The Effects of Moderate Aerobic Activity on Short-Term and Long-Term Memory

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Keywords: Aerobic, Cognitive Recall, Memory, Word Recognition, Memory Retention, Visual, Blood Pressure, Long Term Memory, Short Term Memory, Working Memory, Exercise, Oxygen Saturation, Heart Rate, Pulse, Moderate, Word Pairs

Abstract

Physical stress induced by moderate aerobic exercise leads to the release of hormones that increase blood flow and nutrient availability to the brain. Research has shown that these changes could be beneficial for long-term memory retention, possibly leading to improved ways to study and memorize material. The current study hypothesized that those performing aerobic activity while participating in memorization tasks would perform better on a long-term memory test. A difference in performance on short-term memory tests was not predicted. 32 participants were given a list of 50 random word pairs and given ten minutes to study, either while stationary or while riding an exercise bike. All participants then took a five minute fill-in-the-blank memory test both immediately after the study period and again one week later. The scores were analyzed using a Welch's two sample t-test. No statistically significant evidence was found to support the role of exercise in improving long-term or short-term memory retention.

Introduction

Research has provided significant evidence for the benefits of exercise on physical health. It is widely known that aerobic exercise is an important component in one's lifestyle to help reduce the risk of cardiovascular disease, prevent bone loss, and regulate weight gain (HSPH, 2015). In recent decades, the study of physical activity and its influence on cognitive function has become a growing topic of interest. Recent data reveal that cardiovascular exercise triggers a cascade of neurobiological mechanisms that may have a positive effect on cognitive function, specifically memory (Flöel *et al*., 2010).

During physical exercise, the body requires the expenditure of energy generated by cellular respiration. The vast amount of energy needed to fuel the body during moderate aerobic exercise exerts major metabolic demands on the brain and skeletal muscle tissue involved in movement (Balsom *et al*., 1995). Heightened physical activity induces physiological responses that mitigate the stress such as increased cerebral blood flow and availability of oxygen, glucose, and nutrients to vital tissue (Neumann *et al*., 2014).

Stress due to aerobic exercise also prompts the increased production and secretion of brain-derived neurotrophic factor (BDNF) and epinephrine, two stress-induced chemicals which notably modulate and enhance memory retention. (Winter *et al., 2007*). BDNF is shown to support the survival of neurons and facilitate the growth and differentiation of new neurons and synapses associated with memory formation (Yamada *et al.*, 2001). Epinephrine also serves a facilitative role in memory retention by exhibiting the neuromodulatory function of strengthening synaptic activity during encoding and consolidation of information (Serrera Figallo *et al.*, 2012, Ferris *et al.*, 2007). Increased epinephrine levels have been associated with improved long-term memory (Winter *et al*., 2007).

Few studies have found conclusive evidence to support a positive correlation between moderate aerobic exercise and improved long-term memory retention. Furthermore, previous studies primarily examined short-term memory retention in relation to exercise (Stowell, *et al*., 2012, Newman *et al*., 2014). Comparable studies have failed to find a significant improvement in performance on short-term memory evaluations immediately following aerobic exercise (Hotter, *et al.,* 2013, Stowell *et al.,* 2012). Additionally, other studies have not instructed participants to learn material while exercising but instead had participants exercise and then perform memory tasks (Myles, *et al.*, 2013, Hotter, *et al*., 2013). In the current study, participants were asked to memorize material while performing aerobic exercise and increased the time period between learning and testing to one week to examine the effects of aerobic exercise on long-term memory retention. This study defines long-term memory as retention of information seven days after exposure to material.

We hypothesized that moderate aerobic exercise would improve performance on long-term memory assessments but would not affect performance on short-term memory tasks. To test this hypothesis, control participants were given a list of 50 word pairs to memorize while remaining stationary, whereas experimental participants were given the same material to memorize while riding an exercise bike. After studying the information for ten minutes, the subjects immediately completed a short-term memory assessment and returned one week later to complete a long-term memory assessment. For the purposes of this study, short-term memory is defined as retention of items over a period of seconds and long-term memory is defined as retention of items over longer intervals (one week) (Baddeley and Warrington, 1970).

