Effects of Moderate Exercise on Short Term Memory: An Analysis of Beta Wave Forms and Heart Rate

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Abstract

This experiment tested the hypothesis that coupling studying with moderate exercise will increase short-term cued-recall ability. Ten individuals (five male and five female) between the ages of 20-21 were tested under the preliminary control conditions of studying without exercise and taking a memory test, which required the subjects to recall words that fit their corresponding definitions. Then, a similar test was given to the same subject, under experimental conditions, after they studied during moderate exercise. Therefore, each subject served as its own control. We monitored the amount of exercise each participant engaged in by keeping them under 80% of their maximum heart rate to prevent the effects of exhaustion. Physiological responses to exercise were studied and used to help explain the change in short-term memory. Electroencephalogram (EEG) and pulse oximeter devices were used to measure brain wave frequencies, heart rates and their changes throughout baseline, exercise and study periods. Our results indicated a significant increase in short-term recall when comparing the average correctness scores of tests between exercise and sedentary groups. Finally, beta wave frequencies increased throughout exercise, indicating an increased level of brain activity and cognitive reasoning.

Introduction

College students live in an era where grades strongly influence future careers. Consequently, many students are in search of techniques to improve their study methods. One common suggestion for improving learning is to include exercise in a student's daily list of activities. As students interested in the impact our activity level could have on our academic success, we evaluated the validity of the physiological implications of exercise on learning.

As learning can have multiple definitions, for our purposes, we chose to define learning as improvements in short-term cued-recall. Cued-recall is defined as remembering a list of words based on the presentation of related words that were initially learned together (Carpenter et. al., 2006). By using cued-recall, we tested the ability to associate a word with its definition corresponding to a paired learning relationship, as compared to simple and random recall of a list of words. Cued recall is relevant with regards to college student studying because repetitive flashcard review of course material is often used to learn course content.

By concentrating the data collected on the physiological effects of the exercise, we hoped to determine what might cause the improvement in memory. Utilization of several physiological measurements allowed us to monitor responses to exercise and the corresponding relationship to cued-recall ability. It is well established that heart rate increases during physical exercise. Differing increases in heart rate will distinguish between light, moderate, and heavy forms of exercise using maximum heart rate method. Maximum heart rate is defined as 220 – age (Karvonen et. al., 1988).This max heart rate method allowed monitoring intensity levels of exercise in subjects, keeping their heart rate below 80% their max heart rate. This eliminated the possibility of impairments due to physical exhaustion from heavy exercise as brain activity is altered when one becomes exhausted (Nielsen et. al. 2001). The rationale behind measuring heart rate during the exercise is that an increase in heart rate is the first step in the process from physical exercise to improved memory. As the heart rate increases, the heart works harder to pump blood throughout the body. During exercise, increased levels of oxygen are needed, and this increased blood flow delivers the needed oxygen to oxygen-deprived tissues.

An elevated heart rate has been shown, in mammals, to result in increased cerebral blood flow (Sumiyoshi et. al., 2012). During exercise, regional cerebral blood flow (rCBF) increases by 16%, as blood velocity in major cerebral arteries and blood flow in the internal carotid artery increase (Ide et. al., 1999). Electroencephalograms (EEGs) measure electrical activity in the brain using the frequency of the waves produced by electrodes on the scalp (McMillan, 2008) (Appendix Figure 1). Decreased blood flow to regions of the brain has shown to reduce the activity of EEG readings (Leech et. al., 1974). The varying frequencies in brain waves correlate with a multitude of brain functions. Increased activity of all frequencies corresponds to increased learning; however beta waves are going to be measured in this experiment to analyze memory formation processes. Beta waves between frequencies of 13 and 30 Hz are present during problem solving and conscious thinking (Huddleston et. al., 2008). Increased blood flow resulting from exercise, and corresponding increases in EEG activity measurements, are expected to deliver necessary oxygen and nutrients to the brain to improve cognitive function and result in improved recall.

Based on these previous studies, we hypothesized that an increase in physical activity resulting in increased heart rate and brain activity levels while studying improves short-term, cued recall. Furthermore, we proposed that the learning process which occurred during the exercise corresponded to improvements in recall, compared to immobile studying performed by the same individual.

