# Exercise: The Secret to the 4.0?

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**Abstract**

Limited data are available regarding the effect of an acute bout of exercise on cognitive function in young adults. We hypothesized healthy college-aged students would exhibit an improvement in short term verbal recall memory after 5 minutes of moderate intensity exercise. In addition, we hypothesized beta brain wave activity would increase after 5 minutes of exercise, and improvements in short term verbal recall memory would be correlated with increases in beta brain wave activity. Fourteen healthy college-aged students (7 female, 7 male) participated in the study. All subjects took a verbal recall memory test while an EEG recording was taken to measure alpha, beta, delta, and theta brain wave activity. Subjects then performed 5 minutes of moderate intensity cycling (Borg's Rating of Perceived Exertion = 4), and then repeated the verbal recall test and an EEG recording was taken once their heart rate (HR) returned to resting levels. Data are expressed as mean +/- SE. After exercise, there was an increase in verbal recall test scores (10.86 to 11.5) which did not reach significance ($p = 0.38$). Beta brain wave activity during the formation of memory portion of the test increased (0.0003 μV to 0.003 μV) but again did not reach significance ($p = 0.38$). There was no correlation between changes in memory recall test scores and changes in beta brain waves. The current findings suggest there is no significant improvement in short term verbal recall memory after 5 minutes of moderate intensity exercise. Furthermore, beta brain wave activity is not significantly increased after short term exercise. A significant limitation was using the RPE versus an absolute HR. A pilot study (see Appendix Table 1) was conducted where participants exercised at a HR that was 60% of their predicted maximum HR. The results from this pilot study did not show a significant change in memory recall test scores between pre-exercise and post-exercise. These data provide novel physiological insight into what the best prescribed duration, frequency, and intensity of exercise should be in order to help undergraduate students improve short term memory.

**Introduction**

Cognitive function is a term used to describe an individual's ability to perceive and judge the world as well as to comprehend ideas and process thoughts. It involves four different factors: perception, thinking, reasoning, and remembering. An individual's cognitive function can be assessed through these four factors. Throughout the years, many studies have been conducting research to assess how certain lifestyles, behaviors, or even drugs affect cognitive function.

Exercise has been theoretically determined to improve cognitive function by a variety of factors. This theory has led to extensive research on all age groups to uncover its general effect. Theoretically, exercise does improve overall cognitive function through increasing cerebral flow, increasing glucose metabolism by accelerating glucose uptake, and increasing the amount of oxygen extracted during aerobic activity (Churchill et al, 2002). In addition, exercise facilitates the activation of growth factors that control structural changes such as capillary density (Skorjanc, D. et al, 1998). A recent meta-analysis on studies with subjects ranging from the age of 7 to 18 demonstrated a positive relationship between physical activity and cognitive function (Sibley, B. A. & Etnier, J. L, 2003.). The study showed six different measurements of cognition function were positively correlated to physical activity including perceptual abilities, intelligence quotient, achievement, verbal tests, mathematic tests, and developmental level (Sibley, B. A. & Etnier, J. L, 2003.). In addition to the effect exercise has on a child's brain, older adults have been the subjects of many experiments aimed at deciphering how exercise benefits the aging population. In yet another meta-analysis, researchers looked at 11 different studies on adults without cognitive impairments over the age of 55 and the effect exercise had on them. The 11 studies ranged in their intensities and durations of physical activity, but the majority of them came to the same conclusion: physical activity helps to improve motor function, cognitive speed, and both auditory and visual attention (Angevaren M et al, 2008). This improvement coincided with an increased cardio respiratory fitness indicating it could underlie the reason for increased cognitive function (Angevaren M et al, 2008).

Although much research has gone into uncovering the effects of physical activity on the cognitive function of young children, adolescents, and older adults, there is a large gap in research concerning young adults and how acute bouts of exercise affect their cognitive function (Hillman et al, 2002). The goal of our study is to assess the effect of one bout of moderate physical activity on the cognitive function of college students. We hypothesize young adults will exhibit improvements in cognitive function after 5 minutes of moderate intensity aerobic cycling. Specifically, we predict subjects will show improvement in verbal recall memory once their heart rate has returned to resting levels.

