Effects of Divided Attention on Working and Long-Term Memory

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Keywords: Working memory, Long-term memory, Distractions, Respirations, EDA, Heart Rate,

Phrase recognition

Word Count: 3,702

Abstract

In today's classroom, students commonly watch videos, play games, or browse the internet while completing homework or participating in class. With the increasing use of technology in all aspects of our life, research into the effects of multitasking has increased in relevance. We aimed to evaluate whether distractions would impact working and long-term memory and to what extent. We hypothesized that visual and cognitive distraction would decrease the encoding of working memory and subsequent consolidation of long term memory directly and indirectly via inducing stress. Participants were assigned to one of two groups: a control group with no distractions or a treatment group exposed to a distraction. Both groups listened to a list of selected phrases and took a quiz at the end of the recording to evaluate their recognition of those phrases. This was done to assess the effects of distractions on working memory. Participants came back a week after their initial testing to assess their long-term memory with a similar quiz. Heart rate, respiration rate, and electrodermal activity were measured to evaluate stress. Results showed a difference in the week one quiz between the control and treatment group (p-value of 0.0002) and between quiz two of the control vs. treatment (p-value of 0.0002). These results suggest that students who use technology while studying or in class do significantly worse on multiple choice quizzes. All other physiological measures comparing treatment vs. control were not significant (p-value of 0.50, p-value of 0.71, and p-value of 0.36). Future studies can be enhanced by increasing the number of participants and investigating the effects of other sensory distractions on working and long-term memory.

Introduction

It is commonly recognized among educators that the use of phones or laptops during class interferes with the learning process. The rationale behind this involves a link between the use of technology as a visual and cognitive distraction to not only the user but those around the user as well. Increasing use of technology has brought attention to research investigating the impact of visual and cognitive distraction on memory. While technology can enhance students' learning experience in many ways, studies have also shown it to be a significant distraction in classrooms (Kay et al, 2017). Our study aims to further explore this issue by investigating the correlation between visual and cognitive distraction and its impacts on the encoding of working memory (WM) and consolidation of long-term memory (LTM). Our study will also consider physiological measurements of stress in response to distraction, and their potential impact on memory.

The process of making memories incorporates different cognitive components that function together in the task of encoding and consolidation. Factors such as the mode of information, location of storage, and length of storage distinguish between WM or LTM (Kelly & Whatson, 2013). WM is responsible for the temporary storage and manipulation of information needed to perform complex learning tasks (Baddeley, 2000) (Liu & Fu, 2007). LTM refers to strongly embedded memories that are less susceptible to degradation (Baddeley & Patterson, 1971). LTM is consolidated and stored in regions of the cerebral cortex (Jonides, 2008), whereas WM is encoded and retrieved within the hippocampus (Kumaran, 2008).

In order for encoding and consolidation to occur, attention to sensory stimuli is necessary. However, during periods of distraction the WM experiences an added workload. It has been proposed that WM is a collection of resources, some dedicated to distinguishing between relevant and irrelevant information and some to the consolidation of memory to LTM (Olesen et al, 2007). When participants are exposed to a distraction, there is competition for these WM resources (Craik, 2014). Not only does this impact WM's ability to manipulate information, it has also been suggested that processing during the initial stage of WM may be critical to LTM formation (Ranganath et al, 2005).

There are various factors that affect memory and its retrieval. These factors include concentration (Chun and Turk-Browne, 2007), sensory activation (Wheeler, Petersen and Buckner, 2000), and chronic stress (Vogel and Schwabe, 2016). Our study specifically investigates the impact of increased sensory activation. This was simulated by implementing a visual and cognitive distraction (Asteroids®, an Atari game) during encoding. Due to the increased cognitive load, we expect an elevated stress response which will negatively impact the WM encoding process. Additionally, the body responds to a stressful event by releasing glucocorticoid hormones. These glucocorticoid hormones have been shown to impair memory formation and recall by affecting noradrenergic receptors in neuronal connections (Roozendaal, 2002). To quantify the elevated stress response, physiological measurements such as heart rate, respiration, and electrodermal activity were taken.

We hypothesize that our study will show that visual and cognitive distractions interfere with the memory consolidation process directly via occipital lobe stimulation and indirectly through inducing stress caused by increased cognitive load. In addition, we expect that LTM consolidation will be impacted to a greater extent than WM encoding. We hope our results bring us one step closer to determining the true impact of technology in the classroom and while studying.

Methods and Materials

Participants and groups

A voluntary group of 31 students from the University of Wisconsin-Madison were taken from the Physiology 435 class with participants' age ranging from 20-23 years of age. Three students were unable to retest for the second week so their data was not included for week 2. All participants were briefed about the study before voluntarily signing a consent form. The participants were asked to complete a memory experiment over two consecutive weeks.

