The effects of acute aerobic activity at rating five and seven of perceived exertion on the performance of a word-recollection, short-term memory task

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Abstract

Aerobic exercise has many benefits in improving human health. By increasing oxygenated blood flow and glutamate release into the brain, aerobic exercise has been related to improved long-term memory. Additionally, aerobic exercise has been shown to induce adult neurogenesis, which is correlated to improved long-term memory, in the prefrontal cortex and the hippocampus by stimulating the production of various neural growth factors such as brain derived neurotrophic factor (BDNF) and insulin-like growth factor 1 (IGF-1). Although many studies have shown a correlation between aerobic exercise and improved consolidation of short-term memory to long-term memory, many studies on the effects of brief aerobic exercise on short-term memory have been inconclusive, perhaps due to fatigue-related memory or cognitive impairment. In this study, we sought to examine the effects of acute aerobic activity on the performance of a word-recollection, short-term memory task. Word recollection tasks were conducted following a control, no-exercise condition and after two levels of perceived physical exertion, characterized using the new Borg Rating of Perceived Exertion Scale (RPE). Heart rate, blood pressure, and respiration rates were measured from each participant following an exercise condition to assess the intensity of physical exertion. Despite a statistically significant increase in heart rate, systolic blood pressure, and respiration rate between control and exercise conditions, no statistical significance was found between the number of words recalled in the short-term memory task to exercise intensity; short term memory task performance of the control, no exercise condition was compared to a moderate exercise level (RPE rating 5) and to an intense exercise level (RPE rating 7). Overall, we believe that our study could serve as a basis for conducting future studies that elucidate the relationship between short-term memory and acute aerobic exercise.

Introduction

Throughout recent years, educators have been utilizing simple methods to improve their students' ability to recall information prior to taking an exam. Educators have employed techniques such as making students laugh with jokes or giving students gum to chew during an exam (Powell et al., 1985; Wilkinson et al., 2002). Apart from these, another technique that has been suggested to help improve memory as well as overall human health, is exercise (Alves et al., 2014).

Exercise involves the generation of forces from skeletal muscle contraction that requires an expenditure of energy (Hillman et al., 2008). Due to increases in the metabolic demands of skeletal muscle, physiological changes such as increasing heart rate and respiration also occur in order to accommodate the body's increasing need for oxygen and nutrients. Acute aerobic exercise upregulates the production of glutamate, an excitatory neurotransmitter involved in learning and memory (Malenka et al., 2009; Broussard, 2012; Descarries et al., 2008). Furthermore, it has been shown that aerobic exercise promotes adult neurogenesis through stimulating production of neural growth factors such as brain-derived neurotrophic factor (BDNF), insulin-like growth factor (IGF-1), and vascular endothelial growth factor (VEGF) (Tarumi et al., 2014; Szuhany et al., 2014; Gomez-Pinila et al., 2013). An increase in adult neurogenesis has been shown to increase gray matter volume in the prefrontal cortex and the hippocampus that may be associated with measured improvements to spatial memory (Gomez-Pinila et al., 2013; Erickson et al., 2014; Guiney et al., 2013; Buckley et al., 2014; Erickson et al., 2012; Lees et al., 2013; Carvalho et al., 2014).

Memory is a concept typically divided into two categories: short-term and long-term. For the purposes of this study, we will focus on short-term memory, which is defined as "the capacity of holding information in mind for a short period of time" (Alves et al., 2014). Although numerous studies have been performed on the long-term effects of exercise on memory and cognition, much less has been done on short-term memory, and results have been widely varied.

A study by Segal and colleagues (2012), examined the effects of short intense exercise intervals on memory in the elderly. This experiment yielded results that showed a positive correlation between exercise and memory. Specifically, it was determined that visual memory was improved due to an increase in norepinephrine that was induced by exercise. Similar studies, such as those performed by Roig and colleagues, support these findings; in a 2013 study, they showed that acute exercise may improve memory by increasing neurotransmitter release in the hippocampus that may be associated with the consolidation of short-term memory to long-term memory.

Although these studies have shown that a positive correlation between exercise and an improvement on short-term memory, a more widespread finding has been that there is no correlation between the two variables. One study, involving the use of intensive cycling at 75% of an individual's maximum volume of consumable oxygen (VO_{2max}) while simultaneously performing a short term memory task, showed that there was no significant effect of exercise on memory performance (as cited in Tomporowski, 2003). Additionally, a study performed by Cian and colleagues demonstrated that individuals that ran for two hours at 60% VO_{2max} prior to taking a cognition test, did not see any significant improvement in their results (as cited in Tomporowski, 2003). However, we believe that simultaneous performance of a short-term memory task and exercise may have negatively impacted results due to the distraction caused by exercise.