Materials and Methods

General Procedure

Researchers tested ten undergraduate Physiology 435 students from the University of

Wisconsin-Madison. Subjects were chosen to represent an equal amount of five males and five females, ranging from 20 to 21 years of age. Each participant voluntarily consented to the experiment and provided background information regarding age, sex, and approximate number of hours of exercise performed per week. Each participant served as its own control by participating in the experiment; first without exercise and then with exercise and took a randomly selected test for each trial.

Groups

There are two groups tested in this experiment, one is the control and the other is the experimental group that will be exercising. The same person was used in both groups to initially serve as their own control. For the control group, each participant studied and was tested without exercising. After being connected to the EEG apparatus and the pulse oximeter, baseline measurements were taken to ensure normal values should be expected and that the equipment was set up correctly. Five minutes were allotted for studying, an additional five minutes were provided to rest and potentially allow the information to set in, and then five minutes were given to complete the test. While still connected to the EEG apparatus and pulse oximeter, participants began the experimental test and were asked to sit atop a stationary bike and begin to bike for five minutes to increase their heart rates to a moderate level. The same series of five minutes of studying, five minutes of rest and five minutes of testing was allotted to obtain cued-recall test results.

Measurements

EEG

First, subjects were connected to the Electroencephalograms (EEG) apparatus (Biopac Systems). Electrodes were placed on the earlobe, the lower parietal lobe, and the occipital lobe. The electrodes placed on various locations of the cerebral cortex were used to measure thought and reasoning, the electrode on the earlobe served as the grounding state (Biopac Systems, Inc.). The participants were required to wear a swim cap to hold the electrodes in place. EEG measurements were taken throughout the entire 35 minute interval, both control and experimental timelines, to detect changes in brain activity.

Pulse Oximeter

The Nonin Pulse Oximeter device was used to take measurements from the right index finger. The subject was positioned either in a chair or on the stationary bike, and baseline measurements were taken. These measurements were continuously monitored throughout the entire experiment to ensure appropriate heart rate levels. The level of moderate exercise was determined using the maximum heart rate method and the physical activity was not to exceed a moderate level, or 80% of their maximum heart rate (Appendix Figure 3) (Karnoven et. al. 1988).

Cued-Recall Tests

In both groups, the participants were allowed five minutes to study a list of words randomly selected from Dictionary.com's "Word of the Day" along with their corresponding definitions (Dictionary.com). The subjects were then examined on their ability to recall these words after five minutes of resting time. The five minute break in between studying and testing was used to avoid immediate recall. We had four different sets of fifteen words from the online dictionary and their corresponding definitions. Furthermore, the words were all of similar difficulty to avoid conflict regarding content between tests. The forms given to study had two columns: words on the left and definitions on the right (Appendix Figure 2). The test had the definitions in a random order on the right with blank spaces on the left. The participants were asked to write the correct words with their corresponding definitions.

Data Analysis

EEG Analysis

Portions of the EEG data sets were measured to recognize an increase in beta wave frequencies (Appendix Figure 4). The occurrence of these waves were also compared to baseline data to provide evidence for an increased frequency of brainwaves that correlate to increased brain activity. Ten second intervals were looked at to provide concentrated sections of results that showed increased beta wave frequencies. Numbers of wave cycles were counted from the 45-55 and 200-210 second period in the control group and the 205-215 and 400-410 second period in the experimental group. These periods were chosen because they were baseline timeframes, when nothing was being altered; in the middle of the studying without exercise; during exercise without studying; and the studying during exercise periods, respectively; and they each provided over 100 cycles of beta waves to analyze. After total cycle numbers were obtained, they were divided by the period of ten seconds to calculate an average frequency for the time frame.

Pulse Oximeter Analysis

Throughout each procedure, both control and experimental timelines, the pulse oximeter was monitored to ensure appropriate heart rate levels. Statistical analysis was done to compare ranges and determine a correlation between percentage of heart rate increased with percentage improvement on the cued-recall tests (see Results).

