Effects of Physiological Stress Response on Short-Term Memory Recall

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ABSTRACT

A variety of studies have explored the effects of stress on short-term memory formation and recollection. The objective of this study was to examine the effect of physiological stress response on short term memory. Stress response was evaluated by measuring changes in respiration rate, electrodermal activity (EDA) and heart rate in response to an unanticipated stressor—the sounding of an air horn. Subsequently, researchers sought to observe the implication of this stress response on participant memorization of two lists of words. Participants were run in two trials. The first trial served as the control condition and no stressor was presented during word memorization or recall. During the second trial, the experimental condition, the stressor was presented before recall. It was hypothesized that an increase in physiological values from baseline values would decrease the number of words memorized. Results found that in every trial a stress response was elicited; that is, values in respiration rate, EDA and heart rate deviated from baseline data. However, the intensity of the stress response did not significantly affect memory test performance. Overall, this data suggested that no correlation can be made between the degree of physiological stress response and the success of short-term memory recall.

INTRODUCTION

Stress is present in everyday life. Missing the bus, receiving a poor grade, arguing with family members—all of these events can elicit stress. For the purpose of this review, stress could be defined as physiological or psychological strain that poses threat to homeostatic controls (Randall, 2011). Current research examines the role of stress in concentration and memory; however, these studies have found mixed results.

Mutchnick and Williams (2012) observed the effects of anxiety on memory test performance. The study compared self-assessments of anxiety (on a one to ten scale) and success in a word-recall test in patients of all ages awaiting open-heart surgery. Researchers believed that using this test group would ensure that participants were eliciting stress responses in reaction to preoperative anxiety. Their results were disjointed. Little to no correlation was found between self-declared rating and memory test performance. However, the study discovered a higher average anxiety rating in younger patients (Mutchnick and Williams, 2012).

Davidson et al. (2006) found more conclusive results. Davidson and his colleagues ran an N-block test under threat-of-shock conditions. The study utilized two experimental groups: one that was told they would receive shocks and received shocks; another that was told they would not receive shocks and did not receive shocks. Both groups were asked to memorize the movement of blocks across a screen. Results supported researchers' hypothesis that those experiencing stress from anticipation of shock would have reduced success on the block test. Those that were told they would not be shocked were more successful in utilizing their working memory (Davidson et al., 2006).

After evaluating this research, we devised an experiment to incorporate elements of both studies. We found that the Mutchnick and Williams (2012) study relied too heavily on the assumption that all patients experience anxiety strong enough to elicit stress response in physiological variables. However, this study provided strong evidence that younger individuals are more susceptible to stress. Therefore, our experimental group was selected to be UW-Madison Physiology 435 students, ages 20-24. Davidson et al. (2006) more efficiently applied stress to their participants and found greater variation in baseline and experimental data.

For this reason, we chose to use an air horn—an object that would provide significant audible stimulus, very likely to cause a stress response as did Davidson's threat-of-shock conditions. In both of the above studies, we noted a common flaw: lack of acknowledgment to intrinsic variation in human cognitive abilities and normative physiological values. Individuals vary greatly in their ability to perform memory tasks and in their values of standard biological vital signs. To reduce bias caused by separation of experimental groups and control groups, we decided to present both the experimental condition—a test with the air horn stimulus—and the control condition—a test sans air horn—to each participant.

In this study, we will be observing changes in respiration rate, electrodermal activity (EDA) and heart rate. During a previous Physiology 435 study designed to observe the physical effects of stress, students measured these physiological values. They found that during times of stress, quantitative values of all three of these physiological values increase from baseline values (Bowler et. al, 2015). Because of this, our team anticipated that the sound of an air horn would elicit a stress response—an increase in these physiologic measurements—in participants. We hypothesized that increase in physiological activity will distract participants from the task at hand, ultimately hindering their performance on a test of short-term memory.

