

HOW VARYING LEVELS OF ACUTE EXERCISE  
INFLUENCE COGNITIVE FUNCTIONS

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HOW VARYING LEVELS OF ACUTE EXERCISE  
INFLUENCE COGNITIVE FUNCTIONS

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## Abstract

Previous studies have demonstrated cognitive benefits associated with memory following acute bouts of aerobic exercise. Associated with its effects on memory, aerobic exercise has been shown to inhibit the progression of cognitive deterioration associated with aging as well as increase the regenerative capability of the brain's neural network. Within this study, the effects of three levels of physical exertion on long-term memory are compared to one another by asking 30 participants to undergo three hour-long sessions. Each session utilized one of the following 13 minute conditions: watch a slideshow using PowerPoint (sedentary); maintain 55% of their maximum heart on a treadmill (moderate); or maintain 75% of their maximum heart rate on a treadmill (heavy). We then asked the participant to study a 30-word list of English nouns, which they would attempt to recall 10 minutes after studying. The participants were asked how likely, on a scale of 0 to 100, they were to remember each individual word, which was used to assess the participants' judgment of learning (JOL). It was hypothesized that the recall scores would be significantly higher in the moderate session when compared to their scores in the sedentary session. The heavy session was adopted in order to see if there was a potential threshold to the positive effects that exercise could have on cognition. The results of the experiment confirmed our initial hypothesis, revealing that the average of the recall scores in the moderate session ( $M = 44.0\%$ ) were in fact significantly higher when compared to the sedentary session ( $M = 35.8\%$ ),  $t(26) = 2.79$ ,  $p < .05$ . Along with this, the heavy condition ( $M = 42.1\%$ ) recall scores, while slightly

lower than the moderate session, remained significantly higher than the scores within the sedentary session,  $t(26) = 3.02, p < .05$ . Pertaining to the participants' understanding of their own memory retention, JOL scores reflected a similar trend as recall scores with them being significantly higher in both the moderate ( $M = 56.5\%$ ) and heavy session ( $M = 56.5$ ) when compared to the sedentary session ( $M = 47.9\%$ ),  $t(29) = -2.093, p < .05$ , and  $t(29) = -2.381, p < .05$ , respectively. This reveals that individuals had an increase in confidence of recalling the list of words within the moderate and heavy sessions.

## Introduction

Human cognitive functions and how they relate to individuals' state of being have been an enduring topic within the scientific community. One such state of being that is a relatively new interest in this relationship is physiological arousal produced by exercise. Within a review of studies, Brisswalter, Collardeau and René (2002) show that certain methods of exercise are capable of improving individuals' cognitive performance. In their analysis of bouts of exercises, the optimal zone for improvement of cognitive performance was shown to be directly related to the physical fitness of the individual. In studies utilizing a method that assesses maximal oxygen intake ( $VO_{2max}$ ), less physically fit individuals had an optimal cognitive performance increase when they exercised at 40-60% of  $VO_{2max}$ . Optimal cognitive performance occurs at a higher  $VO_{2max}$  range for those individuals who are more fit. These "optimal zones" are found to occur alongside the presence of certain biological factors, specifically the adrenaline threshold, which is indicated by a spike in the concentration of adrenaline in the blood. This threshold is often accompanied by enhanced respiratory and heart rate as well as increased perspiration.

Further detailing the methods of physiological arousal manipulation, Lambourne and Tomporowski (2010) analyzed a compilation of studies on the effects of physical exertion on cognition in adults. The studies chosen for analysis either utilized a treadmill or a stationary bicycle for a means of physical exertion. The researchers' intent was to compare the differences that could be linked to the machines used for exercise. Another focus was analyzing the time in which the participants' cognitive performance was tested

in relation to when the participants exercised, with the thought that the time of testing may affect the assessment of cognitive performance. For this analysis, the studies were divided into two groups, those that tested participants during the exercise and those that tested participants after the completion of the exercise. For both types of exercise, participants showed impairment of cognitive performance while exercising when measured after a 20-minute mark. This impairment persisted after the 20-minute mark for those participants on a treadmill. However, the participants exercising on a bicycle showed improvement when measured while exercising after the 20-minute mark. For those studies that tested participants after the exercise had concluded, both the cycling and treadmill studies revealed an improvement in assessed cognitive functions. However, those studies utilizing the treadmill revealed less cognitive improvement post-exercise than those utilizing a stationary bicycle. The difference within the cognitive performance scores during exercise was attributed to the amount of mental focus needed for each type of exercise. Running on a treadmill requires more conscious effort than cycling in place. This can be explained by the fact that, as a whole, your body remains stationary while cycling in place. In contrast, running on a treadmill requires a conscious effort to stay balanced as the entire weight of the body is shifted from one foot to the other. In turn, the amount of attention available during the cognitive assessments is lower while running on a treadmill. This study reveals the importance of knowing how certain types of exercise affect cognitive functions as well as the optimal time for testing.

While short bouts of exercise have been shown to improve cognitive functions, there may be a threshold at which the cognitive functions become negatively affected by exercise. Tomporowski (2003) analyzed 47 studies on acute exercise and cognition,

separating them into three groups for analysis: brief, maximal exercise; maximal and submaximal exercise protocols of short duration; submaximal protocols of relatively long duration. Within these groups, it was found that cognitive ability increased with exercise, so long as physiological reserves were not depleted. It was found that both cognition and information processing were impaired within conditions where participants became dehydrated due to running for a prolonged period of time. When not resulting in the depletion of nutritional reserves, exercise was found to have an overall positive relationship with memory, especially within the conditions that used acute bouts of moderately intense exercise. So much so that it was equated to the positive effects of psychostimulant drugs. Paralleling this increase in cognitive ability, participants' often reported a higher clarity of thought and capacity for concentration after aerobic exercise, revealing that a person's perception of their own cognition is also affected.