People were randomly assigned to either the control group or the treatment group. The control group was not exposed to any form of distraction during the encoding portion of the experiment. The treatment group was exposed to a visual and cognitive distraction, Asteroids®, during the encoding portion of the experiment (Atari 2703TN-N, Jakks Pacific INC., Malibu, California 90265). Participants were told that their game score would be recorded in order to ensure their maximum participation and attention. This was a sham statement as we did not record the game scores. Similarly, participants were told that their score on the memory quizzes would be recorded. Emphasizing the importance of both scores reduced the probability that the participant would purposefully perform poorly on the game to increase their quiz score.

Design and Procedure

A timeline of our procedure is included in Figure 1. To determine the effects of visual and cognitive distractions on WM and LTM consolidation, a phrase recognition exam was first created. To produce the exam, a bank of ten randomly selected phrases were recorded on an iPhone 6s. The phrases included descriptive adjectives and action verbs to describe a noun. An example of a randomly selected phrase used was “rusted bronze trophy” as shown in Figure 2. Prior to the start of the experiment, positive control data was collected and reported in Table 1.1, 1.2 and 1.3 as well as in Figures 3.1, 3.2 and 3.3. Before beginning any experimental test procedures, baseline readings of heart rate, respiration rate and electrodermal activity were recorded for each participant. The baseline readings were recorded for 30 seconds. Heart rate was monitored using a Pulse Oximeter (Pulse Oximeter/Carbon Dioxide Detector --- 9843, Nonin Medical INC., Plymouth, MN 55447), respiration with a BIOPAC Respiration Belt (BSL Respiratory Effort Xdcr --- SS5LB,BIOPAC Systems, INC.), and galvanic skin response with a BIOPAC electrodermal activity (EDA) finger electrode (BSL --- SS3LA, BIOPAC Systems, INC.). The Pulse Oximeter and EDA were placed on the nondominant hand of the participant. The BIOPAC Respiration Belt was positioned across the chest of each test participant. Respiration was monitored through breaths-per-minute (BPM). Heart rate was measured in beats-per-minute. Finally, max EDA was measured in microSiemens. During this time, the participant viewed an instructional powerpoint about their role in the experiment: one powerpoint for the control and another for the treatment group. The recording was then played to each group of test participants through Beats wireless headphones (*Beats Solo^3 Wireless On Ear Headphones*). The recording was played twice, with a total duration of 110 seconds; 55 seconds per loop. During this time, participants were asked to memorize the phrases on the recording. While listening to the recorded phrases, peak heart rate, respiratory rate and max EDA were recorded.

The control group completed this procedure with a blindfold over their eyes to ensure that there were no external visual or cognitive distractions. The treatment group completed this procedure while playing the Atari video game, Asteroids®. The video game was utilized to interfere with the participant's encoding process while listening to the recording.

After completion of the recording, both groups were asked to complete a demographic survey consisting of eight questions. Next, a multiple choice exam was presented to the participants. The exam consisted of 5 questions. Each question was comprised of 4 phrases with one phrase being the correct option based off of the recording. The phrases differed by an adjective, verb, or noun to make it slightly ambiguous, but relatively similar to the original phrase. An example question is included below in Figure 2.

Both the control and treatment groups were asked to select the correct phrase for each question, thus completing the WM portion of the experiment. During the testing phase, neither the control nor the treatment group was subjected to a distraction. Participants were not told if their answers were correct upon completion to deter any encoding outside of the allotted period. Respiration, heart rate and EDA were measured again as participants completed the quiz.

Participants were then asked to return for a follow up exam that would take place one week later. Prior to the second testing period, a baseline reading for heart rate, respiratory rate, and max EDA for each participant was taken again. During this follow up appointment, the participants were given another assessment with the same format as the original quiz. However, this quiz was comprised of different questions written to assess phrases that were included in the recording, but not previously tested on. This was done to ensure that all memory encoding took place during the recording, and not during the exam. Again, both the control and treatment group completed the second exam without the presence of distraction stimuli. Peak heart rate, respiratory rate, and electrodermal activity were recorded during this time. After completion of the second exam, the experiment was concluded for that participant. Peak heart rates, respiration and max EDA for baseline readings, during the experiment, and during both exam periods were compared and analyzed.

The impact of visual and cognitive distractions on WM and LTM consolidation was analyzed by looking at the change in correct responses. Physiological stress was measured relative to baseline during the listening and both testing phases for both the control and treatment cohorts.