Cued-Recall Test Analysis

The results of the exams were judged on the basis of spelling and number of correct matches. The scores were used to determine if there was any improvement in recall with exercise.

Statistical Analysis

A paired t-test was used because of the small sample size with paired data sets, which allowed for comparison of each subject between experimental conditions. Two tailed P-values were obtained from each analysis performed because no inherent trend was known for the data set with an alpha value set at 0.05 for significance determination. P-values less than the alpha value were considered as significantly different with a null hypothesis of no difference being observed between the conditions. This analysis was used for all data sets considered henceforth.

Results

Heart Rate

Heart rate was used primarily to monitor the intensity of the exercise. Heart rate was seen to increase in subjects while studying, as well as while exercising (See Figure 1). The (exercise, studying) groups are reported as average beats per minute ± standard deviation. The (-,-) group was 68.2±13.6. The (-,+) group was 74.9±15.4. The (+,-) group was 106.7±16.8. The (+,+) group was 119.3±24.4 (See Figure 1). A difference in percent increase of heart rate was shown to be positively correlated with an increase in memory test scores (See Figure 4). When these two variables were plotted against each other, the line of best fit was y=0.8666x-0.0664 with an R2 of 0.2341.

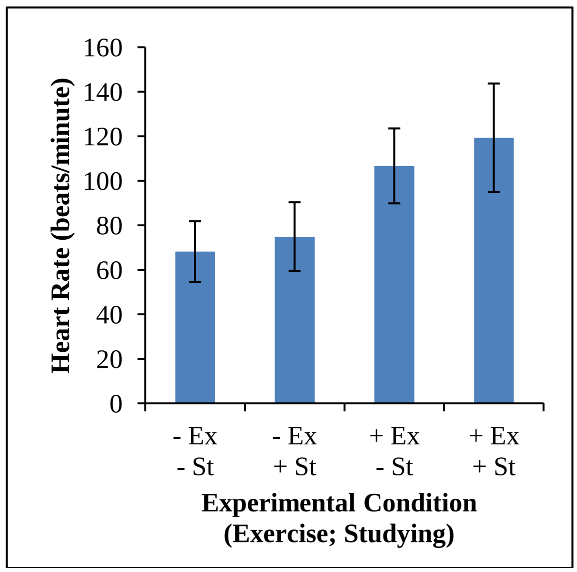

Figure 1. Bar graph displaying the average heart rates of the ten subjects under each experimental condition. The average heart rates observed were 68(±14), 75(±15), 107(±17), and 119(±24) beats per minute respectively for the experimental conditions of no exercise no studying, no exercise with studying, exercise no studying and exercise with studying.

Memory Tests

One of four memory tests was randomly selected and given to the subjects both with and without exercising while studying. Correct answers were judged according to spelling and correctly matched to definitions. The average test score for the test without exercise was 60.0±26.3 percent, and the average test score for the test after exercise was 72.7±22.5 percent (See Figure 2). Difference between sedentary and exercise memory test scores resulted in a paired two-tailed t-test value of 0.014 with an alpha value of 0.05. There was a significant difference between the no exercise and exercise groups' memory tests were concluded.

EEG

Brain activity was measured using an EEG to measure the increase in frequency of beta waves from controlled baseline timeframes to exercise only time spans, and immobile to exercise study. Beta waves are waves present during critical thinking and cognitive problem solving. Data for subject 2 was unfortunately lost due to a computer malfunction during data analysis. Average increase in frequency of 18.825±1.508 and 20.02±2.102 for exercise and non-exercise experiments, controls are also shown in Figure 3. A two tailed t-test was performed the t-test value was 0.01291 with an alpha value of 0.05 which means that the difference of 1.208 Hz between average beta wave frequency in exercise versus stationary studying groups was significant.