On the other side of the spectrum, the lack of exercise and physical activity often negatively influences a person's behavior, neurology and biology. Biddle and Assair (2011) reviewed four different reviews that covered multiple studies each, known as meta-analyses, resulting in an analysis of 24 studies involving children and chronic physical inactivity in relation to depression, anxiety/stress, self-esteem and cognitive functions. Results of the studies revealed a correlation between sedentary lifestyles and poor mental health in children. Also, the analysis showed that children with higher levels of physical activity within the studies had lower rates of depression.

A review of 29 studies was conducted by Smith et al. (2010) on the effects of aerobic exercise on multiple measurements of cognitive function. The age groups within this collection of studies spanned from young adults to the elderly. The methods used to

obtain a state of physiological arousal varied, but centered on mixed weight training and the use of a treadmill. The length of the exercise programs ranged from 8 to 72 weeks, with participants having exercise sessions once to five times a week. The length of each exercise session varied from 25 minutes to an hour and a half. The review of these studies revealed a moderate correlation between aerobic exercise and improvement within the participants' attention, memory and executive functions (such as problem solving and verbal reasoning), with mixed results in improvement on working memory (such as following directions to a task). These reviews reveal the evident relationship between levels of physiological arousal and cognitive functions as well as the negative effects of sedentary lifestyles on mental health.

The effects of exercise on cognitive performance have been further documented in lab animals. Aguiar et al. (2010) measured the effects of heavy exertion on the cognitive ability of rats. For 9 weeks, the rats performed chronic physical exercises consisting of 60-minute periods. These sessions were broken up into two 20-minute intervals and two 10-minute resting periods. In order to test the relationship between the physiological arousal and working memory, the researchers designed a repeated measures test by having the rats go through a maze multiple times. Before the rats underwent the maze task, they were primed by being placed in similar constructs. The data showed that heavy exertion caused implicit memory (their ability to relate previous maze constructs to the present one) to decrease by a significant amount. However, there was no effect on the rats' working memory (their ability to complete the maze task). The decrease in implicit memory paralleled the rats' fatigue, which was caused by the heavy levels of exertion. These findings reflect the results of the review of exercise studies by Tomporowski



(2003), in that cognitive functions can be negatively affected by prolonged periods of heavy exertion. These studies reveal that the positive effect that exercise has on cognition is related to the level of exertion and can become detrimental to cognitive processes when exhaustion is induced by high levels of exertion.

Praag et al. (1999) tested the proficiency of maze completion between mice who had access to an electric wheel within their confines and those that did not. In order to test cognitive ability, the researchers measured the time it took each sample to complete a water maze that consisted of a single platform that is placed in a container full of water. The platform is short enough to where it does not break the top of the water, thus not making it visible to the rat. The rat is placed within the container and required to swim to the platform. The findings revealed that the mice with access to an electric wheel had improved their times significantly in comparison to the mice without access to an electric wheel. This increase in learning outcomes in relation to exercise in animals has been documented in multiple animal studies (Ahlskog et al., 2011). However, it is difficult to assess an appropriate parallel for human exercise regimens when comparing it to animal studies (Dishman et al., 2006). It is evident that animal studies have their limitations when attempting to ascribe the results to humans.

The positive influence of exercise on cognition is not a simple causal reaction, but rather one dealing with both neurological and physiological responses to physiological arousal. Within Kramer and Erickson's (2007) review, neurological components are explored within articles assessing the relationship between exercise and cognition, including an epidemiological observation, which consists of observing patterns, effects, and causes of specific health conditions. This review also included a randomized clinical

intervention (long-lasting experimentation), and a lab animal study. After reviewing these three studies, the researchers concluded that exercise is capable of increasing the production of brain-derived neurotrophic factor (BDNF) in the hippocampus. BDNF is a molecule involved in neurogenesis and neuroprotection as well as learning and memory operations. In addition, the review revealed that exercise can reduce the risk of neurological diseases, such as Alzheimer's disease.

During a study assessing the levels of exertion that cause BDNF values to increase in humans, Ferris, William and Chen (2007) found that there was a correlation between the increase of BDNF and the increased presence of blood lactate. Using the ventilatory threshold ( $V_{th}$ ) as a method of standardization, the researchers asked participants to undergo both low ( $V_{th}-20\%V_{th}$ ) and high intensity ( $V_{th}+10\%V_{th}$ ) sessions of exertion.  $V_{th}$  is determined by ventilatory change, specifically when the individual increases ventilation beyond their increase in oxygen uptake. In other words,  $V_{th}$  is when an individual takes in more oxygen than they are capable of processing. Both levels of exertion revealed an increase in cognitive task performance. However, the BDNF levels only increased within the high intensity session. Other studies have found that an increase in blood lactate, specifically the lactate threshold, is closely tied to  $V_{th}$  (Plato et al., 2008). Lactate threshold is the point in time which the body begins to produce more lactate than it is capable of metabolizing. The increase in lactic acid and BDNF within the high intensity session (exertion above  $V_{th}$ ) of Ferris et al.'s (2007) study reveals a similar correlation.