Statistical Analysis

In order to determine whether there was a significant difference between the performances of group one (negative control) and group two (treatment group) we conducted t-tests to compute three separate p-values. The t-tests were all two-tailed, unpaired, and homoscedastic. To be considered significant, an obtained p-value must be less than or equal to 0.05. The first p-value compared the groups' performance on quiz 1. This yields information regarding how a distraction task influences WM. The second p-value compared the groups' performance on quiz 2. This provided information regarding the impact of a distraction task on LTM consolidation. The third p-value compared the groups' average difference in quiz scores between quiz 1 and 2. This showed the extent of memory degradation experienced by each group. We also calculated three more p-values to compare the physiological difference between the two groups. These p-values were computed from t-tests using the same parameters specified above. The first p-value compared the groups' mean breaths per minute (BPM) relative to baseline. The second p-value compared the groups' mean peak heart rate relative to baseline. Finally, the third p-value compared the groups' mean max EDA value relative to baseline.

Results

Memory Assessment

An overall distinction between both the difference in week 1 and week 2 quizzing as well a difference between our treatment and control group was observed. (Figure 4). For the control group, the average quiz score for week 1 was 4.8 and for week 2 was 3.4. Comparatively, the average quiz score for the treatment group week 1 was 3.4 and week 2 was 2.13. The difference between the scores is indicated in Figure 4. When looking at the results of quiz 1 between the control group and the treatment group (p-value of 0.0002) , and the results of quiz 2 between the control and treatment group (p-value of 0.0002), which was significant. However, when looking at the difference in scores for both control and treatment between week 1 and week 2, there was not a significant change in scores (p-value of 0.77).

Physiological Assessment

Based on the heart rate data collected relative to baseline, we saw a general trend of higher value for the treatment group during the encoding, but a less of an observable difference during week 1 and week 2 quizzing. (Figure 5) With a p-value of 0.36, however, there was not a significant difference between measured heart rates of the treatment and control groups.

Similarly, the data showed an observably higher respiratory rate, measured using average breaths per minute, for the treatment group relative to the control group. This difference was, again, more prevalent during week 1 encoding and testing. Week 2 testing showed little difference in average values. (Figure 5) With a p-value of 0.70, there was no significant difference between the respiratory rate of the control and the treatment group.

Finally, for the EDA data showed the least observable difference between the control and treatment groups. Week 1 encoding showed a larger difference than week 1 and week 2 testing. (Figure 5) With a p-value of 0.50, we again can not confirm a significant difference between the EDA change in the control and treatment group.

Each participants' score for quiz 1 and 2 were plotted against their accompanying physiological measurements to investigate a correlation between quiz performance and physiologic change from baseline (Figure 6). In these graphs, there were no clear trends indicating a relationship between any of the physiological measurements and quiz scores.

A table presenting the statistical analyses comparing physiological measurements and quiz scores for the control and treatment groups can be found in Table 2.

Discussion

Interpretation of Results

Participants who experienced a visual and cognitive distraction (playing Asteroids®) while encoding a list of phrases performed significantly worse on both of the subsequent quizzes compared to the control group. This supported our hypothesis that both WM (quiz 1) and LTM (quiz 2) would be negatively impacted by distraction.

However, there was not a significant difference between the control and treatment when comparing the difference between week 1 and week 2 quiz scores. In fact, on average both groups' performance decreased by about 1.5 phrases between quizzes. This decrease in phrase recognition was representative of the participants' failure to consolidate information to their

LTM. These results do not support our hypothesis that participants subjected to distraction would experience significantly increased consolidation interference.

The maximum EDA measurements, breathes per minute, and maximum HR relative to their respective baseline values were not significantly different between groups. This ran contrary to our hypothesis that the distracted group would have increased values for these variables, indicating stress. There are many variables within this study’s design and execution that may explain this lack of significant results.

These results show that, in general, people who experience a visual and cognitive distraction during the encoding phase show decreased encoding ability. While both test groups showed an identical change in quiz scores, the group with no distractions had higher quiz scores overall each week. Knowing that the treatment and control groups had statistically significant differences shows that distractions are correlated with detrimental memory impacts. The insignificant difference in our physiological measurements suggests that the role of stress was not as significant as we had hypothesized.

Limitations

When using the Atari, it needed to be plugged into a power source and in proximity to computers that operated the BIOPAC system. This limited the location of testing to the classroom where other experimenters were being conducted. Due to the high demand of the room, the experiment was not isolated from others. People were able to talk with one another about the experiment or see the experiment take place, making it easy for them to anticipate playing the game and taking a quiz involving memory recognition. The increased number of people in the room also caused the room to get noisy at times, which made it difficult to focus on the assigned tasks. Not being able to hear the phrases could have attributed to the performance on the quiz scores. The quizzes were short, so missing a few questions, because of the inability to hear the phrase, could have an undesired impact on the results.