MATERIALS

- BioPac electrodermal electrodes (BioPac Systems Inc. Goleta, CA. Model MP36)
- Nonin pulse oximeter (Nonin Medical Inc. Minneapolis, MN. Model 9843, Serial Number: 118103098)
- BioPac respiratory belt transducer (BioPac Systems Inc. Goleta, CA. Model SS5LB, Serial Number: 1602007558)

- BioPac student labs software (BioPac Systems Inc. Goleta, CA. Model MP36, Serial Number: MP36E1204002784)
- Attwood safety air horn (Attwood Marine Products. Lowell, MI. Model 11837-7)
- Lists of random words (Generated from https://www.randomlists.com/random-words)

METHODS

Participants

Research was conducted on human participants (n=26) of normal mental and physical health status. Subjects were recruited from students currently enrolled in Physiology 435 at the University of Wisconsin-Madison, will range in age between 20 and 24 years, and was distributed equally between males and females. All students were informed of potential risks involved with the study prior to participation and provided signed consent. In addition to a consent form, participants completed a survey of demographics which recorded their age, gender, and any pertinent medical history that may impact the data collected (i.e. learning disabilities, concussions, etc).

Experimental Procedure

Prior to participant data collection, positive control data was recorded using a member of the research team. Respiration rate, EDA and heart rate were recorded and averaged over a twenty second period both before and after performance of physical activity (one minute of running in place). For electrodermal activity, the mean value and the peak to peak value was recorded. The results, displayed in Figure 1, provided quantitative evidence for changes in these physiological values in response to an external stimulus.

Following this test of positive controls, participant data collection began. In order to ensure the largest sample size possible within a limited time frame, each subject participated in two trials with data from two participants being recorded via the BioPac simultaneously. The first trial served as the control condition and the stressor was not presented. The second trial served as the experimental condition and the stressor was presented prior to memory recall. For the purpose of this study, a stressor was defined as a stimulus which evoked a physiological stress response (McLeod, 2010). Our designated stressor was the sounding of an air horn (two second presentation). All experiments took place in an isolated space (Medical Science Center, Room 281) so as to ensure that all noises made during the experiment were not heard by other participants.

After instruction had been given and paperwork completed, participants were seated and fitted with equipment suited to record respiration rate (breaths/min), EDA (microsiemens/min) and heart rate (beats/min). Respiration rate and EDA were measured continuously using the BioPac, while heart rate was recorded using a pulsometer and manually transcribed in a notebook at thirty-second intervals. Physiological recordings began one minute prior to the first trial in order to establish accurate baseline values. Recording did not stop until the end of trial two.

Participants were arbitrarily assigned one of two lists of 50 words, randomly generated using an online application (Random Word Generator, 2017). The two lists can be viewed in Figures 2 and 3. For trial one, subjects were given five minutes to memorize as many words as possible and were allowed to use any technique they chose to memorize the words (i.e. write on the word list, talk out loud, etc). After the five minute time period had expired, the list was removed. Following a ten second pause, the participant was asked to write down as many words as they could remember from the list within a five minute time limit. If a participant should reach a point at which novel words from the list cannot be recalled, they were allowed to set down their pens to indicate the end of trial one.

Baseline data was again collected for one minute prior to the start of the second trial. The second trial began similar to the first but with a unique list of 50 randomly generated words. After five minutes of memorization followed by a ten second pause, a researcher presented the stressor—the sounding of an air horn (two second presentation). Following presentation of the stressor, subjects were again allowed five minutes to write as many words as they could recall with the option to end the trial when novel words could no longer be produced. A comprehensive timeline of the experimental procedure can be viewed in Figure 4.

Statistical Procedure

Individual participant values of heart rate, respiration rate and EDA were analyzed following completion of both trials. Average values of these physiologic responses were recorded and averaged for durations displayed in Figure 4. The percent difference from baseline 1 was calculated for recall 1, while the percent difference from baseline 2 was calculated for the post-stressor value and recall 2. These percentages were averaged for all participants to provide comprehensive quantitative values of physiological stress responses.

