# Brief Aerobic Exercise Increases Mathematical Ability in Undergraduate Students

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**Key terms**: aerobic, cognitive function, cognitive recall, delta waves, electroencephalogram, exercise, memory, theta wave, working memory

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## Abstract

Aerobic fitness has been associated with improved mental function, psychological outlooks and decreased stress. Our study looked at the ability of participants to improve in performance on mathematical and memory tests after a short period of aerobic exercise. Participants were asked to bicycle until they reached a perceived exertion of six or seven on the Borg activity scale which corresponds to a moderate to high level of activity. Following the exercise, participants performed a math and memory test. Electroencephalogram (EEG) power data, heart rate, and oxygen saturation level were recorded during the experiment. We found statistically significant improvement in performance on the mathematical test. There was also a slight, but not significant, decrease in the success of the memory test. There was a statistically significant relationship between theta waves and mathematical test accuracy, but no conclusions can be drawn due to the small number of participants, and variable EEG data. These trends showcase there may be a relationship between exercise and math, but more research needs to be conducted to reach a conclusion.

## Introduction

Exercise and aerobic fitness has become an increasingly important part of life. People have become focused on living healthy, active lives, and the national spotlight has shifted towards this lifestyle choice. Exercise has been linked to positive psychological outlooks, social interactions, and overall happier lives (Lovell, Ansari, & Parker, 2010). The Center for Disease Control notes how physical activity can allow for longer lives and reduce the risk for heart disease, stroke, depression, and some forms of cancer. Aerobic exercise has been linked to increased brain volume in the elderly, which could provide the sparing of brain tissue during aging (Colcombe et al., 2006).

Several studies looked at school-aged children and the positive effects of aerobic exercise on both school abilities and cognitive function. An activity as simple as recess after lunch may be a necessary break from standard classroom learning and can improve the overall school climate (London et al., 2014). There is also evidence of increased academic achievement in students who were more physically fit (Chomitz et al., 2009). Chaddock-Heyman et al. (2015) found that there were positive correlations of the activity level of children to their mathematical ability and brain development. Students who were more active showcased higher mathematical test results along with a thinning in grey matter during developing years, a hallmark of increased mental ability, but only in this specific developmental period. Other studies on children showcase how aerobic activity can increase the myelination and interconnections of the brain in developing children (Sowell et al., 2004). Several studies in the current literature found that physical activity causes a release of several neurotrophins that help with the growth, survival, and differentiation during neuronal development (Barde 1989, Vaynman and Gomez-Pinilla 2006). This finding is what many believe to be part of the key neuronal processes that link cognitive function, learning, and exercise. Studies have also demonstrated that physically fit people, both young (Hillman et al., 2006) and old (Dustman et al., 1994), have greater cortical activation and that corresponded to the cognitive performance of these groups. These strong links between cognitive ability and physical activity were also further studied in animal models (Brinke et al., 2014; Praag et al. 2005).

Exercise may play a role in the important academic ability of memory. Studies have shown that exercise can promote an increased hippocampal volume in older adults (which is involved in the consolidation of new memories) (Brinke et al., 2014). Praag et al. (2005) conducted a study in which they observed aged mice and the effects that exercise such as wheel running and running on the treadmill would have on their cognitive and executive functions. Exercise enhanced the aged mice's learning abilities and memory. Vaynman, Ying, & Gomez-Pinilla (2004) demonstrated that rats with a short period of exercise showed marked improvement in the learning and memory based Morris water maze task. BDNF was shown to be released due to the aerobic activity and the protein modulated cAMP response-element-binding protein expression (CREB), which is needed for the formation of memories (Yin et al., 1995).

Math is a key part of learning and there is also significant evidence that students who do better in math end up leading happier and often more productive lives (Lubinski, Benbow, & Kell, 2014). If outside sources like exercise can help with the consolidation of new memory, it may be reasonable to extend this idea to mathematics. The study done by Chaddock-Heyman et al. (2015), as discussed earlier, showcased that aerobic activity can cause an increase in math success (Chaddock-Heyman et al., 2015) Other evidence from the literature found no change in math ability, but did see an increase in executive function development (O'Malley 2011). Overall, the study of the connection between increased math success and aerobic activity is lacking a consensus in the current literature.

Even though there is a wealth of information on how physical activity influences cognitive related functions in children, older adults, and animal models, there is a notable lack of evidence in undergraduate students. Our goal is to focus on this underutilized group and see if there is a connection between aerobic activity and the cognitive ability of students on memory (confirm a well studied phenomenon) and mathematics based tasks (currently lacking in the literature), two critical domains that have far reaching effects on performance in the classroom setting.

We hypothesize that short periods of aerobic exercise can improve performance on cognitive tests. In the study, we will subject our participants to two cognitive tasks: a memory test and a math test. Throughout the study we will monitor participant's heart rate and oxygen levels using a pulse oximeter, and brain activity using an electroencephalogram (EEG). The heart rate and oxygen level data will be used to normalize participant's level of exertion during the moderate exercise. These will also verify whether or not each participant was able to reach the exertion threshold during aerobic exercise. The EEG will determine whether or not there is a difference in neural activity during rest and each of the tasks. The brain activity data will be used along with results of each math and memory test to determine the effect of moderate exercise on cognitive performance.

## Materials and Methods

### *Participants*

The sample population consisted of undergraduate students recruited because of their enrollment in Physiology 435 at the University of Wisconsin-Madison. Participants included a mixed number of males and females between the ages of 19 - 22 years old and were randomly chosen to participate in the study. Each participant was provided a consent form to give a summary of the experiment and inform them of any potential risks or benefits of the study. Each participant was assigned an identification number to keep all identities confidential. After completing the consent form, the participants were instructed to complete a background survey, which will be used to help analyze the data collected. At the end of the study n=10 (5 males, 5 females) participants completed the study.

