Visual, Audio, and Kinesthetic Effects on Memory Retention and Recall

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Abstract

Memory retention and recall is a neural process controlled by the brain and is affected by numerous variables. Studying such variables can have important implications for learning and education. On this basis, the group hypothesized that multimodal stimulation should achieve higher memory retention and recall than unimodal stimulation. In addition, it was hypothesized that visual stimulation should be more effective than audio stimulation and the added component of writing should be advantageous over non-writing. As such, an experiment was designed with four different stimuli to affect the participants' memory and test his/her retention and recall. Test scores indicate a difference in multimodal stimulation when compared to unimodal stimulation. An analysis of the test scores also indicates that visual stimulation is more effective than audio stimuli at achieving higher memory retention and recall (with a p-value $< .05$). Additionally, results of the EEG, pulse meter, and respiratory belt, show fluctuations in brain activity, heart rate, rates of respiration, and stress levels that vary between the stimulus and testing portions of the experiment. These findings highlight the effectiveness of multimodal stimulation and visual stimulation concerning memory retention and recall and further suggest a physiological relationship between the brain, lungs, and heart while under the stress of using one's memory. Specifically, it seems that the use of visual stimuli with the act of writing seems to elicit the best recall; this can be synonymous with the importance of taking notes as they are seen in lectures being augmented with a PowerPoint presentation.

Introduction

In order to interact with the world, the human mind is forced to use its senses as a means to experience and interpret its environment. For example, the mind is able to process, comprehend, and retain new information through visual and auditory stimulation. Such stimulation is often unimodal, affecting only one of the five senses. A specific case can be seen in a class setting where students are encouraged to learn by accessing audio podcasts or by visually reading text. According to Neil Fleming's VARK model, every individual has a preferred method of unimodal learning (visual, auditory, reading, writing, or kinesthetic) (Fleming et al. 1992). However, for the integration of knowledge into the working memory of an individual, the use of multiple approaches for learning is necessary. There is evidence for improved memory recognition and recall when a multisensory input is used, but which combination of the inputs is most advantageous for learning remains debatable (Thelen et al. 2012).

While there are benefits to unimodal learning and to knowing one's preferred method of processing new information, studies have shown that multisensory inputs have a greater effect on brain activity when compared to unimodal input. Research performed in 1999 by *Girard et al.* supports the notion that multimodal stimuli elicited a greater brain response when compared to unimodal stimuli. Furthermore, *Santangelo et al. (2007)* reinforced the notion that audiovisual stimuli elicited a larger brain response than the sum of audio and visual stimuli combined.

In the study done by *A Seemuller et al.* in 2011, the measure of a larger brain response was taken using an EEG device. A multisensory coupling of visual and sensorimotor stimuli led to an increase of EEG-coherence which was indicated when subjects were tested for memory recognition. Therefore, by including a sensorimotor aspect in addition to visual stimuli, the study could analyze the benefits for either the combination of the two or simply a unimodal benefit for recognition memory. The study concluded that combining multiple stimuli evoked more brain activity, which then favored an increase in memory recognition.

Based on such research, it is reasonable to infer that increased brain activity involves the firing of more neurons, which may lead to better memory retention. In addition, since multisensory input increases brain activity, there is a possibility for more communication between multiple areas of the brain. It is evident that an increase in communication between multiple areas during interpretation and processing will increase the working memory of an individual (Seemuller et al. 2011). Finally, a study performed by *Botta et al.* (2011) suggests that multisensory stimuli have a larger impact on visual-spatial working memory when compared strictly to visual stimuli.

The purpose of this experiment is to test whether unimodal stimuli or multimodal stimuli is the more effective method of achieving higher memory retention. Multimodal stimuli should yield more effective results in memory retention than unimodal stimuli because of the increase in brain activity required to perform multimodal tasks. In addition, between the two different forms of multimodal stimuli (visual with writing or auditory with writing) the specific combination of visual stimuli with writing should lead to better memory retention than auditory stimuli with writing. Presumably, visual stimuli leads to higher levels of brain activity than auditory stimuli (Santangelo et al. 2007). Furthermore, Neil Fleming’s VARK model (stated above) suggests that each individuals preferred mode of learning may affect how the individual performs on the memory retention test. As a result, it is reasonable to expect a positive correlation between an individual's self-perception as to what type of learner they are and how they perform on the memory retention test (i.e: individuals that believe they are visual learners will perform better on the visual test than those who do not). In addition, factors that negatively affect brain activity, such as starvation and stress should lead to a decrease in memory retention.

Methods and Materials

To perform the experiment effectively in relation to the hypothesis, a stimulus and memory test were created at a difficulty level where improvements in memory would be noticed. Participants were divided into four groups and were given one of four stimuli involving a list of 30 words given every three seconds.

Various Stimuli:

A. Audio only- participants listened to an audio recording of 30 words (three seconds between each word).

B. Visual only- participants were shown a PowerPoint listing the same 30 words, with again, three seconds between each word.

C. Audio/writing- participants heard the same recording and were asked to write down the words as they heard them.

D. Visual/writing- participants saw the same list of words and were asked to write them down as they saw them.

Memory Test

The memory test consisted of administering a separate list of 30 words: containing some words the participant had previously been exposed to as well as words that he/she were not presented with. The list was presented as a video of an experimenter flipping cue cards every 3 seconds with the words typed on them. The test results would indicate whether multimodal stimuli or unimodal stimuli is more effective at achieving higher memory retention. Analysis of the test results through a T-test will also provide confidence for whether visual or auditory stimuli will be more effective at achieving higher memory retention. A pre-experimental and post-experimental survey was included and given to each participant to account for additional factors that could affect his or her performance.

Physiological Measurements

In order to carry out the experiment, an electroencephalograph (EEG), pulse meter (BPM, O_2 saturation), respiratory belt, and four computers were assembled to collect data from each participant.

Electroencephalography (EEG)

The EEG, connected to computer one, was positioned on the participant to record the participant's alpha wave rhythm (measured in mV/sec.). Alpha waves were used because they show the greatest amplitudes in the parietal and occipital regions of the cerebral cortex and can be used to determine which actions generated the most brain activity. For the EEG, the area under the curve was used to measure brain activity. This is because the area under the curve relates to the level of alpha wave brain activity in the subjects. A larger area correlates with more brain activity. See Appendix B for additional information about the EEG data and analysis techniques.

Pulse Meter (BPM, O_2 saturation)

The pulse meter was connected to the participant's fingertip in order to measure any changes in the beats per minute and O_2 saturation. An increase in heart rate can be indicative of increased brain activity. As such, the brain would require more oxygen and would require the heart and the lungs to actively satisfy this demand. An increase in heart rate can also be due to an increased stress level in the participant. Heart rate was recorded every 15 seconds with recordings of substantial increases or decreases being noted in the data analysis.

Respiratory Belt

The respiratory belt was connected to computer two and was set up accordingly on the participant with the sensor being placed in the middle of the participant's sternum. The belt used frequency to measure the participant's respiratory rate in mHz. Increased respiration may be indicative of more brain activity because of increased demands for oxygen. It may also provide insight into the participant's stress level during the experiment. See Appendix A for additional information about the respiratory data and analysis techniques.

