The Effect of Moderate Aerobic Exercise on Information Retention

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Abstract

Regular physical activity is associated with many benefits including decreased stress, improved mood, and improved memory and learning. Studies in mice and rats have shown that exercise directly affects hippocampal activity resulting in improved memory. While previous studies provide substantive evidence for the benefits of regular physical activity, we examined whether short-term physical activity before learning yields similar positive effects on information recall. In testing human participants' recall both in resting and active settings, we examined if a positive correlation between acute exercise and memory would be apparent. Conversely, we examined if testing after rest, or participants not elevating physiological variables, would yield poorer performance results. The study investigated three physiological variables—heart rate, respiratory rate, and respiratory airflow—and compared recall performance with the variables baseline and elevated values. The effects of exercise were not statistically correlated with increased performance in our memory test. We found slight evidence supporting our hypothesis, but our results were mostly inconclusive. With some modifications, further research can better explain the role of exercise on memory and other cognitive function in humans.

Introduction

Exercise is a key factor in living a healthy lifestyle. According to the Physical Activity Guidelines for Americans, published by the U.S. Department of Health and Human Services, regular exercise “reduces the risk of many adverse health outcomes,” including diabetes, stroke, heart disease, and even some types of cancer. In addition to the positive effects on physical health, exercise can improve cognitive function, which is the focus of our study (Department of Health, 2008).

Regular physical activity is associated with improved memory and learning. Part of this effect is an indirect result through improved mood and decreased stress (Brinke, 2014). Exercise has a direct effect through the hippocampus, which plays an important role in memory and learning. Recent research on animals like rats and mice shows that physical activity causes an increase in neurogenesis in the dentate gyrus of the hippocampus, leading to the hypothesis that exercise can improve cognitive function through these new hippocampal neurons (Van Praag, 2008). In rats, exercise causes “enhanced expression of long-term potentiation in [the] dentate gyrus and enhanced object recognition” (O’Callaghan, 2007). A 2009 study in rats showed that exercise caused rats to demonstrate improvements in both spatial and nonspatial learning (Griffin, 2009).

The benefits of exercise on learning are not limited to rats and mice but are believed to extend to humans as well. As people age, damage to the hippocampus leads to a decline in cognitive function, a “key biomarker in the preclinical stages of Alzheimer’s disease” (Varma, 2014). Through the positive effects on the hippocampus, recent findings show that exercise can help to slow cognitive decline. Moderate aerobic exercise, like low-intensity walking, is associated with larger hippocampal volume in older adults (Varma, 2014). In a study of 120 older adults, aerobic exercise led to improvements in spatial learning and a 2% increase in hippocampal size, therefore “effectively reversing age-related loss in volume by 1 to 2 [years]” (Erickson, 2011). In addition to preventing hippocampal degeneration related to aging, regular exercise produces benefits for healthy adults. Among healthy young adult females, a ten-week military training course improved mood and cognitive performance in a variety of tests (Lieberman, 2014).

Our study focused on the more immediate effect of aerobic exercise on cognitive function, as tested on healthy subjects. Previous findings suggest that high-intensity exercise prior to cognitive tests result in a better performance. For example, high-intensity interval training (HIIT) is associated with improved selective attention in a Stroop test performed immediately after the HIIT session (Alves, 2014). In another study with healthy participants, learning of a new vocabulary was increased by 20% after high impact running exercises, and retention of this vocabulary over one week was significantly better in the high-impact exercise condition (Winter, 2007). While these studies targeted high-intensity exercise, our focus will be moderate exercise. We hypothesize that moderate aerobic exercise immediately before learning will improve recall of information. If our results had shown to be positive, moderate exercise could potentially have been performed in a variety of settings prior to learning in order to enhance memory.

Methods

Participants

The sample population for this study consisted of 20 (n=17 female and n=3 male) undergraduate students in Physiology 435 at the University of Wisconsin-Madison. Students were asked to volunteer for the study and to sign a consent form outlining any risks or benefits of participating in the study. Participants were between the ages of 21-28 years old. There was no monetary or class credit compensation given to volunteers.

Materials

- Model 9843 Pulse Oximeter/CO_2 Detector (Nonin Medical, Inc.)
- Respiratory Transducer SS5LB (Biopac Systems, Inc.)
- Airflow Transducer SS11LA (Biopac Systems, Inc.)
- Disposable Mouth AFT2 (Biopac Systems, Inc.)
- Noseclip AFT3 (Biopac Systems, Inc.)
- Cycle Trainer 390R (Gold's Gym)
- Random.org Random Number Generator

The Respiratory Transducer and Airflow Transducer were both connected to Biopac Student Labs 4.0 software, which was used to record and analyze the data. The Biopac Student Lab Laboratory Manual provided instruction on the use of equipment and software.

Procedure

The experiment examined whether brief exercise has an effect on learning and memory. To begin the study, volunteers completed a consent form and a brief survey about their age, gender, sleep from the previous night, and average weekly activity. Each participant completed both the active and control condition approximately two weeks apart, and a virtual coin toss determined which condition would be completed first. Researchers read a script to participants to inform them what was expected of them and how the memory test would be administered (**Figure 1**).