*Controls*

Our negative control is a participant showing minimal fluctuating brain wave frequencies as he/she relaxes with his/her eyes closed. This was tested with a group member who demonstrated very few fluctuating brain wave frequencies as she relaxed **(see Figure 2 Resting Period**).

*Brain Wave Specificity*

Our experiment specifically focused on studying theta and delta waves. Both these wave types are are observed during tasks that require memory and deeper concentration. Wave patterns can be analyzed individually to find the average frequencies yielded from each participant for the various tasks. By expanding a wave, one can compare the different wave patterns of theta versus delta waves and pinpoint the start of a new task. (**Figure 2 and 3**).

*Procedure*

The baseline values of each participant were taken on the first day of the study. We considered this first day (day 1) to be the control we based our day 2 comparisons off of.

A pulse Oximeter/CO2 Detector (Model 9843 Nonin Medical, Inc., Plymouth, MN, USA) was used to measure the baseline heart rate and $O_2$ saturation level of each participant. The value recorded for each heart rate and $O_2$ saturation level was taken throughout the experiment an average of the measurements was recorded over a five second period. These baseline values were taken prior to having them perform any type of exercise, math test, or memory test.

The electroencephalogram was 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. Specific equipment used in the experiments is described throughout the procedure. Three electrodes were applied to the left side of the participant's head (**Figure 4)**; SigmaGel Electrode Gel, Model Gel 100 (Biopac Systems, Inc., Goleta, CA, USA) was used to aid in transmission of waves. Participants were told to close their eyes and relax so the baseline brain wave values could be determined through a calibration test with an Electroencephalogram (EEG) (SS1LA, EL254, EL354S Biopac Systems, Inc., Goleta, CA, USA). The EEG measured the output brain waves throughout all the tests. The timeline of EEG recordings for all tasks can be observed in **Figure 1.**

To begin, participants were shown a series of random words in a slideshow on a computer screen (**Figure 5** displays timeline) . Fifteen words appeared on the computer screen for five seconds each, totaling to a 75 second test (Words used located in Appendix). The participant's heart rate and $O_2$ intake were recorded at the end of the slideshow.

After the word slideshow, a math test was administered. The math test consisted of 162 problems including a mix of addition, subtraction, multiplication, and division. Each participant was given two minutes to solve as many problems as they could. At the one minute mark of the math test, the participant's heart rate and $O_2$ intake will be recorded. These values were recorded at the end of the test as well. Accuracy and completion percentage were recorded as well.

Finally, the participant finished with the memory test; they were given a piece of paper and one minute to write down as many words as they could remember from the word slideshow. Heart rate and oxygen levels were recorded at 30 seconds and again at the end of the memory test.

On the second day of participation, approximately one week after Day 1, participants first exercised on a Cycle Trainer 390R (Gold's Gym) (electronic bike) and then completed the same type of tests as Day 1.

Baseline heart rate and oxygen levels were recorded before the exercise on the cycle begins. Participants were shown a Borg Scale (**Figure 6**) and encouraged to reach a level of 6-7 so that each exercise session is tailored to a participant's personal fitness level.

Resistance levels on the cycle were adjusted to reach the Borg Scale exertion level in adequate time (4-5 minutes). Heart rate and oxygen levels were recorded at each minute during the exercise training.

The word slideshow, math test, and memory test were used again but different words and problems were used (Words used located in Appendix). All the same measurements were recorded as stated above in Day 1 **(Figure 5)**.

**Results**

Data was analyzed using Microsoft Excel and pairwise t-tests were performed by statistics students at UW-Madison. A p value $\leq 0.1$ was considered statistically significant.

Heart Rate Fluctuations

Each participant's heart rate was taken at the same 4 time points on both days of the study: baseline, slideshow, math, and recall. **Figure 7** shows that throughout the course of the study heart rate on day 1 without aerobic exercise was consistently lower than on day 2 with aerobic exercise at their corresponding time points. In both groups the highest average heart rate recorded was during the math test. Average heartbeat on day 1 during the math test was 91.3 beats/min, and on day two the average heart beat was 103.65 beats/min. Although, there was a consistent difference in average heart rate during the time points there was no significant difference (p=0.231).

Oxygen Level Fluctuations

There was no clear trend observed between average oxygen levels on the control day versus the aerobic exercise on day 2. Baseline and slideshow values both had greater oxygen levels in the control group in comparison to the aerobic exercise group and these results showed a significant difference. Average oxygen levels when taking the math test and recalling the word list were higher in the control group than in the aerobic exercise group, but the difference was not significant (p=0.132).

Cognitive Test Results

Accuracy and completion on cognitive math tests were measured in the control day and after moderate aerobic exercise, and data can be seen in **Figure 8 and 9**. When control data was taken, an average of 77.3 math questions were answered with an average accuracy of 97.59%. After moderate exercise an average number of 88.8 questions were answered among participants with an accuracy of 98.13%. A pairwise t-test showed accuracy increased between Day 1 and Day 2 with a p-value of 0.0095 so this data was determined to be significant.

Recall completion and recall accuracy on the cognitive memory tests were analyzed for both the control day (Day 1) and after moderate aerobic exercise (Day 2). **Figure 10** shows the average recall completion for the control was 8.8 words of the 15 given words and average recall completion for the exercise day was 8.4 words. The maximum number of words recalled in the control was 11 and the maximum number of words recalled in the exercise data was 12. The standard error for the control was +/-0.62893 and the standard error for the exercise group was +/-0.71802. These standard error values conclude the difference in recall completion was not significant (p=0.9662).

Average participant recall accuracy on the cognitive memory test was 96.14% for the control and 95.89% for the post-exercise data. **Figure 11** shows this data is not significant due to a standard error value of +/-0.0292 for the control and +/-0.02097 for the exercise group.

Brainwave Power Analysis

*Delta Waves and Theta Waves*

Delta and theta wave average power values ($uV^2/Hz$) were analyzed for each participant on Day 1 and 2 during the math test and memory test. To find the average power, the brain wave was selected during time period associated with a particular test **(Figure 1** shows the various time periods on the wave) and the max power value was recorded. The values of nine participants were averaged; one value was not used because it was an outlier. This value was determined to be an outlier because it's power values were 4x greater than the average of the participants. Standard deviation values were also calculated.