The experimental setup for our study is based on information that past researchers have already discovered. Since research shows older populations can improve verbal recall memory with long-term aerobic exercise, we chose to include a verbal recall test to observe whether a younger population would have the same result (Hillman et al, 2002). A commonly accepted belief is a bout of exercise at maximum effort actually attenuates memory, so subjects will perform 5 minutes of moderate intensity cycling using the Borg's Rating of Perceived Exertion. On a scale of 1-10, subjects will be instructed to maintain a rating level of 4 (somewhat hard). A rating of 4 also represents the most probable rating during everyday aerobic exercise, and could easily be encouraged by clinicians.

If our hypothesis is supported by our results, our research could have significant effects on the study habits of college age students. If short intervals of physical activity do improve cognitive performance, students could be advised in more effective ways to study. Instead of drinking coffee or energy drinks and attempting to study for long periods of time, students may be better off to increment short breaks to exercise. Our research could also help students plan their daily activities to achieve an optimal amount of learning. If we are correct, then students should plan their physical activities before they study or take an exam in order to do their best. Apart from changing students' priorities, our research could open the door to a more in depth look at the question of physical activity's effect on cognitive function. Further research could include finding an optimal time of physical activity to improve cognitive function. Other research could also be done on various age groups, such as young children. These further research opportunities could have large effects on student performance and possibly scheduling, such as when to hold gym classes in elementary schools. Apart from just improving students' abilities in school, our research could lead to a better overall health if physical activity is incremented within study time.

## Materials and Methods

*Subjects*

Subjects will include men and women ages 18 – 25 years old. All subjects are in sufficient cardiovascular condition to endure moderate (somewhat hard) exercise, are enrolled in a collegiate level, and have no prior knowledge of this experiment. All the subjects have read and signed a consent form and are aware of the risks associated with this experiment if any.

*Heart Rate*

Each subject's resting heart rate was measured and recorded prior to testing using a pulse oximeter (Nonin, Plymouth, MN). After exercise, heart rate was monitored in order to ensure the subject has reached resting heart rate within 5 beats per minute (bpm). The pulse oximeter was clipped to the subject's right index finger.

*Electroencephalogram (EEG)*

Prior to testing, EEG electrodes were attached to the subject's head and held in place with a swimming cap. Three electrodes were attached. One testing electrode was attached behind the left ear, one testing electrode was attached above the left ear, and one ground electrode was placed on the left side of the mandible. The EEG was calibrated prior to the cognitive testing. Once calibrated, an EEG baseline was recorded during the first administration of the cognitive test before exercise. The EEG was disconnected from the computer and the electrodes remained attached to the subject during exercise to ensure no change in placement. After exercise, the EEG was reconnected and calibrated. A second recording was taken during the second administration of the same cognitive test (separate list of words with equal difficulty).

For each EEG recording, alpha, beta, delta, and theta waves were recorded for comparison (Appendix Figures 1-3). However, we focused on beta waves, because an increase in beta wave activity occurs in individuals who exert specific mental effort and represent arousal of the cortex to a higher state of alertness (Biopac Student Lab; V3.0: pg 4).

*Cognitive Test*

Subjects took a word test found on www.braingle.com/mind/test_words.php both before and after exercise (Appendix Figure 4). Subjects were given a list of 40 words (8x5) all of which contain 5 letters. The words were displayed for 90 seconds during which the subjects memorized as many words as possible. After 90 seconds passed, the screen changed to a text box where subjects had unlimited time to type as many words as they could recall. The number of correct words recalled was then recorded. This test was administered twice, once prior to exercise and once after exercise (the two tests contained different words). This test was used to assess cognitive ability through short term memory.

*Exercise*

After baseline tests were administered, the subjects completed 5 minutes of moderate (somewhat hard) exercise according to the Borg's Rating of Perceived Exertion. The Borg's Rating was used to standardize the effort level of all subjects. We used the 0-10 Borg's Scale, and had subjects cycle at a rating of 4 (somewhat hard). We chose a rating of 4, because research has shown maximum exercise efforts can have negative effects on cognitive function. A rating of 4 also represents the most probable rating during everyday aerobic exercise. Once the subject reached an exertion level of a 4, the subject began 5 minutes of exercise. Exercise was completed on a stationary Schwinn Bio-Dyne bike.