Many experiments have been conducted to determine the effects of exercise on memory, but no conclusive correlation between short-term memory and exercise has been shown, despite strong evidence indicating a correlation between long-term memory and exercise in the aging population (Bherer et al., 2013). To develop a better understanding for the potential effects of exercise on improving short-term memory, we designed an experiment to test the effects of two perceived intensity levels of exercise on its potential in improving performance in a short-term memory task. Not only will this experiment provide information of the physiological changes brought about by exercise, but it will also provide insight, particularly to college students, as to whether or not exercise is a useful strategy to improve memory.

For our study, acute aerobic activity is defined as cardiovascular exercise performed for three minutes at level five and level seven of an individual's perceived maximum physical exertion using the new Borg Rating of Perceived Exertion Scale (RPE). RPE measures an individual's perceived effort or fatigue during aerobic exercise (Borg, 1982). The new RPE scale ranges from levels zero to ten, with increasing perceived exertion with increasing level (Borg, 1982). Perceived intensity levels from RPE are shown to correspond to indicators of exercise intensity such as lactate accumulation, oxygen consumption, and changes in heart rate in a linear fashion (Borg, 1982; Reed et al., 2015). RPE levels used for this study are levels five and seven that approximate 50% and 70% maximum exertion levels that are similar to previous studies that showed inconclusive results. Previous studies, showing no correlation between aerobic activity and improvement in short term memory, conducted memory tasks and exercise simultaneously. Effects of fatigue may have impaired the concentration of participants, thereby negatively impacting the obtained results (Dawson et al., 1997). Due to these confounding factors, we chose to conduct our experiment at similar exertion levels.

Ultimately, we hypothesize that physical exertion at level five of the RPE scale, will maximize performance on a short-term memory task, compared to a control group that did not perform exercise prior to the task. We hypothesize that exercise at this moderate intensity level may provide the physiological benefits of aerobic exercise without causing physical exhaustion, thereby maximizing short-term memory recollection. Additionally, we hypothesize that at a higher level of acute aerobic activity, level seven of RPE, individuals will have reduced performance on the short-term memory task compared to the control, no exercise group due to effects exhaustion and lack of ability to fully concentrate on short-term memory task.

To test this hypothesis, individuals performed two different levels of aerobic activity, level five (moderate exercise) and level seven (intense exercise) of the RPE, prior to a short-term memory task involving word-recollection. The effects of the various levels of acute aerobic activity on physiological phenomena such as oxygen saturation level, respiration rate, blood pressure, and heart rate will be measured in addition to performance on the short-term memory task. However, we believe that higher intensity levels of aerobic activity may negatively affect short-term memory due to the effects of physical exhaustion and fatigue.We will measure an individual's baseline oxygen saturation level using a pulse oximeter, respiration rate using a respiration belt, and blood pressure using a blood pressure cuff prior to administering a word recollection, short-term memory task. Following the baseline measurements, participants will perform two intensity levels of cycling exercise, level five (moderate) and level seven (intense) of RPE. Immediately after exercise, measurements will be repeated and the short-term memory test will be readministered, using a different set of words. Through this experiment, we hope to obtain a better understanding for the relationship between varying intensity levels of exercise on short-term memory recollection.

Methods

Participants

The sample population used for this study was comprised of twenty-two (n=12 females and n=10 males) undergraduate students from the Physiology 435 course at the University of Wisconsin-Madison. Participants ranged from 17-25 years of age. No monetary compensation, course credit, or other incentives were provided for participants. All students were voluntary participants that signed a consent form outlining all risks involved with the study (Appendix A).

Materials

The following is a list of materials used in this experiment:

- Omcron Automated Blood Pressure Monitor, Model BP791IT (HEM-7222-ITZ), Serial Number: 20141004369LG, Manufactured by Omcron Healthcare Inc. (Lake Forrest, IL)
- Biopac Respiration Belt, Model SS5LB, Serial Number: 1602007558, Manufactured by Biopac Systems (Goleta, CA)
- Monin Pulse Oximeter, Model 9843, Serial Number: 118103098, Manufactured by Monin Medical Inc. (Minneapolis, MN)
- Biopac Student Labs 4.0 Software, Model MP36, Serial Number: MP36E1204002784, Manufactured by Biopac System (Goleta, CA)
- Goldman's Gym Cycle Trainer 390R Stationary Bicycle, Manufactured by Gold's Gym

Data collected for respiration was obtained using a respiration belt connected to Biopac Student Labs 4.0 software and hardware.

Procedure

Written consent was obtained from all participants prior to data collection and experimentation (Appendix A). Details regarding the need for intensive aerobic activity was explicitly described to participants. Participants were told that they had the ability to cease physical activity or end participation at any point during the experiment and were encouraged to inform researchers of discomfort. Additionally, a certified cardiopulmonary resuscitation (CPR) individual was present at all times during the experimentation process, and automated external defibrillator (AED) was readily accessible at all times during the experimental procedure.

