Effect of Decibel Level Background Noise on Short-Term Memory Recall and Stress Response

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Abstract:

Noise can induce the human body's stress response, thus producing physiological changes and possibly impairing certain cognitive abilities. Our study measured the effect that noise level had on the performance of a short-term memory task and several physiological measurements. The experiment consisted of three trials where the participant attempted to memorize and recall a list containing 20 five letter words. The participant was exposed to a different decibel level of background noise for each trial. Participants served as their own control and three physiological indicators of stress (EDA, ECG, and EEG) as well as the percent words recalled were measured. We hypothesized that the percent of words correctly recalled would be highest with no background noise, followed by low and then high decibel level noise conditions. Additionally we expected higher decibel level to correspond with a larger physiological stress response. Although not significant, the data suggested a trend that performance on the memorization task decreased with increasing noise level. Negative correlations between physiological data and words recalled mostly occurred in high decibel level treatments, indicating that the effect of background noise might be more apparent as the decibel level increases. Correlation of EEG beta waves with memorization also showed a negative trend, possibly suggesting that individuals with greater, more active thought under stress might perform worse on the recall task. Understanding the effect of auditory distraction on cognitive ability is important, especially considering the popularity of multitasking. Our study, though lacking statistical power, provides evidence that memorization ability decreases with increasing background noise.

Introduction:

In a world full of countless distractions, many young adults seek different ways to maximize their efficiency when studying or completing work. Research examining college students' study habits has shown that the ability to concentrate is a significant factor in determining semester grades (Nonis 2010). Thus, in the effort to boost efficiency, attaining a quiet and stress free environment is a typical place to start. The popularity of libraries among students demonstrates the demand for effective studying environments (Applegate 2009). In these situations, unwanted noise can be the source of great distraction. Psychologically, noise is not only a nuisance, but also a potential human stressor that has the ability to trigger "fight or flight" responses (Walters & Westman 1981). Such responses would be detrimental to any efforts to concentrate on material. Thus, our study aims to measure the physiological and cognitive effects resulting from different decibel levels of background noise.

An important part of learning and understanding material is memorization. Specifically, short-term or working memory refers to the active preservation of information in short-term storage (Gilbert et al. 2015). Using working memory allows for manipulation and recall of material for a limited amount of time (Gilbert et al. 2015). Working memory is utilized in many cognitive tasks, but is vulnerable to auditory distractions. A prominent example of this is the irrelevant sound effect. This phenomenon refers to how "low-intensity background noise" interferes with the ability to complete an "immediate serial recall task" (Beaman 2005). A previous study showed that noise in the form of unattended speech clearly impaired immediate memory, especially if the noise and the subject of memorization were phonologically similar (Baddeley & Salamé 1982). Another study found similar results, with the performance in recall tasks while exposed to noise "reduced to about one third of the level of that in quiet" (Banbury & Berry 1998). Background noise is therefore a potentially significant source of distraction in memory-based activities.

A possible explanation as to why memory becomes impaired in the presence of noise is that noise is perceived as stress. The human auditory system evolved to aid in our survival by interpreting sounds from the surrounding environment. The central nervous system (CNS) processes the incoming auditory information and initiates reactions based on how the sounds compare to previous experiences (Rylander 2004). Thus, noise can be interpreted as a warning that results in a stress response. However, this auditory-based warning system evolved to respond to sounds from natural settings. It is possible, that the intensity of modern noise sources could lead to auditory overload in humans (Walters & Westman 1981). Previous studies have found that serious physiological effects could result from such prolonged noise exposure (Rylander 2004). These effects include oxidative stress, raised heart rate, increased blood pressure, and increased stress hormone levels (Babisch et al. 2014).

This study addresses the effects of the presence as well as the intensity of background noise on stress level and memory recall. Differences in stress level were determined using three physiological measurements: electrodermal activity (EDA), electrocardiogram (ECG), and electroencephalogram patterns (EEG). Psychophysiological responses such as "sweating, change in heart rate and muscle tension" result from sound stressors (Walters & Westman 1981). EDA and ECG can track these responses by measuring changes in sweating and heart rate during the experiment. In situations of mental stress, alpha waves are suppressed and beta waves vary with the difficulty of the task (Malik et al. 2012). EEG will record changes in brain wave activity throughout the experiment. We expect that presence of background noise during the recall test will act as a stressor. This will result in increased heart rate (ECG) and sweating (EDA) when compared to the trial with no background noise. We also expect there to be suppression in alpha waves (decreased frequency of peaks), and improvement in beta waves (increased frequency of peaks) when compared to the trial with no background noise, due to stress and increased difficulty in the task of recall. Finally, we expect the stress response to be greater during the high decibel trial than the low decibel trial.

Past student research explored the detrimental effect of background noise on working memory and its relationship with stress responses (Andropolis et al. 2016). The researchers measured recall, heartrate, electrodermal activity and blood pressure of participants subjected to auditory distraction. Change in blood pressure in response to noise was the only significant result the study found. The study also sighted many potential sources of error to explain the lack of significant results. This study will elaborate on this past experiment to determine if different decibel levels result in differences in stress response and memory test performance. Additionally, changes to experiment methodology and data analysis will help eliminate previous error.

List of materials:

Decibel 10th: Pro Noise Meter, Sound Pressure Level Application (SkyPaw, Co, Ltd. Hanoi, Vietnam)

iPhone (Apple. Cupertino, CA)

"People Talking in BAR 9 Hours Long" YouTube Video SoundLikeTube

2 BIOPAC Electrode Lead Sets (SS2L)

2 BIOPAC Disposable Electrodes (EL503), 6 electrodes per subject (3 for each, ECG and EEG)

2 Skin Conductance Sensors

Supportive Coban Wrap (3M. MN, USA)

2 BIOPAC Electrode Gel (GEL1) and Abrasive Pad (ELPAD)

BIOPAC Student Lab System: BSL 4 Software; MP36, MP35 or MP45 hardware

Computer System: Windows 7

Wireless Headphones (Beats Electronics. Santa Monica, CA)

Short Term Memory Recall Test: group made (Paper)

JMP Statistical Software (SAS, Cary, NC)

Methods:

14 participants (8 female/6 male) between the ages of twenty-one and twenty-four were selected at random from a pool of Physiology 435 students at University of Wisconsin - Madison. Participants were required to sign a consent form, which contained information pertaining to the purpose of the study and any risks the participant may encounter. After the form was signed, the participant was given a brief overview and timeline along with a set of instructions for the experiment (Figure 1).