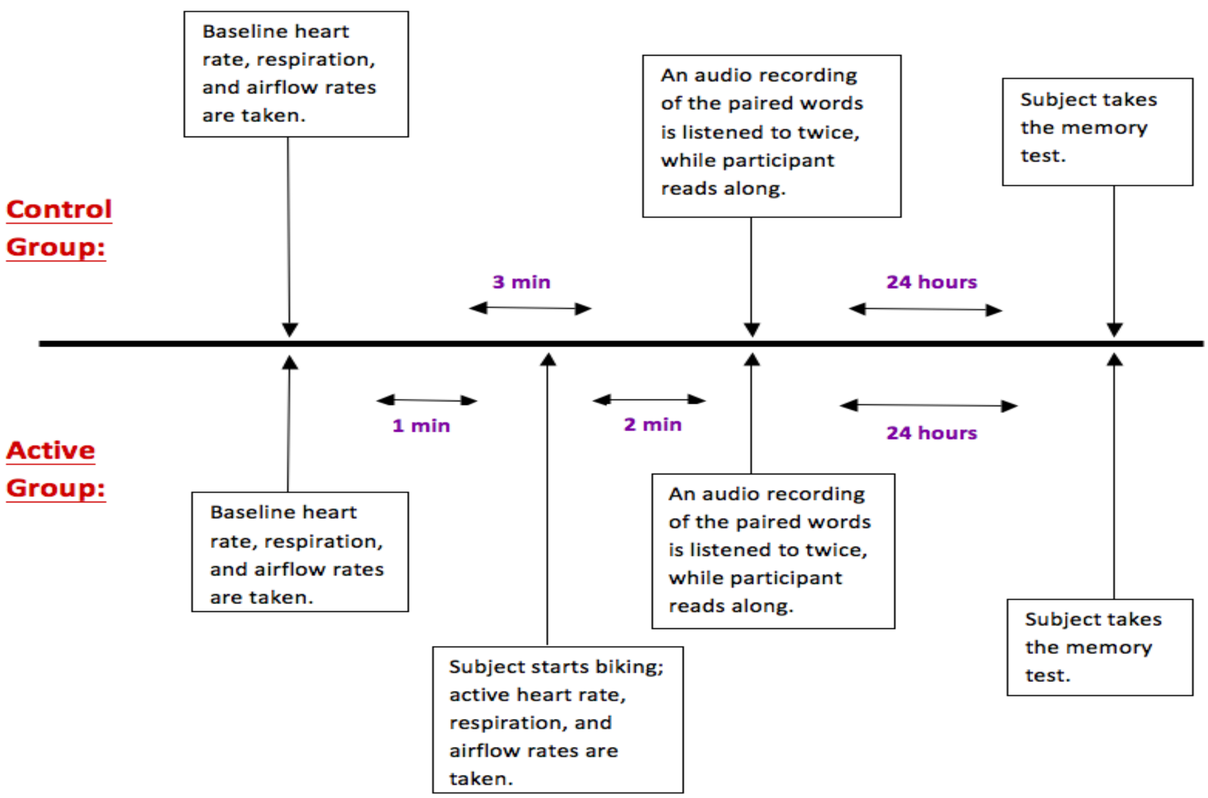


Figure 1. Experiment timeline

In both the active and control conditions, participants sat at rest for one minute while baseline heart rate and respiratory data were collected. Heart rate was measured with the Model 9843 Pulse Oximeter/CO_2 Detector. The sensor was applied to each participant's right index finger, with their hand relaxed at their side. The Respiratory Transducer SS5LB was used to collect the respiratory rate. This belt was placed around the chest immediately below the armpits, with the sensor placed directly in the middle of the chest at the breastbone. Respiratory volume was collected with the Airflow Transducer SS11LA and Disposable Mouthpiece AFT2. Subjects used the Noseclip AFT3 to restrict airflow through their nose, and held the device up to their mouth using their left hand.

After these baseline measurements were taken for one minute, participants in the active condition biked at low resistance until their heart rate was at or above 120 beats per minute. This threshold was chosen based on the CDC website's guidelines for moderate exercise (Van Praag, 2008). Participants were instructed to maintain their heart rate while biking for one additional minute. Active heart rate, respiratory rate, and respiratory volume were continuously monitored and recorded at regular intervals throughout the trial. Participants in the resting condition did not use the stationary bike, and moved on to the following step after baseline measurements were complete.

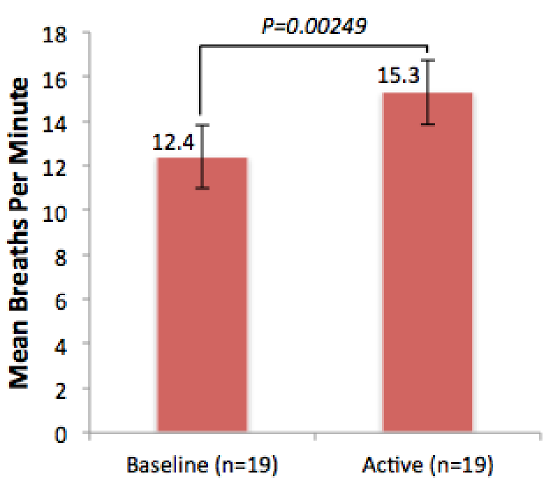
An audio and visual portion of the experiment immediately followed. Participants listened twice to an audio recording of twenty random word pairings consisting of an adjective and a noun, while reading along with a printed set of the words. **Appendix A** contains the list of words used for the first trial. This list was always used for a participant's first trial, regardless of whether it was active or resting. The following morning, approximately twenty-four hours later, a memory test was conducted. The test listed the first word of each word pairing, and instructed participants to recall the second word. There was no time limit for taking the test. One-to-two weeks later, participants completed the other test parameter and memory examination with a different set of word-pairings (**Appendix B**). The same word list was used for every participant's second trial. To monitor for individual variability in ability to memorize lists of words, statistical analysis was completed using each person as his or her own control. An ANOVA test was used to compare results.