The use of a joystick for playing Asteroid® may have hindered the game performance. The outdated and almost non-existent use of a single-shaft joystick may have been unfamiliar to the participants. Trying to configure and get accustomed to the joystick may have impacted game score and caused further distraction.

Different participants had different levels of familiarity playing an Atari. Their level of knowledge and practice with the game may also have impacted their performance. People who are frequent gamers may have found playing Asteroid® to be more implicit, where they relied on their muscle memory rather than WM, which could have acted as a lesser distraction to the testing participant.

Preceding external uncontrollable factors such as dominant handedness, hours of sleep the night before, eating breakfast (61.3%), and the consumption of caffeine (51.6%) before the study may have also impacted the attentiveness and physical stress levels. This was beyond the scope of this study and we did not have the statistical power to address this, but we hope that randomization would have limited the influence of confounding variables. People who were dominantly left-handed may have found it difficult to play an Atari gaming system while physiological measurements were being taken due to the design of the joystick. The hours of sleep, breakfast and caffeine consumption, and stress levels could have impacted quiz performance based on their physical motility, jitteriness, and external concentration levels.

EDA and HR readings may have been unintentionally affected during the experiment as well. As both sensors were attached to the hand of a participant, the sensors may have been moved or interfered with while playing the game or while sitting and waiting. Members of the group reported an occasional abnormal heart rate reading as well as EDA reading, which shows that this is a factor that should be addressed. Having the ability to attach these sensors elsewhere on the body may have yielded more accurate results.

Future Studies

Future studies surrounding this experiment should include changes to the methodology and design in order to gain a better understanding of how various stressors affect people differently. First, increasing the number of participants would provide more statistical power and a better representation of the student population. Second, more questions could be given on each of the quizzes. This may allow us to more accurately measure the memory degradation experienced between quizzes. Third, increasing the stakes of the quizzes could have be useful. If a reward was given to those who performed well on the quizzes, motivation to outperform other participants would play a larger role.

Other changes that could be made for future experiments include different methods for the treatment group, different types of quizzes, and investigating the impact of different types of distractions. Different methods for the treatment group could include having the participant rewrite a paragraph, either on a phone or a computer, while encoding the phrases instead of playing the Atari game. This could be equated to texting or doing miscellaneous things on a computer, while trying to listen to an instructor during a lecture. Another way in which the treatment group could be tested differently is by having the participant kick or throw a ball back and forth while listening to the phrases. This method is more engaging and produces less variability in how each person plays the game. One way in which the quizzes could be changed is to test recall rather than recognition. Recognition is easier than recall because the question and the answers themselves often contain clues that may help trigger a memory rather than trying to retrieve information without anything to trigger the memory. Therefore, a quiz in which the participants were asked to recall all the phrases would most likely yield different results than the quizzes in which they had to choose from a list of possibilities. A recall quiz would then also eliminated the possibility of a participant getting a question correct due solely to guessing. One last potential change to be made for future studies includes the influence of different distractions. Rather than having a visual distraction such as an Atari game, auditory distractions could be studied by having things such as music or side conversations going on around the participant as they listened to the phrases. Other forms of distraction can originate internally, such as tinnitus. Tinnitus is the perception of sound even when no sound is present due to sensorineural damage in the brain and in the auditory system, and is known to cause concentration and anxiety problems among others (Understanding the Facts, 2017). Different forms of distraction may yield alternate results and could be the focus of future experiments.

Significance

In classroom settings where computers or cell phones are allowed and often utilized to improve efficiency by having access to data and other tools, they may actually be counterproductive by introducing distractions. Due to this misuse of technology, students are more likely to be set back in their classes. While our results showed that distractions significantly affected the memory processes, it was not shown that stress induced by the distractions was a significant contributory factor. This was supported by an insignificant difference in physiological stress response between the control and treatment groups.