The number of words correctly recalled words in both trial one and trial two were recorded. Researchers compared the differences of these values in order to analyze the validity of the original hypothesis. T-tests were used to determine any statistically significant difference between the degree of physiological response and number of words memorized. For the purpose of this experiment, the null hypothesis stated that the degree of physiological response (percent variation from baseline) does not alter memory test performance (number of words correctly recalled). A comparison was made using a paired t-test for two sample means. P-values below the standard critical value of 0.05 were deemed significant, while p-values above 0.05 indicated that the relationship was insignificant, which would lead to the null hypothesis not being rejected.

RESULTS

Subject Characteristics:

Data was collected from twenty-four participants (14 females; 10 males) whose ages ranged from 20 to 24 ($\bar{x}$=21.62, SD=1.22). The participants were of average mental and physical health and were currently enrolled in Physiology 435 at the University of Wisconsin-Madison.

Word Recall:

In conditions 1 and 2, subjects recalled on average 20 words (range 11-29; SD= 5.38) and 21 words (range 12-38 ; SD= 7.12) respectively. Within individual subjects, words recalled in condition 2 compared to condition 1 increased by 1.66 words on average with a standard deviation of 1.22 words. The results were not statistically significant (p=0.0903).

Electrodermal Activity:

The difference in EDA ranged from 0.7 to 10.69 microsiemens/min. ($\bar{x}$=2.31, SD=1.19). There was no significant relationship (*p*-value=0.2827). In conditions 1 and 2, subject's electrodermal activity averaged 5.06 microsiemens/minute (range 0.7-8.69; SD= 2.00). The relationship between the difference in EDA and the change in the number of correctly identified words showed no significant correlation (*p*-value=0.4926) (Figure 5).

Respiration Rate:

The average number of the respiration rate was 12.96 breaths per minute. The difference in respiration rate ranged from 4.5 to 24.49 breaths/min. ($\bar{x}$=12.96, SD=4.83). The relationship between the difference in respiration and change in the number of correctly identified words showed no significant correlation (*p*-value=0.1554) (Figure 6).

Heart Rate:

The difference in heart rate ranged from 42.3 to 107.5 beats/min. ($\bar{x}$=79.34, SD=14.73). The relationship between the difference in heart rate and change in the number of correctly identified words showed no significant relationship (*p*-value=0.2164) (Figure 7).

Statistical Analysis:

In addition to the above plots, the values of words recalled, respiration rate, EDA mean, EDA peak to peak, and heart rate for each condition were averaged (Figure 8). The average percent change for each variable (words recalled, respiration rate, EDA mean, EDA peak to peak, and heart rate) was calculated for both the control condition and for the experimental condition (Figure 9).

A paired t-test was run to evaluate the validity of the original hypothesis. A p-value of 0.1211 was calculated. Because the p-value is above the standard critical value of 0.05, we failed to reject the null hypothesis. The collected data does not provide statistically significant evidence that deviations from baseline values of EDA, respiration rate or heart rate influence memorization success rates for the given lists of words either positively or negatively.

DISCUSSION

The results of this study negated our hypothesis that the physiological stress response elicited by the sound of an air horn would disrupt short term memory and result in a decreased performance on a word-recall test. The physiological data showed that a stress response was generated after being distracted by the sound of the air horn in every trial, as observed in the increase in respiration rate, EDA and heart rate. The stress responses during the trials varied in severity, but were still elicited. However, no correlation was found between the physiological effects of a stress response and the student's ability to recall words in a short-term memory performance, as observed in the p-value of 0.1211.

The p-values indicate if there are statistically significant differences between observations for the change in the number of correctly identified words and a specific physiological effect, such as electrodermal activity, respiration rate, and heart rate. From the electrodermal activity analysis results, the p-value of 0.4926 did not provide any significant statistical difference in the relationship between the difference in EDA and the change in the number of correctly identified words.

From the respiration rate analysis results, there was no statistically significant evidence between the difference in respiration and change in the number of correctly identified words. Some differences can be observed in the experimental data; however, due to the p-value of 0.1554, these must be attributed to random chance.