Prior to experimentation, blood pressure was measured using an Omcron Automated Blood Pressure Monitor prior to aerobic exercise. Additionally, respiration was collected using the Biopac Respiration Belt, and heart rate was collected using a Monin Pulse Oximeter prior to aerobic exercise. After obtaining the baseline measurements for heart rate, blood pressure, respiration, a short term memory task was administered for four minutes. The short-term memory task involved the memorization of a randomly generated set of twenty-five words for two minutes, followed by two minutes of word recollection. The duration and number of words featured on this task were determined by a pilot study to ensure that a maximum score was not readily attainable nor was the task too difficult for participants to complete within the given time. Recalled words were collected on a survey form, and the amount of words and accuracy were measured.

Following baseline measurements, participants were made to exercise on a stationary bicycle with sixteen levels of adjustable resistance intensity. Participants started with zero intensity, and levels were increased by increments of one every thirty seconds. Prior to adjusting the resistance intensity, participants were asked their perceived level of exertion using the one-to-ten RPE scale. Once participants reached the RPE level of five, they were motivated to continue exercising until they have met three minutes of exercise on their current resistance level. Following three minutes of exercise at a RPE level of five, blood pressure, heart rate, and respiration were measured. The word-recollection task with new unique, randomly-generated words was administered to participants.

After the short-term memory task, participants returned to the stationary bike at the level of resistance that was last used. Resistance intensity was increased by increments of one every thirty seconds, and participants were asked their perceived level of exertion prior to increasing resistance intensity. Once participants reached the RPE level of seven, they were encouraged to continue exercising until three minutes of aerobic activity at the current resistance intensity was performed. Following exercise, blood pressure, heart rate, and respiration were measured and a new word-recollection task with unique, randomly-generated words was re-administered. RPE levels of five and seven, along with the duration of exercise, were determined via pilot study to ensure that an uncomfortable level of physical exertion was reached but was not injurious to the participants and did not compromise their willingness to engage in this study.

Three sets of data containing blood pressure, heart-rate, and respiration measurements along with performance on the short-term memory task was collected per individual following no exercise (Control), exercise at RPE level five at three minutes (Group 1), and exercise at RPE level seven at three minutes (Group 2). Procedures for this experiment are summarized in Figure 1 below. Data obtained from the three different data-sets per individual participant were analyzed for statistical significance.