During set-up, three electrodes were placed on the left side of the participant's head regardless of his/her writing hand dominance and secured with Coban wrap to measure brain waves by EEG. Disposable Electrodes (EL503) were placed directly onto the scalp with electrode gel: one below the ear, one behind the ear, and the last one between the first two. Participants were also be fitted with a pair of *Beats Electronics* headphones which were worn throughout the experiment. Three ECG leads were used throughout the experiment to measure heartbeat. Disposable electrodes (EL503) were placed on the left wrist, left ankle, and right ankle. The white (VIN-) lead was placed on the left (non-dominant) wrist, the red (VIN+) lead was placed on the right ankle, and the black (GRND) lead was placed on the left ankle. Electrodes and leads remained connected to the participant throughout the experiment. Two additional sensors were placed on the participants hands to measure EDA. Conductive gel was applied to the electrode, and participants wrapped the electrode on the skin of their middle and index fingers. All three sensors were plugged into a corresponding channel on the BIOPAC interface.

Decibel measurements were completed before the experiment was preformed using the Decibel 10th: Pro Noise Meter Application on an iPhone. For the low and high decibel conditions, we played a YouTube video of people talking in a bar ("People Talking in BAR 9 Hours Long" YouTube Video). The microphone was pressed against the Beats headphones in a quiet room to detect the level of sound coming from the YouTube video. During the trials, the computer was set to the volume level corresponding to the preliminary decibel measurements. The no noise treatment was characterized by no sound playing through the wireless headphones and was recorded at 52 dB. A low noise treatment, where background noise was played at a low decibel level was recorded at 60 dB. A high noise treatment, where background noise was played at a high decibel level was recorded at 74 dB. The video was chosen as our background noise because it represents unrecognizable speech, which can be distracting in a study situation. Studies done by Broadbent (1978), Poulton (1979), and Loeb (1986) observe that intermittent noise exposure is more disruptive than continuous exposure in addition to these effects being stronger with recognizable speech noise.

At the beginning of each trial, the participant was first asked to relax but keep his/her eyes open for a one minute baseline reading. For the next minute, the participant was asked to look at a list of 20 words. After the minute elapsed, the list was taken away, and the participant was given one minute to write down as many words as they could remember. Once the minute passed, the background noise was removed (if it was being played), and the participant began the next trial, starting with another minute-long baseline reading. For the second trial, a second memory recall test was administered that is identical in structure to the first test, but with different words. After the completion of the second trial, the background noise was removed (if it was being played) and the third and final trial began, starting with a final minute-long baseline reading. For the third trial, a third memory recall test was administered that is identical in structure to the first and second tests, but with different words once again. After the third trial, the equipment and headphones was removed. The participant completed a short survey regarding demographics, study habits, and possible confounding variables. The 60 total five letter words chosen for all three trials consisted of random, elementary level words that did not have alternate spellings (such as peace and piece). This way, the words were simple enough to remember, and non-repeating from trial to trial.

Data for the three physiological measurements was analyzed using BIOPAC Student Lab System: BSL 4 Software. Physiological data were analyzed separately as baseline, memorization and recall phase measurements. Participants acted as their own control using a baseline measurement of heart rate, electrodermal activity, and electrical brain activity before the memorization tasks are given. Memorization and recall phase values for heart rate, EDA, and EEG were all normalized to the baseline by dividing by the baseline value determined before each trial. Memory tests were evaluated by percent words recalled of the 20 total words presented. The experiment consisted of three trials for each participant, with the condition order

(High, Low, or No Decibel Treatment) randomized. A Tukey-Kramer mean test (JMP statistical software) was performed on the physiological and memory task data in order to compare many different means at once with little error. Statistical significance is depicted by the array of circles, indicating that any two treatments tested are significantly different if the circles do not overlap. Overlapping circles and non-overlapping circles are shown by black and red color respectively. A bivariate linear fit test was performed to analyze correlation.

Figure 1 - Timeline of Experimental Design

Results

Physiological Response

The effect of each treatment on the change in heart rate from baseline was analyzed in Figure 2. In a comparison of each treatment's memorization phase, the general trend is a heart rate closer to baseline the lower the decibel level of external noise. A similar trend can be seen when comparing the means of each treatment during the recall phase. However, statistical comparison by the Tukey-Kramer test showed no statistical significance between any two treatments, with the lowest p-value being 0.90 between the no decibel and high decibel treatments for the memorization phase. Interestingly, the average fold change in heart rate from baseline was generally greater for the recall period compared to the preceding memorization period for each decibel treatment. The lowest p-value between phases was 0.22 when comparing high decibel recall and no decibel memorization treatments.

With respect to the fold change in EDA over the three treatments (Figure 3), statistical significance was even more inconclusive, with a minimum p-value of 0.57 between high decibel recall and no decibel memorization treatments. Similar to ECG trends, EDA tended to be greater during the recall periods compared to memorization periods, and the mean data show a slight trend downward from high decibel to no decibel treatment for each phase.

The three treatments compared to baseline show no statistical significance. The memorization and recall tasks were combined and a slight positive correlation of the EEG peaks per second with noise level is noticed in the standard EEG data (Figure 4) ($p=0.27$ between high and no decibel conditions). This trend is negligible in EEG alpha and slightly apparent in EEG beta recordings (Figure 5 and 6) ($p=0.83$ and $p=0.47$ respectively).

Short-Term Memory Task

Comparison of percentage words recalled between each of the three treatments shows the most apparent trend of this study (Figure 7). Although not statistically significant, comparing the percentage between high decibel and no decibel treatments showed a promising trend, with a p-value of 0.34. Participants scored on average $47.5 \pm 0.175\%$ on the short-term memory task under high decibel level and on average $56.8 \pm 0.175\%$ under no decibel level. Under low decibel level treatment, participants tended to perform somewhere in the middle, where on average, $51.4 \pm 0.175\%$ words were recalled.