From the heart rate results, the p-value of 0.2164 showed no statistically significant differences in between the heart rate and change in the number of correctly identified words. Through some small observable trends can be seen in Figure 7, the differences were likely due to random chances. Changes in the future such as testing more participants could help to increase the chances of finding statistically significant differences.

In the future, there are many changes that could have been to improve our experimental study. Future experiments should be conducted with a larger sample size of participants and a longer time frame for data collection. Testing more participants would have provided a greater and more representative range of data. A few participants had put the respiration belts on incorrectly, leading to inaccurate and unusable respiration rate data. The sound from the air horn in some trials were not as loud as other trials and might have not induced as great of a stress response in the participants.

Another change could have been the amount of time given for word memorization. A shorter period of time might have resulted in less recall of words, but would still show the same physiological responses. However, their baseline levels would be elevated because of the lack of time for memorization, increasing physiological stress created by the recall test itself. A longer period of time might have resulted in more words recalled and would still a physiological stress response.

Our experiment presented only one trial under each condition. Having more trials in each condition would have increased the amount of words recalled due to the continued exposure to test taking. A few practice trials would have helped the participants settle into a more baseline level during their word recall portion of the experiment. However, the prior presentation to the stressor in the previous trial would have decreased the physiological response to the stressor.

The experimental condition was always presented second, which raises concern about an order effect. This continued exposure to test taking could have led to an increase in a participant's likelihood of an improvement on their second short-term memory performance. By presenting the experimental condition always second, there is concern of an order effect. It was observed that participants would develop a better strategy for recalling words the second time that they took the test. The data reveals that in 57.69% (15/26) of trials, participants recollected a greater number of words in trial two. This difference results from strategy development. Trial one served as a motif from which participants could explore strengths and weaknesses of their memorization techniques and modify their strategies for the subsequent trial. Frequent strategies observed include the grouping, categorizing, sentence making, mnemonic devices, and writing out lists. As a result, the cognitive aspect of the participant overcome the physiological aspect.

In future experiments, the presentation of the stressor randomly in either trial one and trial two may diminish bias in word recall and concern over an order effect. It may have been beneficial to use the airhorn first because the participants might be less aware of a stressor, resulting in a more elevated stress response. However, having the stressor first could have elevated the baseline values due to constant concern about being stressed again by the airhorn. This may have resulted in less of a focus on word recall.

Another factor that must be taken into account was having the two participants sit next to each other while performing the experiments. In a future study, it would be more beneficial to separate the individuals to avoid competition and other distractions, which could have factored into the increase in the participant's physiological activity. However, in the interest of trying to get a larger group of participants within our set time frame, there was not enough time to separate the two test takers.

While being scared by an airhorn is not a typical cause of stress, there are many other potential stressors in everyday life. Stressors can lead to a physiological stress response, adverse health effects, and possibly a poorer performances.

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FIGURES AND LEGENDS

	Before Physical Activity	After Physical Activity
Respiration Rate (BPM)	12.57658	18.87385
EDA Mean (microsiemens)	-0.35661	0.37017
EDA Peak to Peak (microsiemens)	0.02441	0.76751
Heart Rate (beats/minute)	54	112

Figure 1: Positive control data for a member of the research team prior to participant data collection. Respiration rate, EDA and heart rate were recorded for 20 seconds for both before and after performance of physical activity (one minute of running in place).

endurable	toe
heavenly	half
spotty	brother
stare	consider
awake	son
upset	quilt
branch	elegant
ill	chop
massive	coordinated
government	decisive
trade	dizzy
possess	calculating
shaggy	effect
scratch	vase
nutty	man
male	spade
bounce	greedy
reply	nauseating
poor	drown
wrench	flawless
raspy	instinctive
rot	equable
scandalous	kneel
meeting	belong
versed	noiseless

Figure 2: List 1. This list was randomly administered to participants and was utilized in both trial one and trial two.

frantic	direful
record	temporary
cast	interesting
pray	dry
guide	unbiased
conscious	trashy
keen	cluttered
ugly	sponge
witty	jam
cars	seal
crack	allow
defeated	clammy
trip	stare
wide	stretch
noiseless	living
brother	flight
shiny	pump
crawl	talented
petite	waves
guitar	live
verdant	shrill
mice	idiotic
horse	snail
judge	earsplitting
puzzled	fact

Figure 3: List 2. This list was randomly administered to participants and was utilized in both trial one and trial two.