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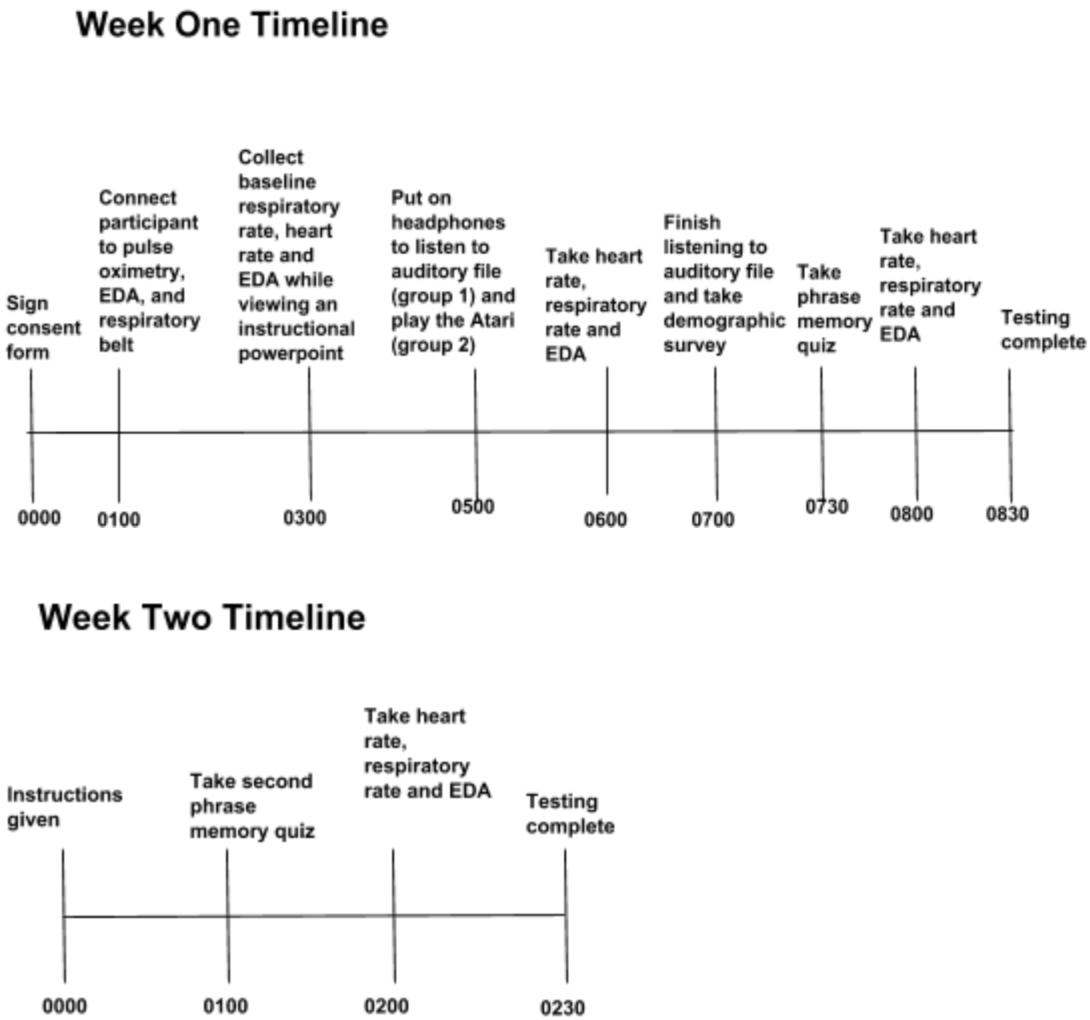

Figure 1
Figure 1 indicates a timeline of the procedure for week one and week two.

a. Rusted gold trophy
b. Rusted bronze trophy
c. Rusted silver trophy
d. Rusted brown trophy

Figure 2

Figure 2 is an example of one of the ten multiple choice questions we asked participants to complete. Five were asked during week 1 and five other ones were asked during week 2

Positive Control Data

Baseline

	HR	BPM	Standard Dev.	Mean	Max EDA	Correct Phrases
Week 1						
Control	68	13.9	2.5	3.5	1.93	5
Treatment	73	17.6	2.3	5.4	1.203	4
Week 2						
Control	73	11.4	1.2	2.6		5
Treatment	84	23.2	1.02	1.7		2

Table 1.1

Table 1.1 describes the average physiological measurements before the experiment began. Heart rate, respiration and EDA were measured and analyzed in this table.

Control

	Peak HR	BPM	Standard Dev.	Mean	Max EDA	Correct Phrases
Listening	79	19.3	2.8	7.4	3.29	---
Quiz Wk 1	86	38.5	2.5	5.9	4.29	5
Quiz Wk 2	70	42.4	1.3	2.9		5

Table 1.2

Table 1.2 describes the average physiological measurements of the control group during the experiment. Heart rate, respiration and EDA were measured and analyzed in this table.