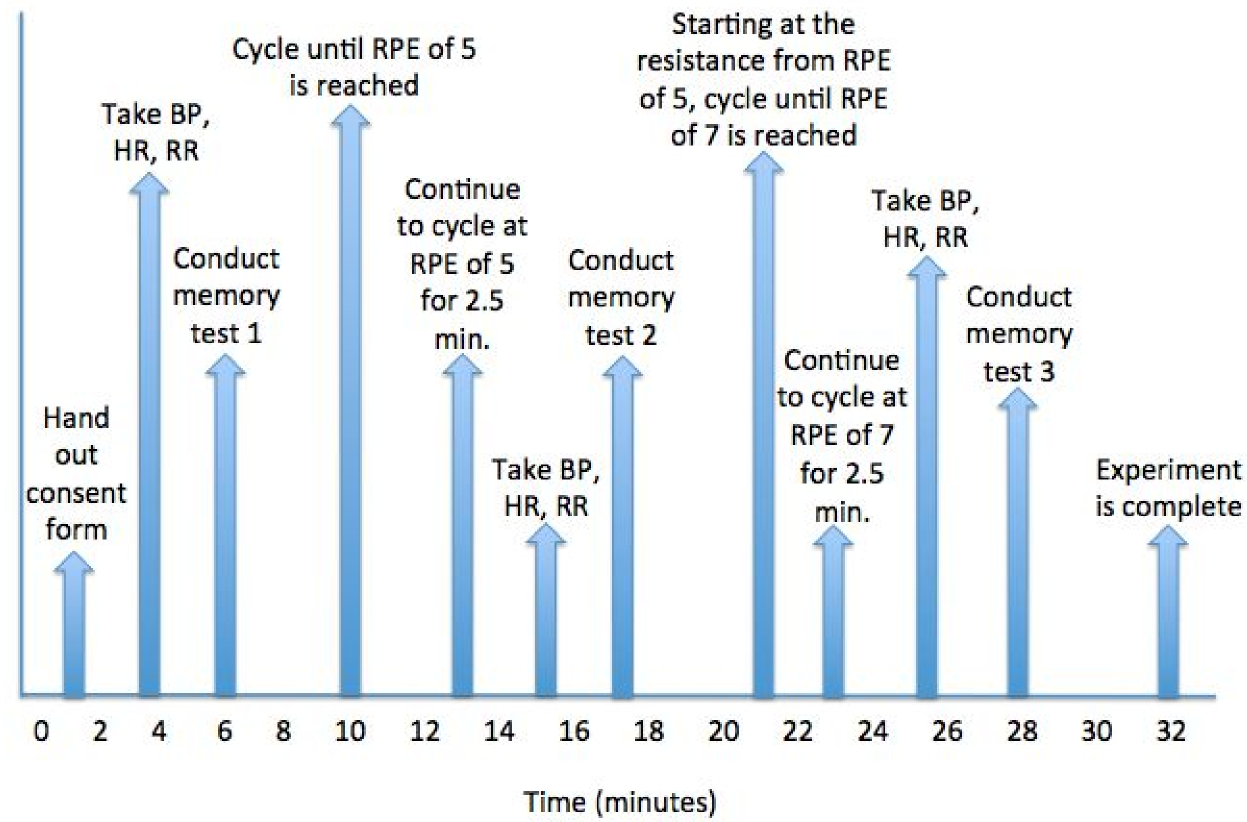

Figure 1: Timeline of experiment. Following the signing of a consent form, the participant's heart rate (HR), blood pressure (BP), and respiration rate (RR.) were measured by the experimenter. HR and BP were measured continuously until the completion of each memory task. Physiological measurements taken before exercise served as the control for each subject. Once BP and HR were taken, the participant completed memory test 1 (Appendix B). The duration of each memory task was four minutes. After completion of memory test 1, the participant started cycling at a resistance of 0 that increased until RPE of 5 was reached. Once RPE of 5 was reached, the participant continued to cycle for 2.5 minutes. Next, the participant's HR, BP, and RR were measured, followed by memory test 2 (Appendix C). The participant cycled again starting at the previous resistance from RPE of 5 and continued to cycle until RPE of 7 was reached. When RPE of 7 was reached, the participant cycled for 2.5 more minutes. Following cycling at RPE of 7, the participant's HR, BP, and RR were measured. Lastly, memory test 3 (Appendix D) was completed by the participant, concluding the experiment. Results were analyzed using paired, two-tail, student t-tests between control and exercise conditions.

Results

All data was processed with assistance from a graduate statistician from the University of Wisconsin - Madison using Microsoft Excel and R Studio Software.

Respiration Rate

Paired, two-tail, student t-tests were used to analyze the difference in respiration rate before and after exercise for moderate exercise and intense exercise groups. Differences in respiration rate, measured in breaths per minute, before and after exercise, were statistically significant for the moderate exercise group (RPE rating 5, n=22, P=0.0501) and intense exercise group (RPE rating 7, n=22, P=0.0015). Average increase in respiration rate following moderate exercise was 0.4545 breaths per minute. This difference was taken from the average respiration rate before exercise, 19.682±0.685 breaths per minute, and after exercise, 22.000±0.963 breaths per minute, for moderate exercise. Average increase in respiration rate following intense exercise was 2.3636 breaths per minute. This difference was taken from the average respiration rate before exercise, 20.136±0.943 breaths per minute, and after exercise, 24.364±0.932 breaths per minute, for intense exercise. For the no-exercise, control condition, an average respiration of 19.6818±0.685 breaths per minute was measured.

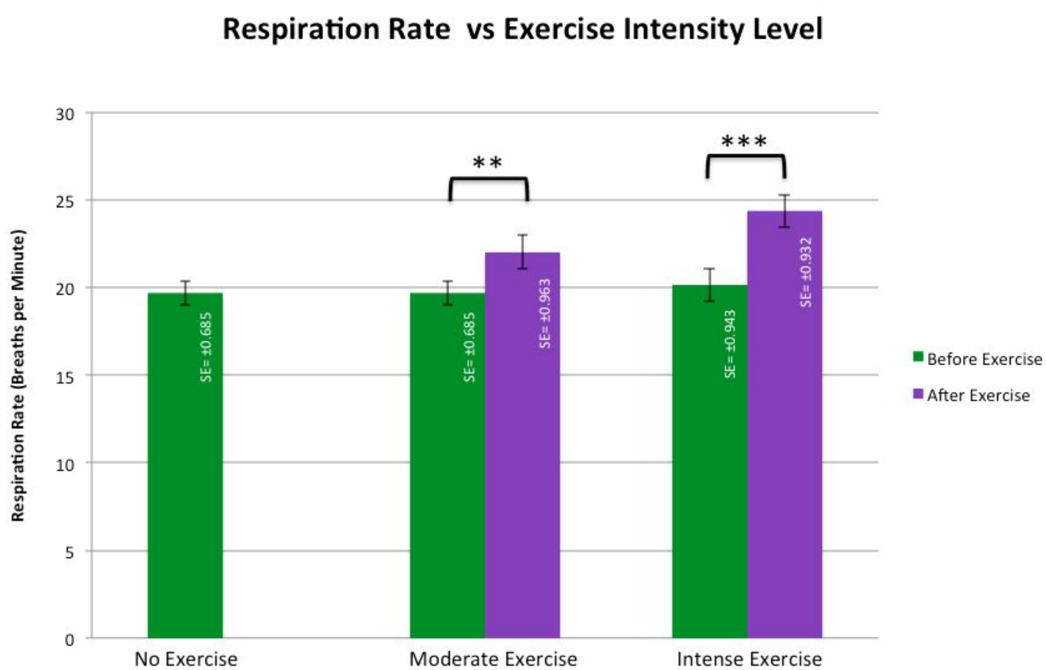

Figure 2: Average respiration rate, measured in breaths per minute, before exercise and after exercise for the no exercise, control condition (n=22), moderate exercise condition (RPE rating 5, n=22), and intense exercise condition (RPE rating 7, n=22). Statistical significance of differences were designated as ** or ***
**Indicates statistical significance in respiration rate before and after the moderate exercise condition. ***Indicates statistical significance in respiration rate before and after the intense exercise condition.