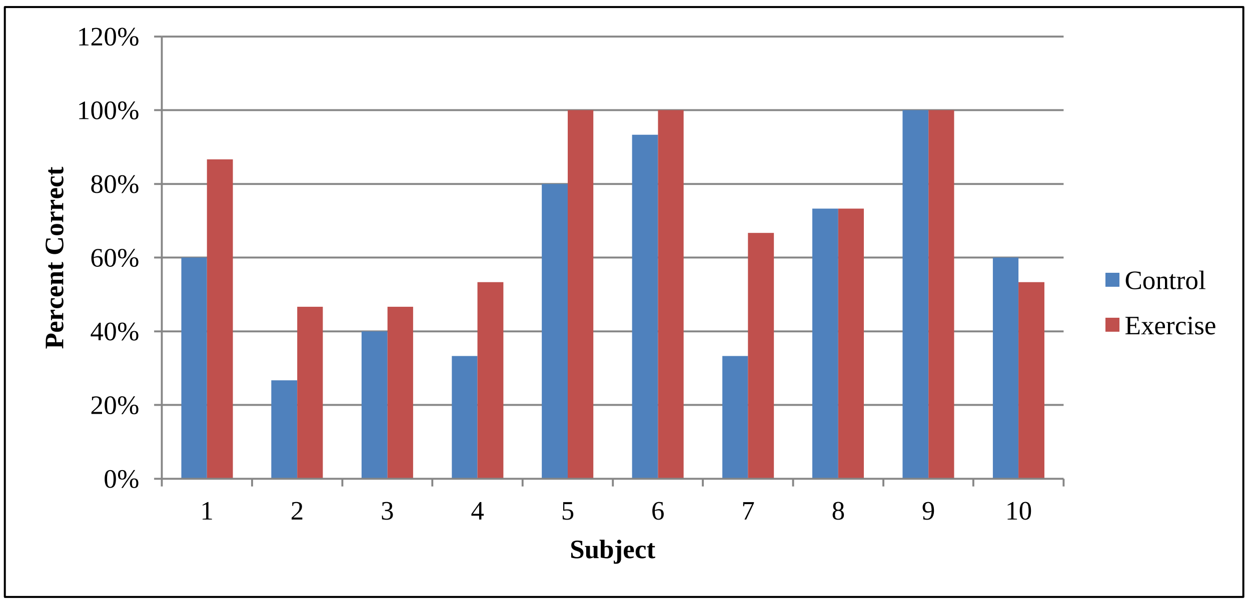

Figure 2. This graph illustrates the results of the memory tests taken by each subject. Average scores for the no exercise tests were 60.0±26.3 percent, and average scores for the tests after exercise were 72.7±22.5 percent. Seven out of the ten subjects improved on their tests, two of the ten saw no change, and one decreased.

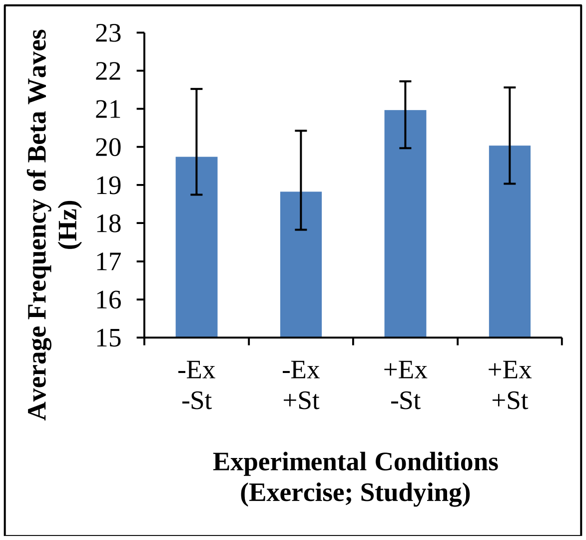

Figure 3. This graph shows the average hertz measured by the EEG over 10 second periods during control periods, studying alone, exercising alone, and study and exercise together. The average hertz for the without exercise trial and exercise trial were 18.825 and 20.02 respectively. Standard deviation is represented on the graph using error bars.