Treatment

	Peak HR	BPM	Standard Dev.	Mean	Max EDA	Correct Phrases
Listening	82	25.2	2.2	5.7	2.02	---
Quiz Wk 1	94	16.1	2.7	8.1	1.68	4
Quiz Wk 2	95	22.8	0.6	1.5		2

Table 1.3
Table 1.3 describes the average physiological measurements of the treatment group during the experiment. Heart rate, respiration, and EDA were measured and analyzed in this table.

BIOPAC Graphs

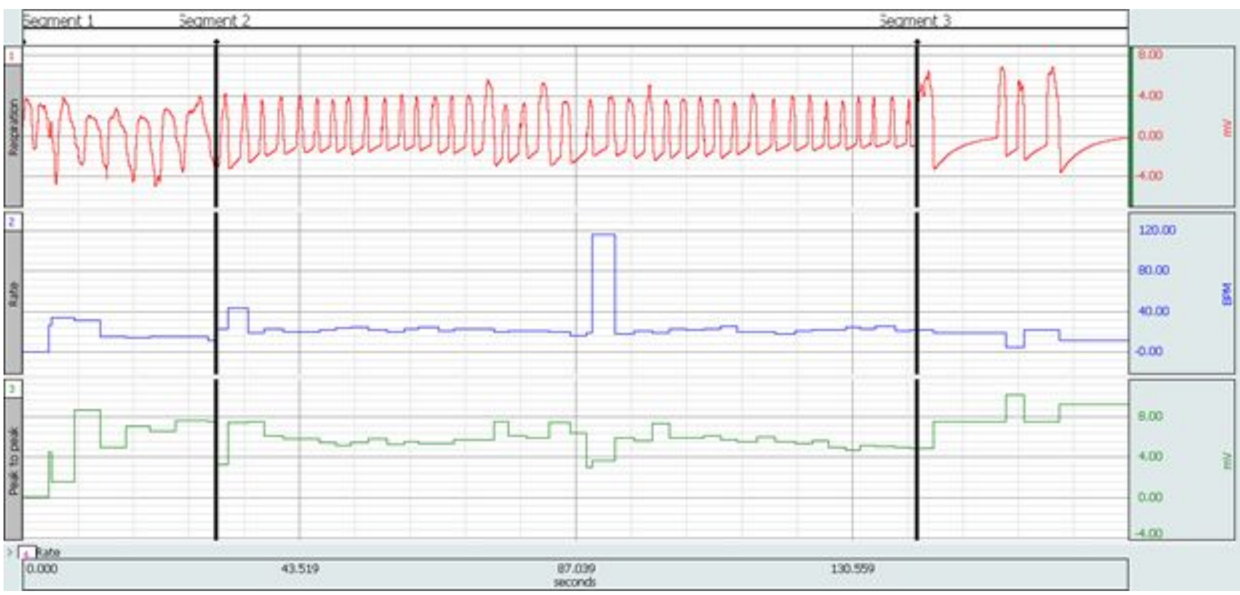

Figure 3.1
Figure 3.1 shows the BIOPAC data analysis of respiration data recorded during Week 1.