Computers

Each computer held a specific purpose in the experiment. Computer one was connected to the EEG measuring the alpha waves rhythm of the participant. Computer two was connected to the respiratory belt in order to record the participant's respiration rate. The BIOPAC program was run on both computers and used to collect all data for computers one and two. Computer three was used to administer the stimulus and the test while computer four was used to record the participant's test answers.

Procedural Controls

The experiment was administered in a quiet and consistently illuminated room. The time between each given word for the test was consistently three seconds and the rate at which the stimuli were presented was also three seconds. The timing for both the test and stimuli were held constant for all of the experiments. All of the participants received the same consent form and prompt (which was specific to their group, see attachment A). Additionally, all of the stimuli were administered with a timed PowerPoint via computer three. The testing of recognition was administered through a recorded video via computer three to ensure consistent presentation and timing of the test portion of the experiments to each participant. All participants entered their answers into computer four for data analysis.

Procedure

For the experiment, eleven participants (N=11) were prompted and given a preliminary survey to complete before the experiment (Attachment B and C). The population was composed of college students from the University of Wisconsin-Madison with nine males and two females. Each survey included a code as to which group they were a part of - audio control (A), visual control (B), audio/writing (C), and visual/writing (D). The participants were then be numbered as they began the experiment (participant 1,2,3,...n). Therefore a participant with code 2A, would be the second participant to be in group A. Five participants were categorized for group A and B (two in audio and three in visual), while six participants were categorized for group C and D (three for each group) totalling eleven participants.

Following the prompt, survey, and signing of the consent form, each participant was set up with the EEG, pulse meter, and respiratory belt to make baseline recordings/calibrations. For the EEG and the respiratory belt, the participants kept their eyes closed and remained motionless during the calibration. For the pulse meter, each participant had the pulse meter attached to his or her non-writing hand. Once situated, all participants were asked to remain as still as possible throughout the remainder of the experiment.

For the next part of the experiment, the participants received one of the four stimuli via computer three. After receiving one of the four stimuli, a brief break (15-30 seconds) was given before the testing portion of the experiment. The test consisted of administering a separate list of 30 words to gauge the participants' memory. Participants were asked to tap the "1" key on the keyboard number pad of computer four when they remembered seeing a word in the list and to tap "2" when they did not remember seeing the word. After the end of the experiment, the participants were given a post-participation survey to complete (Attachment C). An outline of the procedure can be seen in Figure 1.

Results

The experiment, which was primarily conducted to determine whether unimodal stimuli or multimodal stimuli was the more effective method of achieving higher memory retention, yielded the following results. Based on a sample size of eleven and their performances on the memory test, it appears that multimodal stimuli generated better memory retention than unimodal stimuli. Participants stimulated with a writing component, along with a visual or auditory stimulus, performed better that those who did not write down the words as they were being presented (non-writers). Based on performance, it appears that between the two different forms of multimodal stimuli (visual with writing or auditory with writing), the combination of visual with writing led to better memory retention than auditory stimuli with writing. Similarly, all participants who were presented with a visual stimulus scored higher on the test than all who were presented with an audio stimulus regardless of whether or not the stimulus involved a writing component. These results are summarized in Table 1 and Graph 1.

It was also determined that each individual's preferred mode of learning affected their performance. For example, the participants that performed the best on the memory retention test were visual learners that were presented with a visual and writing stimulus. Conversely, some of the participants that scored the lowest on the memory test were self-perceived visual learners that instead received a non-writing auditory stimulus. The same is also true for self perceived audio learners who received visual stimuli.

EEG

During the stimulus portion of the experiment, an increase in averaged EEG activity (mV/sec) was recorded in subjects who were presented with a visual stimulus when compared to subjects who were presented with an auditory stimulus (Graph 2). Interestingly, during the testing portion of the experiment, subjects who were initially presented with an auditory stimulus showed greater averaged EEG activity than those presented with a visual stimulus (Graph 3). During the stimulus portion, writers showed elevated EEG activity compared to non-writers (Graph 2). Once again, during the testing period, the opposite was true. For those who had previously written down the words presented to them, they showed less EEG activity when compared to non-writers (Graph 3). Overall, when looking at multimodal stimulus, averaged EEG activity was greatest when participants were presented visual stimuli and allowed to write the words as they saw them (Graph 2). See Appendix A for clarification on EEG data and analysis.

Respiration

Based on recordings of the participants' respiration during the stimulus portion, there was an increase in averaged frequency (mHz) when participants were presented with an auditory stimulus compared to when they were presented with a visual stimulus, as seen in Graph 4. Interestingly, there was a large increase in averaged frequency when participants were asked to write down the words as they heard them compared to those who did not write. Even though there was a large increase in frequency in participants presented with an auditory stimulus containing a writing component, on average, participants stimulated without a writing component had higher averaged frequencies than writers. See Appendix B for explanations regarding the data and analysis.

During the testing period, participants who were shown visual stimuli had slightly higher averaged frequencies than those who were presented with audio stimuli, as seen in Graph 5. Participants stimulated without a writing component also had much higher frequencies when compared to writers. In addition, respiratory averaged frequency was higher during the test period when previous writers were presented with an auditory stimulus compared to previous writers who were presented with a visual stimulus.

Heart Rate

During the stimulus portion of the experiment, the participants' averaged heart rates (BPM) were higher when they were presented with a visual stimulus compared to those who were presented with an audio stimulus, as seen in Graph 6. Non-writers also had higher heart rates than writers during the stimulus portion. Upon further investigation, it was also discovered that the averaged heart rates were consistently higher in those who were presented with a visual stimulus compared to an audio stimulus when both stimuli included a writing component. The O_2 saturation levels remain almost constant throughout the entire experiment between 97-99% without any major changes that could be correlated with other variables.

During the testing portion of the experiment, the participants' averaged heart rates were higher after being presented with a visual stimulus when compared to those presented with an audio stimulus, as seen in Graph 7. Throughout the test, non-writers had higher heart rates than writers. Within the group of writers, those who were presented with a visual stimulus had higher heart rates throughout the test than those who were presented with an audio stimulus.

Discussion

The graph of test scores for each category of testing and combinations of testing groups can be seen in Graph 1. A statistical analysis using a T-test was done comparing audio and visual performances. An ANOVA test was not used because the data had too many dependent variables (i.e. each experimental group's data was not independent of the other groups). The T-test for audio versus visual resulted in a significant difference between the two groups with visual subjects performing better than audio subjects ($N=11$, unpaired t-test, $p=0.0221<0.05$). This can also be confirmed visually in Graph 1. A p-value less than 0.05 provides evidence for a statistical difference between the data, therefore visual stimuli without writing did significantly better than audio stimuli without writing.

Another T-test was done comparing subjects with writing and without writing stimuli. The results did not provide evidence for a statistical difference between the two categories (N=11, unpaired t-test, p=0.869>0.05). Again, this can be seen in Graph 1 between the all writing and all non-writing groups. There is a slight difference between the two groups, but not a significant one.