	Average Duration (secs)
Baseline 1	0-60
Memorization 1	60-360
Pause 1	360-370
Recall 1	370-500
Baseline 2	500-560
Memorization 2	560-860
Pause 2	860-870
Stressor	870-872
Recall 2	872-1050

Figure 4: Timeline of experiment.

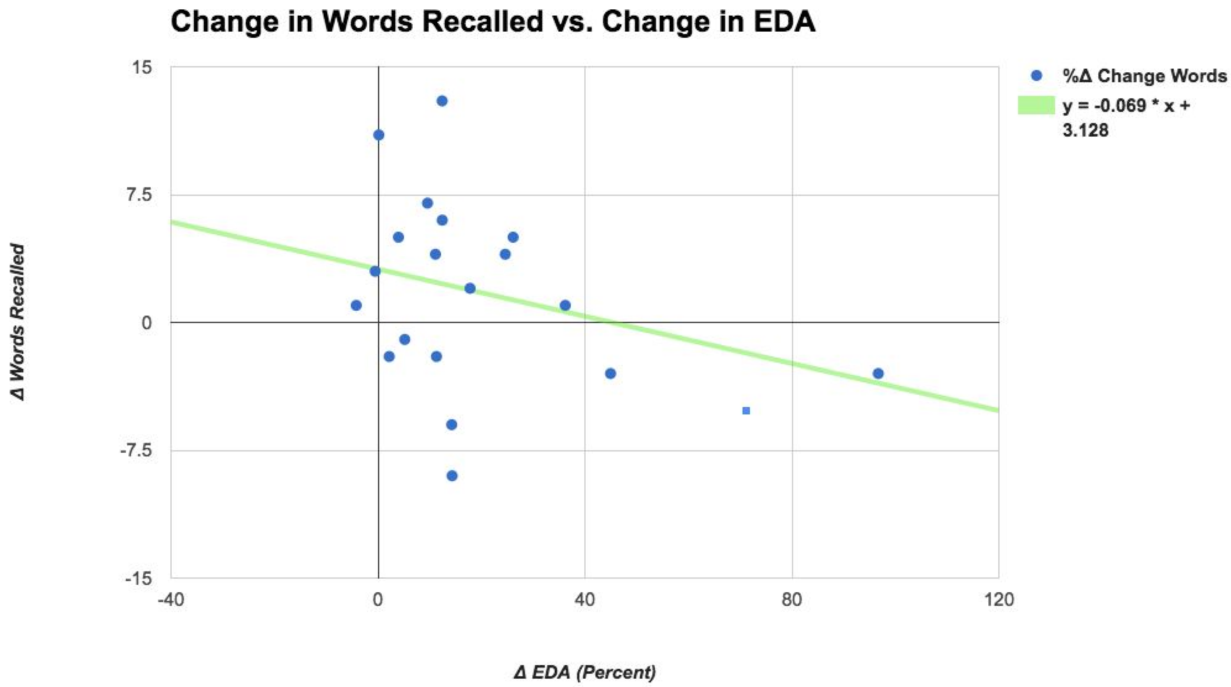

Figure 5: This graph showed the linear regression for the change in EDA mean values (percent difference of EDA after stress stimulus - EDA at baseline) vs. the change in number of words remembered (percent difference of words remembered after stress stimulus - words remembered at baseline). The difference in EDA ranged from 0.7 to 10.69 microsiemens/min. ($\bar{x}$=2.31, SD=1.19). There was no significant relationship (*p*-value=0.2827).