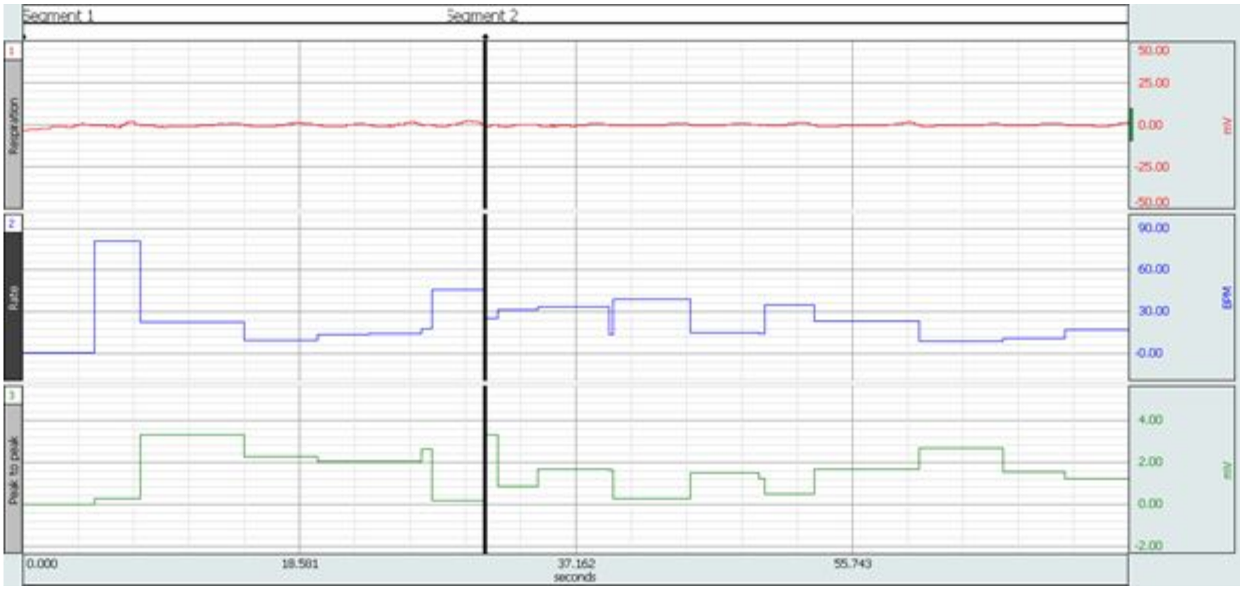

Figure 3.2
Figure 3.2 shows the BIOPAC data analysis of respiration data recorded during Week 2.

Figure 3.3
Figure 3.3 shows the positive control BIOPAC data analysis of the EDA data.

Variable	p-value	Confidence interval	t-value	Degrees of freedom
Max EDA	0.501897	1.1111-1.4959	-0.68	29
Breathes/minute	0.706537	13.2959-17.8583	-0.38	31
Max HR	0.364677	12.1407-16.3067	-0.92	31
Quiz #1	**0.00024**	0.6591-0.8853	4.15	31
Quiz #2	**0.000266**	0.622-0.8374	4.17	28
Quiz#1 - Quiz#2	0.766393	0.9226-1.2421	0.3	28

Table 2
Table 2 shows the statistical analyses of 6 different parameters comparing the control and treatment groups. The 3 physiological measurements shown are all relative to baseline, and taken during the encoding period of the experiment.

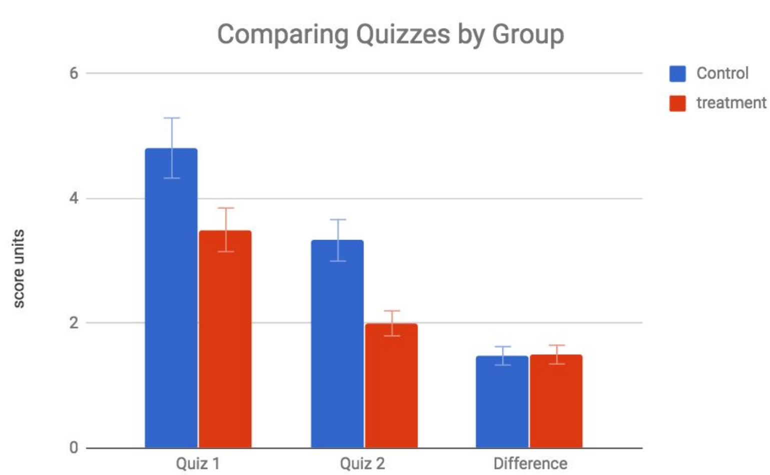

Figure 4

Figure 4 compares the test scores during week 1, week 2 and the difference between the two control scores and the two treatment scores.

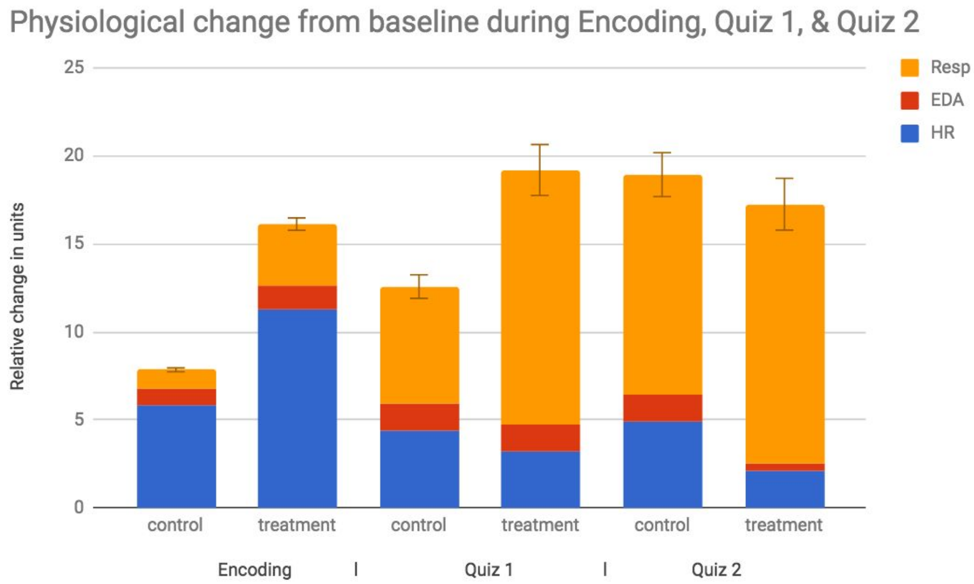

Figure 5

Figure 5 shows the relative difference in physiological variables between the control and treatment groups within all three phases of the study