Correlation Data

In order to determine the correlation between the physiological data and the memory task performance, bivariate linear analysis was performed on a scatterplot of each physiological metric against the percentage words successfully recalled. Figure 8 and 9 show the linear correlation between the percentage of recalled words and the change in participant heart rate during the memorization phase and the recall phase respectively. These data are meant to elucidate an association between heart rate fluctuation and short-term memory ability. The association between recall phase heart rate and success in the short-term memory task was most significant in the low and no decibel level treatments with correlation p-values of 0.056 and 0.167 respectively. However, these data showed a positive correlation, where we expected a negative correlation. On the other hand, memorization phase heart rate negatively correlated most with success in the memory task in the high decibel treatment, with a correlation p-value of 0.112.

Figures 10 and 11 are similar in that they compare the physiological to memory task success in both the memorization and the recall phase of each trial, but these data analyze the association between percentage words recalled and the EDA measurements. Statistical analysis of these two figures showed no real correlation between EDA and percentage recalled. The smallest correlation p-value is 0.379 between the mean EDA value during the memorization phase in the high decibel level treatment. In the recall phase, EDA measurements and memory task success positively correlated slightly in the low and no decibel level treatments, but the p-values for this phase were all greater than 0.60.

Correlation data between EEG activity and percentage words recalled was gathered to determine any associations between the two variables (Figure 12-14). There were no significant correlations between any of the three EEG measurements and word recall. The lowest p-value found was the high decibel treatment for the general EEG waves, indicating a strong, but not significant positive trend.

Discussion

Data Analysis

Our hypothesis that lower decibel levels would result in lower EDA, heart rate, and EEG activity and a higher percent of words recalled was not significantly proven. It was hypothesized that a lower decibel level of noise would prove less distracting by creating a less stressful environment for the participant to think and work. Although not statistically proven, EDA measurements showed a slight positive trend with increasing decibel level in phase. This trend is also apparent in the data comparing heart rates between each treatment. However, the data actually show more statistical significance between phases, where the heart rate and EDA measurements tend to elevate in the recall phases compared to the memorization phases, independent of the treatment. This might be a result of the added stress from a participant actually writing down words from memory or struggling to remember a forgotten word. More data would be needed to determine if this recall phase increase is stronger in one decibel treatment over another. In this present study, the no decibel level treatment shows the most significant recall phase increase and is most apparent in the ECG recordings.

The data found from the general EEG recordings were not significantly different between the no decibel and low decibel treatments or between the no decibel and the high decibel groups. The latter had the greatest significance. Alpha and beta wave activity also showed no significance. Beta waves showed to be better correlated with decibel level between the no decibel and high or low decibel treatments. A previous study done in 2011 titled "Effects of Musical Tempo on Heart Rate, Brain Activity, and Short-term Memory" have shown a trend of increasing beta activity in low or high tempo music given, a similar phenomenon seen in subjects in this study given low or high decibel noise compared to no noise treatments. The trend followed our hypothesis that with greater noise level, more beta wave activity will be present, but did not show any hint of repression of alpha activity (Figure 5 and 6).

The trend found in Figure 7, although not significant, showed that with increasing levels of sound exposure, the ability to recall words during the short term memory task decreased. Despite lack of significance, with the addition of more participants, statistical significance may increase if there indeed is a correlation between noise levels and recall in short-term memory tasks. A previous study done in 2011 titled "Physiological Changes Associated with Varying Music Tempo" also have shown an increased heartrate when given low and high tempo music. This trend was also seen in this study when given low or high noise in study and recall phases.

Correlation data all demonstrated no significant p-values between any of the physiological data and the percentage words recalled. The trends were not particularly well defined either, where some no decibel and high decibel treatments had a positive and negative correlation in the same set of data. An increase in number of participants might still help with determining the true correlation between these variables. Figure 14 depicted the high decibel level EEG beta wave recordings as negatively correlated with percentage words recalled. This was consistent with our hypothesis and possibly suggests that even if higher beta waves arise during stressful thought, the percent correct still decreased. Similarly in Figure 13, words recalled actually decreased with greater levels of alpha wave activity, which was inconsistent with our hypothesis. An explanation might be that greater alpha wave activity is reflective of relaxed thought, and those who are in that state might not be able to overcome the high noise distraction as easily as those who are thinking more actively. One interesting finding in our study is all of the high decibel treatments had the lowest p-values and the greatest correlation, indicating that the differences are more detectable with higher decibel levels. Yet, the lack of significance in this study could mean these trends are not accurate, so a study with more participants would have to be done to solidify the statistics.

The results of this experiment differ from previous studies done by Baddeley & Salamé (1982) and Banbury & Berry (1998), which found statistically significant detrimental effects of background noise on recall. This difference in findings could have resulted from differences in experiment methodology or our limited sample size. A similar experiment conducted by Andropolis et al. (2016) showed inconclusive results. Their study resulted in no statistically significant difference in EDA or heart rate between control groups and groups exposed to background noise. A study done in 2003 titled "The Effects of Music on Short-Term Memory and Physiological Arousal" found a trend of increased skin conductance in subjects exposed to low or high volumes of music during short-term memory tasks. This trend was similarly observed in our study where there were slight increases in EDA in low and high noise treatments compared to no noise.

Sources of Experimental Error

Factors that may have influenced our data recording include having adequate contact of the EEG electrode to the scalp of the participants. Although the Coban wrap aided in ensuring the placement of the electrodes, there was no way to ensure that the conducting gel of the electrode was in fact contacting the skin. This was also a problem while recording EDA activity on the participants' hand. Many times during the experiment, it was observed that the participant would move their nondominant hand. Not only did this increase EDA signal, but also led to brief periods of severe loss of conductance as seen while recording data. Another factor that could have skewed the results are whether the participants normally study while listening to music outside of class. The volume of their music may have also been in some participant's favor during the memorizing and recalling phases of the experiment. Early on, each individual begins to form a personalized set of study habits and environments, otherwise known as study patterns. An effective strategy increases success, meaning that it is important to develop these patterns and know what works best for each person. These patterns include, but are not limited to, the time of day during which studying takes place, the environment one is in, as well as sound level of said environment. If a student has found that listening to music is beneficial it may possible skew the data. If someone uses the music as a study pattern, then it is possible that the higher decibel level background noise may aide them instead of hinder their recall, as we hypothesized. These preferences may have negated a potential statistical significance calculated within the data. Another source of error that could have altered our data is interference between the Biopac channels. Interference between the EEG signal and ECG signal was usually alleviated by moving the ECG input to a channel that was located further away on the Biopac than the EEG input. When this didn't solve the ECG trace completely, it appeared to disappear after moving either one or more electrodes to a new location on the head. It is thought that accidently having placed an electrode on a blood vessel on the scalp was the cause of the ECG interference. Thus, it is reasonable to suggest that smaller blood vessels may have interfered with our EEG data that is not perceivable to the eye.