A T-test comparing subjects using audio with writing and visual with writing produced no statistical difference between the two groups (N=11, unpaired t-test, p=0.252>0.05). Additionally, Graph 1 provides visual evidence for the slight difference, but it is not significant enough to claim one stimuli produced higher performance than the other.

A final T-test was done comparing audio without writing and visual without writing. The result of the test did not provide statistical support for a difference between the groups (N=11, unpaired t-test, p= 0.0862>0.05). However, the p-value is fairly close to the 0.05 value for statistical significance and thus is visually supported in Graph 1. Therefore there is a difference between the two groups, but not a significant difference.

Results from the EEG recordings show a few trends worth noting. See Graphs 2 and 3. For one, there was an increase in EEG activity (mV/sec.) measured from subjects who were given the visual stimuli versus those given auditory stimuli, but only during the stimulus portion of the procedure. Contrary, subjects who were originally given the audio stimuli seemed to show greater EEG activity during the test itself. This could be attributed to subjects receiving the visual stimuli having a higher level of confidence during their test (i.e. they did not have to work as hard to remember what words were previously shown to them).

Those who were also asked to write down the words as they heard or saw them showed greater EEG activity versus those who were asked to simply listen or watch as the words played. In Graph 3 during the test, those who had previously written down the words showed less brain activity than those who had not written. A possible explanation of this would be that those who did not receive adequate stimuli while given their set of words (i.e. those who were not asked to write the words) had to work harder (indicated by increased brain activity) when completing the test, as to remember what they had previously heard/seen.

The results show that those who were asked to write down the words as they saw them (visual with writing) performed better on the test and had larger brain activity during the stimulus portion of the procedure (and corresponding less brain activity during the testing period). Again, this could correspond to subjects not needing to concentrate as hard during the testing period because they had adequate stimulus levels and were able to encode the words easier when they were presented the word list. In summary, greater EEG activity during the stimulus phase corresponds with less EEG activity during the testing phase and better performance on the test.

When looking at the results from the respirator device, there are many trends in the data. There was a decrease in frequency (mHz) when subjects were asked to write the words down as they were heard (audio with writing) as compared to an increase in frequency for those that exclusively heard the words (audio without writing, see Graph 4). This increase in frequency means the subjects without writing during the audio stimulus were breathing faster, which is indicative of higher stress levels. The higher stress levels lead to poorer test performance for those with only audio stimulation compared to those with audio and writing as seen in Graph 1.

Comparing this to the visual with writing and visual without writing stimuli again in Graph 4, there is a noted difference in respiration rates. Those who were asked to write down the words as they saw them seemed to not only have lower respiration rates, but also performed remarkably better on the test. The higher respiration rates with those that were subjected to only visual stimuli may be due to an increase in stress, which then increased the respiratory rate. There seems to be a correlation between the rates of respiration and test performance: those with less frequent breaths during the stimulus phase of the procedure tended to show superior performance on the test. Again, this could be connected to the level of stress the subject was undergoing when receiving the stimulus.

When solely looking at results from subjects who were asked to write versus those that were not, those who were not writing had increased breathing rate, i.e. the physical act of writing did not increase the frequency of breathing. This could correspond to subjects having a higher level of stress because it was harder for them to listen to the words being presented while trying to remember all the words they had heard previously, rather than having written the words down and being able to physically see them as the stimulus portion proceeded.

The heart rate comparing subjects based on many categories was graphed and can be seen in Graph 6. The highest category for BPM for the four different stimuli was with visual only and the lowest heart rate was for audio with writing. It also is shown that all non-writing subjects had an overall higher BPM than the combined all writing subjects.

Initially, the writing portion was assumed to be correlated with a higher heart rate due to the increase in physical activity. Since the physical activity of writing did not increase the heart rate as shown by Graph 6, the increase in heart rate may be attributed to the increase in demand for oxygen by the brain due to stress. The stress from the stimulus leads to increased activity by the sympathetic nervous system, which increases the heart rate. The increase in heart rate for the non-writing subjects can therefore be related to an increase in stress felt by the participants.

Then, when comparing the non-writing and all writing subjects, the all writing subjects had a slower heart rate correlating to decreased stress. The decrease in stress may be attributed to more confidence in their ability to memorize the words because they were writing the words down as well, which was increasing their brain activity and integration therefore.

The comparison for audio without writing and audio with writing for the heart rate follows the same trend as the overall writing versus overall non-writing, again seen in Graph 6. The only audio subjects had increased heart rates than the audio with writing subjects. The only audio subjects must have had more stress associated with the test. The increase in heart rate can provide evidence for this.

The heart rate comparison between only visual and visual with writing again follows the trend as seen in Graph 6. The visual only subjects had a slightly higher heart rate than the visual with writing subjects. Again, the visual with writing subjects were under less stress because they had more confidence to memorize the words. Less stress during the test means less activity from the sympathetic nervous system. As such, the heart rate will not be increased as significantly.

The survey administered before and after the experimentation for each subject provided data that could be cross-examined with the performance on the test. The stress level is numerical data that is graphed with percentage correct on the test. See Graph 8. Overall, the stress level did not have a significant effect on the performance for the test. This is confirmed by the graph and the R^2 value. In order for the data to be significant, meaning there is correlation in the data, the R^2 should equal or be very near 1.00. As shown in Graph 8, the R^2 value is very low, meaning there is no correlation between the percentage correct and the stress level on the individuals.

The data concerning how many times the individual ate breakfast during the week was also collected in the survey and could be analyzed with the performance of the subjects. See Graph 8. Again, based on the very low R^2 value, there is no correlation in the data between the amount of times the subject eats breakfast during the week and their performance on the test.

If the experiment in this paper will be replicated in the future, changing the experimental groups and their differing stimuli to allow for increased comparisons would be beneficial concerning statistical analysis. The experiment done did not allow for ANOVA testing due to the experimental groups having multiple variables of difference. Having this additional statistical evidence would increase the confidence in the conclusions and trends in the data.

In future experiments, adding an additional experimental group could be beneficial for the understanding of how multimodal stimuli aids or hurts performance on a memory recall test. This group would receive all three stimuli during their testing period: visual, audio, and the kinesthetic (writing). Looking at how all three stimuli work to either increase or decrease performance would be of practical use for those in a classroom setting.

Additionally, increasing the population size would help increase the statistical support and confidence in the conclusions. Therefore, in future experiments more participants representative of a diverse and stable population would be extremely beneficial for the overall confidence in the experiment.