The increase of BDNF due to exercise is closely associated to the increase in the volume of a person's hippocampus, which is directly related to memory and learning

capability (Erikson et al., 2010). Within this study, 120 elderly individuals without dementia were placed into either a stretching and toning or an aerobic exercise group. Each group was asked to perform their tasks 3 days a week for an entire year. Within the stretching and toning group, which was used as a control to compare the experimental group with, participants used dumbbells or stretch bands, performed yoga techniques, underwent two procedures to improve balance, and were allowed to add one of their own that fit into the group paradigm. Within the aerobic exercise group, the participants were asked to walk for a 10 minute period, increasing the duration by 5 minutes every week until the sessions lasted 40 minutes at the seventh week. They were then asked to maintain the 40 minute walking regimen for the remainder of the experiment. Results of the study revealed that the volume of the participants' hippocampus within the exercise group increased after the 6 month intervention program, while the stretching and toning group had a decrease in hippocampal volume. The decrease in volume within the stretching and toning subsample parallels the natural onset of hippocampal volume loss that occurs with age. It has been found that this decrease in volume has a high comorbidity with the onset of Alzheimer's disease (Schuff et al., 2009). The participants in this study consisted of those with mild cognitive impairment. As participants underwent MRI's, it was found that Alzheimer's disease became more prevalent as hippocampal volume decreased. The severity of Alzheimer's disease consistently increased with the steady decline in hippocampal volume over the first 6 months of the study. Those participants who exhibited a steady decrease within the first six months had an accelerated decrease in hippocampal volume that occurred over the period of a year, directly relating to an acceleration of the onset of Alzheimer's disease.

Furthering the analysis on the relationship between Alzheimer's disease and exercise, Laukka et al. (2010) analyzed a group of participants that either had the early stages or the precursors of Alzheimer's disease. It was concluded that those participants who acquired new vascular diseases during the course of the study exhibited the quickest cognitive deterioration, hastening the onset of Alzheimer's disease. Vascular disease, one of the main factors in the progression and development of Alzheimer's disease, is triggered by dysfunctional endothelial cells (the thin layer of cells that lines the interior surface of blood vessels). These dysfunctional endothelial cells cause a thickening of the blood vessel walls, forming a plaque that inhibits nutrient and oxygen transport to the brain. The study by Laukka et al. (2010) showed that a history of vascular disease has a negative impact on cognition in elderly people.

Yaguez et al. (2010) studied individuals with Alzheimer's type dementia and tested whether simple non-aerobic exercises had any effect on the cognitive abilities of these individuals. The exercises consisted of minor movement-based actions, such as placing their hands on a table and lowering their chin onto their chest and breathing in and out heavily, or side-stepping back and forth while staying within a small proximity of where they were initially standing. The experimental group doing the exercises had a significant improvement in sustained attention, visual memory and working memory compared with the control group. Another influential variable pertaining to the onset of Alzheimer's disease is the amount of grey matter present, which consists of the regions of the brain involved in muscle control, sensory perception (vision and hearing), memory, emotions and speech. It was found that seniors who were physically unfit had less grey matter than those who are fit, resulting in a hindrance of the processes that grey matter is

related to (Ahlskog et al., 2011). The study did not just assess these two groups of elderly people and their grey matter, but also applied an aerobic exercise routine that lasted 6-12 months revealing significant improvements in neural connectivity over extended periods of time. Along with this, some of the participants had cerebrovascular disease, which had been shown to improve when a follow-up assessment was done after they had undergone the exercise intervention. As stated earlier, vascular disease is closely related to the time it takes for Alzheimer's disease to set in as well as its severity.

It now appears that the benefits of exercise on cognition may generalize across age groups. Neider et al. (2011) conducted a study to the effects of exercise on cognition in preschoolers. The method used was a cluster sampling of preschools in the German and French speaking parts of Switzerland. The children were asked to complete three different aerobic fitness tasks: obstacle course; shuttle run test of 20 meters; and balance beam. The fitness level of each participant was determined by the shuttle run, in which aerobic capacity was assessed by a gradual increase in the child's speed as directed by a researcher. When the child became incapable of following the pace prescribed by the researcher, their capacity had been reached. The working memory variable was tested with a retention-recall test wherein the child had to memorize a certain shape. Following the initial exposure, the shape would appear on another picture with two other shapes, but the color of the original shape changed (used as a distracter). This assessment would stop when the child would answer wrongly three consecutive times. The results of the study revealed that there was significance in the relationship between exercise and working memory, but only in the children that had a higher baseline aerobic fitness level.

Another major focus of research concerns the effects of exercise on cognition within healthy adults. Hillman, Castelli and Buck (2005) analyzed the relationships between age, level of fitness and cognitive ability. The sample was divided into four groups based on age (adult, child) and level of fitness (low, high). The level of fitness for each participant was determined by a fitnessgram test, which assesses the amount of daily physical activity as well as type of activity of each participant. In order to determine the level of cognitive function, the participants' working memory, attention, cognitive processing speed and response speed to cognitive tasks were measured. The results of the study revealed a significant positive correlation between fitness levels and cognitive functions, such as attention, working memory and response speed. Overall cognitive health was also shown to be higher in those that were more fit.

Many studies focus on investigating the relationship between aerobic exercise and working memory, which often pertains to the ability to follow specified directions accurately. Working memory is one of many cognitive processes that become more susceptible to deterioration with age. Kramer et al. (2005) conducted a meta-analysis of articles assessing the efficacy of exercise on improving cognitive functions in older adults with potential mental deterioration. Each of the studies consisted of programs to achieve physical fitness over an extended period of time. The studies that had the most significant positive effects were those that tested the relationship between exercise and tasks assessing a participant's planning, scheduling, working memory, interference control, and task coordination. Each of these cognitive functions are termed "executive control processes" and are attributed to a part of the brain called the prefrontal cortex, which also becomes increasingly susceptible to deterioration with age.