Heart Rate

Average heart rate, measured in beats per minute (bpm), for the control, no-exercise condition (n=22) was 80.955±3.274 bpm. Average heart rate for the moderate exercise condition (n=22) and the intense exercise condition (n=22) was compared to the control using paired, two-tail, student t-tests. The average heart rate for the moderate exercise condition (RPE rating 5, n=22) was 112.409±5.925 bpm. There was a statistically significant increase in heart rate of 31.455 bpm for the moderate exercise condition compared to the control, no exercise condition ($P=8.03\times10^{-8}$). The average heart rate for the intense exercise condition (RPE rating 7, n=22) was 128.182±4.867 bpm. There was a statistically significant increase in heart rate of 47.227 bpm for the intense exercise condition compared to the control, no exercise condition ($P=2.736\times10^{-11}$).

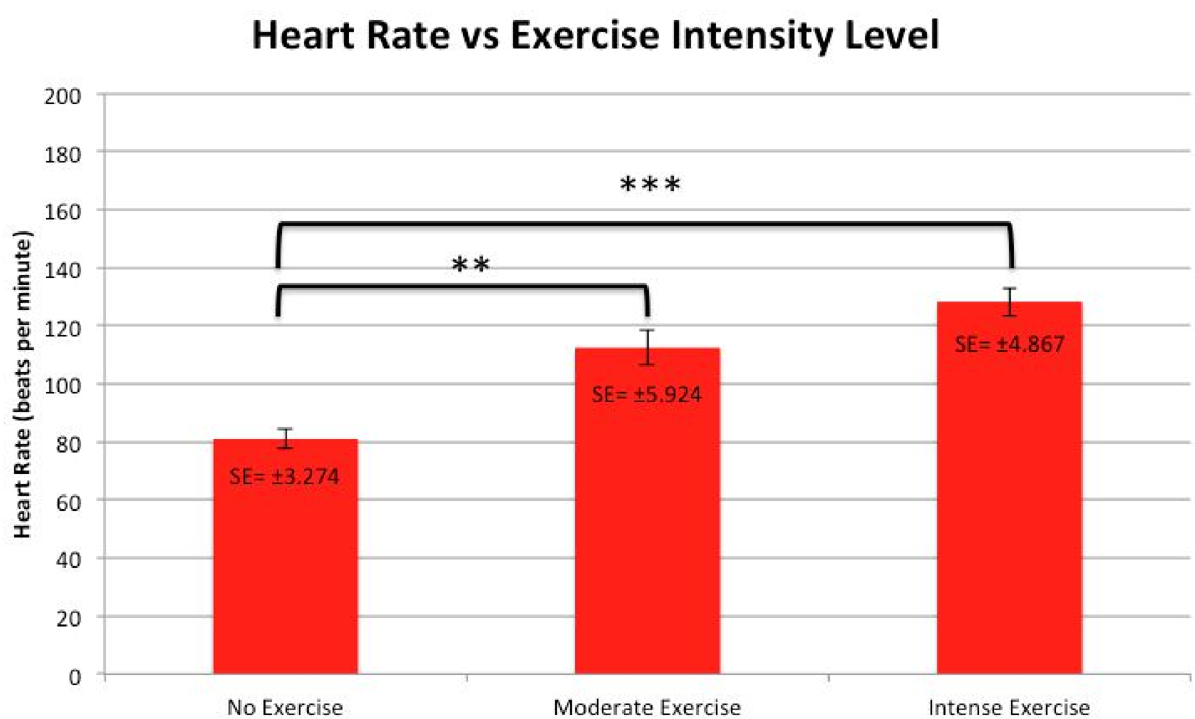

Figure 3: Average heart rate, measured in bpm, for the control, no exercise (n=22), moderate exercise (RPE rating 5, n=22), and intense exercise conditions (RPE rating 7, n=22). Statistical significance of differences were designated as ** or ***
**Indicates statistical significance in heart rate between the control, no-exercise condition, and the moderate exercise condition. ***Indicates statistical significance in heart rate between the control, no-exercise condition, and the intense exercise condition.