The **Figure 12 and 13** shows the average delta and theta power wave values including the standard deviation values. No significant difference was observed between the average power of both waveforms between the two days.

*Theta Wave Power and Math Accuracy*

A significant inverse relationship was observed between the power of theta waves and the accuracy on the math test. A decrease in the power of theta waves was correlated to an increase in accuracy on the math test with a significance of p=0.081. Because our p-value is included is $\leq .1$ this is considered statistically significant.

## Discussion

General

This study evaluated the effects of aerobic exercise on cognitive functioning measured in the form of math and memory tests; an EEG provided additional understanding in changes on brain waves during these two tasks compared between a Day 1 and Day 2 . Our hypothesis proved to be somewhat supported by the statistically significant value for an increase in math completion and showed a strong trend in theta wave decrease associated with math accuracy increase after aerobic exercise. Other possible conclusions can be speculated from our data and this is discussed below.

Heart Rate Fluctuations

The general trend observed in the participants' heart rates was that average heart rate was greater on the day two of the study when the participants were supposed to do aerobic exercise using a stationary bike. It makes sense that during the viewing of the slideshow, math test, and recall test that the participants' heart rates were on average greater because along with the stress of a task, they had just exercised, so their heart rates should be greater. On the other hand, **Figure 7** shows that average baseline heart rates were expected to be the same because on both days, participants had just come into the room and had not performed any sort of task or done any exercise, but average baseline of day two (86.4 beats/min) was greater than that of day one (79.2 beats/min). This may have been due to participants' anticipating the exercise task they were about to perform. The differences were not significant, so it could have also been a coincidence.

Oxygen Level Fluctuations

With no clear trend in oxygen level fluctuations identified between the control and aerobic exercise days, we suspect that the miniscule changes observed in oxygen levels throughout the entirety of the experiment was the reason no significance was found in relation to any other data we collected. These levels hovered around 97-100% oxygen saturation for both days reflecting no observed change, despite participants performing moderate aerobic exercise during the exercise test day. Originally, we had expected an increase in oxygen saturation levels after the participants performed aerobic exercise on day 2 compared to the levels on day 1 (control) because their increased heart rate would increase the cardiac output to the lungs. Due to our small sample size and relatively small changes in oxygen saturation levels, no significant conclusions could be drawn from the oxygen saturation data we collected.

Cognitive Test Results

The recall accuracy and number of words recalled on memory tests between Day 1 and Day 2 showed a slight decrease in performance. However, these results were slight and no significant conclusion could be made. We speculate the results were not significant due to the format and simplicity of the memory test.

Performance on math tests showed improvement with moderate exercise compared to the control, and these results were determined to be significant. Therefore, support for the hypothesis can be made that performance on basic math tests improves after moderate exercise. We conjecture that a longer duration or higher exertion of activity would further improve math and other cognitive tests.

Brainwave Power Analysis

The power of brain waves was analyzed based on previous studies such as Pivik et al, 2012 who analyzed power of frequency EEG activity during mathematical tests in children.

The decrease in delta and theta wave power between Day 1 and 2 produced no significant conclusion and we speculate this to be because of the wide range of values obtained on the EEG. Our EEG power value average produced large standard deviations for both theta and delta waves due to the large spectrum of values obtained. One participant's values were removed because his/her theta and delta wave values for Day 1 were 4x higher than the average values of other participants. It is most likely this participant had his/her electrodes placed improperly which causes the extreme values.

The downward trend of delta and theta wave power between the Day 1 and Day 2 suggests that exercise may decrease demands on the brain during cognitive tasks but no definitive conclusions can be made.

Theta Wave Power and Math Accuracy

A decrease in theta wave power values was found to be correlated to the math accuracy testing between Day 1 and 2. Theta waves are associated with greater demands on working memory, particularly during mental arithmetic (Pivik et al, 2012). Theta waves suppression is actually associated with improved concentration and ability to focus attention (Neurohealth Associates, 2016). Therefore, it is possible that on Day 2, individuals had a decreased in the average power of their theta waves as they concentrated on the math test. Theta wave occurrences are typically measured in the frontal, superior parietal, and superior temporal regions (Sammer et al, 2007); our ability to obtain distinct theta waves may be related to our ideal placement of the EEG electrodes in these specific areas on the participant's head.

The decrease in average theta wave power could be due to aerobic exercise from Day 2, however no causation can be inferred. After exercising, participants may have had not needed to exert as much force from their working memory and less mental effort was required for accuracy in their answers to the math problems. Children given a 10 minute exercise break had moderately improved performance on math tests compared to children who were sedentary for 10 minutes (Howie et al, 2015). This suggests that exercise is involved in increasing mathematical performance in some way, however the connection to theta waves needs to be further researched.

**Limitations**

There were several limitations to our study that may have contributed to the poor data we received. The EEG utilized for our experiment was one of the main issues. This EEG only provided three electrodes, which limited our ability to record the waves from a larger area, or look at differences between the left and right hemisphere. It also reduced our ability to expand to different brain areas, instead of focusing on the parietal, we could have looked at frontal activity as well to see any further impact. The EEG readings seemed to differ between participants, as some would have high background and others would not. This equipment failure could explain why our power values were so far from each other in each group (control and aerobic exercise), this may also be due to the slightly different placement of the electrodes on each participant. Outside factors could have affected our EEG readings, as sometimes electrodes fell out during testing, outside noise caused spikes to occur that were related to hearing rather than brain activity on our task. We tried to reduce these factors, but it is impossible to completely remove them from our experiment.

The pulse oximeter that was used to record heart rate, may not have been the most appropriate way to measure it. Sometimes this unit jumped to heart rates that were extremely low or high compared to the expected. When recording we worked to avoid using these outliers by ignoring them, and when recording the heart rates we calculated an average over the course of five seconds to get a more accurate reading. Even with these steps taken this may have impacted our recordings.