Results

We processed our data with the assistance of a UW-Madison undergraduate statistician who used R software and Microsoft Excel. A series of statistical tests yielded the following results.

Respiration

Exercise significantly induced higher respiratory rates compared to the baseline value recorded immediately before exercise trial. With a p-value of 0.00249, there is strong statistical evidence that exercise increases respiration rate. On average about 3 more breaths per minute were taken during exercise than baseline during the study. Though exercise encouraged higher respiratory rates, there was no correlation between the amount of words correct on the memory test with increased respiratory rates.

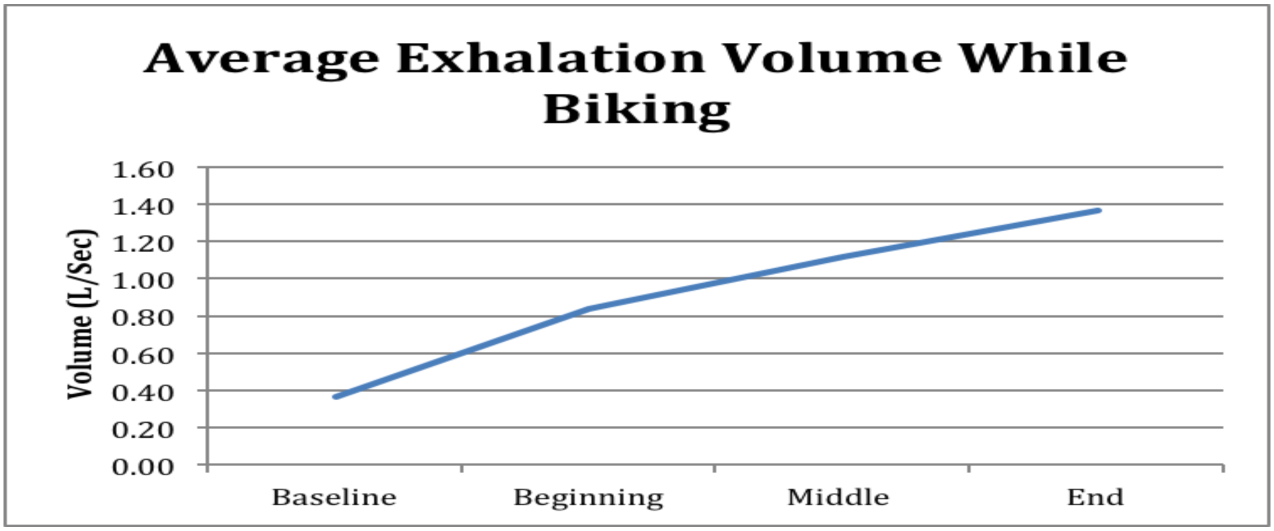


Graph 1: The average breaths taken by the participant during the biking trial. There were 20 total participants in the biking trial, but due to faulty data recording from equipment malfunction we excluded one participant's

respiratory data.

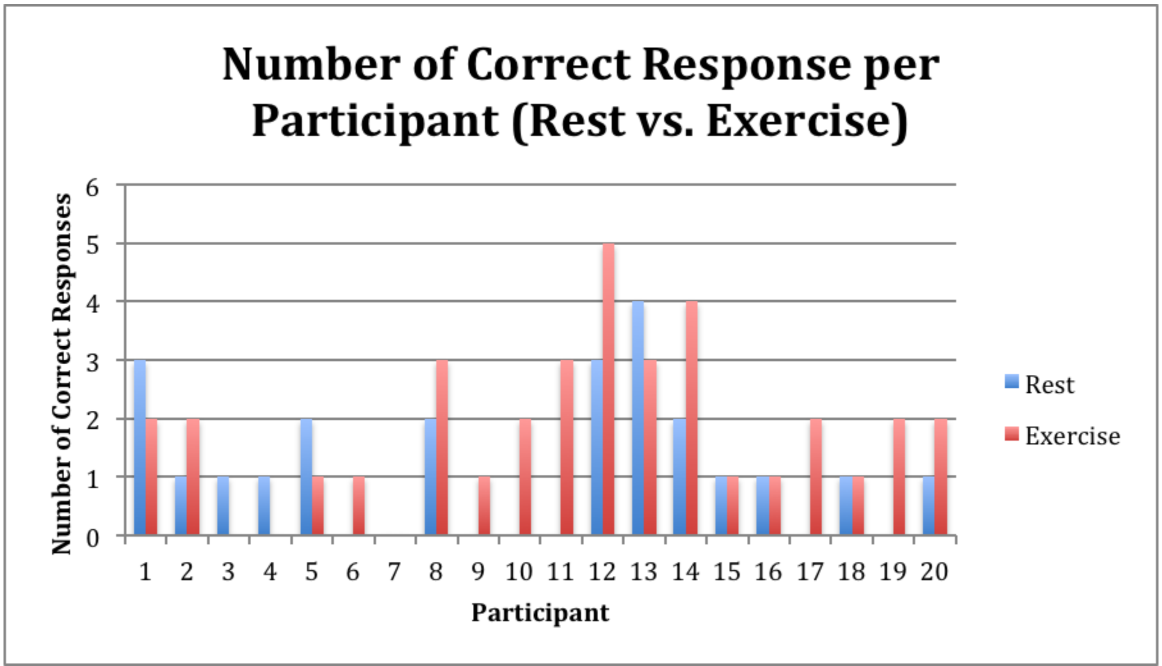
Airflow

Airflow was measured as Liters/Second exhale. Airflow did change significantly throughout three time intervals--the beginning (seconds 0-10), middle (seconds 45-55), and end of the experiment (last 10 seconds the individual was biking) (Graph 2). As the participants biked, it was assumed that their average volume of airflow would increase.