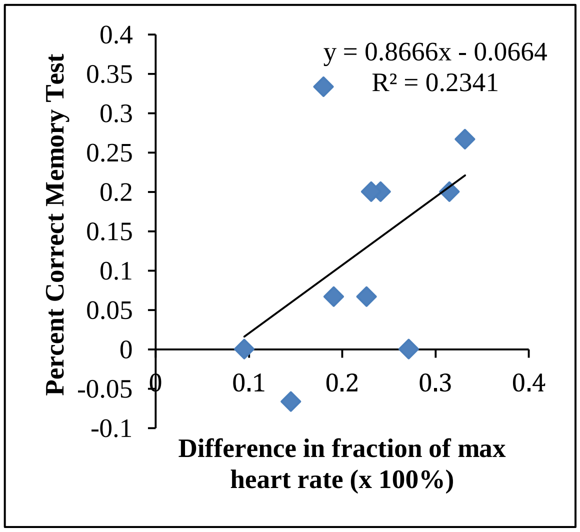

Figure 4. This scatter plot shows the change in scores on the memory test as a function of the difference in percent of subject's maximum heart rate from resting to moderate exercise with studying. The equation for the line of best fit was y=0.8666x-0.0664 with an R^2 of 0.2341.

Discussion

This experiment was performed to test the effects of moderate exercise on short-term memory recall. This experiment focused on the physiological aspects of both exercise and memory. The results gathered overall had supported our hypothesis that studying during moderate exercise would increase short-term recall ability as opposed to stationary studying.

Heart rate, although primarily used to establish moderate exercise, was also seen to increase during studying when compared to baseline readings (figure 3). Elevation in heart rate has been shown to increase cerebral blood flow (Sumiyoshi et al, 2012) and therefore supports our conclusion that this cerebral blood flow increases oxygen and nutrients delivered to the brain which enhances memory ability. Our data also showed that as you approach 80% of the maximum heart rate, the improvements on the memory test become less pronounced because the effects of physical exhaustion begin to kick in (figure 4).

Results gathered from the EEG apparatus indicated a statistically significant increase in average frequency of beta waves in the exercise plus study group when compared to the sedentary plus study group. There was not a significant, but very close, difference between the exercise without study and baseline readings. We did have a small sample size, and this close to significant relationship may indicate that exercise alone may increase brain wave activity. In contrast, study without exercise versus baseline showed no significant difference in brainwave activity. Overall, our statistics showed that exercise alone has a stronger effect on brainwave activity than does studying. As described in our methods, this increase in average frequency means that there were more beta waves during the analyzed time frame. The results we obtained support previous studies which link exercise with increased brain waves. We took the next step and concluded that such an increase in brain activity may improve cognitive functioning and therefore improve the ability to store information in your short-term memory.

Our memory tests provided a clever way to test short-term memory utilizing more than simple recall. The tests required participants to learn relationships among words and understand definitions, which correlates to a more accurate depiction of learning. We found an average of 12.66% increase in memory tests scores between exercise and stationary groups. All of our data collected from these three physiological and cognitive variables supported our hypothesis. Thus, the physiological changes involved with exercise may cause your body to function in a way that favors critical thinking and improved memory in the short term.

Limitations

As with any scientific experiment, there were several limitations and unexpected problems we came across. Due to the nature of needing to meet class deadlines, time restricted our ability to expand our sample size and diversity. Given only ten subjects, we were unable to obtain significant statistical data to show that our exercise-induced learning was due solely to exercise and not other variables. Furthermore, we concluded that increases in correct cued-recall could have been due to the repetition of the tests and the subjects' ability to study differently during the exercise portion, after starting with the immobile experiment. This factor could have been eliminated by randomizing the order of the test. We chose not to do this because we didn't know how long the effects of exercise would take. A larger sample size also would have been beneficial to standardize the variation of hours per week each subject already exercised. Several subjects normally exercised in significant amounts during the week, which may have had outside effects on their ability to increase their heart rates. For example, if someone rarely exercised and this was out of their comfort zone, the resulting stress and exhaustion would have influenced their ability to facilitate learning. The largest obstacle we came across was the limitations of the EEG program. In order to accurately deduce an increase in beta wave frequency, we had to count by hand the number of wave cycles and calculate a frequency from there. Had the program provided a way to calculate this through computer algorithms, we would have been able to analyze larger sections of data.