Methods and Materials

Forty volunteers were randomly selected from the student population enrolled in the 2015 spring term of Physiology 435 at the University of Wisconsin-Madison. Consent was received from all participants prior to the beginning of the experiment. Each subject was asked to complete a survey describing their sex, age, amount of weekly exercise, learning methods, and protein consumption that day. An overview of the experimental protocol is presented in Figure 4.

The forty volunteers were randomly assigned to two groups. All participants' baseline blood pressure was measured using digital automatic blood pressure cuffs (Omron Healthcare Co., Ltd. Lake Forest, IL. Model#BP791IT). Heart rate and blood oxygen saturation were measured using digital pulse oximeters (Nonin Medical Inc. Minneapolis, MN. Model#9843). The pulse oximeter sensor was placed on the left index finger, and the blood pressure cuff was placed on the upper left arm. Once recorded, the blood pressure cuff was removed until the next measurement was taken, but the pulse oximeter sensor remained on the index finger throughout the duration of the experiment. Experimental subjects biked on a Cycle Trainer 390 R Exercise Bike (Gold's Gym®. Irving, TX. Model#GGEX61712), modified with an armrest positioned to stabilize subjects' arms and hands for accurate pulse oximeter measurements during exercise (Figure 1). The experimental subjects had their upper left arm secured to the bike armrest by a velcro strap from a BSL Respiratory Effort Xdcr kit (BioPac Systems, Inc. Goleta, CA. Model#SS5LB).

Once baseline measurements were recorded, the experimental group was prompted to begin biking. When the subject's heart rate increased by 75% from their baseline heart rate, indicating significant bodily stress, the participant was given a list of 50 word pairs (Figure 2) and was asked to study the list for ten minutes as they continued to bike and maintain an increased heart rate. Heart rate and oxygen saturation were collected every minute during this period to make certain the participant maintained an elevated heart rate. Control groups were also given the list of 50 word pairs and asked to study it for ten minutes. Heart rate and oxygen saturation were collected by a pulse oximeter during this period to ensure a consistent heart rate throughout the experiment.

After ten minutes, the word pairs were taken away from the participant and their blood pressure was taken. No specific parameters were set for a blood pressure increase or oxygen saturation decrease but instead were used only as secondary verifications of stress induced on the body. Experimental subjects were then requested to cool down for another five minutes on the exercise bike. To ensure both groups had equal time between studying and testing, control subjects were asked to sit quietly for five minutes. After five minutes, both group's blood pressure, blood oxygen saturation, and heart rate were recorded.

Participants then performed a memory assessment to evaluate their short-term memory retention. The test consisted of randomly ordered pairings in which one word from each pair was removed and participants had to fill in the correct missing word (Figure 3). The subject had five minutes to recall and write in as many missing words with its correct pair as possible. After the allotted time, the test sheet was taken from the participants thus concluding the memory test. Seven days later, the subjects of both groups returned and were given five minutes to repeat the same memory assessment to evaluate their long-term memory retention (Figure 3).

Interpreting Data

Although our target heart rate increase for all experimental participants was 75% above their baseline heart rate, all subjects who obtained at least a 65% increase from their resting heart rate were included. Three subjects that did not reach at least a 65% increase from their resting heart rate were excluded from the study.

The memory test score data was analyzed on a point system. If a participant filled in a correct word pair with two or less extra or missing letters, they received 2 points. If the participant incorrectly paired a word that was found elsewhere on the original study list and contained two or less extra or missing letters, they received one point. If the participant correctly paired a word that was misspelled by 3 or more letters, they received 1.5 points. If the participant incorrectly paired a word found elsewhere on the original study sheet that was misspelled by 3 or more letters, they received 0.5 points. Words that were repeated by test subjects were omitted during scoring. The total possible number of points was 100. This scoring system was used in order to give a more accurate assessment of memory retention by giving partial credit to subjects who recalled parts of a word or remembered that a word was on the list, even if they could not correctly pair it. Scores out of 100 were reported in Table 1. Individual raw scores from each group were averaged and compared using a Welch's two sample t-test and a one-way ANOVA test.