The other limitation to our study was our participants. We ended up with a very small number of participants (n=10) due to the time constraints put on our study. Having a two week study made it difficult to get more. This meaning any significance we may have found in the study would need to be replicated on a larger scale. The other issue is our participant pool demographics were all undergraduate, science majors and from a good university. In the future it may be worthwhile to draw from a more diverse group of participants.

**Further Research**

It has been proven that aerobic exercise is important for cognitive functioning based on many previous studies, however college students should be further studied because of the lack of research done on this group. The use of larger sample sizes could aid in obtaining significant values or determine even if there is a strong correlation. Another recommendation for a future study would be looking to a differing cohort of undergraduates with a variety of majors/specializations (i.e. not just science based majors). It may be relevant in the future to look at different brain analysis tools, such as fMRI, to gain a better spatial understanding of the brain regions involved in these activities. We were unable to research correlations between aerobic exercise and specific brain wave fluctuations; identifying association between specific brain waves, aerobic exercise, and cognitive tasks could provide future recommendations for benefits of exercise to specific academic disciplines.

A potential bias that may have occurred involved the procedure that was used. In the future it may make sense to switch the order that groups go through the study. Where on Day 1 participants will go through the aerobic exercise, and on Day 2 they would have no aerobic exercise and just perform the cognitive tests. This would reduce the possibility that the results may be due to a familiarity with the tests from Day 1.

Although our study was unable to find truly significant data on how aerobic activity could affect the mental capability of our participants, the general trends discovered shed some light on a possible relationship that could be looked at more comprehensively in the future.

**Appendix**

Random Multiplication Problems Generator - Themathworksheetsite.com

Link to the American College of Sports Medicine's information on the Borg Scale
https://www.acsm.org/docs/current-comments/perceivedexertion.pdf

Day 1 Memory Words: Water, House, Dog, Book, Shoe, Spaghetti, Fire, Glove, Hill, Wood, Fruit, Computer, Cloud, Ball, Chalk.

Day 2 Memory Words: Ocean, Trick, Dust, Toe, Wilderness, Magic, Coil, Metal, Marble, Lake, Jam, Earth, Flower, Glass, Bee.

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## Figures

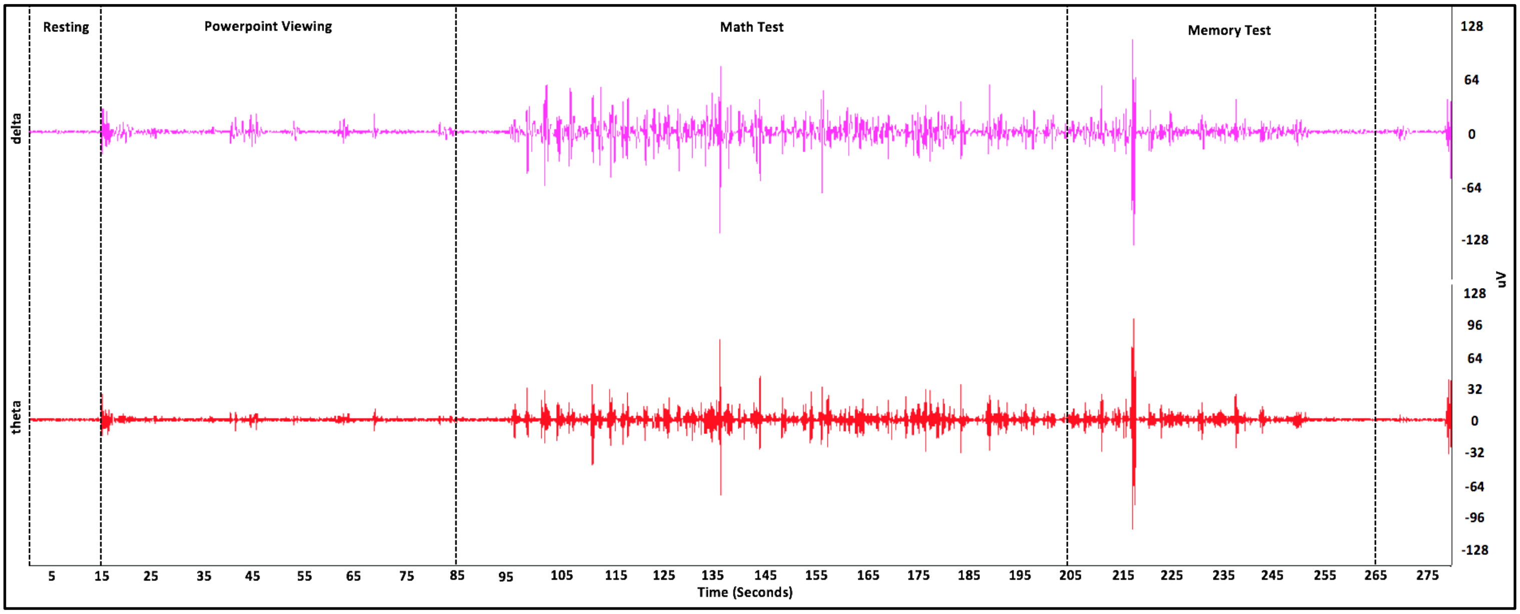


**Figure 1** This is the timeline of the events that took place during the experiment in the form of an EEG graph. These events (left to right) are Resting (0-15 sec), Powerpoint Viewing (15-85 sec), Math Test (85-205), Memory Test (205-265 sec). The graph does not include EEG readings during aerobic activity. X-axis is time (in seconds). Y-axis is uV.