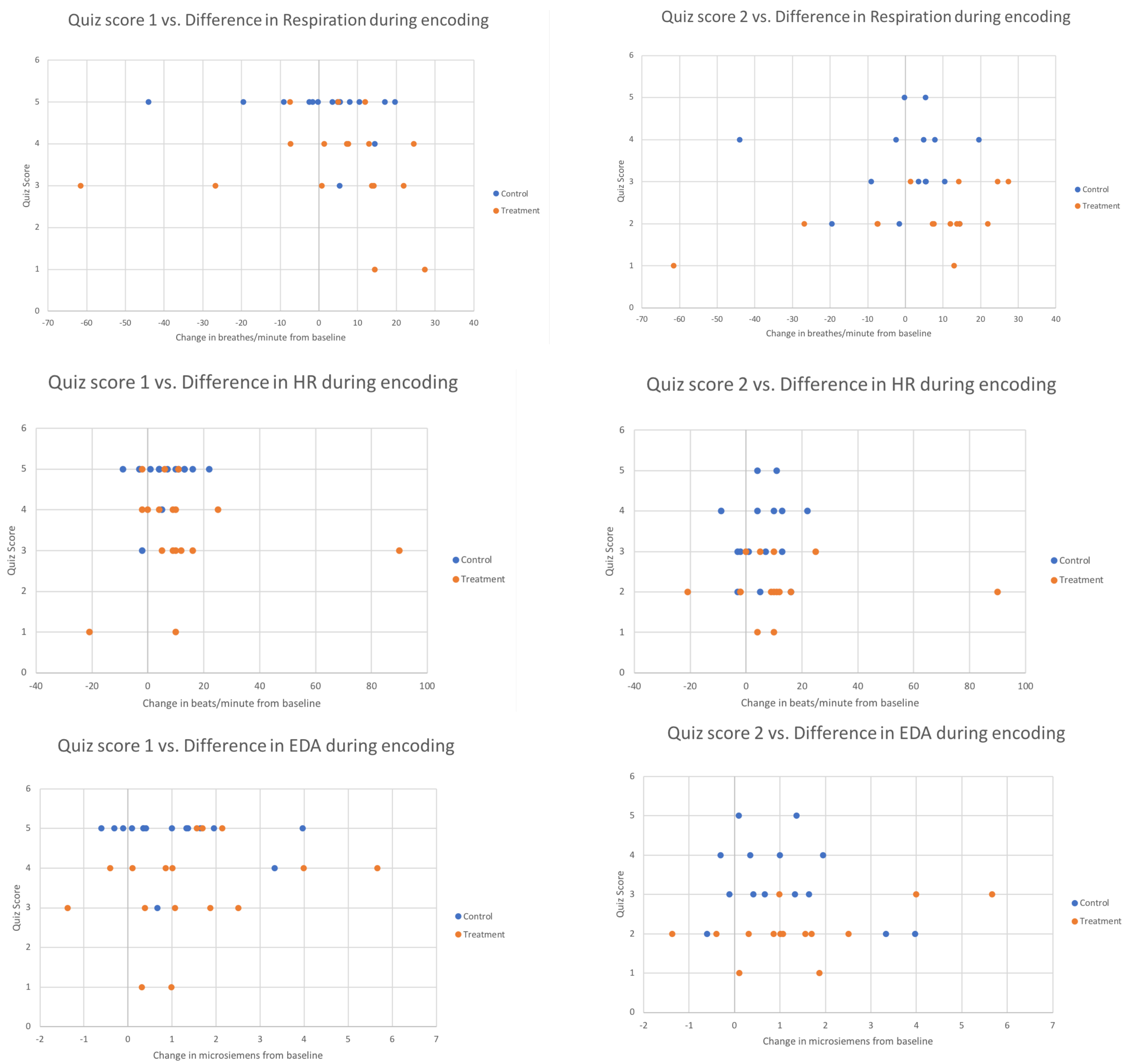

Figure 6

Figure 6 shows a cluster of charts indicating the correlation between quiz scores and three different physiological measurements. Each dot represents one participant in either the control or treatment group. A correlation would have been seen if the data points showed a general trend or difference relative to the variables.