Successes

Although these limitations arose, there were several strengths to our experiment. Our main strength was that we sought out to find a correlation between exercise and learning, an aspect of life that is extremely relatable to our peers and ourselves. Furthermore, even though our sample size was small, we were able to deduce a strong correlation between the physiological responses of the body and the cognitive ability to recall information over a short-term time frame. Additionally, we were sure to use each subject as his own control to provide a comparison between each individual's ability to recall throughout immobile or exercised studying. We knew that if we used two separate groups for control and experimental testing there would have been too many outside variables to consider when determining if the exercise had its anticipated results. This would have eliminated the possibility to monitor each individual and make note of any improvements between exercising and sedentary groups. Another strength was the use of cued- recall testing, as opposed to simple recall. The use of cued-recall required the memorization of a relationship between two words, which involves higher level thought processes and therefore is closer to learning than simple repetition. Finally, our statistical analysis, although based on small sample size, it did show a positive correlation between exercise and the ability to recall.

Future Implications

Given the above critiques, there are future studies that would be beneficial to perform in order to deduce stronger correlations between exercise and learning. First and foremost we would suggest a much larger sample size in order to make the results more statistically significant, along with providing more variation between subjects' backgrounds. A more comprehensive EEG program would be very beneficial to analyzing larger sections of data and potentially measuring gamma wave frequencies, which are high-level beta waves that closely correspond to learning. Perhaps we could change either the exercise or memory tests to provide more variation between the intensity of exercise and the medium of material to study, respectively. Finally, to make the study even more relevant to physiology, we suggest measuring cortisol levels. Everyone reacts differently to exercise and by measuring cortisol levels we could further qualify the effects of stress on learning. We also suggest bringing back subjects multiple times over the following weeks to determine longer-term effects of exercising on learning.

In conclusion, this study provided evidence to support a positive correlation between exercise and memory recall. Several benefits of the study included an ability of subjects to use exercise as a way to minimize distractions and focus on deducing relationships between the materials being studied. Additionally, this study may give students an incentive to stay active, leading to several other health benefits in both long and short terms.

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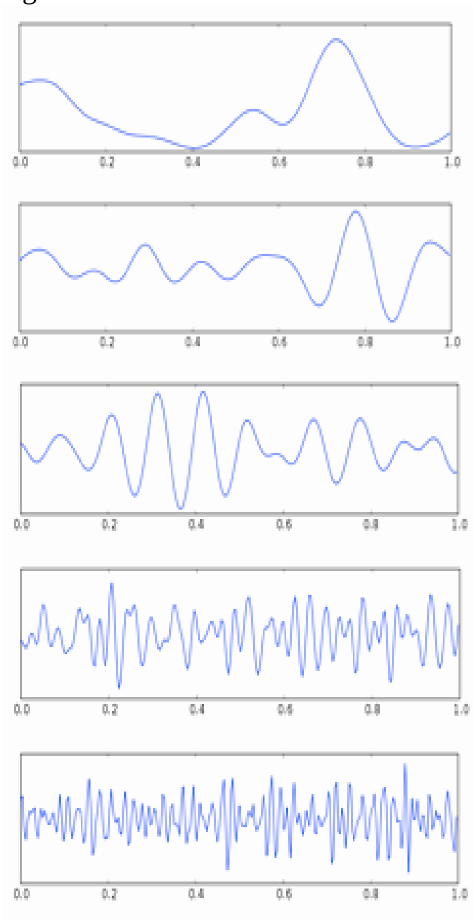
Appendix

Figure 1



A

B

C

D

E

Figure 1. Stanford University – Neuropharmacology Laboratory. The waves can be identified as follows: A, delta waves; B, theta waves; C, alpha waves; D, beta waves; E, gamma waves.