Results

Statistical analysis found no significant difference between the experimental and control group short-term test scores ($t=1.6051$, p-value=0.1168). The mean score of the control group was 56.8250±6.3865 and the mean score of the experimental group was 42.5500±6.1889, as seen in Figure 5.

Statistical analysis found no significant difference in long-term test scores between the experimental and control group ($t=1.2562$, p-value=0.2169). As illustrated in Figure 6, the mean test score of the control group was 24.9500±3.8930 and the mean test score of the experimental group was 18.5500±3.2865.

The individual raw test scores of each participant in the short-term and long-term assessments are shown in Figure 7A. To compare the absolute retention of word pairs for each subject, each participant's raw long-term score was subtracted from their raw short-term score. Statistical analysis found no significant difference between each group's ability to retain the word-pairs one week after memorization (1.3996, p-value=0.0849). The mean difference of the control group was 31.8750±3.7997 and the mean difference of the experimental group was 24.0000±4.1498, as seen in Figure 7B.

Discussion

The present study found no significant difference in short-term test scores, long-term memory test-scores, or absolute memory retention between the control and experimental test groups. As seen in Figures 5 and 6, participants who did not exercise tended to score higher on the short-term and long-term memory assessments than participants who studied the material while exercising. However, Figure 7B illustrates that participants in the experimental group tended to retain more word pairs one week after learning with regard to their short-term test scores. No significant correlation could be drawn between moderate aerobic exercise and improved memory retention.

These observations are consistent with previous comparable studies that examined exercise's effect on short-term memory (Hotter, *et al.*, 2013, Stowell *et al.*, 2012). The current study does not support previous studies examining exercise's effect on word retention immediately after and one week after exercising (Winter *et al*., 2007). The present study analyzed the effects of exercising while studying whereas Winter's study addresses the effects of studying immediately after exercise. This difference in experimental protocol could explain the difference in results.

Though the current study found no significant correlation between exercising and improved memory retention, we did observe some interesting trends. While participants in the control group achieved higher raw scores on both the short-term and long-term assessments, the higher retention rate of the experimental group suggests that exercise may have a positive influence on one's ability to remember information. It is possible that exercising distracted participants from memorizing the material and therefore subjects were not able to learn as many word pairs as the participants who did not exercise while studying. However, exercising could have benefited participants by improving long-term retention of the word pairs they were able to successfully recall in the short-term test.

Due to a limited number of participants, our study did not control for fitness level or learning style of each subject, two components which could have had an effect on their ability to memorize the list of word pairs. We were also not able to control the exact noise level of the experimental environment, so some participants may have experienced more background noise than others, providing another distraction from learning. Our study also did not control for any other stressors on participants, such as stressful life events or learning disabilities that would have prevented participants from memorizing the material.

The greatest limitation of our study was a limited number of participants. Future studies should increase the number of subjects tested and include more specific selection criteria, such as fitness level or learning style, to decrease the effect of individual variability on test results. The current study only required participants to exercise for ten minutes, and it is possible that the benefits of studying while exercising cannot be observed after such a short period of time. Future studies should increase the time spent exercising to address whether or not additional time exercising improves memory retention.

Future experiments should consider having participants perform the memory assessments under both control and experimental conditions in order to minimize error due to individual differences. One group of randomly assigned participants should perform the memory assessments under the exercising treatment first and then memorize another list of words and perform the memory assessments without exercising. A second randomly assigned group would perform the tasks in the opposite order. The study would also have to use two different lists of word pairs so each participant is not memorizing the same list twice.

One final way to increase the validity of the current study would be to only analyze the word pairs retained on both the short-term and long-term evaluations. This directs our analysis to long-term memory retention of the words that participants were able to recall on the short-term and long-term memory tests and excludes any words participants were only able to recall on the long-term memory test.