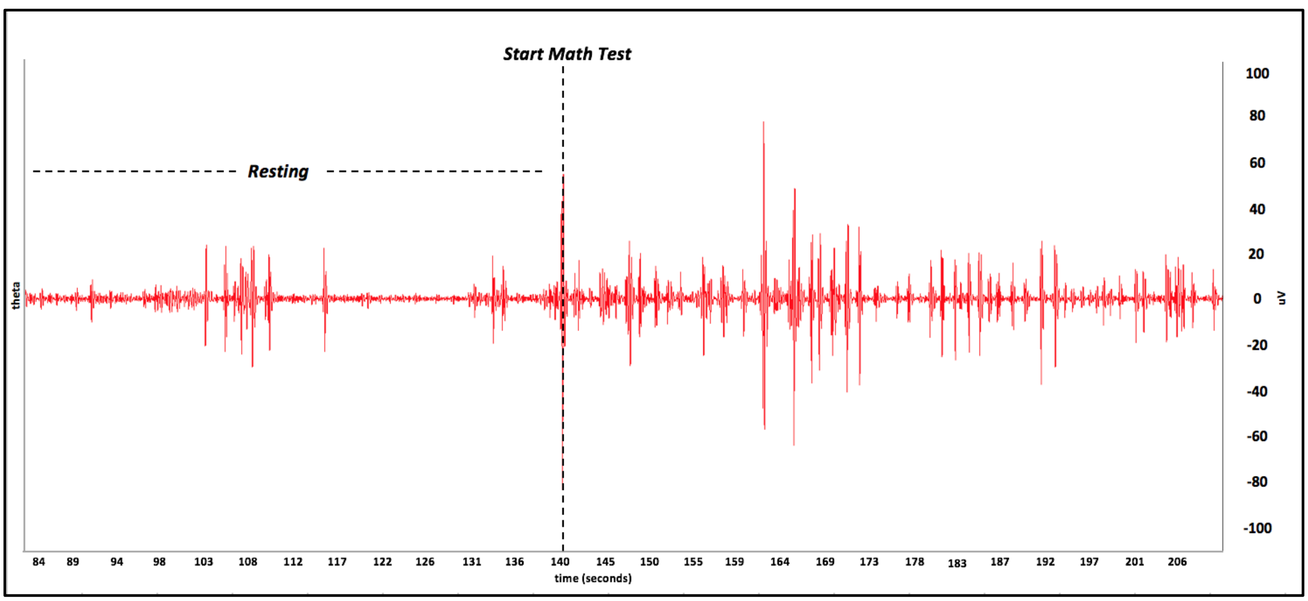


**Figure 2** This EEG reading of a theta wave is changing from low frequency during a resting period to high frequency oscillation at the start of a math test. Theta waves are associated with demands on working memory (Pivik et al., 2012). X-axis is time in seconds. Y-axis is uV.

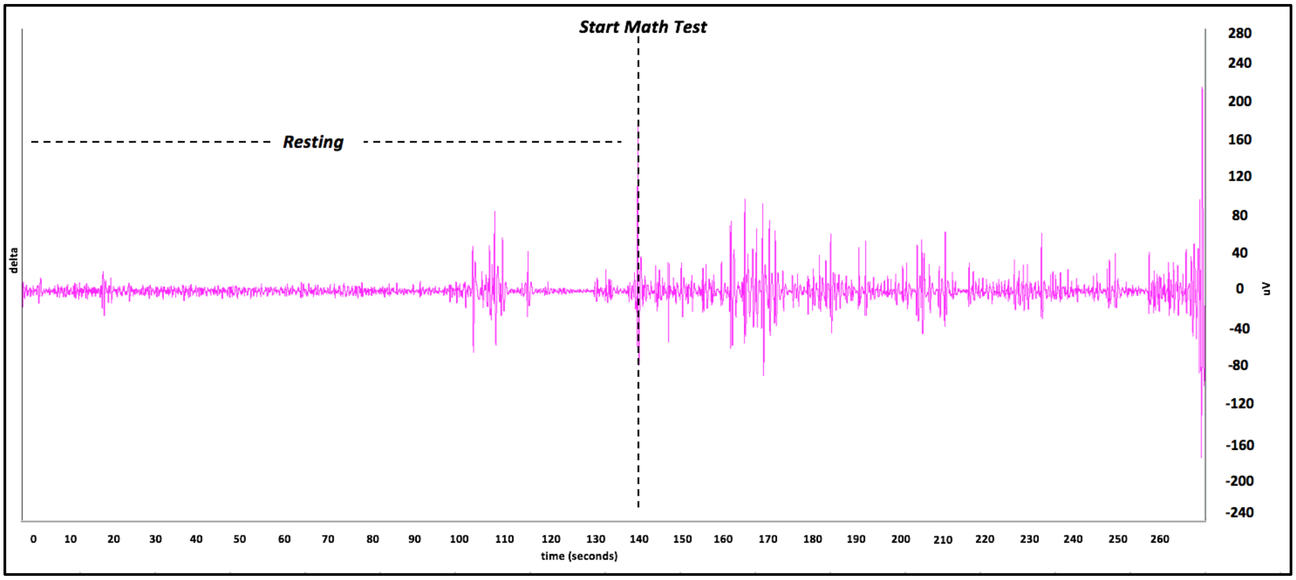


**Figure 3** An example of what expected Delta waves should look like during EEG data collection. Delta waves are known to increase during strenuous mental activities (BIOPAC, 2012). This can be observed when the waves began to increase at the point stated "Start Math Test." Same variables as Figure 2. X-axis is time in seconds. Y-axis is uV.

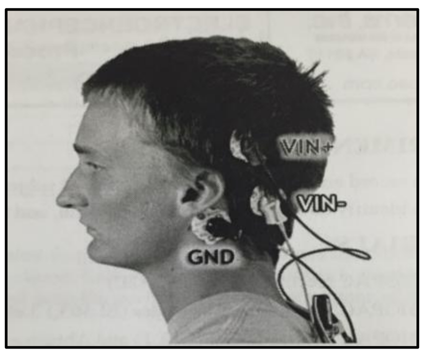


**Figure 4** The placement of the three electrodes on each participant can be seen. There were three electrodes: Vin+, Vin-, and GND. All three are placed on the participant's head. These electrodes were used to collect theta and delta waves data via EEG.