Blood Pressure

Mean arterial pressure, systolic pressure, and diastolic pressure were calculated using blood pressure cuff data for each condition. For the control, no exercise condition (n=22), the following average pressure measurements were calculated: 92.108±1.561 mmHg for mean arterial pressure, 118.545±2.872 mmHg for systolic pressure, and 78.909±1.672 mmHg for diastolic pressure. For the moderate exercise condition (n=22), the following average pressure measurements were calculated: 94.801±2.462 mmHg for mean arterial pressure, 128.545±2.567 mmHg for systolic pressure, and 77.955±3.084 mmHg for diastolic pressure. Lastly, for the intense exercise condition (n=22), the following average pressure measurements were calculated: 95.318±2.218 mmHg for mean arterial pressure, 126.455±3.354 mmHg for systolic pressure, and 79.772±3.354 mmHg for diastolic pressure. Overall, no statistically significant differences in mean arterial pressures and diastolic pressures were found between the control, no exercise condition, and the moderate exercise and intense exercise conditions. However, a statistically significant increase in systolic pressure was measured for both exercise conditions compared to the control, no exercise condition. An increase of 10.000 mmHg (P=0.00327) was found between the moderate exercise condition (RPE rating 5, n=22) and the control, no exercise condition. Similarly, an increase of 7.909 mmHg (RPE rating 7, P=0.04384) was found between the intense exercise condition and the control, no exercise condition.

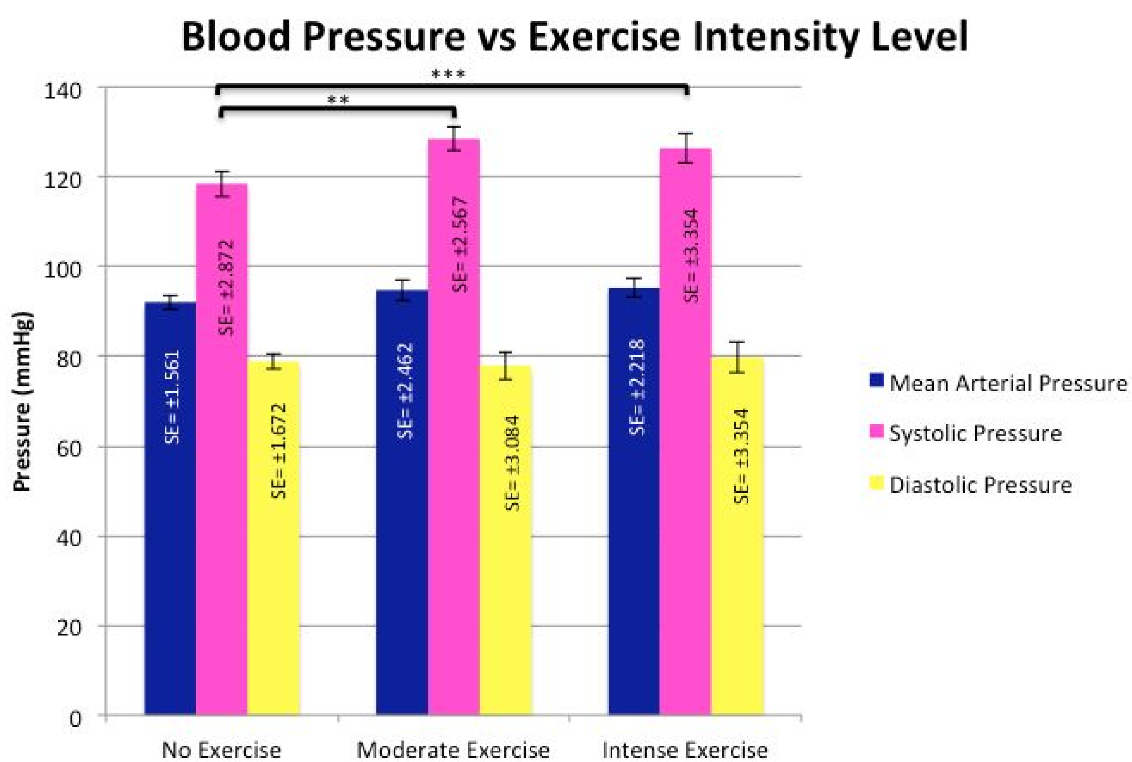

Figure 4: Average blood pressure (Mean Arterial Pressure, Systolic Pressure, and Diastolic Pressure) measured in mmHg was obtained for the control, no exercise (n=22), moderate exercise (RPE rating 5, n=22), and intense exercise (RPE rating 7, n=22) conditions. Statistical significance of differences were designated as ** or ***

**Indicates statistical significance in systolic pressure between the control, no-exercise condition and the moderate exercise condition. ***Indicates statistical significance in systolic pressure between the control, no-exercise condition and the intense exercise condition

Word Recollection Memory Task

Short-term memory was assessed by scoring the number of words that were correctly recalled by participants following the control, no exercise condition (n=22), the moderate exercise condition (n=22), and the intense exercise condition (n=22). No participants were able to recall the maximum number of words, twenty-five, featured in this task. Differences between word recollection of the moderate exercise condition compared to the control, no exercise condition, and the intense exercise condition compared to the control, no exercise condition, were analyzed using paired, two-tail, student t-tests. The average number of words recalled in the control, no exercise condition (n=22) was 10.682±0.639 words. The average number of words recalled in the moderate exercise condition (RPE rating 5, n=22) was 11.591±0.758 words; a statistically insignificant difference of 0.909 words (P=0.1751) was found between the moderate exercise condition and the control, no exercise condition. The average number of words recalled in the intense exercise condition (RPE rating 7, n=22) was 10.727±0.639 words; a statistically insignificant difference of 0.0455 words (P=0.9473) was found for the intense exercise condition and the control, no exercise condition.