Although the current study did not find any conclusive evidence to support the benefits of exercising while studying, our results do suggest that moderate aerobic exercise may be slightly correlated with improved memory retention, and further research should be conducted to investigate the role of exercise in cognitive function.

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Acknowledgements

This study was funded by the University of Wisconsin-Madison Department of Physiology. Special thanks to Dr. Andrew Lokuta, Caitlin Murphy, and Physiology 435 student and research participants.

Figures

Figure 1: Photo of modified exercise bike with left armrest used by participants in the experimental tes group

Adult	Kerosene		Sports	Rain
Garden	Nervous		Conditioner	Physics
Sewage	Ibuprofen		Toothpaste	Skipper
Table	Marble		Coconut	Message
Pipe	Fudge		Caffeine	Lobster
Binder	Crockpot		Babcock	Giraffe
Respiratory	Valley		Resort	Coach
Warlock	Ocean		Callus	Wave
Vampire	Cruise		Toe	Synergy
Intersection	Hollywood		Morocco	Paint
Calculator	Vowel		Churro	Desktop
Button	Suffrage		Wolverine	Chai
Furnace	Vodka		Kardashian	Recycling
Filter	Sabotage		Cardigan	Salmon
Projector	Diamond		Grammy	Almond
Outlet	Concert		Lightening	Sesame
Computer	Eyebrow		Wasabi	Zeus
Stardust	Footprint		Chalk	Alpha
Cocaine	Rugby		Draft	Gibbon
Beaker	Cement		Mustache	Tangerine
Stapler	Catnip		Mushroom	Twilight
Flashlight	Shoelace		Calendar	Bridge
Corkscrew	Walgreens		Notebook	Columbia
Blinds	Nostril		Gatorade	Photography
Disinfectant	Skillet		Masculine	Photosynthesis

Figure 2: List of fifty word pairs given to participants to memorize for ten minutes.

Table			Chai
Wasabi			Cement
Sewage			Rain
Computer			Fudge
Respiratory			Crockpot
Warlock			Lobster
Toe			Cruise
Adult			Almond
Cardigan			Suffrage
Intersection			Columbia
Filter			Diamond
Stardust			Photosynthesis
Conditioner			Concert
Toothpaste			Alpha
Callus			Gibbon
Kardashian			Sesame
Corkscrew			Message
Babcock			Shoelace
Churro			Paint
Furnace			Nostril
Cocaine			Skillet
Stapler			Twilight
Mustache			Photography
Calendar			Nervous
Calculator			Coach

Figure 3: Memory retention assessment given to participants immediately after studying and one week after studying. Participants were instructed to fill in the missing word in each pair.