Conclusion

Conclusively, results show that the primary hypothesis and all sub-hypotheses were supported. Test scores supported the primary hypothesis that multimodal stimuli would yield better memory retention. Participants with an added writing component scored higher than those without (see Graph 1), although the p-value (0.869) showed that the minimal difference was not statistically significant. In addition, the sub-hypothesis that between the two forms of multimodal stimuli, combined visual stimuli would prove better than combined audio stimuli, was supported both by the test scores and by a p-value value of 0.0221, which shows statistical significance. Results also indicated that Neil Fleming's VARK model was supported by this experiment; test scores show that individuals who were self-perceived visual learners did better when tested visually than self-perceived visual learners that were tested with auditory stimuli. The test scores also supported the opposite situation. Furthermore, the sub-hypothesis that factors that negatively affect brain activity, such as stress and starvation should lead to a decline in memory retention was supported by trends showing that performance increased with increased regular breakfast consumption while performance decreased with increases in stress (Graphs 8-9). Lastly, other results besides test scores and p-values, such as data collected during the experiment support these hypotheses. Both respiratory rates and heart rates decreased with multimodal stimuli (visual with writing or auditory with writing). This decrease was correlated to a reduction in stress and consequently an increased ability to memorize the words leading to a higher performance on the test.

References

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Tables

Table 1: Performance summary with percentage correct on the recall and recognition test with calculated T-test results to provide statistical evidence for confidence in the conclusions.

All Visual	All Audio	P-Value
89.98	79.34	0.0221
All Writing	All Non-Writing	P-Value
85.55	84.66	0.869
Visual with writing	Audio with writing	P-Value
88.87	82.23	0.252
Visual with writing	Visual without writing	P-Value
88.87	91.1	0.86816
Audio with writing	Audio without writing	P-Value
82.23	75	0.33845

Figures and Graphs

Procedural Timeline

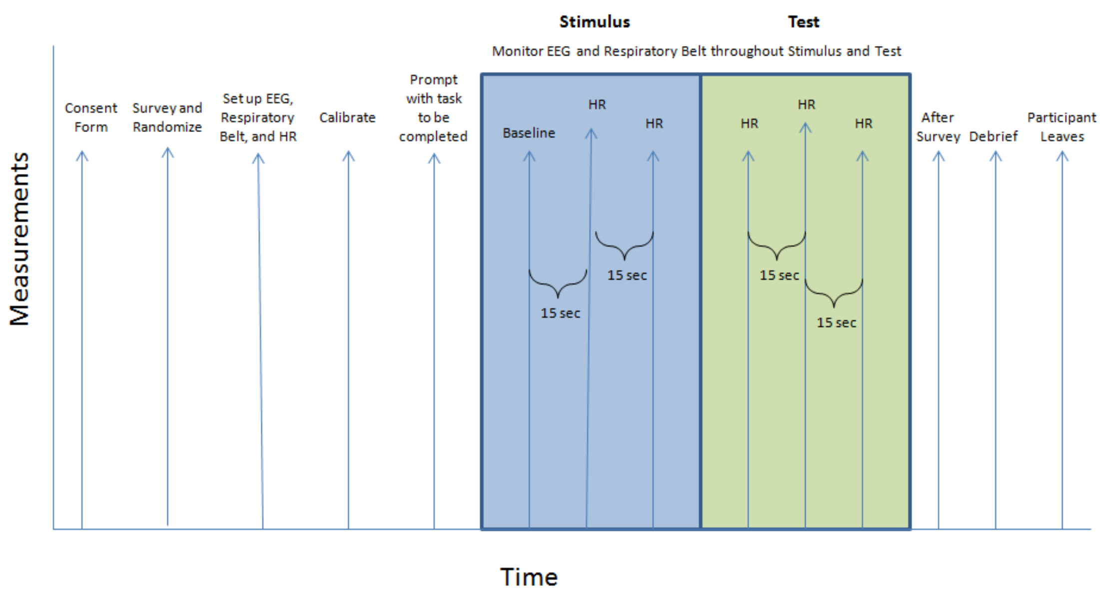
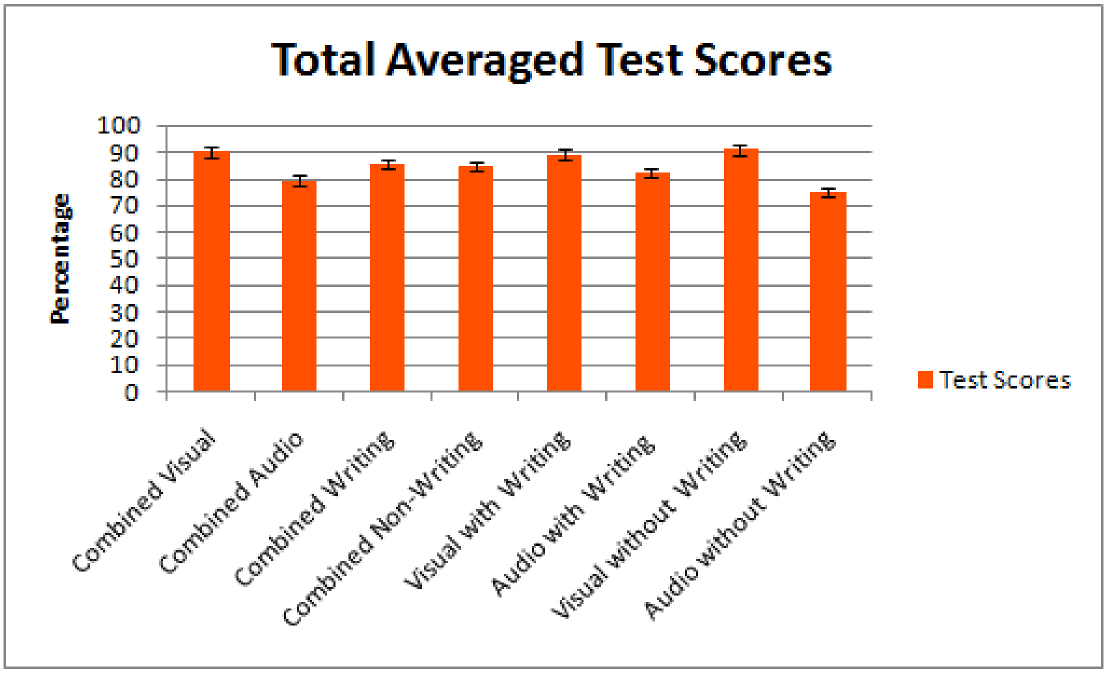
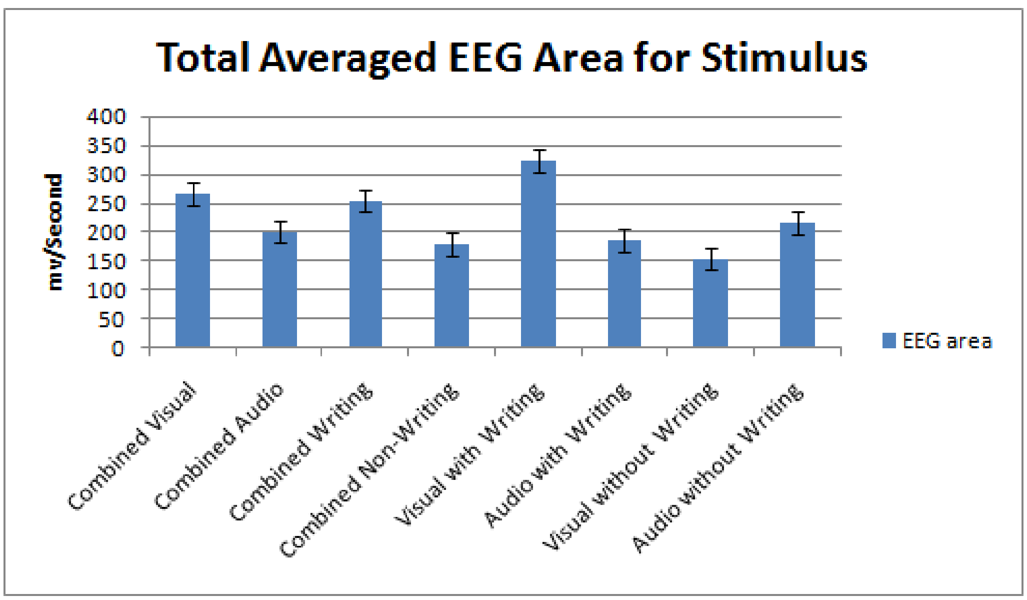