## Results

*Effects of 5 minutes of cycling on memory test scores*

The average of the memory test scores increased from 10.9 to 11.5 as shown in Table 1 and Figure 1. However, this increase did not reach significance ($p = 0.38$). As shown in Figure 3, most subjects had an improvement in memory test scores when reported as relative change from baseline. Eight subjects had a positive relative increase in memory scores, 2 had no change, and 4 had a negative relative change in scores. When all relative changes were averaged, the change again did not reach significance ($p = 0.13$).

*Effects of 5 minutes of cycling on beta brain waves*

We reported beta brain waves as beta-formation and beta-recall waves. Beta-formation waves represent the time when subjects were forming memories while looking at the list of words. Beta-recall waves represent the time when subjects were recalling memories while typing as many words they could remember. Beta-formation waves increased from 0.000287 to 0.003 as seen in Figure 2. However, this increase did not reach significance ($p = 0.38$). As shown in Figure 4, there was a split between those who had a relative increase in beta-formation waves and those who had a relative decrease. Six subjects had an increase in relative changes in beta-formation waves, while 8 subjects had a decrease in relative change in beta-formation waves. When all relative changes were averaged, the change was not significant ($p = 0.38$). In reporting beta-recall waves, 5 subjects showed a positive relative change in beta waves while nine subjects showed a negative relative change. When all relative changes were averaged, the change was not significant ($p = 0.96$).

*Association between memory test scores and beta brain waves*

There was no correlation between the change in beta brain waves (formation or recall) and the change in memory test scores. The model was eliminated using an AIC test (data not shown). Surprisingly, there was a strong correlation among the various brain waves which we did not expect to find.

**Discussion**

The current findings suggest there is no significant improvement in short term verbal recall memory after 5 minutes of moderate intensity exercise. Furthermore, beta brain wave activity is not significantly increased after short term exercise. There are several limitations to the study that may have contributed to the highly variable results in test scores and beta brain waves.

The EEG stickers were placed over the participants' hair, which led to interference in conductivity and a less accurate reading. A better approach would be to shave the participants' hair in order to get direct contact with the scalp or to use an EEG cap with more leads. The EEG measurements were also very sensitive to movement. During the recall portion of the memory test, the participants' tended to move their heads or bump the lead wires while typing. This caused a large amount of noise in the EEG readings. To prevent this noise, more sensitive leads or use of an EEG cap could be used to increase the accuracy of the reading. Another option, to reduce the noise due to head movement, would be to have the participants verbally recall the words instead of typing them out. This would remove the typing portion of the memory recall and reduce any movement of the lead wires. During data collection, it was observed that those participants that took longer to return to their resting heart rate decreased in the number of words they could recall. Future studies might consider recording the time it took for the participants to return to their resting heart rate for more accurate data analysis.

In addition to changes in running the memory test, the exercise portion of the experiment could be improved. The main problem with the exercise portion was the participants were at various levels of fitness. The Borg's RPE is subjective, and it was observed that some subjects could easily maintain a conversation at their RPE of 4, while others were notably out of breath. Future studies might include measuring each subject's $VO_2$ max on a separate study day and matching all subjects for fitness level to eliminate this as a possible confounding variable. If subjects are matched for $VO_2$ max values, one could employ an exercise model with an absolute workload that may yield more accurate results. Although we were unable to repeat the experiment using $VO_2$ max, we did a study on a small cohort of participants where they exercised for 5 minutes at 60% of their maximum heart rate (Appendix Table 1). The maximum heart rate was found by subtracting the participant's age from 220. The memory recall test scores post-exercise that resulted from this additional study did not significantly change from baseline, pre-exercise, memory recall test scores.

The final change, and most important, would be to increase the number of participants. While our data suggests possible correlations, the data set is too small to make any definite conclusions. With a data set of only 14 participants, the outliers had a significant effect on the outcome of the analysis. An ideal number of participants would be greater than 40, but this was not plausible in the time frame given for this experiment.