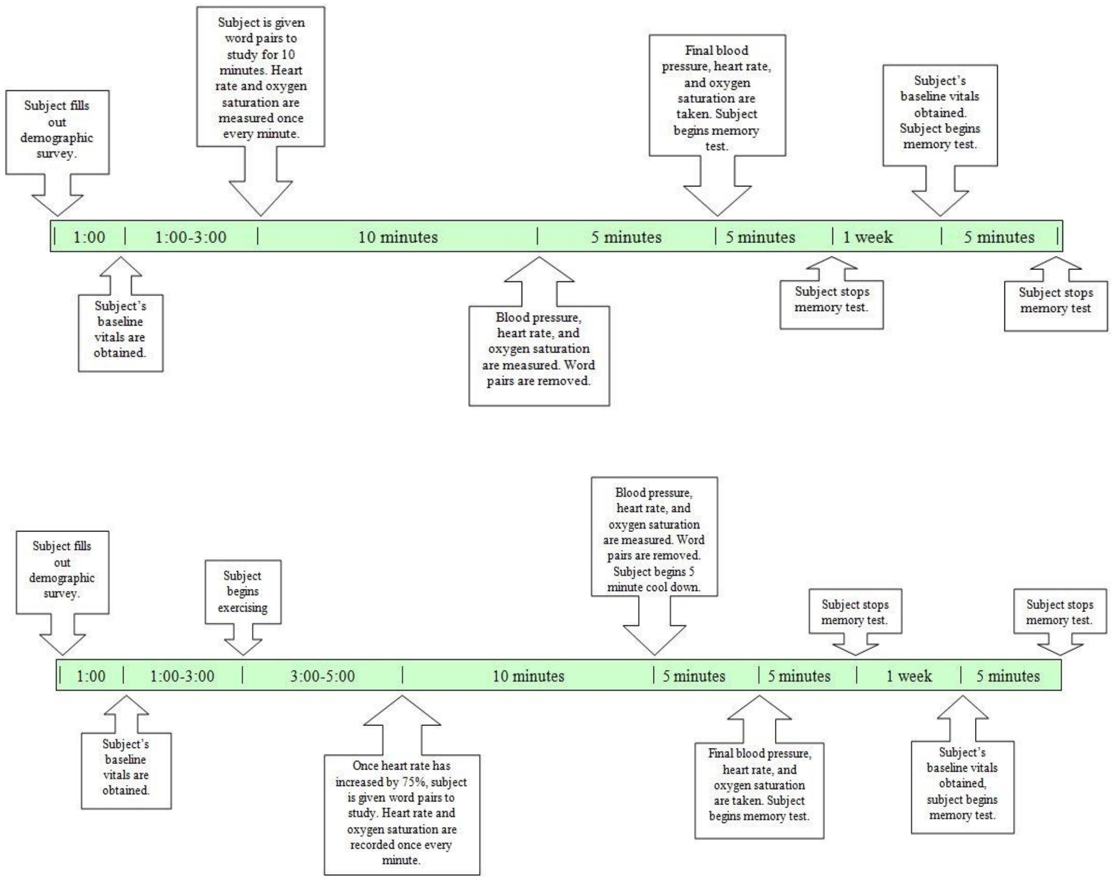

Figure 4. Timeline of experimental protocol for control (top) and experimental (bottom) test groups.

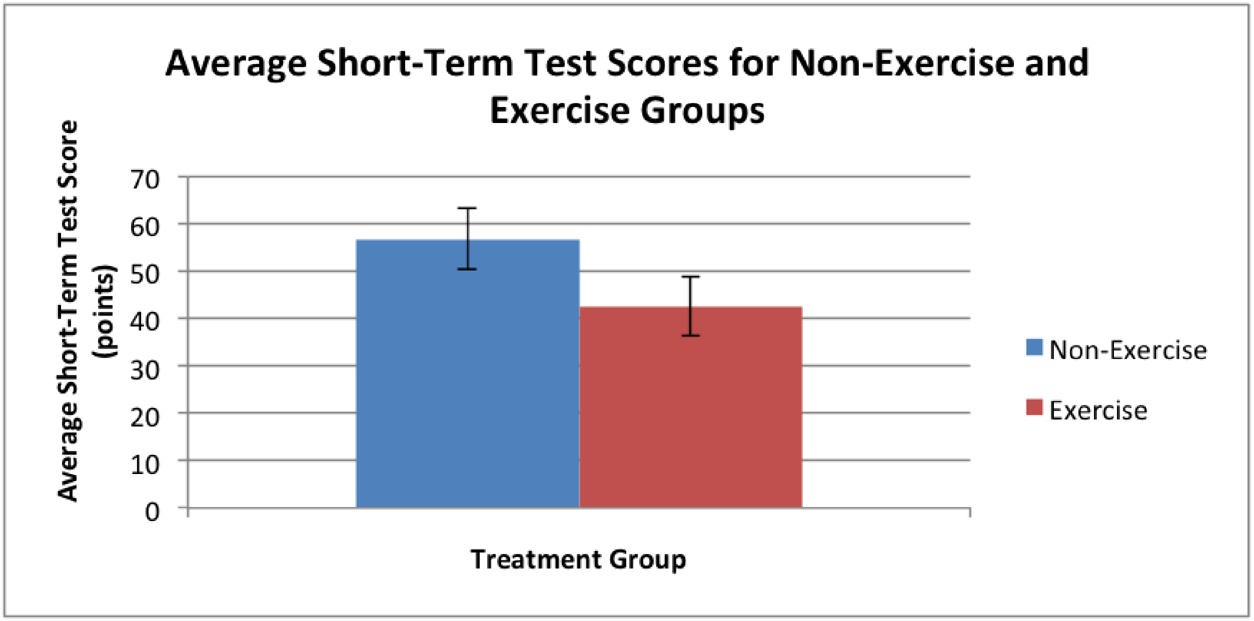

Figure 5. Average short-term raw test scores for non-exercise and exercise groups