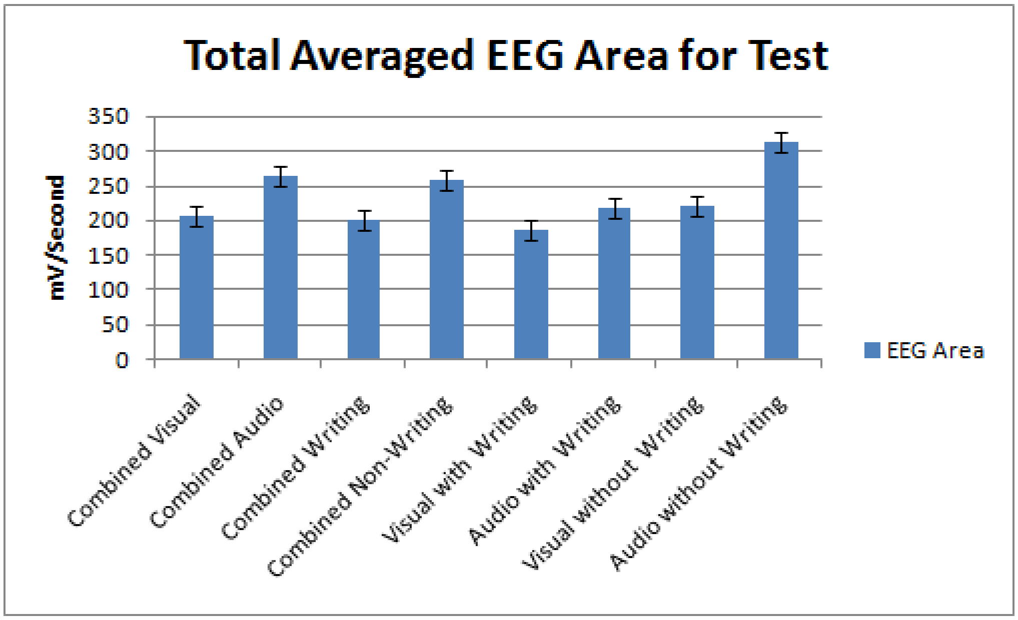
Figure 1. Timeline outlining the procedure as it relates to the participants from the time they enter the testing room to when they leave.



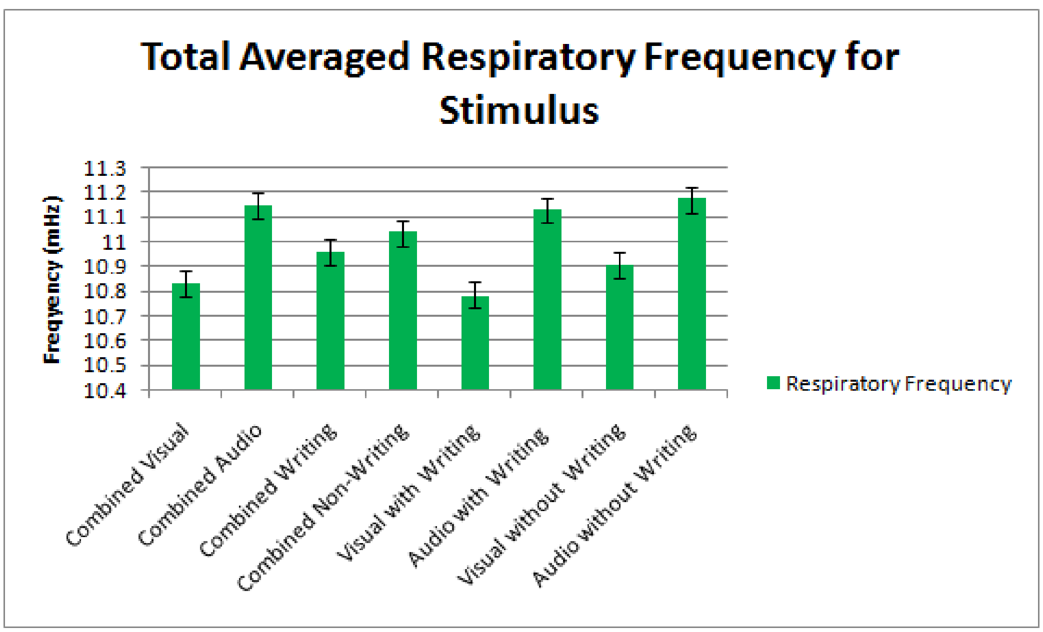
Graph 1. Performance results on memory. The total averaged results of the test scores show visual stimulation as having a greater score as compared to audio stimulation. In addition, tests including a writing component averaged a higher score than non writing tests.



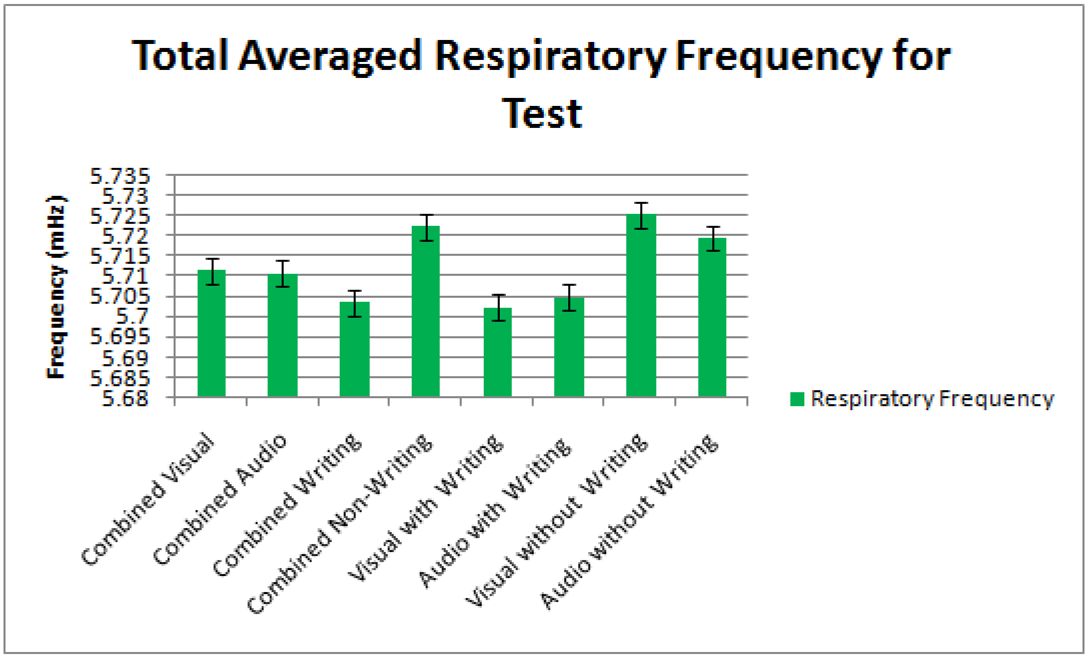
Graph 2. The measurement of alpha waves via EEG during the stimulus. The total averaged results of the area of the EEG during the stimulus suggest that visual and or writing stimuli elicit higher brain activity, through alpha waves, when compared to a stimulus involving hearing and or without writing. This is true for all cases of comparing visual to audio stimuli except for stimuli lacking a writing component.