Future experiments

Future experiments could address these sources of error. Increasing the sample size of participants would help address certain issues that arose. Although this study failed to attain statistically significant results, a larger sample size may help explain the relationship between noise level, recall and physiological stress responses. For instance, although it was not statistically significant, there was an observable decrease in the percent of words recalled during the testing periods with increased decibel level. It is possible that this is due to the stress inducing and thus distracting nature of the background noise. A larger sample size could increase the strength of this relationship. Another proposal for further study is to include measurements of other typical stress responses. For example, during typical fight or flight responses, pupils dilate and respiration increases. These reactions could be measured in response to background noise.

Although lacking in statistical significance, the trends observed in this study contribute to the overall comprehension of the effect of background noise. This experiment will aid future research which will further elucidate the possible physiological and psychological consequences of background noise during cognitive activity.

Acknowledgments

We would like to thank all of our participants took part in our experiment. Additionally we would like to thank our professors, graduate students and undergraduate assistants who helped us along the way.

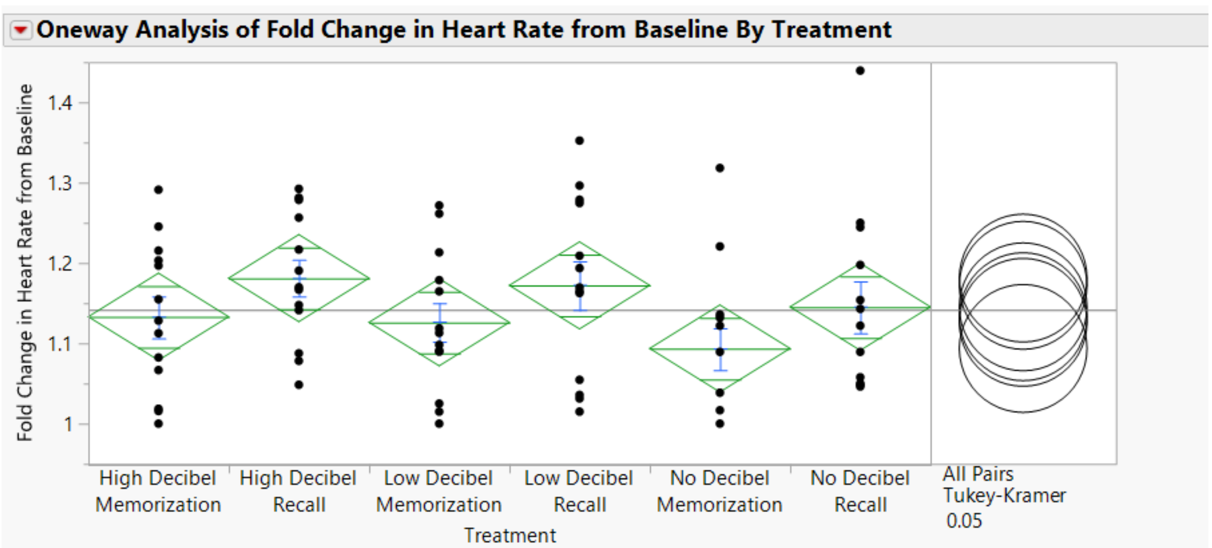

Figure 2 - ECG analysis for each condition: no decibel, low decibel, and high decibel. Data were collected as a baseline for each condition and the memorization and recall values were divided by their respective baseline and averaged for the 13 participants. No significant p-values.

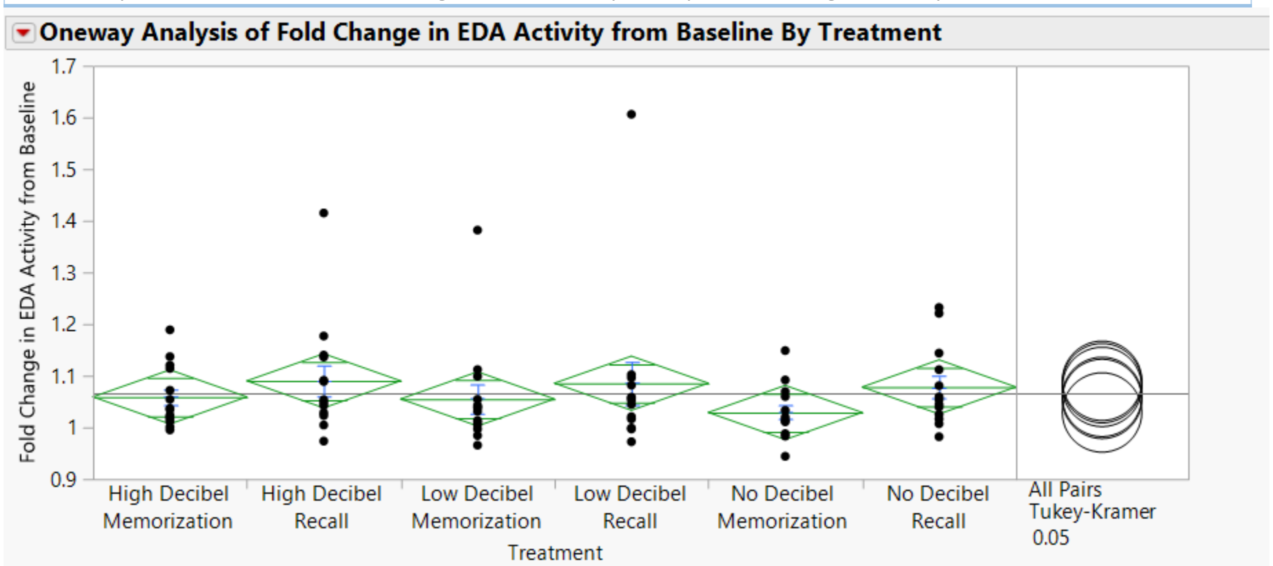

Figure 3 – EDA analysis for each condition.