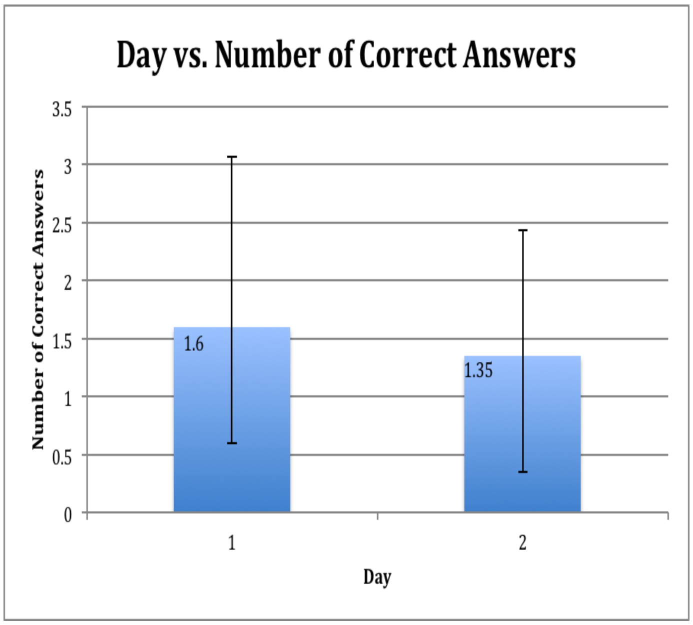
Graph 2: Respiratory volume (L/sec) collected by BIOPAC SS11LA Airflow transducer was used during baseline and biking activity.

Test Scores



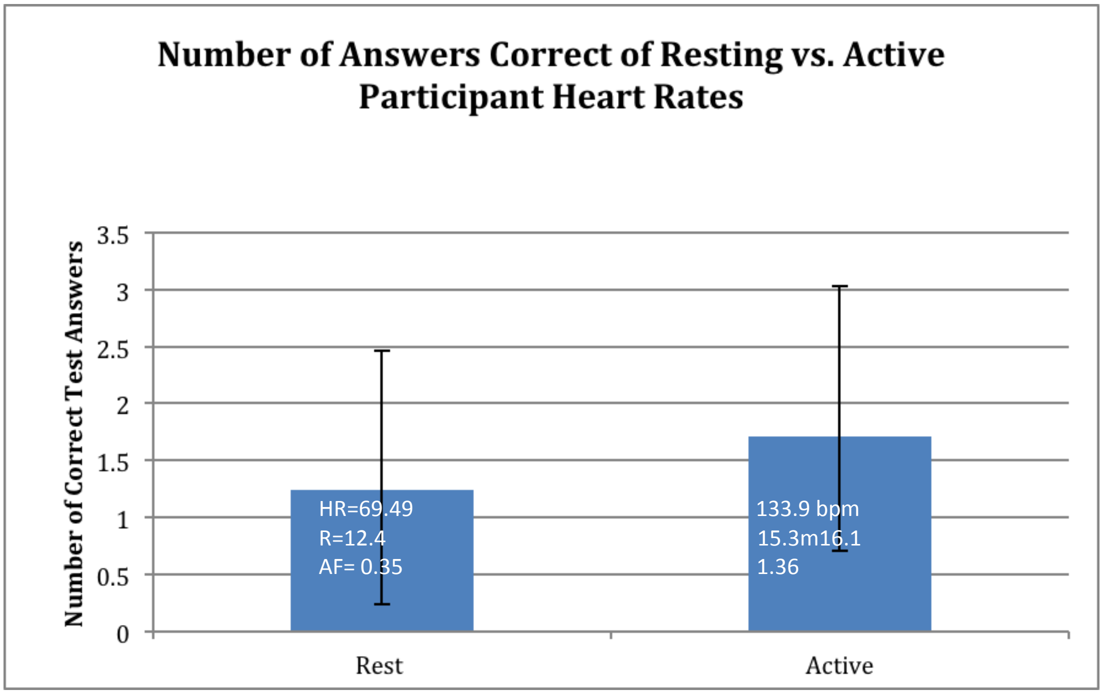
Graph 3: This graph shows each participant as their own control. It differentiates their rest and their active trials.

With a p-value of 0.114, there is a lack of evidence that biking explains the variance in participants' scores when compared to their scores after the resting parameter.