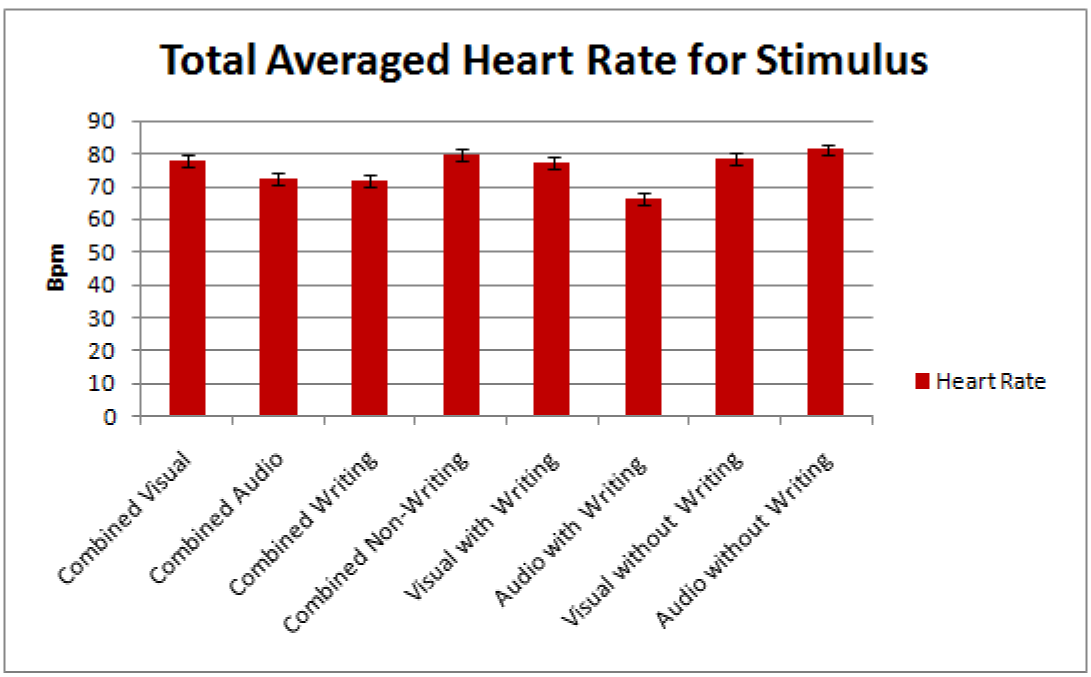
Graph 3. The measurement of alpha waves via EEG during the test. The total averaged results of the area of the EEG during the test suggest that an auditory stimulus elicits higher alpha waves and therefore brain activity than a visual stimulus. Moreover, the results suggest that a stimulus without writing also causes higher brain activity as compared to a stimulus with a writing component.



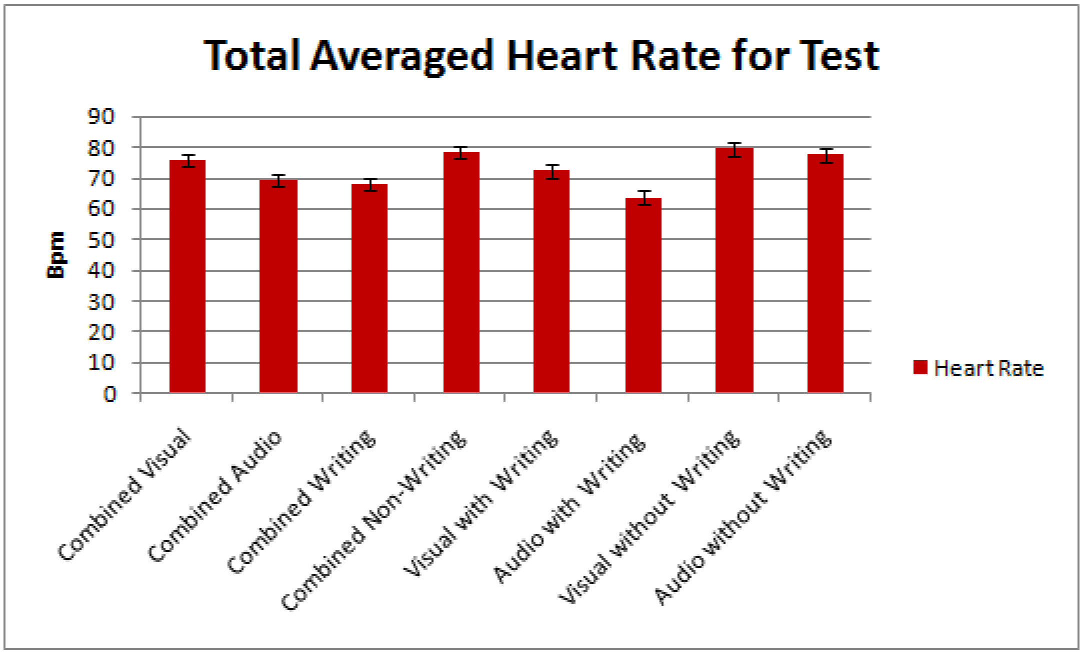
Graph 4. The total averaged results of respiratory frequency (how rapidly participants were breathing) during the stimulus portion of the experiment. The data indicates that audio averaged a higher respiration frequency than visual and that non-writing averaged higher frequency than writing.