Finally, the effects of exercise on working memory are not limited to studies consisting of only long-term programs. Sibley and Beilock (2010) performed a study in which participants walked 30 minutes on a treadmill only once and then completed a cognitive task assessing working memory. This single session study revealed that working memory improves after an acute amount of exercise, but the amount of improvement varies between participants. Those participants that scored lower on the working memory pretest had a higher rate of improvement after exercise than those participants who scored higher on the pretest.

## **Purpose**

Metacognition is, ultimately, the manner in which individuals think about their thinking processes. In other words, it is thinking about thinking. Metamemory, a subgroup of metacognition, focuses on the processes of memory and encompasses the ability of our own memory, self-assessments on memory, as well as strategies to improve memory. There is a cyclical relationship within the process of reflecting on memory that involves the interaction of self-assessment and strategy. Once an individual develops a strategy to improve memory, it is essential to reflect upon—make a self-assessment of—the impact of that strategy. Once the individual assesses the influence that the strategy has on memory, they can then incorporate more guidelines to aid in its effectiveness. Thus, the cyclical relationship begins again.

The focus of the present study was memory and metacognition, specifically judgments of learning (JOLs) and how three different levels of activity (sedentary, light exertion, heavy exertion) influence them. JOLs are a form of self-assessment, in which the individual determines how likely they are to remember an item. A JOL can utilize a scale from 0-100, essentially making it a ‘percentage likelihood to remember’ assessment. This study was the third in a succession of studies created to determine the relationship between exertion and these cognitive variables.

In the first study, Salas, Minakata and Kelemen (2011) used a between-subjects factorial design to compare a walking session with a sedentary session and analyzed the effects on JOLs, memory and metamemory accuracy. Memory was assessed by analyzing the participants’ accuracy of recall. Metamemory accuracy utilized both the JOLs and the



accuracy of recall in order to determine if the participants were accurate in their assessment of how much they would recall. In order to do this, they analyzed the correlation between the JOLs and accuracy scores. Participants would demonstrate low metamemory accuracy if they had high JOLs and low accuracy or if they had low JOLs and high accuracy. They would have high metamemory accuracy if their JOL scores and accuracy were either both low or both high.

The study utilized a sedentary and a walking condition. The participants would begin in either the walking or sedentary condition and would end in either a walking or sedentary condition, making four possible combinations of conditions. This structure of experimentation is known as a 2x2 factorial design. The first portion of the study consisted of an encoding phase where the participant was given a 30 item list to memorize after having been in the sedentary or walking condition. The second portion consisted of a recall phase, in which the participant was asked to recall as many words as possible after having either been in either the sedentary or walking condition. The participants that had walked during the encoding phase had significantly higher recall rates than those participants in the sedentary condition during the encoding phase. There were no significant differences in JOLs between any of the conditions. Absolute metamemory accuracy was more precise in participants who had walked during the encoding phase.

One possible explanation of this is the lack of the students' knowledge of the benefits of exercise on cognition. Knowing how the heightened level of exertion would improve their memory might have caused the participants to have more confidence when assessing how likely they would remember the words given to them during the encoding

phase. Understanding how your memory works is essential in metamemory, specifically when attempting to assess how a strategy works. As stated earlier, the procedures of application within the concept of metamemory have a cyclical relationship. If a strategy proves to be more effective than previously thought, the individual must adapt their perspective in order to improve metamemory as well as to further understand the strategy in place.

In a follow-up study, Nguyen and Kelemen (2011) conducted two between-subjects experiments to assess the relationship between levels of exertion, memory, physiological arousal, and extroversion/introversion. This study was broken up into two experiments, with both of the experiments having participants undergo an encoding and recall task as well as JOL assessment after their prescribed phase of exertion had concluded. The first experiment was designed to determine the difference between a sedentary and walking condition on cognitive functions. Participants in the sedentary condition were asked to remain seated while viewing a 10-minute slideshow, whereas those in the walking condition were asked to walk on a treadmill at a brisk pace for 10 minutes. The first experiment revealed no significance between the sedentary and walking condition within recall scores, JOLs or metamemory accuracy. However, those participants within the walking condition reported having significantly higher levels of energy when compared to the sedentary condition. The reported tension levels were higher in the walking condition than the sedentary, but they were not significant.

The second experiment intended to assess whether there were differences between light and heavy exertion on cognitive functions. Using a 2x2 factorial design, participants were placed in either the light or heavy exertion condition and then divided into an

outside or inside group. The level of exertion that each participant was asked to achieve was set by using the Borg Scale. The Borg scale ranges from 6-20, with the lowest number being the level of exertion at a resting state and the highest being the maximum level of exertion (Borg, 1998). This scale is intended to allow for the individual to assess their own ability and allows them to conceptualize what they perceive as a specific level of exertion by comparing them numerically. Within this experiment, light exertion was ascribed the number '11' on the scale and heavy exertion a '15'. The '11' was intended to replicate a level of intensity that the participant would conceptualize as "light" exercise in their perspective. The '15' was intended to be a level of exercise that the participant perceived as "heavy" exercise. This second experiment revealed that participants in the heavy exertion condition had significantly lower JOLs and recall rates than those participants in the light exertion condition. This variation between group scores within the second experiment reveals a potential threshold on the positive influence that exercise might have.

This present study is designed to allow for a more fine-grained analysis of these effects. Instead of running a between-subjects factorial design, we used a within-subjects design. Thus, every participant completed every condition (sedentary, light exertion, heavy exertion) in the experiment. This method should reduce error variance that occurs with individual differences. To control possible carryover effects, which are caused by the order in which a participant undergoes stages of an experiment, we counterbalanced the conditions so that all possible combination of conditions would be tested an equal number of times. Our intent within this study was to assess how varying levels of

physiological arousal would affect recall, with the hypothesis that the Moderate session would improve recall when compared to the Sedentary.