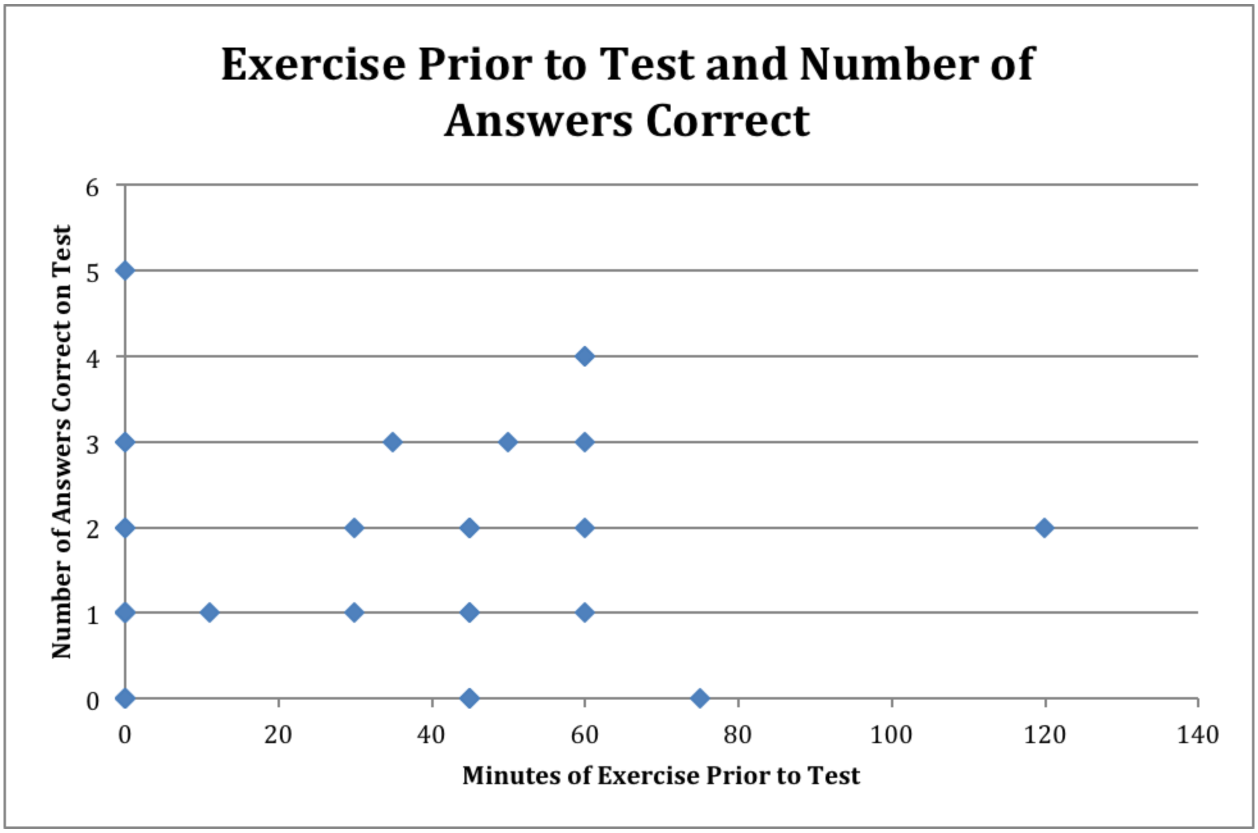
Graph 4: Each participant was asked to participate in an exercise and rest trial. The day (1 or 2) of the exercise trial and rest trial were randomly selected for each participant and then compared to the number of correct answers on the memory test.

Based on the data there was no correlation between number correct on test and the day the participant biked or rested. The correlation value of -0.06 is statistically weak. Correlation values of 1 or -1 have a strong linear relationship.



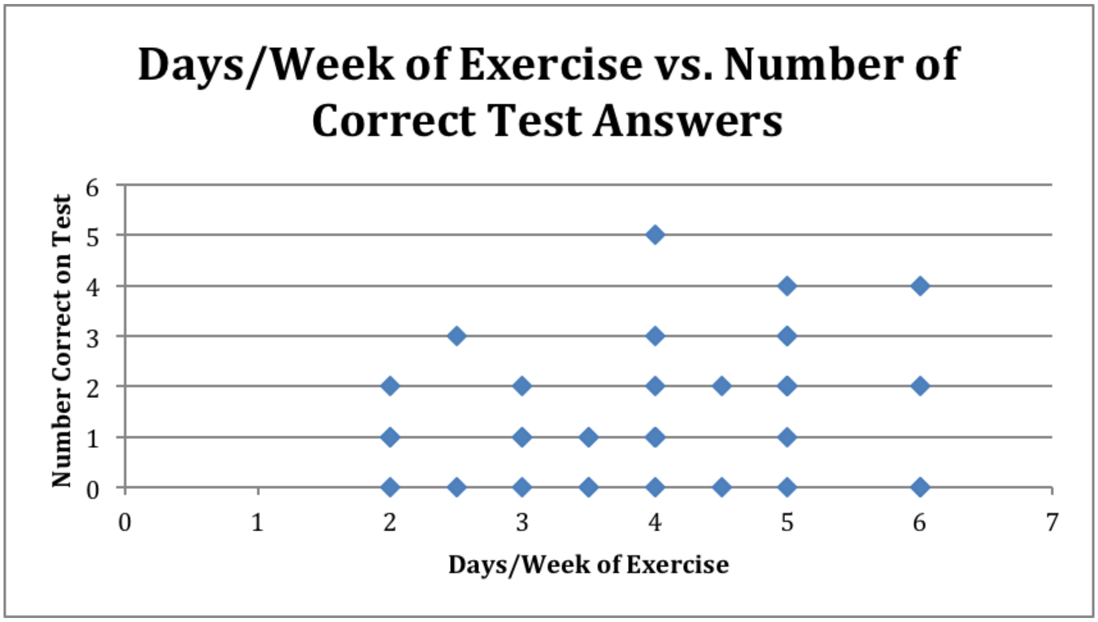
Graph 5. The figure describes the number of correct responses on the memory recall test under resting (non-exercise trial values) and active conditions. Physiological variable averages of heart rate (HR), respiration rate (R), and airflow (AF) are provided to show the increases in each under the active condition, which are reported as average maximum values achieved by participants as they biked. Airflow averages were taken at the beginning, middle and end of the experimental time period. To report maximum values (meaning exhalation volumes), the data from the last time period was used.