Although our results do not support our hypothesis, these data provide novel physiological insight into what the best prescribed duration, frequency, and intensity of exercise should be in order to help undergraduate students improve short term memory. Future studies could explore a similar intensity exercise model but lengthen the duration of exercise as it seems 5 minutes of exercise may be too short to see any significant improvements in cognitive function. We would encourage future studies to continue exploring the effects of exercise on cognitive function in young adults. With increasing educational demands expected of undergraduate students, it is important for teachers and health care providers to know the best prescription for physical activity in order to maximize cognitive function.

Questions future researchers should consider when examining the effects of exercise on cognitive function include: when is the appropriate time to begin exercising in one's life? What types of exercise are most beneficial? What duration and intensity of exercise should be employed?, and finally, does an exercise routine performed in one's young adult years reduce the effects of neurodegenerative diseases (Molteni, R. et al, 2004; Colcombe, S. & Kramer, A. F, 2003)?

**References**

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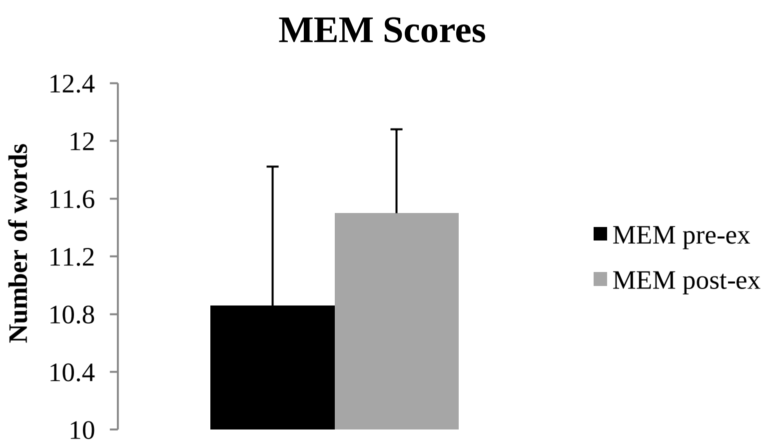
## Figures and Legends

***Table 1: Absolute values for HR, memory recall test scores (MEM), as well as all brain waves (formation and recall). All data presented as mean +/- SEM.***

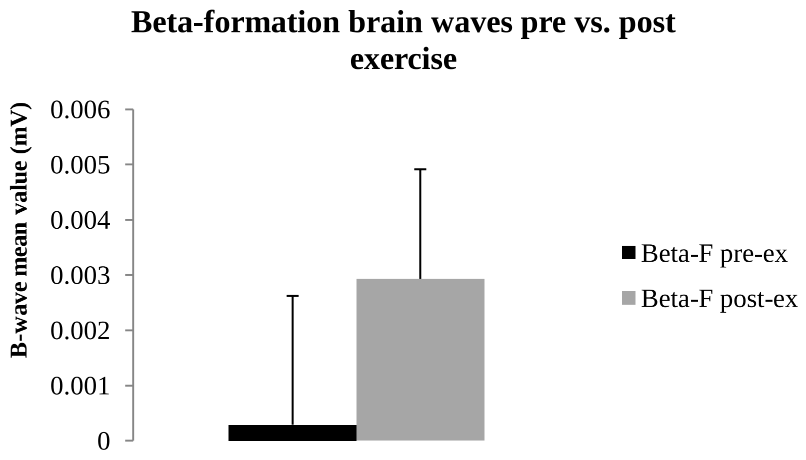
| Variables | Pre-exercise | SE | Post-exercise | SE |
|---|---|---|---|---|
| HR (bpm) | 70 | 2.5 | 74.4 | 3.04 |
| MEM score (out of 40) | 10.86 | 0.97 | 11.5 | 0.58 |
| Alpha-F (μV) | -.00053 | .0008 | -.001 | .001 |
| Beta-F (μV) | 0.0003 | 0.002332 | 0.003 | 0.002 |
| Delta-F (μV) | 0.19 | 1.93 | -2.61 | 1.69 |
| Theta-F (μV) | $7.86\times10^{-5}$ | 0.005 | -0.01 | 0.022 |
| Alpha-R (μV) | -0.001 | 0.0007 | 0.001 | 0.001 |
| Beta-R (μV) | 0.002 | 0.0017 | -0.001 | 0.002 |
| Delta-R (μV) | -1.8 | 1.59 | 1.4 | 2.03 |
| Theta-R (μV) | 0.006 | 0.004 | -0.004 | 0.005 |