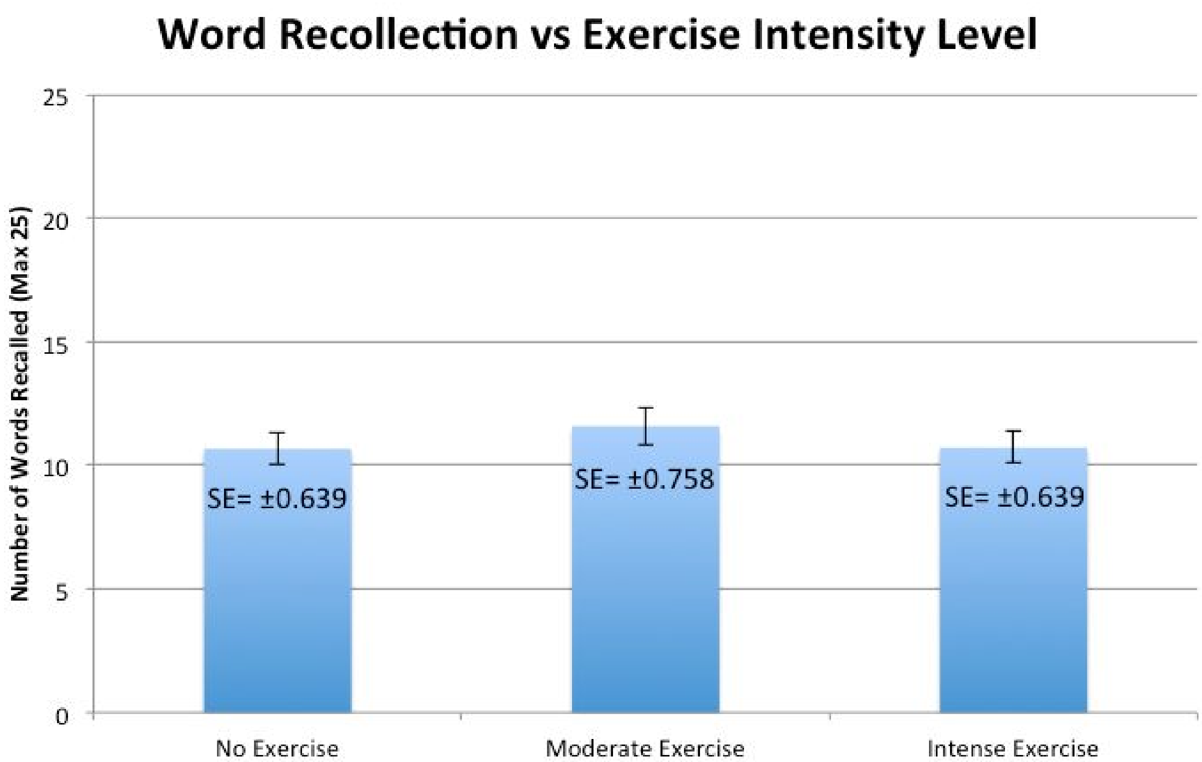

Figure 5: Average number of words recalled in a short-term memory task for the control, no exercise (n=22), moderate exercise (RPE rating 5, n=22), and intense exercise (RPE rating 7, n=22) conditions. No statistical significance in difference was found between groups.

Discussion

Our initial hypothesis states that moderate exercise (RPE rating of 5) will maximize performance on the word-recollection, short term memory task in comparison to the control, no exercise, condition. Additionally, we hypothesized that reduced short-term memory recollection would occur following intense exercise (RPE rating of 7). However, both of these hypotheses were not supported by our results. A statistically significant increase in heart rate, systolic blood pressure, and respiration rate was indicative of exercise exertion following both moderate and intense exercise. Although there was statistical significance in average heart rate, average systolic blood pressure, and average respiration rate, there was no significant difference found between both exercise conditions and performance on the short-term memory task relative to the control, no-exercise condition.

Limitations in our study include the sample size of our participants (n=22) for all three conditions. Similarly, the age range of participants was 17-25 years of age; this sample population does not accurately reflect the general population. Potential confounding factors include the individual participant's unique state of mental and physical health, changes to the environment in which tests were conducted (changes could have created distractions for the participants during testing), and the close proximity of researchers to the participants during exercise and memory testing (which may have acted as a distraction).

Potential sources of error in our study may have been introduced via manual data collection and data analysis. This includes manual respiration-rate counting that was subjective and varied between researchers who were analyzing the data. Furthermore, variations between equipment and the manner with which different researchers handled the equipment could have resulted in variation in the collected data. For example, the tightness of the respiration belt differed based upon participant physique and the researcher administering the respiration measurement. Similarly, the use of multiple blood pressure cuffs and variation on the use of the devices could have altered obtained results.