The number of correct answers given by participants on their resting day was 1.24, whereas on their active day the number of correct answers was 1.71. Although there is a slight increase of 0.47 in average number of correct answers under active conditions, the correlation is 0.26, which indicates that the relationship between the two variables is weak.



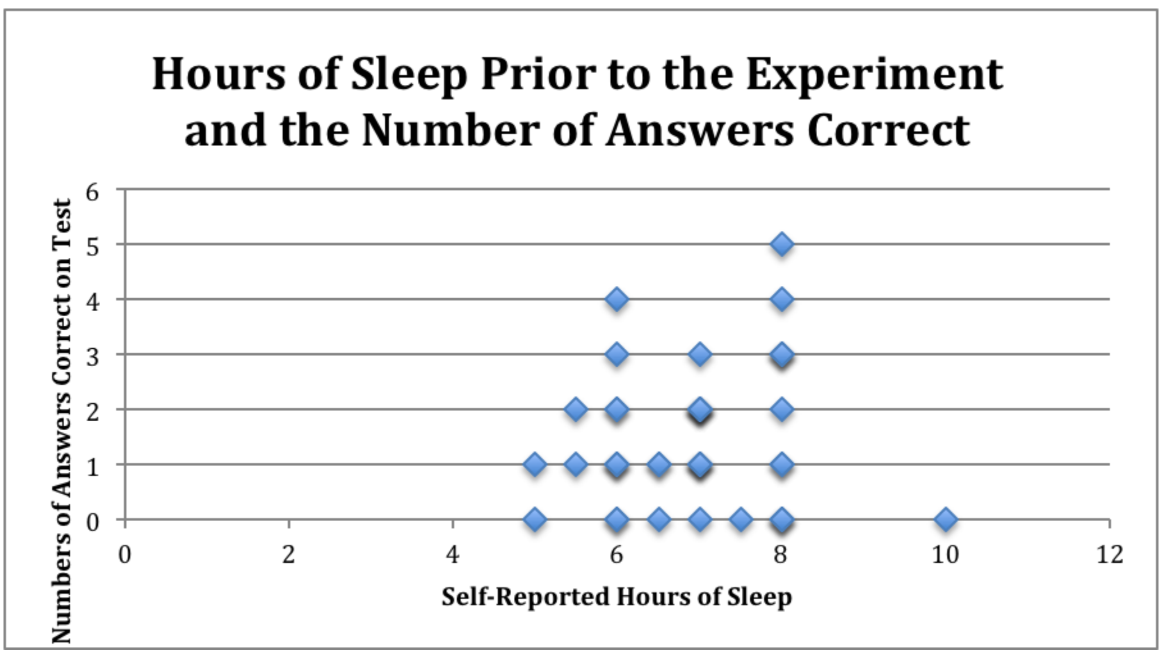
Graph 6: This plot shows the number of correct word-pairings to the self-reported length of time the participant exercised between participating in the experiment and taking the memory test. There was significant overlap between self-reported length of exercise and the results of the memory test.

Our experiment did not directly examine the effects of exercise outside of the experimental parameters. In order to verify that no other variables were affecting our results, participants provided information about their regular exercise on pre-experiment surveys. The correlation between the exercise the night before and the number of correct responses on the test was a weak 0.18. The highest number of correct answers was recorded from a participant who had zero hours of exercise. Surprisingly the lowest test scores were from multiple participants who exercised zero, forty-five, or seventy-five minutes the prior day.

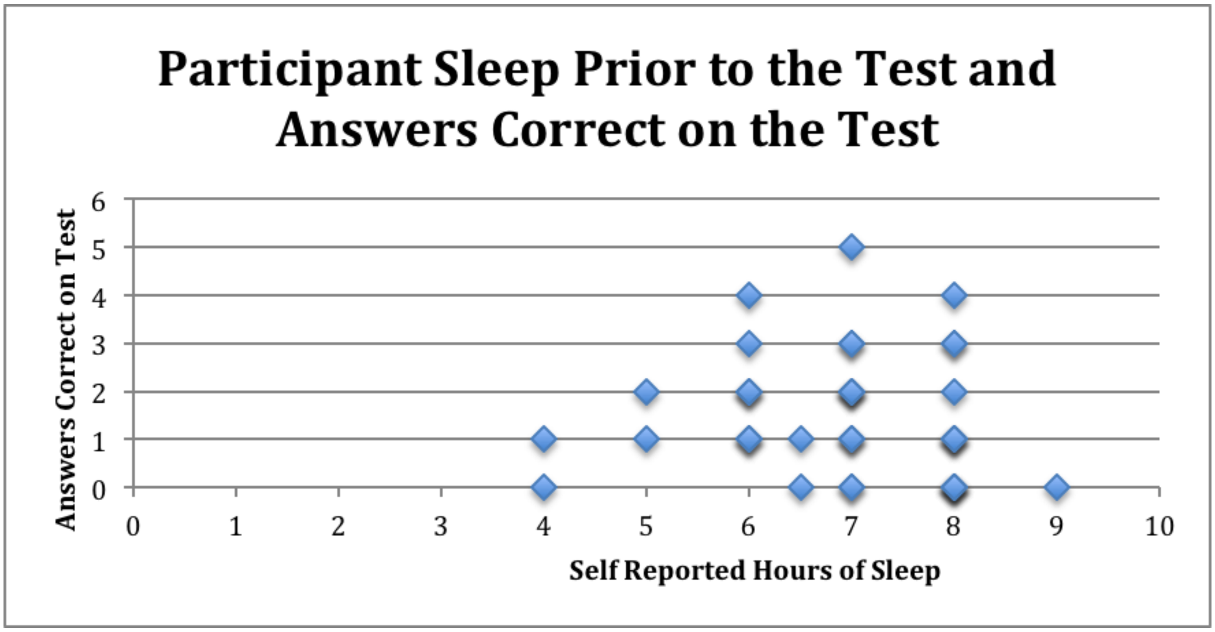


Graph 7: Depicted here is the number of days per week participants exercise compared to memory test performance.