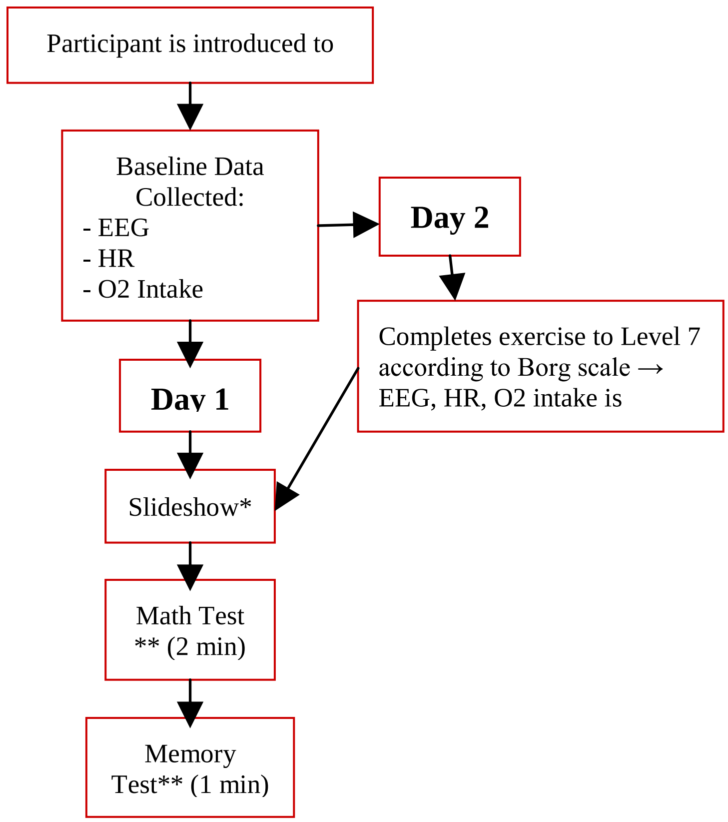


**Figure 5** The timeline of the experimental procedure can be seen in the flowchart above. Day 1 follows the arrows straight down, while Day 2 requires exercise to be completed after the baseline data is collected, before proceeding with the same tasks as administered on Day 1.

Key: * EEG, Heart Rate (HR), and $O_2$ Intake recorded only at the end of the completed task

** EEG, HR, and $O_2$ Intake recorded in the middle of task completion and at the end of the completed task.

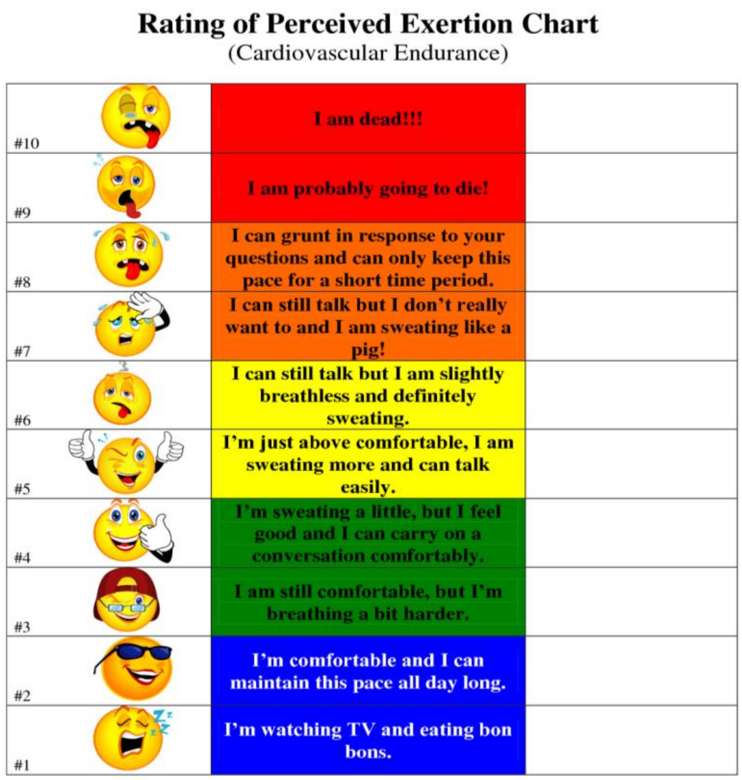


**Figure 6** is a representation of the Borg Scale. This will be shown to participants on Day 2 as they are exercising. Each participant will be asked to exercise until they self-report that they have reached a level 6 or 7 on the scale.

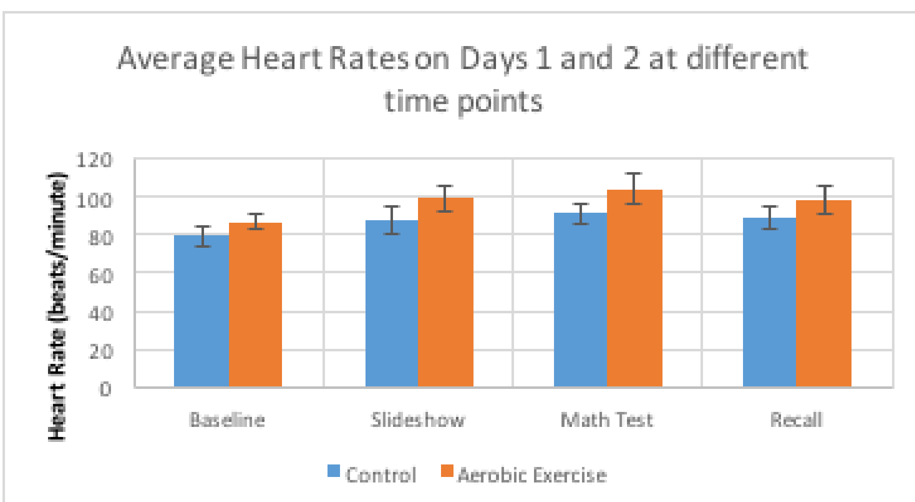


**Figure 7** shows the average heart rates of the participants on day one (control) and day 2 (aerobic exercise). The measurements were taken as baseline, during the viewing of the slideshow, when taking the math test, and during the recall test.