## **Methods**

### *Participants*

Participants were chosen from students enrolled at Texas State University. In order to obtain participants, flyers were placed around campus stating a need for healthy individuals to participate in a study over memory and exercise and emails were sent to inform students of a paid research opportunity. We received a total of 30 participants, averaging in 20.4 years of age, including 10 men and 20 women. Each participant received \$10.00 per session and an extra \$10.00 if they attended all three scheduled sessions, equaling a potential \$40.00. The criteria for “healthy individuals” consisted of those participants who would not be affected by heavily exerting themselves on a treadmill for a moderate amount of time, did not have pre-existing health conditions that would be worsened by physical exertion, were not currently taking stimulants (i.e. Adderall, Ritalin, amphetamine salt complex, etc.). Each participant provided informed consent and the procedures were approved by the Texas State University IRB.

### *Procedures*

This study adopted a within subject, repeated measures design and was completely counterbalanced so that all order combinations of session type would be tested an equal number of times. Each participant was asked to attend three sessions, lasting roughly 45 minutes each. Prior to beginning the experimental phase of the first session, demographic questionnaires were completed by participants. Each participant's body mass index (BMI) was also measured on the first day. BMI was calculated by collecting the participants' height, weight and age and then inserting them into the

formula provided by the Center for Disease Control and Prevention Adult's BMI calculator (CDC, 2012). Height and weight were measured by a researcher using the standard system and the age was self-reported by the participant. Upon arrival to each session (after filling out the demographic questionnaire in the first session), the participants completed a survey assessing their level of sleep, stimulant intake and exercise within the past 24 hours. Prior to the exercise manipulation phase, the participants were asked to fill out a mood survey (ADACL) assessing how the participant felt at that moment in time.

The ADACL is a 20 word list used to assess four variable levels: calm; tired; tension; energy. Each variable had 5 words that, when the scores were combined, assessed the level of that specific variable in that moment of time. The words were scored using a modified Likert scale, which used the designation of (vv) to mean *definitely feel*, (v) to mean *slightly feel*, (?) to mean *uncertain*, and (no) to mean *definitely do not feel*. When analyzed and coded, (vv) was ascribed a score of 4, (v) a 3, (?) a 2, and (no) a 1. However, for the variable 'tired,' there were words that assessed the individual's lack of being tired, such as the word 'wakeful.' For these "reversed" words, we simply inverted the scoring rubric. The range for each assessed variable ranged from 5 being the lowest to 20 being the highest, indicating the respective lack or presence of that assessed variable.

During each session, the participants were asked to meet the procedures for 1 of 3 levels of exertion (sedentary, light exertion, heavy exertion). Each exertion phase lasted 13 minutes. The sedentary level was achieved by asking a participant to watch a PowerPoint consisting of landscapes for the duration of the exertion phase. The light and heavy exertion levels were manipulated by use of a treadmill. The treadmill used was a

LifeSpan TR4000i, which regulated speed according to a set target heart rate (THR) that was monitored via the usage of a chest strap. The treadmill had a required 3 minute period of calibration where the participant would walk at 2 mph with an incline of 0.5 on a scale of 0 to 15. Once the 3 minute calibration period was finished, the treadmill would then alter the speed in order to match the participant's heart rate (HR) to the preset THR for the next 10 minutes. The designation of "light" and "heavy" came from using a THR of 55% and 75% of their maximum HR ( $HR_{max}$ ), respectively. The participants' maximum heart rate was calculated using the equation:  $HR_{max} = 208 - (.7 * age)$  (Tanaka, Manahan and Seals, 2001). HR was recorded by using the chest strap that transferred data to a flash drive attached to the treadmill.

Once the participant finished the exertion portion of the session a second mood questionnaire was filled out, followed by the encoding phase. Using a program called E-Prime, the participants were given a list of 30 words and were asked to memorize as many as possible. The list contained English nouns and for each noun the participant was asked how likely they were to remember the word on a scale of 0 to 100. This scale was used to assess JOLs (percentage likely to recall). In total, there were 90 words used over the three days of participation, with each day having a specific set of 30 words allowing for each set of words to be used an equal number of times within each condition of the experiment. The time that each participant had to memorize the word before they were asked to assess JOL was 6 seconds. This encoding phase uses the same method as in the previous study on cognition and exercise conducted by Nguyen (2011). After the encoding phase, the participants undertook a distracter task for 5 minutes in order to achieve baseline levels. After the distracter, participants were asked to recall as many

words as possible in a 3 minute period, followed by a final mood questionnaire. Once the participants had completed all three sessions, they were debriefed and given information in order to contact our research team if they had any questions.



## Statistical Analysis

### *Demographics*

The demographic background of the 30 participants is shown in Table 1. The average age of the group was 20.37 years, with 10 participants being male and 20 being female. Measurements for BMI revealed the mean height of the participants to be 67.2 inches and the mean weight to be 145.8 pounds.