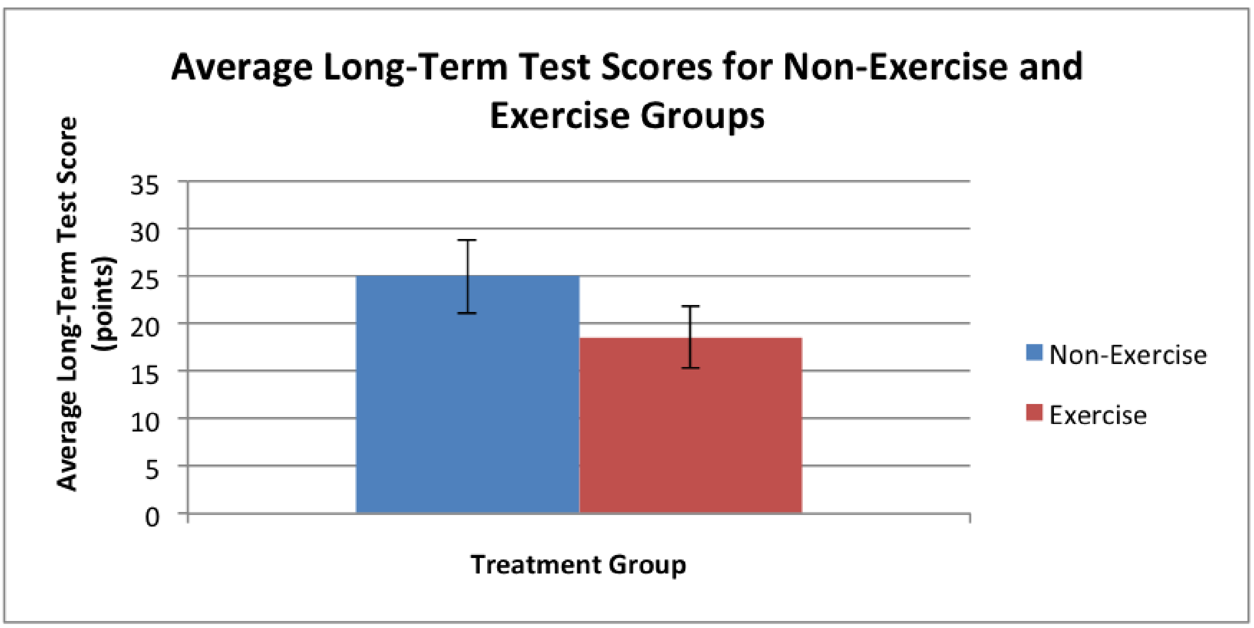

Figure 6: Average long-term raw test scores for non-exercise and exercise groups

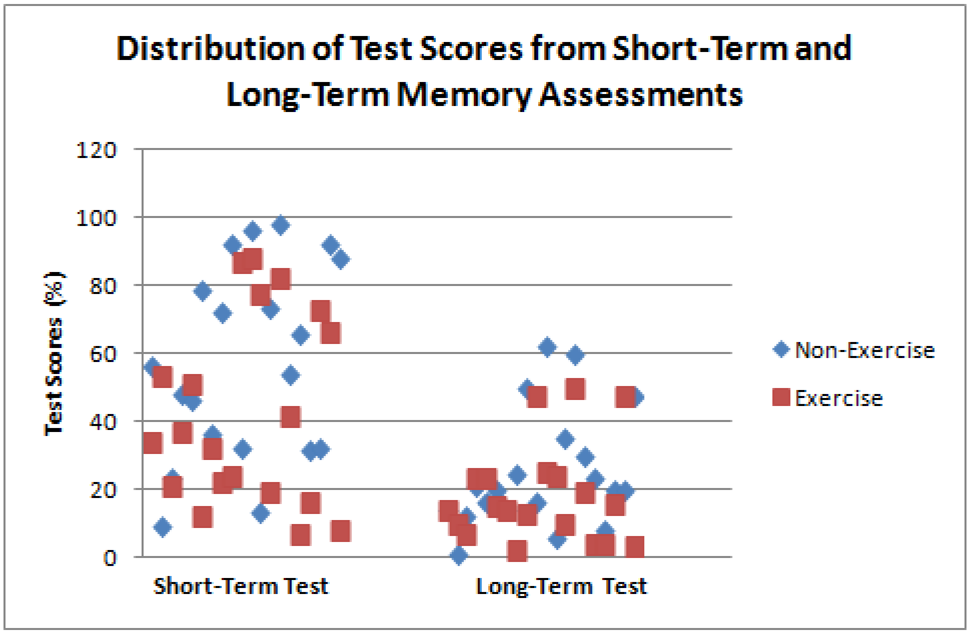

Figure 7A: Raw scores from participants on