Future work in this area of study could include an initial survey to assess each participant's unique fitness level, differentiating the results between sexes in order to understand potential physiological differences, the use of different aerobic exercises to increase RPE, and the use of a variety of short-term memory tests. Furthermore, a wider range of physical exertion based upon RPE ratings could have been studied. By addressing the limitations of this study, future research may be able to find a significant impact of acute exercise on short-term memory.

Overall, our results suggests that there may be no correlation between acute aerobic exercise and performance on a short-term memory, word-recollection task. However, due to confounding factors and potential sources of error in this study, further research on this topic is needed to understand the relationship between acute aerobic exercise and short term memory. This paper served to improve our understanding for the relationship between acute aerobic exercise and short-term memory; as suggested in studies cited in Tomporowski, 2003, this might be an indirect relationship that is not readily quantifiable and requires more research. Therefore, the results and methods featured in this study may serve as a basis for conducting future studies to elucidate the physiological impacts of acute aerobic exercise.

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Appendix A

UNIVERSITY OF WISCONSIN-MADISON
Research Participant Information and Consent Form

Title of the Study: The effects of acute aerobic activity on word-recollection, a short-term memory task

Principal Investigators: Susanna Kwok, Amber O'Brien, Milada Vannarath, Brandon Basinski, and Koua Vang

DESCRIPTION OF THE RESEARCH

You are invited to participate in a research study about the effects of aerobic exercise (namely cycling) on a memory task.

You have been asked to participate because you are enrolled in Physiology 435.

The purpose of the research is to measure heart rate, oxygen saturation level, blood pressure, and short term memory, prior to and after exercise in order to have a better understanding for the effects of exercise on mental acuity.

This study will invite the participation of all students enrolled in Physiology 435.

This research will take place within Physiology 435 laboratory sections.

WHAT WILL MY PARTICIPATION INVOLVE?

If you decide to participate in this research you will be asked to perform aerobic activity that might be slightly uncomfortable for a brief period of time. Additionally, the study will involve taking physiological measurements using equipment that will be placed on your body such as a blood pressure cuff, a pulse oximeter, and respiration belt.

Your participation will last approximately thirty to forty-five minutes. Water and electrolyte beverages will be provided to you upon the completion of exercise.

No credit will be assigned for your complete and voluntary participation. If you do not wish to participate, simply return this blank consent form.

ARE THERE ANY RISKS TO ME?

Aerobic exercise may induce symptoms of physical discomfort such as chest-pain, dizziness, difficulty breathing, nausea, numbness, or pain. If at any time you feel such symptoms, you are encouraged to inform researchers and cease physical activity immediately. The study will have, at all times, a trained CPR certified individual that will be prepared to assist you at any time. Additionally, a defibrillator is readily accessible and can be employed if needed.

This study will stop based upon your personal perceived exertion level; therefore, cessation will be based upon your personal perception of when the exercise should stop.

ARE THERE ANY BENEFITS TO ME?

You will obtain a better understanding for your personal fitness level and will be able to complete your daily requirement for exercise through participating in this study.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

While there may be printed reports as a result of this study, your name will not be used. Only group characteristics will be reported – that is results with no identifying information about individuals will be used in any reported or publicly presented work.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?

Please contact Suzy Kwok at sskwok@wisc.edu or call 608-408-8802 if you have any questions.

If you are not satisfied with response of research team, have more questions, or want to talk with someone about your rights as a research participant, you should contact Dr. Andrew Lokuta, 608-263-7488, ajlokuta@wisc.edu.

Your participation is completely voluntary. If you decide not to participate or to withdraw from the study it will have no effect on your grade in this class.

Your signature indicates that you have read this consent form, had an opportunity to ask any questions about your participation in this research and voluntarily consent to participate.

Name of Participant (please print):_____________________________________

__________________________ _________________

Signature Date

Appendix B

Swindler	Crater	Blaster	Magnet	Anything
Deer	Little	Filthy	Biological	Rival
Blister	Warp	Absurdity	Perfect	Hymn
Engine	Commercial	Heelbone	Royalty	Alliance
Switch	Hypnotic	Trust	Disaster	Mad

Appendix C

Glamour	Blip	Germ	Penguin	Moonbeam
Cosmetic	Gimmick	Error	Promised	Decadence
Racket	Hollow	Hump	Bench	Catch
Clear	Ambient	Predatory	Tyrant	Brightly
Breathless	Wealthy	Conceptual	Mutagen	Money

Appendix D

Sweat	Choking	Galactic	Bible	Breakable
Pelvic	Terrific	Bloodstream	Artist	Skin
Funnel	Communication	Immunity	Feast	Young
Guideline	Barbarian	Glow	Arcane	Chronological
Hopeless	Basket	Impure	Magnificent	Democratic