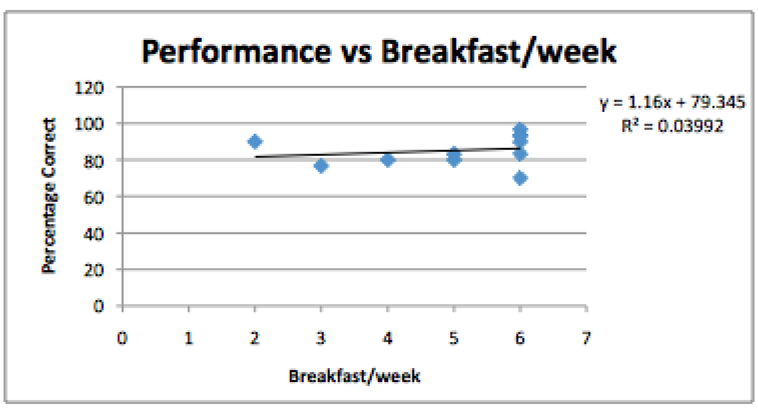
Graph 5. The measurements shows the total averaged respiratory frequency (how rapidly participants were breathing) during the testing period of the experiment. The data indicates that visual averaged a higher respiration frequency than audio (except in the case of with writing) and that non-writing averaged higher frequency than writing.



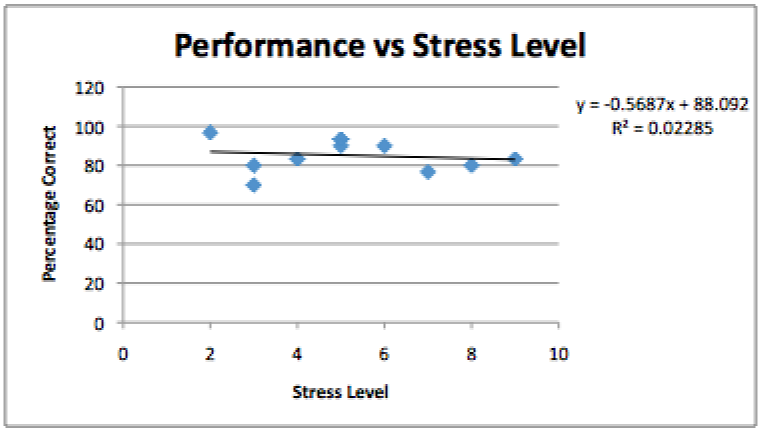
Graph 6. The total averages of the subjects' heart rates taken during the stimulus. Results show an increase in heart rate during visual stimulation (except in cases without a writing stimulus). Heart rate also increases in the absence of a writing component.



Graph 7. The total averages of the subjects' heart rates taken during the test. Results show an increase during visual stimulation when compared to audio stimulation. Additionally, stimuli without writing increased heart rate when compared to stimuli involving a writing component.



Graph 8. Performance of memory recognition and recall in relation to consumption of breakfast per day in a week. The results of the survey and test reveal an increase in memory recognition and recall with individuals who consume breakfast on a regular basis per week.



Graph 9. Performance of memory recognition and recall in relation to stress level. The results of the survey and test reveal a decreasing trend line in performance as stress level increases.

Appendix A

EEG - Clarification and Lab Practical

The EEG was recorded using electrodes that were attached to the participants' head. The brain waves were recorded on one of the computers. Notch markings were manually made on the computer in order to record specific parts of the experiment. See Figure 2. Reading from left to right, the second through third notch indicates the recorded waves of the stimulus period. Similarly, the fourth through fifth notch indicates the recorded waves for the test period. The highlighted portion of the figure corresponds to the stimulus portion.

When initially developing the procedure for the experiment, advice from group leaders was that alpha waves were best for analyzing the EEG data. This is because alpha waves are much easier to detect compared to beta, delta and theta waves which are not as active and can make them harder to analyze and distinguish peaks. In order to analyze the alpha waves, the correct channel in the program must be selected for *all* measurements.

In analyzing the data, we chose many variables, one being area under the curve. This measurement allowed us to gauge the relative activity of a subject's brain waves and to deduce what was larger activity. Compared to baseline measurements, there were larger peaks in the EEG alpha wave during moments of increased brain activity. Under normal circumstances (resting), brain wave activity was much lower than during the stimulus and testing periods. This was represented the best in the area of the graphs where it was clear when more activity was occurring and allowed for significant data analysis. By analyzing the area, we were able to distinguish outliers or errors in recording which was critical in our statistical analysis.

To mark regions of the EEG we wanted to analyze, notch marks were very useful. This was an easy way to mark times of calibration versus the experiment itself and is done simply by pressing F4 or F5. Make sure to be in sync with the other devices being used (e.g. respiratory belt) so that the regions of data being analyzed are consistent.

Additional advice for using the EEG measurement would be to watch data closely while measuring the brain waves of the participants. It is critical that the calibration is normal like the example given and not fluctuating majorly. Also, if the data has extremely large peaks and does not correctly display the activity that the participant was doing it is recommend that the test be stopped or quickly adjust the EEG wires or electrodes.

Our recommendations for future set up is to put the sticker on the electrode and then added gel into the hole with the electrode sensor. Making sure the sticker and electrodes were touching skin was crucial for accurate measurement. The contact needed to be maintained throughout the entire experiment and a swim cap was used to keep the electrodes in place. Also the wires were bundled together with a clip that was then attached to the back of the participant's shirt. This helped keep the cords from pulling on the electrodes or from crossing over, which might create an electrical short. Then after this set up was completed, it was essential to have consistent and accurate calibration. If this was not similar to the example, then a portion of the set up might have been flawed and adjustments were made before any recording or testing.

