	Power85	Lactate>8?	AgeMax	HR>AgeMax?	Group	Start Testing	Ret Testing1	Ret Testing7
TH170105	19.6	21	51	Yes	198	No	1	1	2	1
TH170106	30.5	35	85	Yes	198	No	1	2	2	2
TH170107	17.9	14	34	No	196	No	1	1	1	1
TH170111	19.4	17.5	42.5	Yes	197	No	1	2	2	2
TH170115	14.2	17.5	42.5	No	199	No	1	1	1	2
TH170119	15.8	17.5	42.5	No	183	No	1	2	2	2
TH170121	27.1	28	68	Yes	195	No	1	1	2	2
TH170123	25.7	21	51	Yes	198	No	1	2	1	2
TH170125	21.1	17.5	42.5	Yes	199	No	1	1	1	2
TH170129	18.2	21	51	No	191	No	1	2	1	1
TH170133	15.6	17.5	42.5	Yes	190	No	1	1	2	2
TH170103	30.9	35	85	Yes	190	No	2	1	2	2
TH170104	18.7	14	34	Yes	198	No	2	2	1	1
TH170109	18.2	10.5	25.5	Yes	195	No	2	1	1	1
TH170110	15	17.5	42.5	No	195	No	2	1	2	1
TH170112	25.8	28	68	Yes	193	No	2	2	1	1
TH170118	15.5	24.5	59.5	Yes	193	No	2	2	2	2
TH170122	18.5	17.5	42.5	Yes	199	No	2	1	2	1
TH170124	23.9	17.5	42.5	Yes	198	No	2	2	2	1
TH170127	26.8	24.5	59.5	Yes	197	No	2	1	2	2
TH170131	21.7	17.5	42.5	No	195	No	2	2	2	1
TH170134	17	17.5	42.5	Yes	199	No	2	2	2	2
TH170101	17.9	21	51	Yes	183	No	3	1	1	1
TH170102	24.5	31.5	76.5	Yes	186	No	3	2	1	2
TH170113	26.1	17.5	42.5	Yes	197	No	3	2	1	2
TH170114	21.1	17.5	42.5	No	196	No	3	1	2	2
TH170116	11.4	19.25	46.75	No	199	No	3	1	2	1
TH170120	18.2	21	51	Yes	193	No	3	2	2	1
TH170126	27.3	17.5	42.5	Yes	199	No	3	1	1	2
TH170128	17.7	17.5	42.5	Yes	198	No	3	2	1	1
TH170130	25.7	28	68	No	197	No	3	1	2	1
TH170132	19	21	51	Yes	197	No	3	2	1	2

Subject	SMAcqMeanRMSE1	SMAcqMeanRMSE2	SMAcqMeanRMSE3	SMRet1MeanRMSE	SMRet7MeanRMSE
TH170105	9.898235955	9.403423672	10.18101714	9.424341501	8.49899682
TH170106	11.11529057	8.481392748	7.809289432	7.028823957	6.775129666
TH170107	12.59784478	11.74455035	10.3303012	10.10656241	9.882433612
TH170111	9.862892058	8.075711978	7.823484476	7.762229	8.188643117
TH170115	11.98163233	10.83045746	9.206893815	9.257413436	9.318072369
TH170119	11.119677	9.518212026	8.85275675	8.467771893	7.929682161
TH170121	8.695555241	7.978034919	8.783837085	8.235668212	7.742068244
TH170123	10.02933944	8.822844154	7.232796952	6.286218178	5.855781319
TH170125	10.50672147	9.846629141	8.791694205	6.891293544	8.210818576
TH170129	9.885050975	8.625488689	8.633078206	6.707495811	6.325420575
TH170133	11.03539495	9.368357415	7.856252249	6.164021558	6.831616946
TH170103	8.849493934	8.613509028	6.616882346	7.381177485	6.89126407
TH170104	9.742651218	8.106518338	7.55262245	8.000515792	6.808791477
TH170109	8.953919162	7.331180746	6.197123186	6.594291057	6.07932999
TH170110	12.56819479	11.73117649	10.46429132	11.08961769	10.8347603
TH170112	12.41271306	11.12992386	9.806266958	9.568241101	9.012922582
TH170118	10.44109621	9.133688223	9.169698009	9.184730904	9.074598567
TH170122	10.88633518	9.129619942	6.915788812	7.059376869	7.0460347
TH170124	10.68279987	10.04419218	9.516350005	8.615693002	7.479103103
TH170127	10.51393514	10.19797641	9.214516482	8.986662975	8.044378784
TH170131	10.33836674	9.805977202	9.50076056	9.432416393	9.187188448
TH170134	9.247754301	7.732273912	6.836608075	6.032527455	5.562140776
TH170101	9.72760812	9.784838079	9.084717485	8.139745561	7.530508697
TH170102	8.496216125	7.156016918	7.285494991	7.624167972	6.401081328
TH170113	8.496216125	7.156016918	7.285494991	7.447915794	6.174002018
TH170114	9.526116334	7.848507527	8.696907624	7.304323068	7.548589163
TH170116	10.33813398	7.584293579	7.591205151	6.509026677	6.579066992
TH170120	9.729770237	8.781971835	8.754573882	8.349811447	7.566273506
TH170126	11.99533639	11.4406785	10.85267865	10.62571897	9.413255138
TH170128	9.295291407	8.074183149	6.424671873	6.322952405	6.176598755
TH170130	11.2517018	10.56486261	11.62865074	10.15772029	10.44093212
TH170132	6.222246706	6.391075174	6.534574109	5.289444138	6.204426944