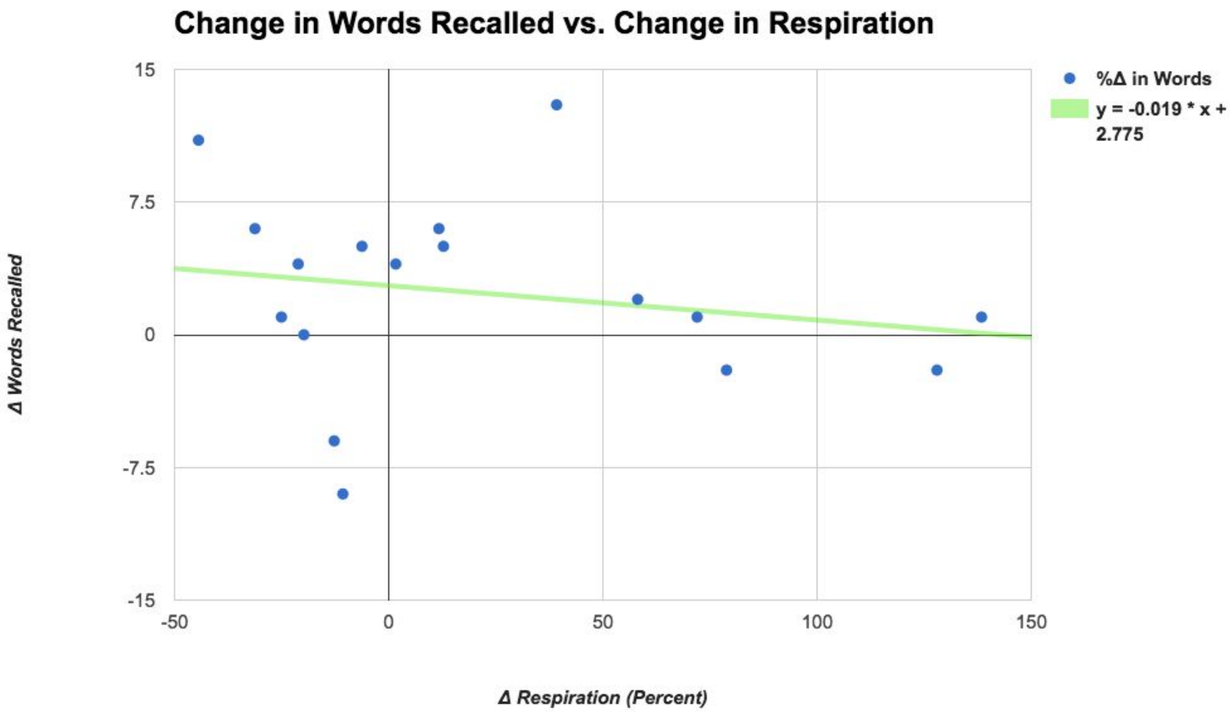

Figure 6: This graph showed the linear regression for the change for respiration rate (percent difference of respiration after stress stimulus - respiration at baseline vs. the change in the number of words remembered (percent difference of words remembered after stress stimulus - words remembered at baseline). The difference in respiration ranged from 4.5 to 24.49 breaths/min. ($\bar{x}$=12.96, SD=4.83). There was no significant relationship (*p*-value=0.1554).