***Figure 1: MEM scores pre & post exercise.***




**n=14. Values are expressed as mean +/- SE. p value = 0.38 using students paired t-test. Range of possible test scores = 0-40. Range of test scores with given subjects = 6-17.**

*Figure 2: Beta brain waves pre & post exercise.*

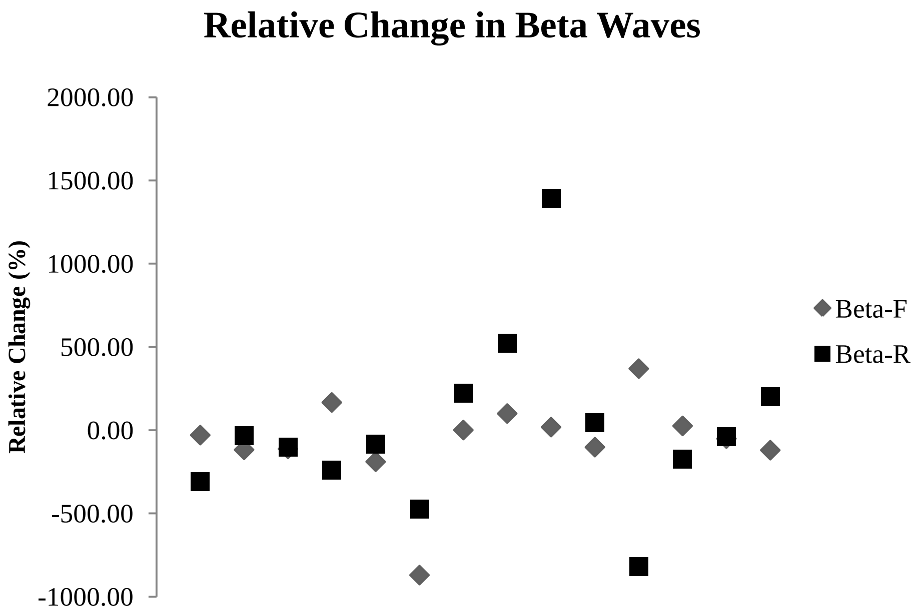



**n=14. Values are expressed as mean +/- SE. p val=0.38 using students paired t-test.**

*Figure 3: Relative change in MEM scores.*


**n=14. p val = 0.13 when compared to no change using students paired t-test.**

***Figure 4: Relative change in Beta brain waves.***



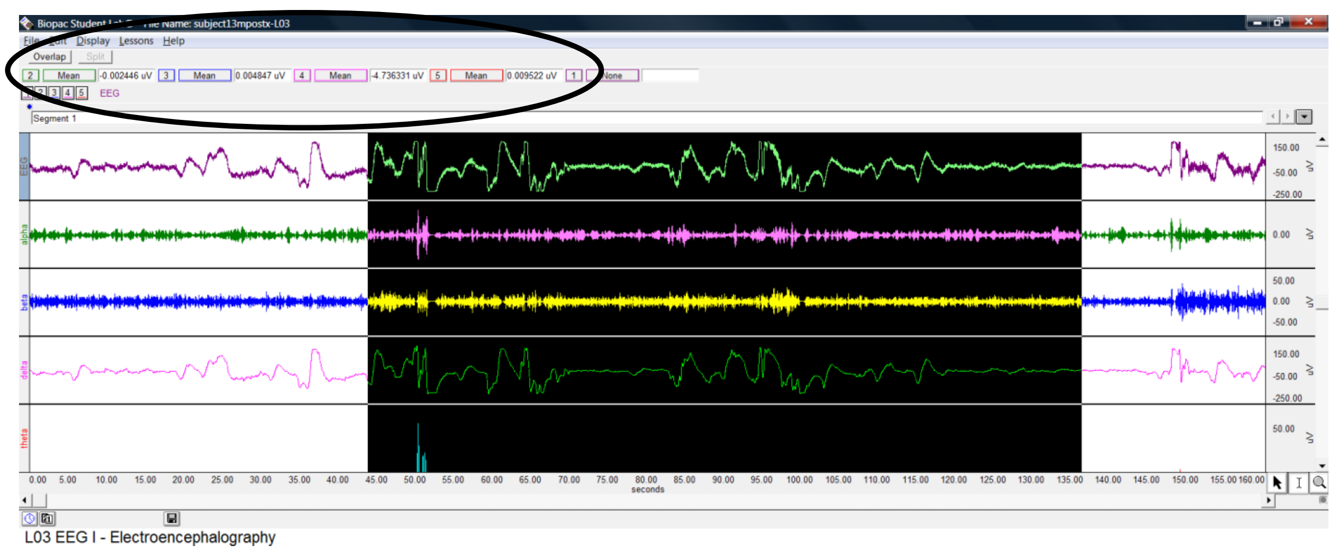