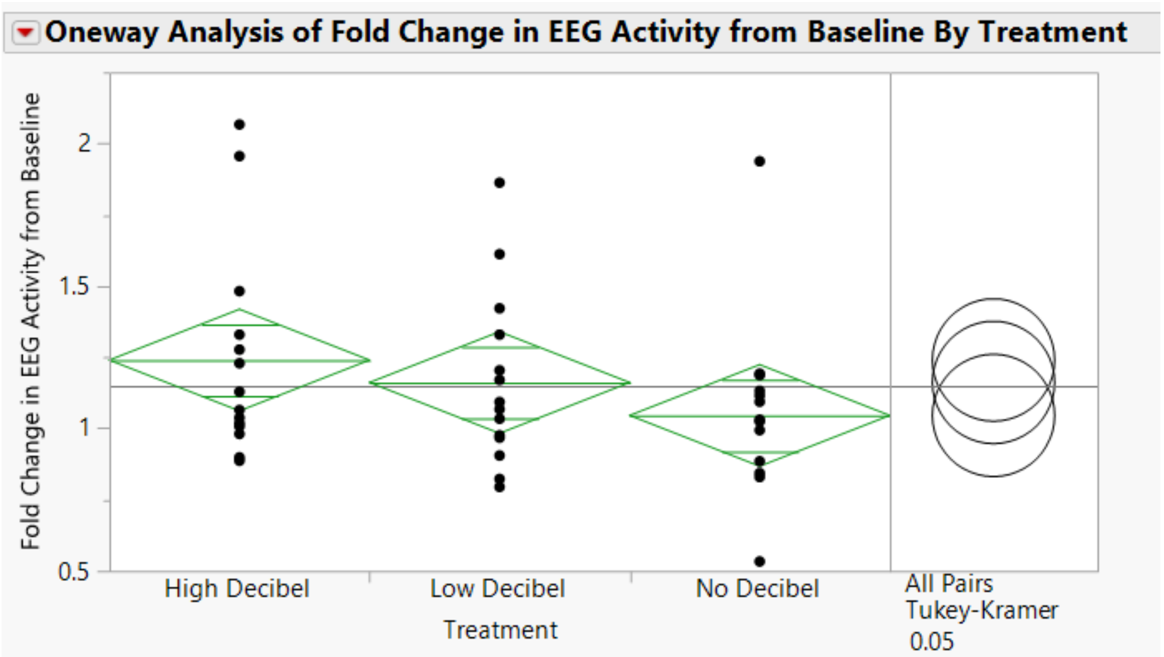

Figure 4 – EEG activity analysis for each condition.

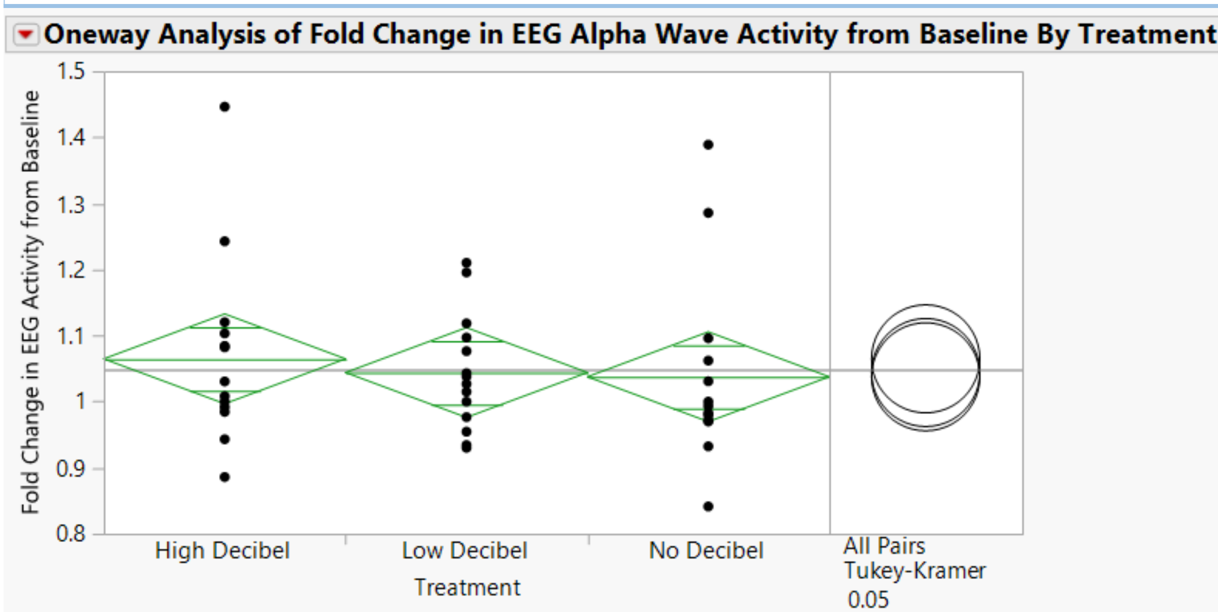

Figure 5 – EEG alpha wave activity analysis for each condition.