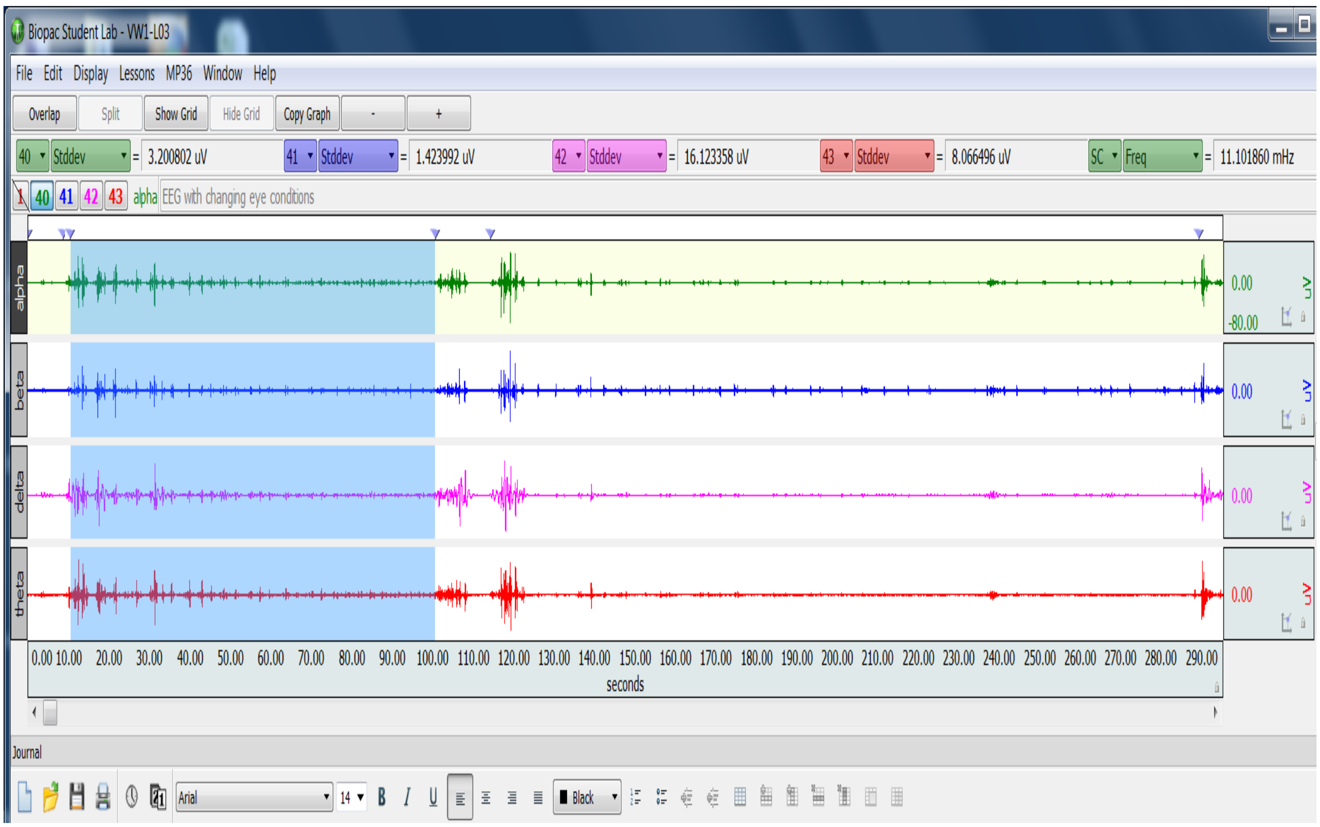


Figure 2: A screenshot of the recorded EEG data for a participant that was given visual and kinesthetic stimuli. The highlighted portion is the stimulus period of the experiment and was manually marked using the notches.

Appendix B

Respiratory - Clarification and Lab Practical

The measurements for respiratory frequency were recorded using a respiratory belt that was wrapped around the participant's sternum. See Figure 3. Notch markings were manually made on the computer in order to record specific parts of the experiment. Reading from left to right, the second through third notch measured the recorded frequency of the stimulus period. Similarly, the fourth through fifth notch measured the recorded frequency for the test period. The highlighted potion in the figure corresponds to the testing portion.

The reported frequency is an aggregate for all of the raw data (including the red and blue waves recorded below). The blue waves measured the movements of the chest (breathing) and were the desired data. The red waves measured the electrical frequency sent from the device to the computer. When looking at recorded frequency value, the value given also contains an electrical frequency and may not accurately represent the respiratory rate. A more accurate representation of the respiratory rate would involve counting the peaks of the blue wave over a set period of time. In terms of the reported data, the reported frequency included the electrical frequency. As such, an increase in electrical frequency of the signal recorded by the sensor was interpreted as an increase in the respiratory rate.

Future set up for the belt should consist of setting up the sensor in the middle of the sternum with a consistent tightness of the belt around the chest for all participants. Doing so will help ensure consistent accurate readings for respiratory frequency.

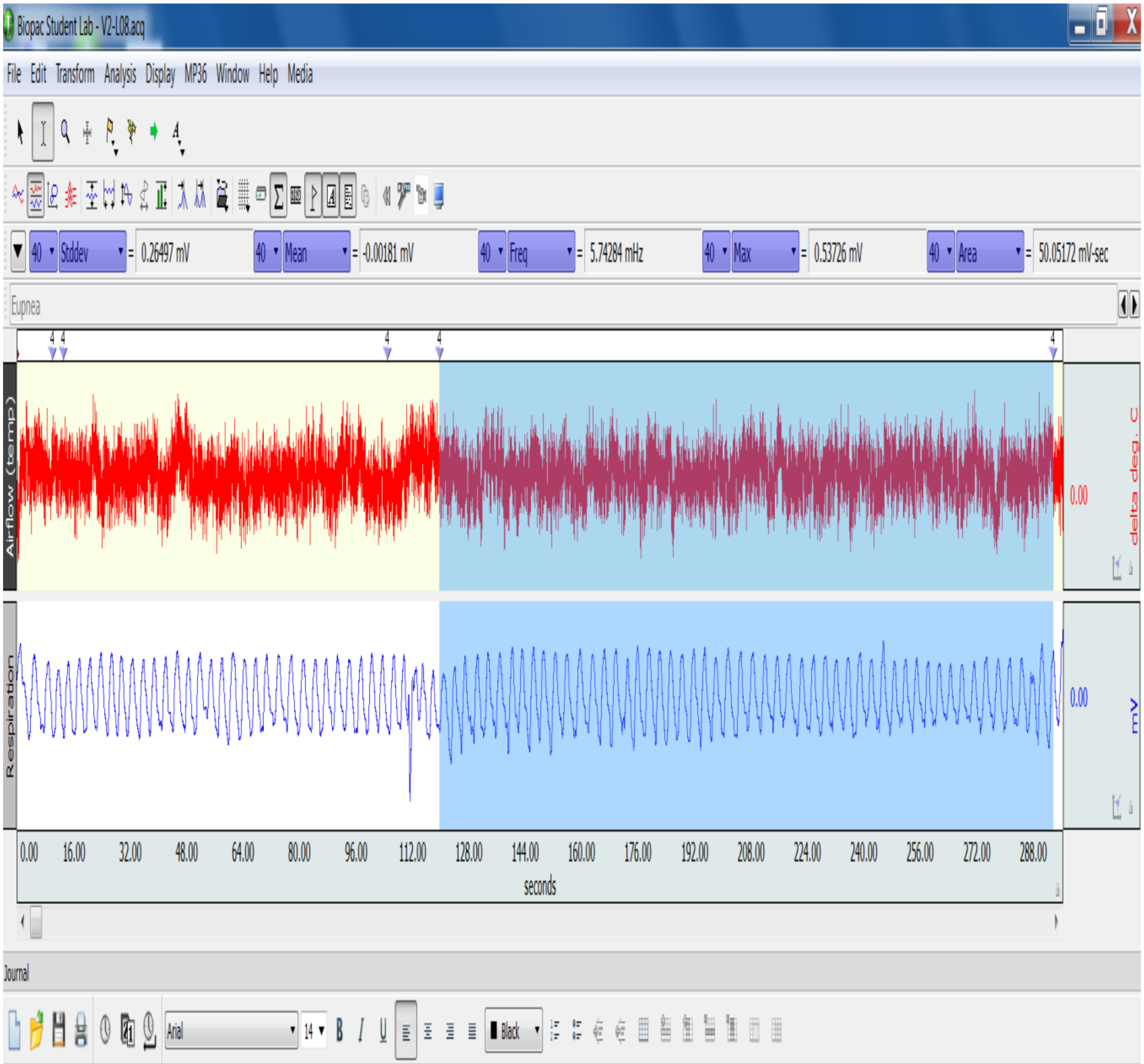


Figure 3: A screenshot of the recorded respiratory data for a participant that was given only visual stimuli. The highlighted portion is the testing period of the experiment and was manually marked using the notches.