**n=14. p val = 0.38 in Beta-F waves when compared to no change using students paired t-test. P val = 0.96 when compared to no change using students paired t-test.**

## Appendix

*Figure 1: Sample EEG tracing at rest*

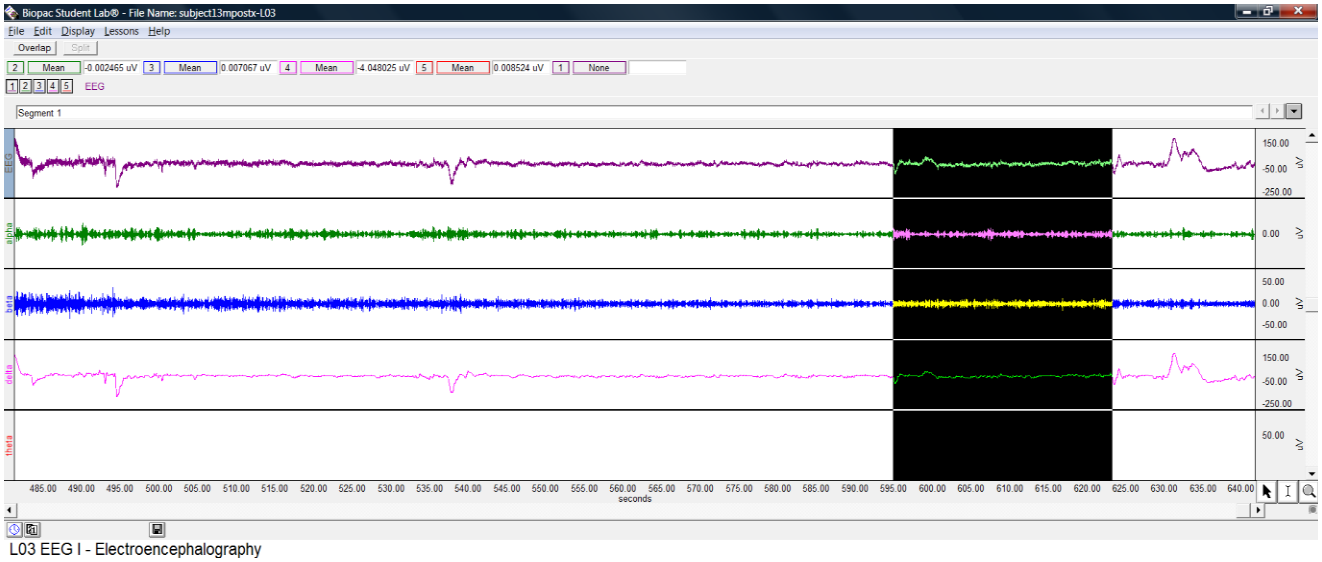

**The data highlighted represents the subject at rest prior to the memory test and exercise. To analyze the data we took the mean value of alpha, beta, delta, and theta waves as is shown in the number boxes in the top left corner.**