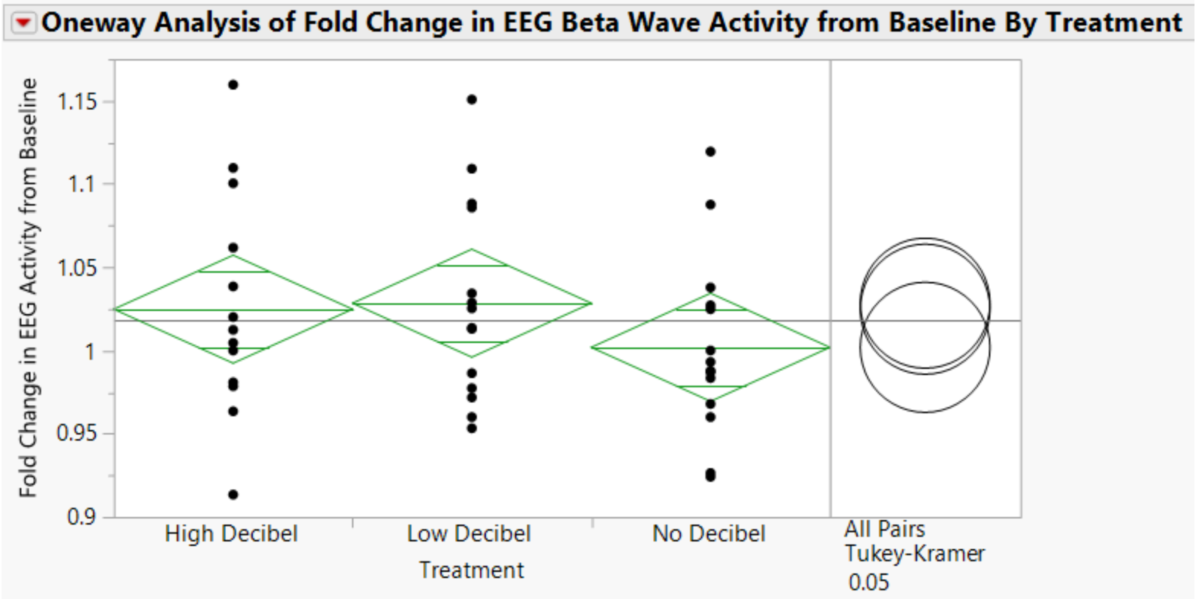

Figure 6 – EEG beta wave activity analysis for each condition

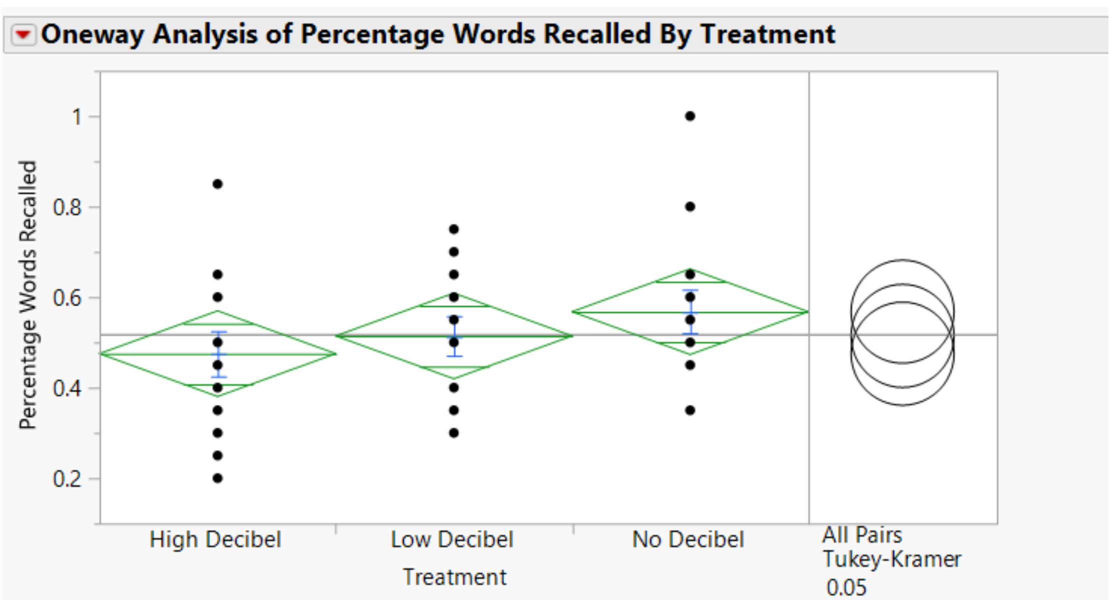

Figure 7 – Percentage of words recalled by each participant for each condition.

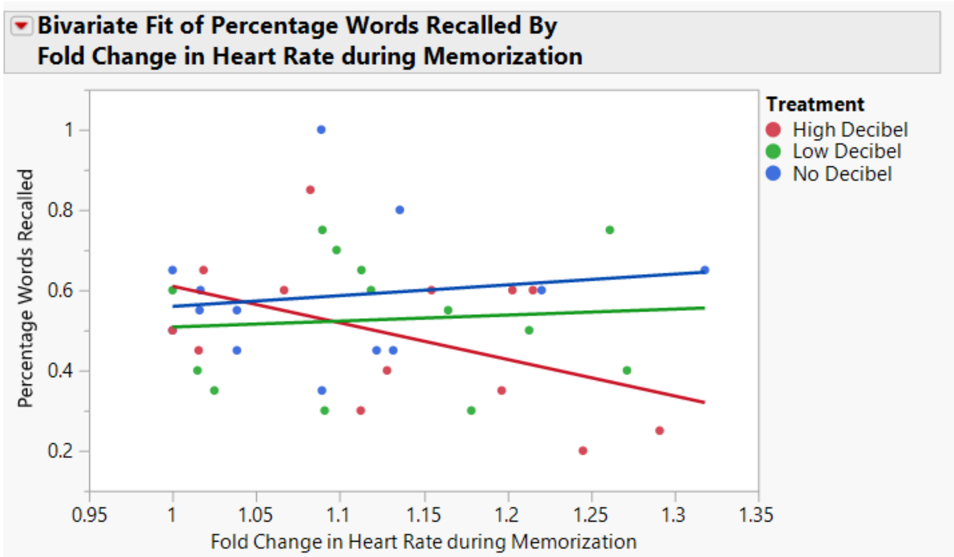

Figure 8 – Linear correlation between heart rate during memorization phase and percentage words recalled for each condition. High Decibel p=0.1116, Low Decibel p=0.7944, No Decibel p=0.6290