We looked at another factor external to the test parameters to see whether it was significant results. Statistical analysis determined that there was an insignificant 0.25 correlation between these two variables.

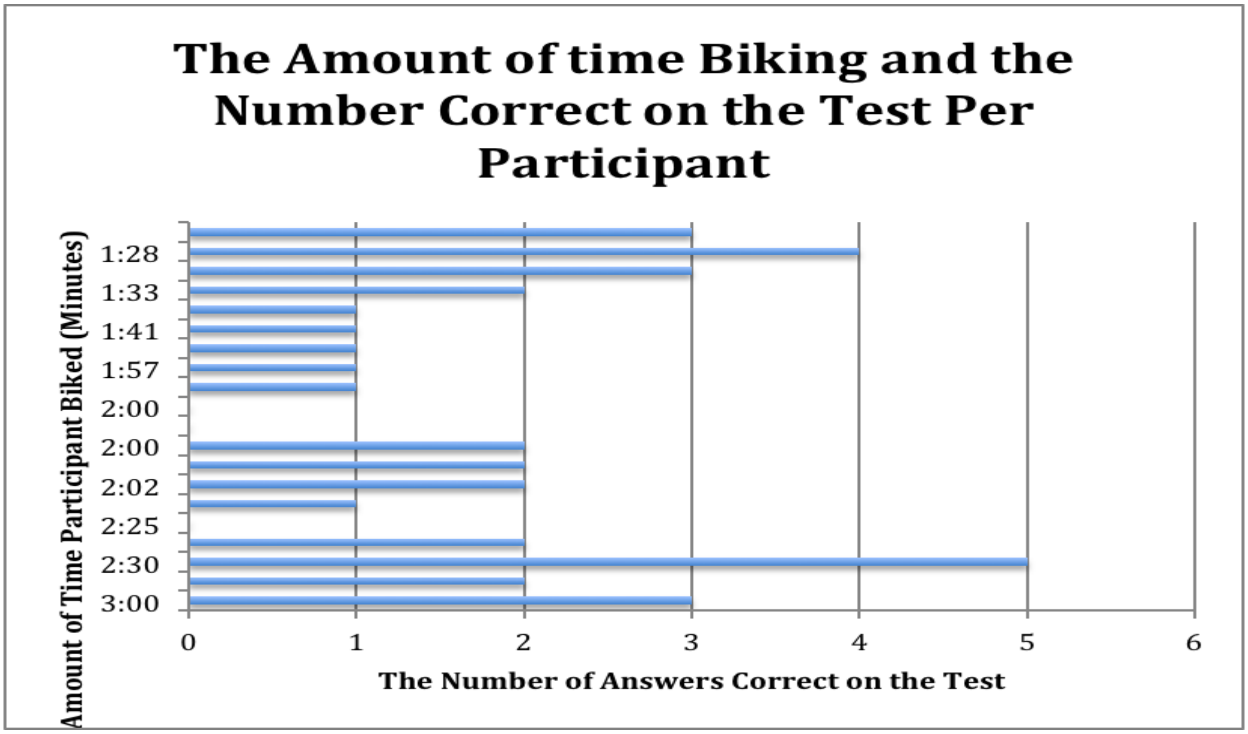


Graph 8: Graph 8 measures the amount of sleep the participants got the night prior to participating in the experiment and the amount of answers that were correct on the test 24 hours after completing the experiment.



Graph 9: Students who got between six to eight hours of sleep were also the students that generated the highest scores on the memory test, recalling the most words. Though the hours of sleep prior to the experiment and the number of answers correct on the test do NOT have a strong linear correlation, with a correlation value of 0.09.

The amount of sleep the participants had prior to the memory test and the amount of answers they got correct on the test. The above data has a weak linear correlation value of -0.06 indicating that no predictions could be made on sleep and memory without further experimentation. The bell shaped curves of Graphs 8 & 9 indicate that those who slept between six to eight hours prior to the exam on average scored slightly higher than participants out of that range. The majority of the students that participated in our experiment were receiving between six to eight hours of sleep.



Graph 10: The amount of time each individual spent biking (moderate exercise) and the amount of words they were able to correctly recall 24 hours later.

The correlation between the amount of time biking and the number correct on the test had a moderate value of 0.15. The former graph displays a dispersed pattern showing that the amount of time biking is not a strong indicator on how well the participant will do on the memory test.

Discussion

Our hypothesis was that short-term aerobic exercise immediately before learning would increase the recall of information. While we found slight evidence supporting our hypothesis, the results of our study were overall inconclusive. We did not observe any statistically significant effect of exercise on learning. Participants answered an insignificant average of 0.47 more correct questions on their biking trial compared to their rest day. Additionally, the physiological effects of exercise were not statistically correlated with increased memory test performance.