short-term memory assessment and long-term memory assessment

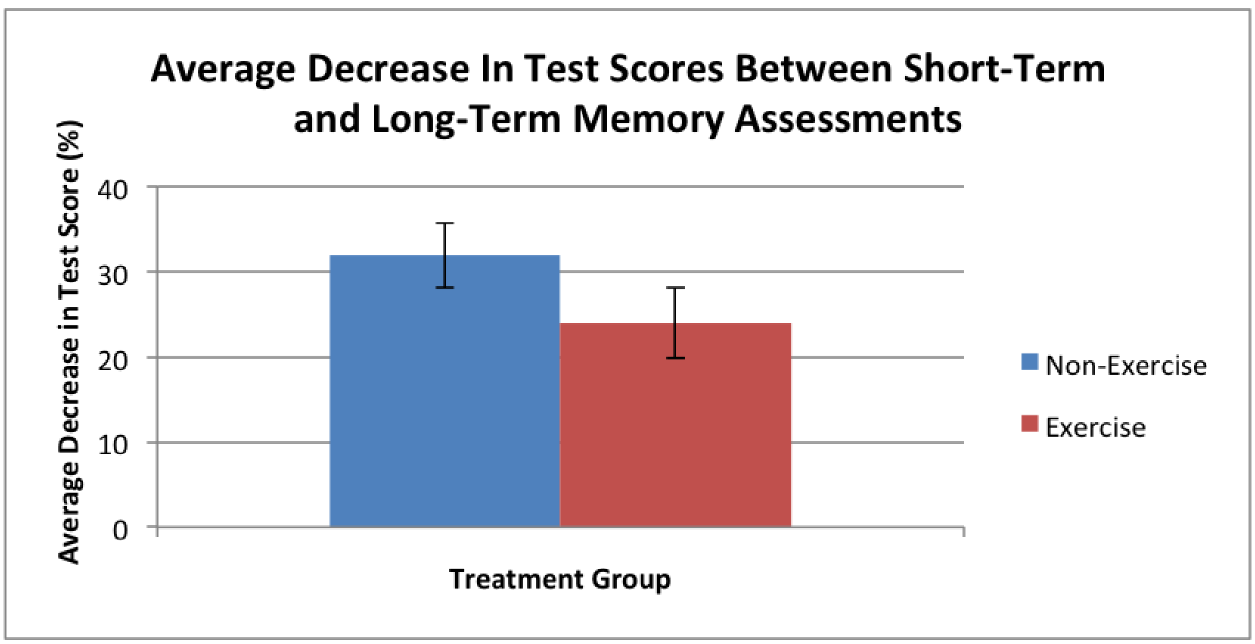

Figure 7B: Average percentage decrease in test scores after seven days for non-exercise and exercise groups