*Figure 2: Sample EEG tracing of formation of memory*



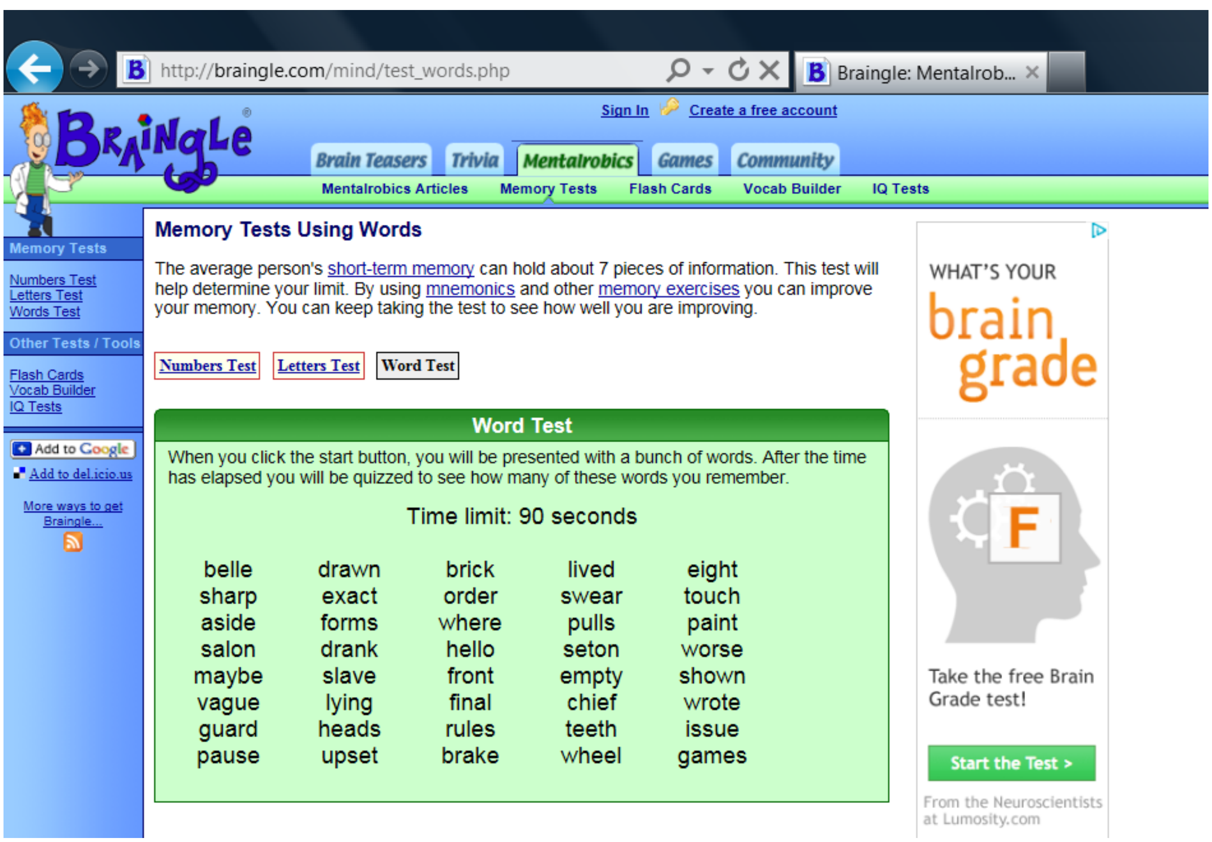

**The data highlighted represents the 90 seconds subjects had to memorize as many words as possible from the list of 40 words. To analyze the data we took the mean value of alpha, beta, delta, and theta waves as is shown in the number boxes in the top left corner.**

*Figure 3: Sample EEG tracing of recall of memory*




**The data highlighted represents the time subjects are typing the words they can recall from the list of 40. They were given as much time as needed, so amount of highlighted time varies. To analyze the data we took the mean value of alpha, beta, delta, and theta waves as is shown in the number boxes in the top left corner.**

*Figure 4: Sample of the memory test subjects took.*




**Subjects saw a list of 40 words made up of 5 letters, and had a time limit of 90 seconds to memorize as many of the 40 words as possible.**

## **Pilot Data**

***Table 1: Change in memory test scores using a 60% of max HR in place of perceived rate of exertion***

| | **Resting HR** | **MEM pre-ex** | **60% of predicted max HR** | **MEM post-ex** |
|---|---|---|---|---|
| **subject 1** | 66 | 7 | 116 | 7 |
| **subject 2** | 73 | 14 | 119 | 15 |
| **subject 3** | 70 | 13 | 120 | 13 |
| **subject 4** | 69 | 17 | 119 | 18 |