While there was no significant data .to support our hypothesis, we now examine why exercise in the current study had minimal effect. While in previous studies exercise has been shown to considerably affect memory, we consider the sample size in our study was not large enough to show this significance. Previous studies of this type had 40-212 participants. The duration of our study limited us to 20 participants, all of which were college students enrolled in multiple courses. Perhaps the significance of remembering word pairings for our study was minor in comparison to retaining material for their other classes. Therefore, our sample population may not be large nor well suited enough for the nature of our study. Possible limitations of sized and restrained diversity may account for our unanticipated inconclusive results.

Additionally, there were inconsistencies between subjects that were out of our control. The type clothing worn by participants was not consistent, which sometimes interfered with the equipment used to record respiration. Because this factor was not controlled, recorded respiration rates may vary from the actual values. This may account for the absence of a correlation with memory and respiration rate. The amount of sleep varied across subjects as well, with participants getting anywhere from four to ten hours of sleep the night before. Adequate sleep has been shown to have significant positive impact on memory (Bjorn and Born, 2012). Although we did not find any statistical significance with this variable, the amount of sleep our participants obtained may have increased the variability in test results. Regulating the amount of sleep among participants could have been beneficial in achieving the full potential of participants, and should be considered in future studies.

Moreover, in using three physiological measures to record data while having participants bike, our study may have been hard for participants to efficiently partake in. It was difficult for subjects to hold the airflow instrument, while keeping one hand slightly elevated to take accurate heart rate measures, and bike at the same time. The participant could have been overwhelmed by the amount of things they had to focus on maintaining in addition to increasing their heart rate to 120 bpm and sustaining this rate, affecting their memory scores and our data. This could also hold true in the participant both having to read and listen to the words they were tested on. Future studies should look at reducing the amount of multitasking involved in the experiment, which may cause better memory correlations to be observed.

The short amount of time spent on the bike could be another limitation to our study as well. Due to practical constraints, subjects only spent an average of 2:01 minutes on a bike, and biked at a moderate pace. It is entirely plausible that moderate exercise simply does not have the same effect on memory that studies have shown with high intensity exercise. For example, the study conducted by Winter et al. found a 20% increase in vocabulary learning in a group that ran 2-3 minute sprints, compared to both a rest group and a group that ran at a moderate pace for 40 minutes. (Winter, 2007) The exercise group in our study biked at a moderate pace, and for a short duration, and therefore would not necessarily be expected to show the same results.

With so many ways to test all the different types of memory, it was difficult to decide what parameters of memory should be examined, and how difficult to make the test. While we decided to test the recall of word-pairings, other studies looked at vocabulary learned, match-to-sample accuracies, and reading comprehension to name a few. While it is possible that exercising did not have an effect on remembering word pairings, it would have been beneficial if another type of memory parameter was implemented as well. It is also possible that the memory assessments used in our study were too difficult, causing our evaluation of memory to be inefficient. The most words any person recalled in our study was five pairings out of twenty, with most participants remembering only one or two words on average. Going along with this idea, only two read-throughs of the words being tested were given to participants. Longer time frames for studying the words, or letting the participants study by their own methods may have been more beneficial. Our research may not have been able to view the true potential of physical activity on memory retention if our memory assessment was too difficult, or if our assessment was not in line with the ideal or typical studying methods of the participants. Future studies on memory and exercise should implement pilot studies in order to determine methods of testing that are not too difficult for the general population, with recall rates around 50% among the pilot groups. This would ensure an efficient and qualified memory examination that would be able to provide accurate assessments.

Motivation may have been a potential confound in our study as well. Motivation has shown to be a huge factor in memory and recall; incentives for motivation will cause increases in memory and attention, especially in young adults (Tomporowski & Tinsley, 1996). In knowing this, our methods of examining the relationship between memory and exercise could have been reliable, but we did not provide any motivation for our participants to really try and remember the words. Cash would be a good incentive, although we did not have the funds to provide this as motivation. Giving participants some sort of “extra credit” in the physiology course we recruited from for the number of words they remembered could have encouraged subjects to try and study the words more efficiently as well. Future research should consider adding incentives to their study, more realistically representing students studying in that a rewarding letter grade for them could be replicated with money, extra credit, or another prize of some sort.

Although our results were not statistically significant, further research should be done to study the effect of exercise on memory and other cognitive function. The physiological evidence in humans and other mammals is strong, and we believe that studies that provide increased motivation, larger sample sizes, and higher intensities of exercise will show a stronger correlation.

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Appendix A

1. immediate-news
2. initial-discipline
3. electoral-birthday
4. efficient-availability
5. civilian-cook
6. polite-treasury
7. intimate-arch
8. expected-sweat
9. vulnerable-spoon
10. cognitive-status
11. tremendous-apology
12. psychiatric-return
13. bottom-few
14. inevitable-hearing
15. voluntary-conception
16. remote-golf
17. genuine-lecture
18. worldwide-domination
19. old-fashioned planning
20. smart-symmetry

Appendix B

1. established-poem
2. peculiar-ignorance
3. absolute-metaphor
4. successive-bite
5. naval-track
6. aggregate-toe
7. dry-beef
8. atomic-observation
9. short-transition
10. key-injunction
11. quick-bay
12. leading-exercise
13. prolonged-organ
14. complicated-job
15. dreadful-miner
16. distinct-shop
17. gothic-procession
18. spiritual-subsidy
19. confidential-female
20. happy-palm