Figure 2

toper:	a drunkard; a sot.
trice:	an instant; a moment.
putsch:	an attempt to overthrow a government.
obviate:	to anticipate and dispose of or make
nebbish:	a weak-willed, timid or ineffectual person
pukka:	genuine, authentic, or good; proper
inamorata:	a woman whom one is in love with

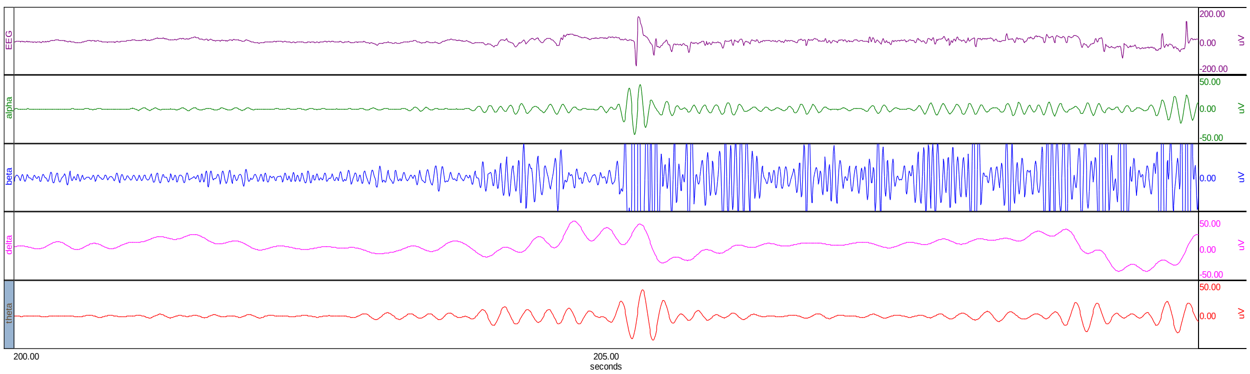
Figure 2. Sample list of words with definitions for cued-recall test. Actual list had fifteen words-definition pairs.

Figure 3

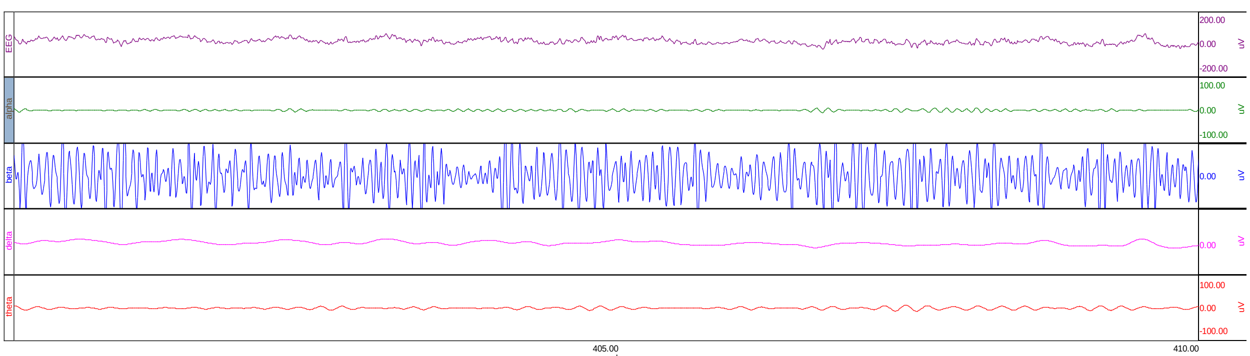
Fitness Level	Low			Moderate			High			Very High		
Percent Max Heart Rate	50	60	66	70	74	77	81	85	88	90	92	100
Percent VO2 max	28	42	50	56	60	65	70	75	80	83	85	100

Figure 3. Classification of heart rate determination with maximum heart rate = 220 – age.

Figure 4



A



B

Figure 4. Examples of EEG data from Subject 3. Panel A shows all brain wave frequencies from 200-210 seconds during studying without exercise. The blue waves are beta waves, showing an increase in intensity during the middle of the time frame, indicating increased brain wave activity as studying progressed. Panel B shows all brain wave frequencies from 400-410 seconds during studying while exercising. The beta waves are at a very high level of intensity throughout the entire time frame, indicating the presence of cerebral activity that results from exercise, coupled with the increased activity that accompanies studying.