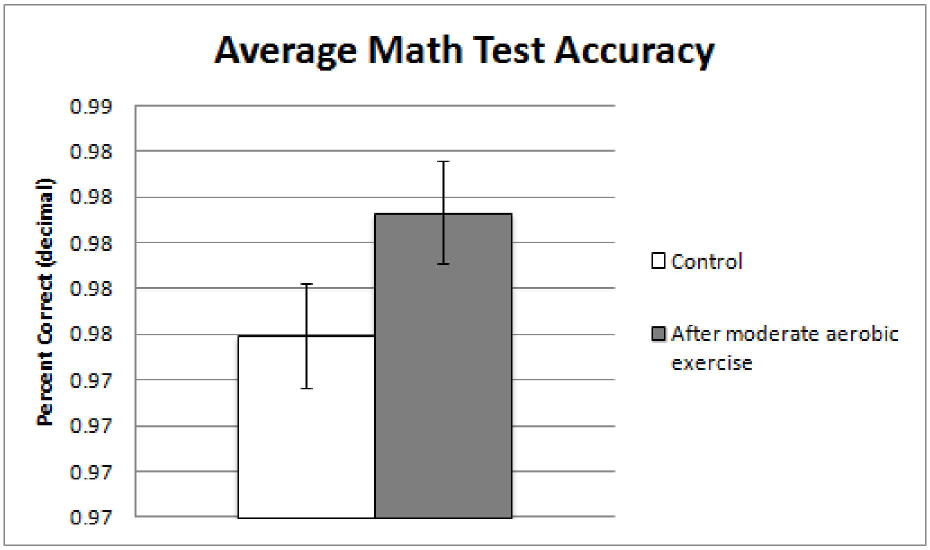


**Figure 8** shows the average percentage of questions that were answered correctly between the control and after moderate aerobic exercise. Standard error is +/-0.00692 for the control data and +/-0.00638 for the exercise data.

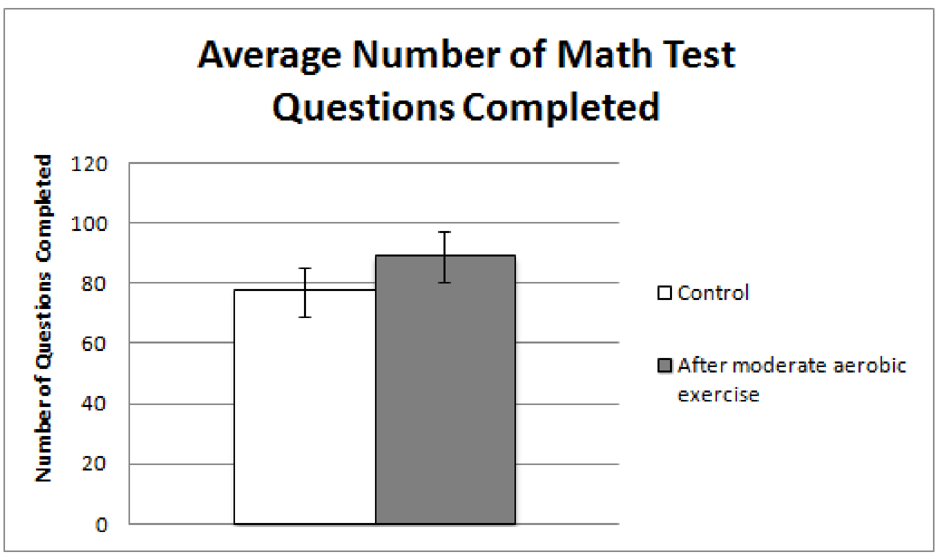


**Figure 9** shows the average number of questions that were attempted on the math test between the control and after moderate aerobic exercise. Standard error is +/-8.301 for the control data and +/-8.448 for the exercise data.

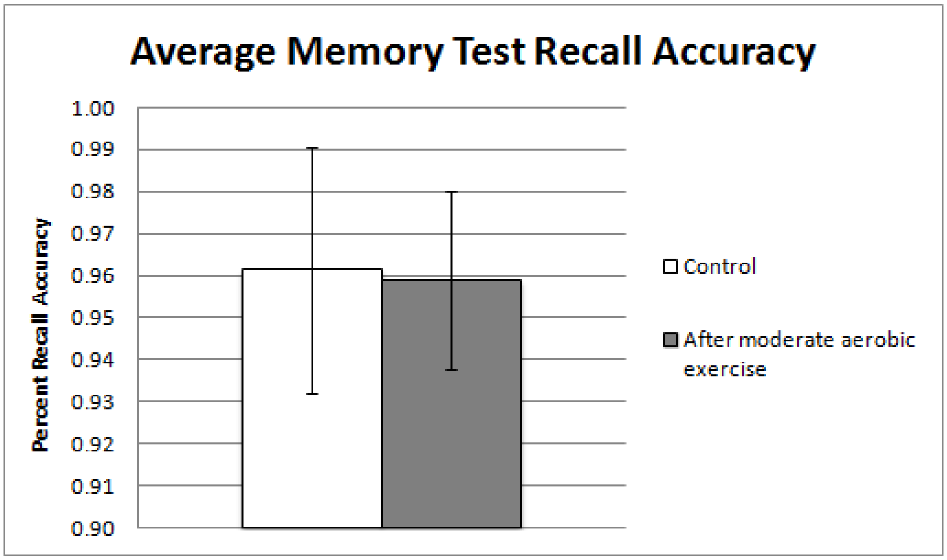


**Figure 10** shows the average recall accuracy for the memory the control and after moderate aerobic exercise. Standard error is +/-0.0292 for the control data and +/-0.0209 for the exercise data.