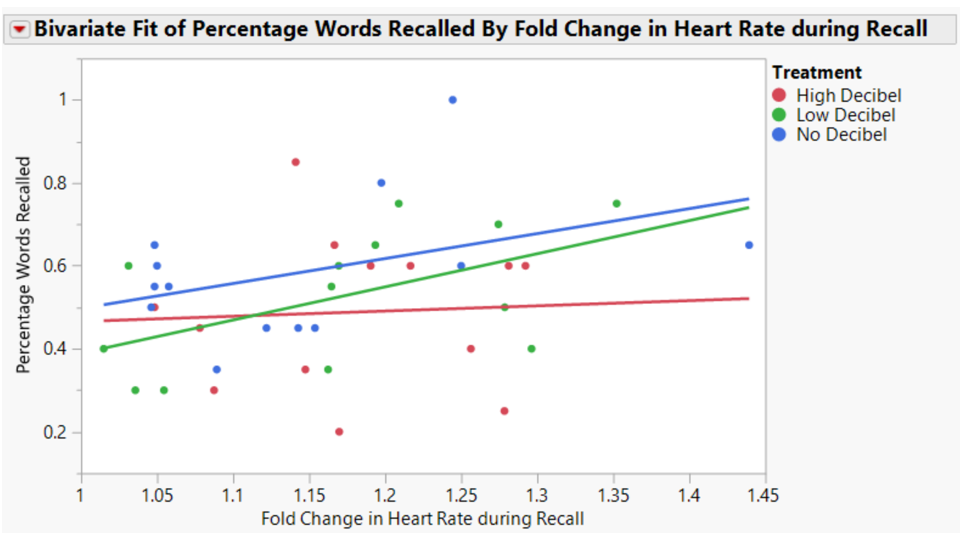

Figure 9 – Linear correlation between heart rate during recall phase and percentage words recalled for each condition. High Decibel p=0.8583, Low Decibel p=0.0558, No Decibel p=0.1671

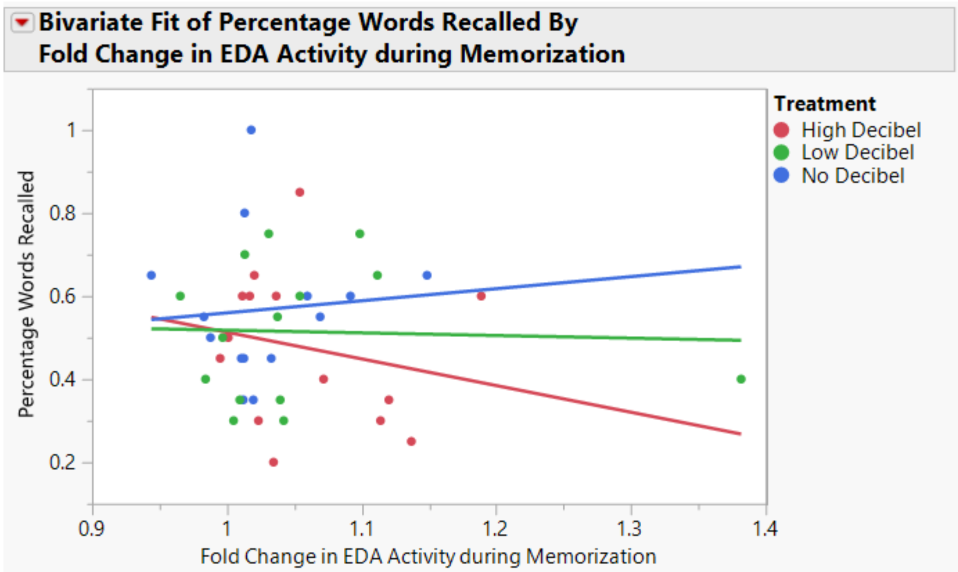

Figure 10 – Linear correlation between EDA during memorization phase and percentage words recalled for each condition. High Decibel p=0.4818, Low Decibel p=0.8925, No Decibel p=0.7751

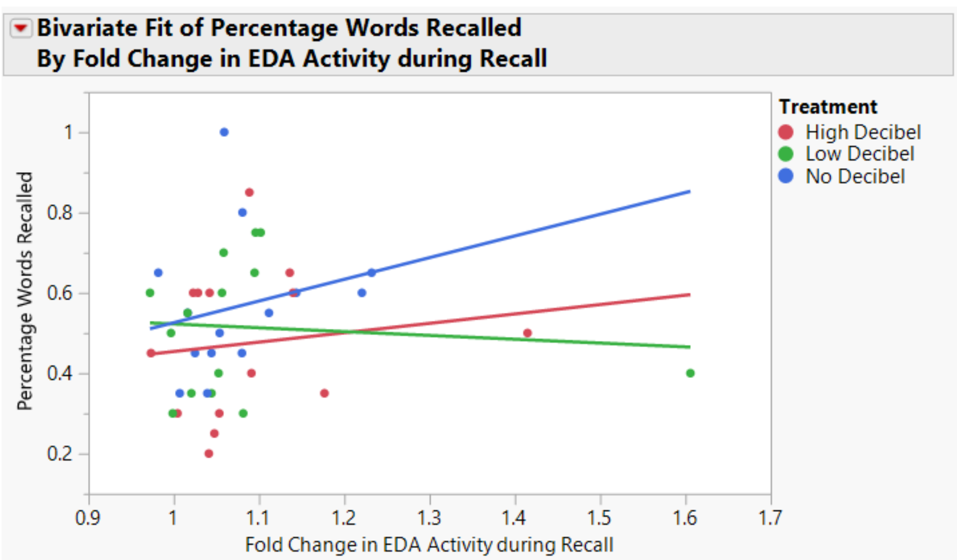

Figure 11 – Linear correlation between EDA during recall phase and percentage words recalled for each condition. High Decibel p=0.6381, Low Decibel p=0.7614, No Decibel p=0.4232