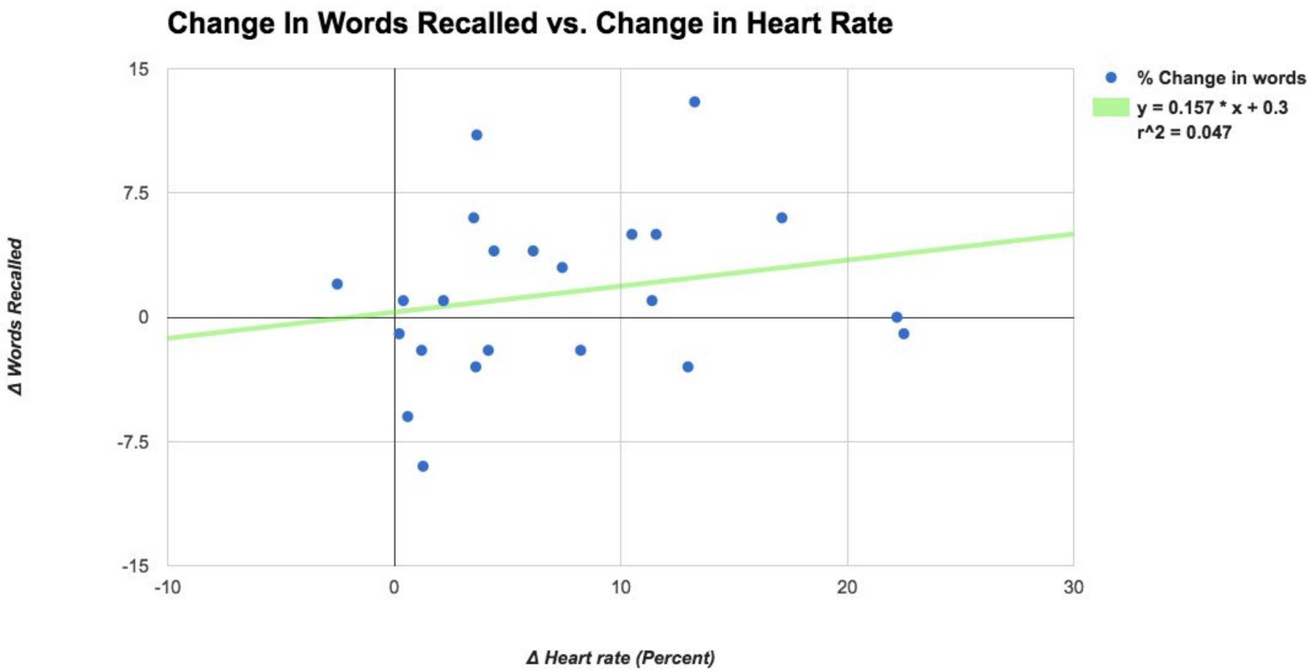

Figure 7: This graph showed the linear regression for the change for heart rate (percent difference of heart rate after stress stimulus - heart rate at baseline vs. the change in the number of words remembered (percent difference of words remembered after stress stimulus - words remembered at baseline). The difference in heart rate ranged from 42.3 to 107.5 beats/min. ($\bar{x}$=79.34, SD=14.73). There was no significant relationship (*p*-value=0.2164).

	Avg. Baseline 1	Avg. Recall 1	Avg. Baseline 2	Avg. Recall 2 with Stressor
Words Recalled	----	20	----	21
Respiration Rate (breaths/min)	11.44	14.18	11.22	12.96
EDA Mean (microsiemens/min)	4.69	5.44	5.61	6.38
EDA Peak to Peak (microsiemens/min)	2.18	1.90	2.97	2.30

Heart Rate (beats/minute)	71	90	68	107

Figure 8: The average values of words recalled, respiration rate, EDA mean, EDA peak to peak, and heart rate for the control condition and experimental condition across four distinct points during the experiment. The baseline data for both conditions was collected for 60 seconds before each memorization period. The recall data was collected after a ten second break, immediately following memorization. The stressor, an airhorn, was blown during recall 2 for a one second duration.

	Avg. Percent Change 1 (Recall 1 to Baseline 1)	Avg. Percent Change 2 (Recall 2 to Baseline 2)
Respiration Rate	23.9 %	15.5 %
EDA Mean	15.9 %	13.7 %
EDA Peak to Peak	-12.8 %	-22.6 %
Heart Rate	26.76 %	57.35 %

Figure 9: The average percent change for each variable (words recalled, respiration rate, EDA mean, EDA peak to peak, and heart rate) was calculated for both the control condition (Avg. Change 1) and for the experimental condition (Avg. Change 2). Average percent change 1 was calculated by subtracting average recall 1 by average baseline 1. This number was then divided by average baseline 1 and then multiplied by 100 to get the average percent change 1.