Table 1  
*Demographics*

Sample Characteristic N=30		Descriptive Statistics
Age		20.37 (1.81)
Gender		
	Males	33.3% (n = 10)
	Females	66.7% (n = 20)
Hispanic or Latino		
	Yes	26.7% (n = 8)
	No	73.3% (n = 22)
Ethnicity		
	Black	6.7% (n = 2)
	Asian	3.3% (n = 1)
	White	80% (n = 24)
	Other	10% (n = 3)
Native Language		
	English	90% (n = 27)
	Portuguese	3.3% (n = 1) (>15)
	Spanish	6.7% (n = 2) (>15, 5-10)
Level of Education		
	Freshman	6.7% (n = 2)
	Sophomore	36.7% (n = 11)
	Junior	20% (n = 6)
	Senior	36.7% (n = 11)
GPA		3.47 (.43)
Height In Inches		67.2 (3.6)

Weight In Pounds

145.8 (33.5)

Note. Main entries are mean and entries in parenthesis are standard deviation for Age, GPA, Height and Weight; second set of parenthesis in Native Language entails number of years the participants had spoken English; N=29 for GPA

*Treadmill Data from Moderate and Heavy Conditions*

Table 2 outlines data recorded by the treadmill during the moderate and heavy conditions. This table is intended to reveal that physiological measurements of exertion corresponded with the designated THR for each session. Within the moderate condition (THR = 55% HR<sub>max</sub>), it is shown that speed, the calories burned, steps taken, and distance covered were all lower than the measurements in the heavy condition (THR = 75% HR<sub>max</sub>). However, while the designated THRs are 20% apart, the actual recorded average HR for the moderate condition is approximately 22% lower than the heavy condition.

Table 2  
*Treadmill Data*

N=30	Moderate	Heavy
Heart Rate	105.80 (5.20)	137.64 (4.57)
Speed (MPH)	2.11 (1.05)	3.98 (.45)
Calories Burned	40.40 (14.46)	69.77 (20.34)
Steps Taken	1082 (324)	1670 (574)
Distance (Miles)	.400 (.191)	.717 (.087)

Note. Main entries are means; entries in parenthesis are standard deviations

*Metacognitive Accuracy and Recall*

Within Table 3, the JOLs, aggregate JOLs, recall accuracy, bias, and gamma are detailed. Aggregate JOL was assessed by asking the participant how many words they were likely to remember after all words were presented to them. Scores more than two standard deviations (two times the number in parentheses next to the mean value) were

discarded in these analyses. Thus, the sample size for each recorded dependent measure varies due to these applied restrictions. However, the sample size for the Aggregate JOL scores is reduced further by 1 participant due to missing data in the Heavy condition. This missing data point is most likely due to the participant having concluded the encoding task by pressing 'Enter' on the keyboard without indicating the number of words they were likely to recall. Significance was assessed by analyzing the variation of each independent variable over the 3 conditions. Significance was found in JOL scores between the Sedentary and Moderate conditions as well as between the Sedentary and Heavy conditions, with the means being higher in both the Moderate and Heavy conditions when compared to the Sedentary,  $t(29) = -2.09, p < .05$ ,  $t(29) = -2.38, p < .05$ , respectively. Significance was found in Recall between the Sedentary and Moderate conditions as well as between the Sedentary and Heavy conditions, with the means being higher in both the Moderate and Heavy conditions when compared to the Sedentary,  $t(26) = -2.79, p < .05$ ,  $t(29) = -3.02, p < .05$ , respectively.

There are three other assessed variables within this table, Aggregate JOL, Bias, and Gamma. Aggregate JOL is the participants' likelihood to remember a specific number of words. In order to assess Aggregate JOL, the participants were asked how many words they were likely to remember after the encoding task was completed. Bias is the subtraction of mean JOL scores from mean recall scores. Positive Bias scores indicate overconfidence, while negative bias scores indicate underconfidence. While the response that JOLs and recall accuracy parallel each other within each session (being significantly higher in both the Moderate and Heavy conditions when compared to the Sedentary), they do not reflect one another, hence the positive bias scores. This reveals that

metamemory accuracy within the participants was actually quite low, but the effects of the exercise still improved confidence in memory retention in spite of the lack of assessment accuracy. Since we limited the analyses on the basis of variation of standard deviation, there is a table in the Appendix with all 30 participants' data pertaining to JOLs, Recall, Aggregate JOL, Bias, and Gamma.

*ADACL Data: Energy Levels Across All Conditions*

Table 4 outlines the data for energy levels taken from the ADACLs completed in each condition. In order to acquire this assessment, the scores from the words assigned to

					correlate with
levels	Table 3				of energy
	<i>JOL, Recall Scores, Bias and Gamma Based On Condition</i>				
		Sedentary	Moderate	Heavy	
were					combined
	JOL	47.94 (21.09)	56.52 (18.53)	56.48 (20.22)	
(active,	N=30				energetic,
	Aggregate JOL	13.75 (5.23)	13.82 (3.58)	14.79 (4.35)	
	N=28				vigorous,
	Recall	.358 (.134)	.440 (.135)	.421 (.098)	
	N=27				full-of-pep).
lively,	Bias	.124 (.248)	.125 (.239)	.160 (.224)	
	N=28				Significance
	Gamma	.343 (.283)	.414 (.210)	.322 (.316)	
	N=27				
	Note. Main entries are means; entries in parenthesis are standard deviations				measurements

were taken from comparing the difference between the baseline, after manipulation, and after recall scores for each condition. Baseline scores are obtained from the first mood questionnaire given to the participants at the beginning of each session. Post-manipulation scores are from the second mood questionnaire that was filled out following the experimental exertion phases. Post-recall scores are from the third survey taken after the individual was asked to recall the words studied in that session. Both Table 4 and

Table 5 have a reduced Sedentary condition sample size due to one participant's post-recall mood survey having not been filled out properly. For the Sedentary condition, both the post manipulation and post recall energy scores were significantly lower than the baseline energy scores,  $t(28) = 2.72, p < .05$ ,  $t(28) = 2.24, p < .05$ , respectively. For the energy scores in the Moderate condition, post manipulation was significantly higher than baseline, and the post recall was significantly lower than the post manipulation,  $t(29) = -2.68, p < .05$ ,  $t(29) = 2.65, p < .05$ , respectively. For the energy scores in the Heavy condition, post manipulation was significantly higher than baseline, and post recall was significantly lower than the post manipulation,  $t(29) = -4.43, p < .05$ ,  $t(29) = 5.36, p < .05$ , respectively. Figure 1 depicts the recorded mean energy levels of baseline, post manipulation, and post recall within the three conditions.