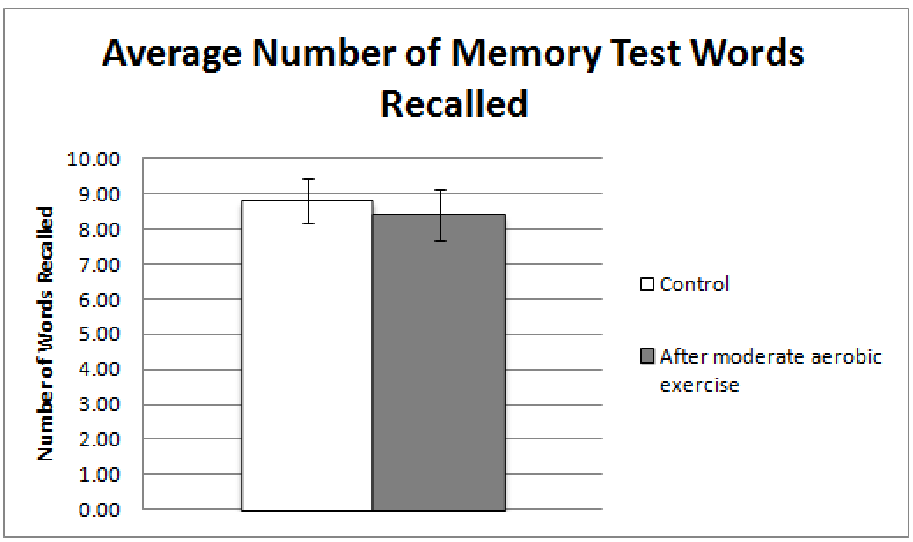


**Figure 11** shows the average number of words that were recalled between the control and after moderate aerobic exercise. Standard error is +/-0.6289 for the control data and +/-0.7180 for the exercise data.

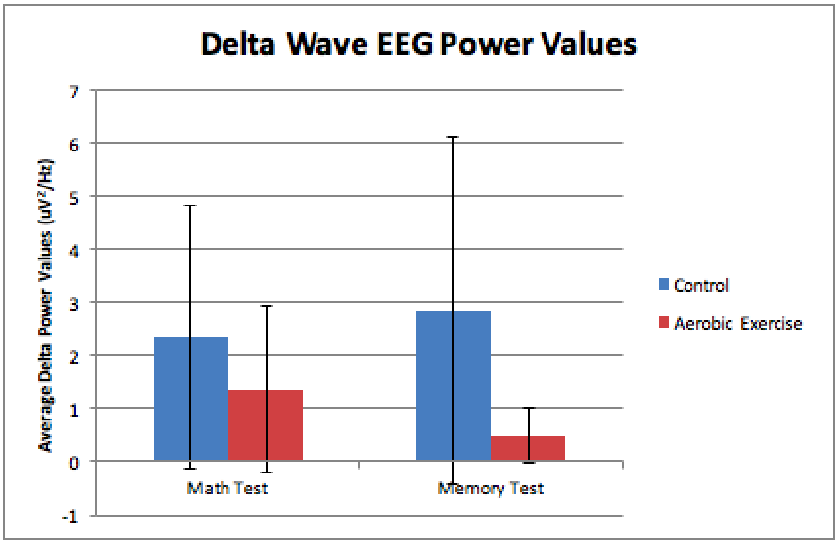


**Figure 12** The average delta power wave values taken during the math and memory tests. There was a decrease of the average power values compared between the control and aerobic exercise groups for each test. The average power value for the math control was 2.344. For the memory control the value was 2.859. For the aerobic exercise the math group average power value was 1.365 and for the memory task it was .5049. The standard deviations were quite large, for the controls they were 2.48 and 3.26 for the math and memory test respectively. The standard deviations for the aerobic exercise groups were 1.57 and .53 for the math and memory test respectively. The control day data

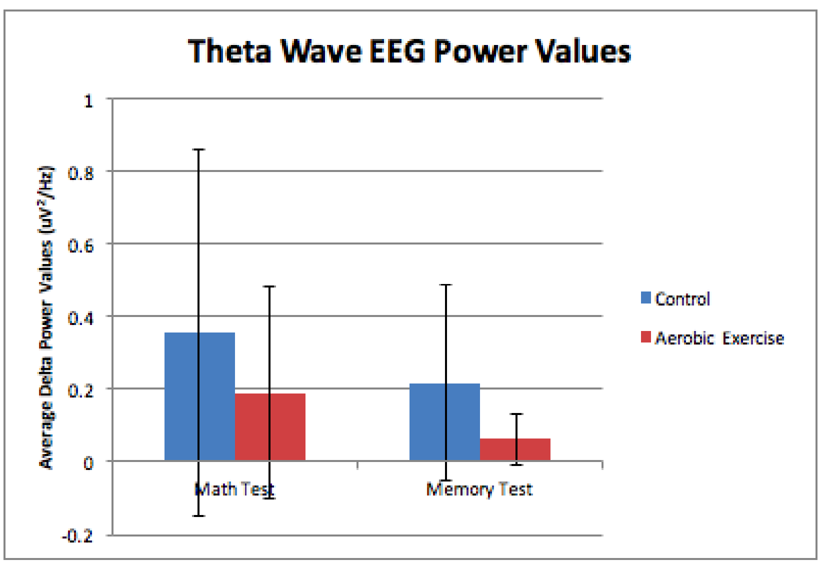


**Figure 13** The average theta power wave values taken during the math and memory tests. There was a decrease of the average power values compared between the control and aerobic exercise groups for each test. The average power value for the math control was .3577. For the memory control the value was .2174. For the aerobic exercise the math group average power value was .1917 and for the memory task it was .0629. The standard deviations for the controls were .51 and .27 for the math and memory test respectively. The standard deviations for the aerobic exercise groups were .29 and .07 for the math and memory test respectively.