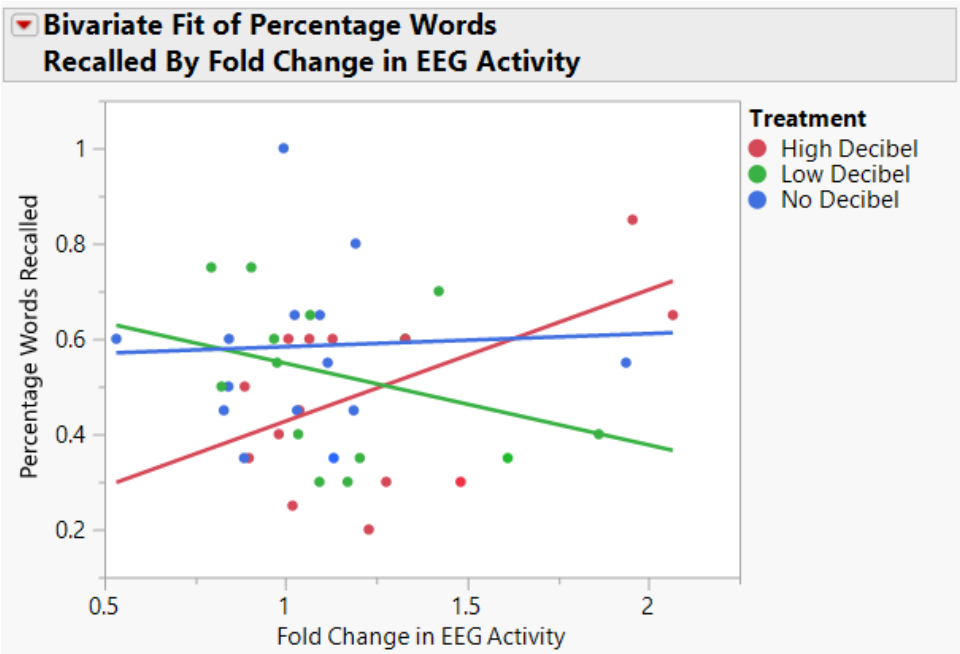

Figure 12 – Linear correlation between EEG activity and percentage words recalled for each condition. High Decibel p=0.0843, Low Decibel p=0.1778, No Decibel p=0.9454

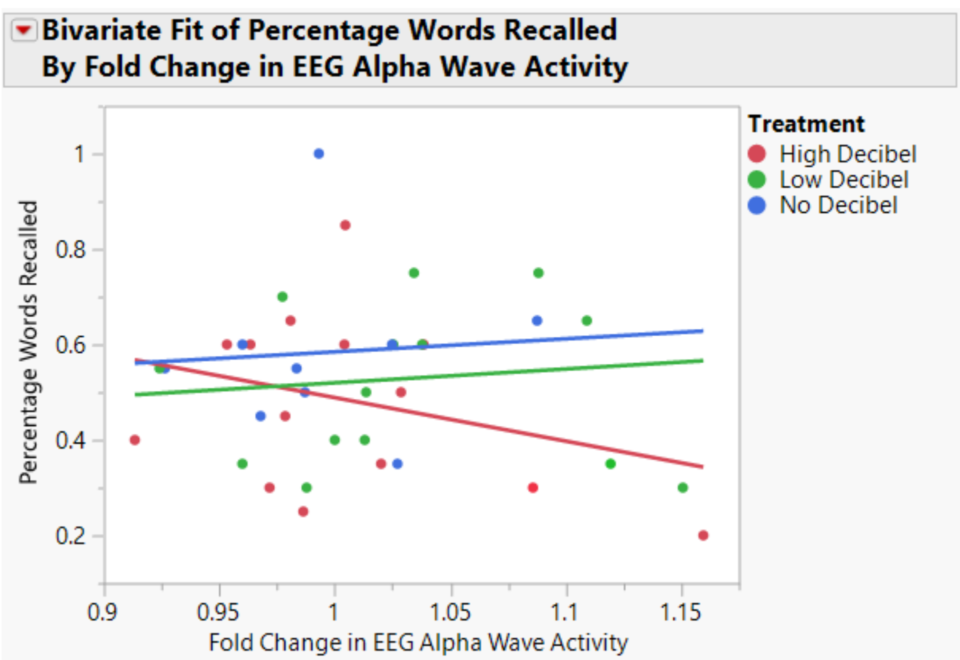

Figure 13 – Linear correlation between EEG alpha wave activity and percentage words recalled for each condition. High Decibel p=0.2069, Low Decibel p=0.9566, No Decibel p=0.8566

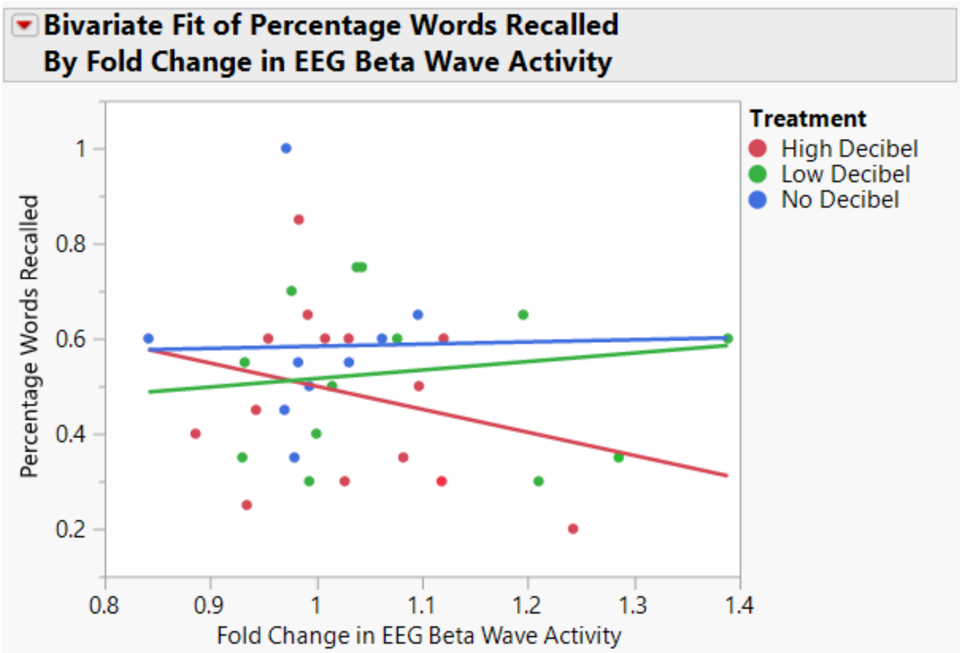

Figure 14 – Linear correlation between EEG beta wave activity and percentage words recalled for each condition. High Decibel p=0.2922, Low Decibel p=0.9960, No Decibel p=0.931

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