Table 4  
*Recorded Energy Levels Across Each Condition*

	Sedentary	Moderate	Heavy
Baseline	9.55 (3.67)	9.80 (3.74)	10.80 (3.82)
After Manipulation	7.59 (3.40)	11.50 (4.37)	13.73 (3.08)
After Recall	8.34 (3.42)	9.73 (4.09)	11.23 (2.99)

Note. Main entries are means; entries in parenthesis are standard deviations; N = 29 for Sedentary; N=30 for Moderate and Heavy

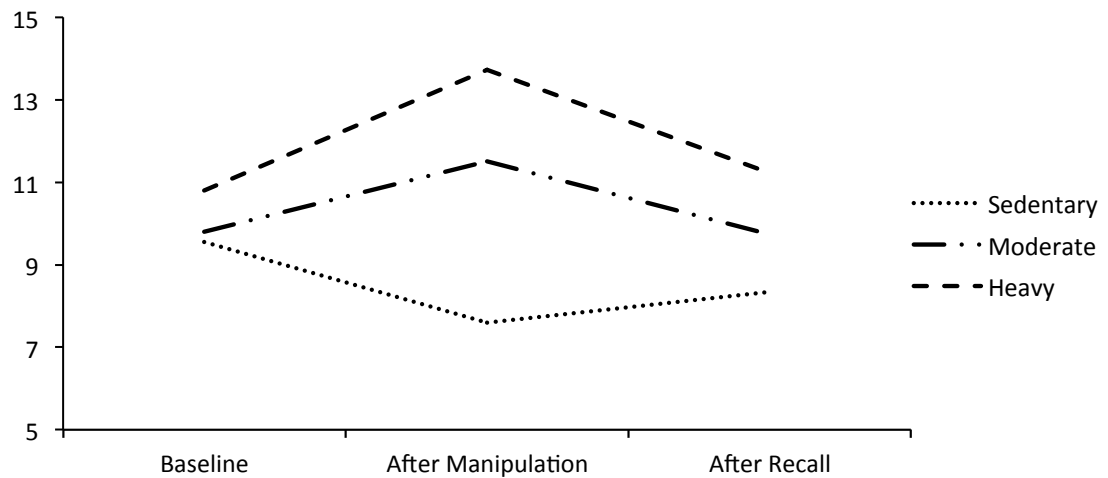


Figure 1. *Average Recorded Energy Levels Across Each Condition*  
 Note. N=29 for Sedentary; N=30 for Moderate and Heavy

#### *ADACL Data: Tension Levels Across All Conditions*

Table 5 is identical in format to Table 4, but instead focuses on the tension levels taken from the ADACLs during each session. The following 5 words were used to assess total tension scores: jittery; intense; fearful; clutched-up; tense. Significance measurements were taken from comparing the difference between the baseline, post manipulation, and post recall scores for each condition. For the Sedentary condition the post recall tension scores were significantly higher than the post recall tension scores,  $t(28) = -2.17, p < .05$ . For the Moderate condition, post recall tension scores were significantly higher than post manipulation tension scores,  $t(29) = -2.17, p < .05$ . Figure 2 depicts the recorded mean tension levels of baseline, post manipulation, and post recall within the three conditions.

Table 5  
*Recorded Tense Levels Across Each Condition*

	Sedentary	Moderate	Heavy
Baseline	6.59 (2.56)	6.07 (2.20)	6.33 (2.02)
After Manipulation	5.72 (1.25)	5.93 (1.60)	7.07 (2.26)
After Recall	6.48 (2.01)	6.67 (2.08)	7.03 (2.40)

Note. Main entries are means; entries in parenthesis are standard deviations; N=29 for Sedentary condition; N=30 for Moderate and Heavy conditions

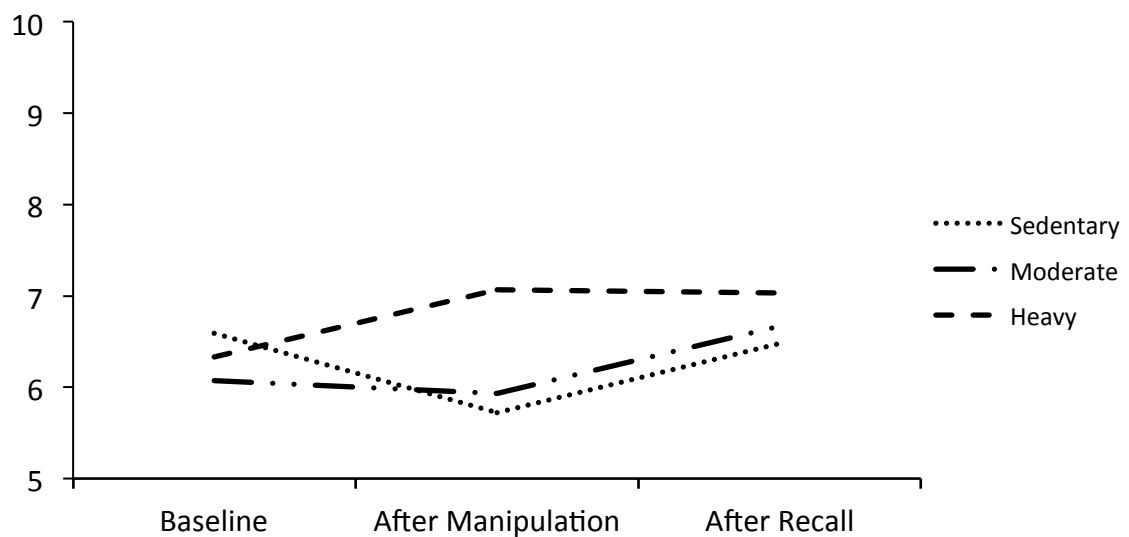


Figure 2. *Average Recorded Tense Levels Across Each Condition*  
 Note. N=29 for Sedentary condition; N=30 for Moderate and Heavy conditions

## **Discussion**

The results of the study reveal that our hypothesis, that exercise would improve recall scores, is supported. However, the inclusion of the Heavy exertion as a means to assess the threshold of exercise's benefits on cognitive functioning proved revealed only a minor (and non-significant) decline in JOLs and recall. As previously research detailed, to achieve a threshold it may require levels of exertion that induce exhaustion or require the individual to surpass their anaerobic threshold, ultimately depriving their body of essential nutrients as well as inducing dehydration (Tompsonski, 2003; Aguiar et. al, 2010).

Within the assessment of the mood questionnaires, it was decided to mainly focus on energy and tension levels, as Thayer (1989), the developer of the modified scale, prescribes the focus on these two assessments due to them being more apt to measure higher levels of arousal. Heightened states of energy are said to associate with improvement of memory, while high tension levels have the inverse effect. Upon analysis of the tension levels, it is apparent that, while significant in specific comparisons, there was not much of a change between the sessions or the time in which mood was assessed. This is likely due to the procedures lacking a level of arousal that would induce notable levels of tension. The improvement in memory when comparing the Sedentary condition to the Moderate and Heavy conditions reflect, as previously mentioned, our lack of inducing a negatively influencing level of exertion. The scores within the participants' energy levels reveals something akin to what was mentioned earlier in Neider et al's (2011) study pertaining to children undergoing aerobic exercise immediately before



attempting cognitive tasks, as well as Tomporowski's (2010) analysis on time of encoding . What seems to have occurred within this study is an energy peak immediately following the exercise conditions as well as a decline of energy levels after recall, so much so that they almost match the initial baseline energy levels. Considering the apex of energy occurred during the encoding phase and retention of those energy levels did not occur for the after recall scores, we can assess that energy levels are likely to have an influence on encoding specifically. The tables detailing the other two variables, calm and tired, is located in the Appendix.

There were some areas for concern that can be addressed in future research. Within the Moderate exertion phase, some individuals THR ( $55\% \text{HR}_{\text{max}}$ ) seemed to be too high. This is being said due to the treadmill having gone at a pace of 0.5 miles per hour for 3 different participants. In such cases, it may require the use of a method, other than HR, with less abstraction from physical capacity. One such possibility is the assessment of  $\text{VO}_{2\text{max}}$  during the exercise condition. However, this variation in speed did not affect the data, so it may be an unnecessary application for the current structure of this experiment. This was made certain by analyzing the scores after excluding those participants whose average speed on the treadmill during the Moderate session was roughly equivalent to 0.5 miles per hour. The results revealed no significant variation from the scores in Table 3, thus there was no need for exclusion. While we are assessing cognitive ability and its relation to physiological arousal, it is still necessary to understand the biological underpinnings of this relationship. Something that could be of value is the assessment of BDNF, as was mentioned earlier to influence hippocampal volume, which is directly related to learning and memory capacity (Kramer & Erikson,

2007). What was not mentioned in the previous studies is that the relationship of BDNF to external stimuli (such as exercise), is regulated by a specific homozygous allele (Hopkins et. al, 2012). The problem here is that not all individuals have this allele; in fact, a majority of individuals do not have this allele (Hashimoto et al., 2004). A method of initial assessment for the presence of this allele would be required in order to properly adhere to exclusion criteria if BDNF were to be assessed.

## Appendix

Appendix 1

*JOL, Recall Scores, Bias and Gamma Based On Condition*

	Sedentary	Moderate	Heavy
Recall N=30	.401 (.190)	.460 (.156)	.461 (.154)
AGGJOL N=29	14.24 (5.77)	14.28 (4.28)	15.14 (4.67)
Bias N=30	.078 (.307)	.105 (.274)	.104 (.305)
Gamma N=29	.303 (.312)	.373 (.254)	.307 (.309)

Note. Main entries are means; entries in parenthesis are standard deviations

Appendix 2

*Recorded Calm Levels Across Each Condition*

	Sedentary	Moderate	Heavy
Baseline	12.24 (3.06)	12.17 (3.53)	11.80 (3.41)
After Manipulation	15.28 (2.66)	10.87 (3.42)	8.30 (2.83)
After Recall	12.79 (3.63)	12.60 (3.67)	10.70 (2.89)

Note. Main entries are means; entries in parenthesis are standard deviations; N=29 for Sedentary condition; N=30 for Moderate and Heavy conditions

Appendix 3

*Recorded Tired Levels Across Each Condition*

	Sedentary	Moderate	Heavy
Baseline	11.45 (4.89)	11.67 (5.03)	10.80 (4.89)
After Manipulation	15.34 (3.89)	9.90 (4.37)	7.93 (2.99)
After Recall	13.62 (4.26)	11.27 (5.01)	9.93 (3.71)

Note. Main entries are means; entries in parenthesis are standard deviations; N=29 for Sedentary condition; N=30 for Moderate and Heavy conditions

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