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Cognitive Task Enhancement Through Alpha Neurofeedback

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TABLE OF CONTENTS

CHAPTER ONE

Introduction

Neurofeedback Training

Neurofeedback training, or NFT, has been used in a variety of fields of research. Neurofeedback training is relatively new, deriving from biofeedback training, a technique that teaches participants to voluntarily control what were previously involuntary actions (Frank, 2010). These involuntary actions can include learning to control processes such as respiratory rate or heart rate. This is done by showing the participant their current state of activity and giving them a set target state of activity to aim for. Biofeedback training has been shown to reduce anxiety, balance the autonomic nervous system, and change the way participants react to stress (Weerdmeester, 2020). Neurofeedback training, also known as EEG biofeedback training, combines this concept with the use of EEG and brainwave levels

Originating in the 1970's, NFT uses several electrodes to provide a participant with real-time feedback regarding their brainwave patterns (Hammond, 2007). The theory behind NFT is that by becoming aware of our own brainwave patterns, we have the ability to manipulate and regulate them through operant conditioning (Vernon, 2003). Operant conditioning can be thought of as a habit and is done by reinforcing the wanted behavior (Staddon & Cerutti, 2003). Neurofeedback often uses a visual or auditory stimulus to reinforce the desired behavior. With the desired behavior being an increase or decrease in certain frequencies of the brain. With training and practice, healthier brainwave patterns can be achieved on a day-to-day basis (Hammond, 2007). The idea of being able to retrain and recondition our brainwaves is congruent with the theory of synaptic plasticity, and has been studied across multiple disciplines. Hebbian synaptic plasticity usually refers to a long-term change in synapses, either a strengthening of the synapses, or a weakening of synapses (Abbott & Nelson, 2000). This idea of long-term potentiation, or long-term depression is the basis for learning and memory as a whole, as the synapses that are used less experience long term depression, and those that are used more experience long term potentiation, and are strengthened (Abbott & Nelson, 2000). The goal of neurofeedback training is to increase long term potentiation in synapses related to the target of the study. Neurofeedback training can also be used to target an increase in short term memory or working memory.

Working Memory

Working memory is a short-term memory theorized to be caused by a temporary change in electrical activity, compared to long-term memory, which is theorized to be a more permanent change in the nervous system (Baddeley, 2003). Working memory is necessary for keeping information in one's mind while working on complex tasks and or reasoning (Baddeley, 2010). There have been several models and explanations for how we process and store short-term memories. For several years, however, the most well accepted approach was the working memory model proposed by Baddeley and Hitch (Baddeley, 2010). Recently, this model has been readapted to include a third piece to the puzzle. This relatively new physiological concept of working memory involves three main components, the phonological loop, visuospatial sketchpad, and the episodic buffer, which all are controlled by what is known as the central executive (Baddeley, 2003).

The phonological loop is considered to be a pathway that connects posterior temporal areas of the brain with the inferior parietal lobe (Aboitiz, Aboitiz & García, 2010). The phonological loop also has portions of it found in the ventrolateral prefrontal cortex (Aboitiz, Aboitiz & García, 2010). These areas are commonly known as Broca's region, and Brodmann's area (Aboitiz, Aboitiz & García, 2010). Baddeley describes the phonological loop as having two main components, the first being that it stores speech-like memory for approximately 2 seconds, and the second being that it is capable of retrieving these speech-like memories through rehearsal (Baddeley, 2010). Further studies have found that this phonological loop likely involves several variables related to speech and language. Some of these variables include Hebb repetition, which is an increase in memory performance when a list is repeated, the primacy effect, and the recency effect (Burgess & Hitch, 1999). All these phenomena, and more, have been studied as potentially linked to the phonological loop of working memory. The phonological loop has also been suggested to have great importance when it comes to learning language, or new words (Baddeley, 2010). This theory is due to the recognition that children with specific language development difficulties also tend to have defects in their short-term memory (Baddeley, 2010).

The visuo-spacial sketchpad is what is often referred to as visualizing, or imagining (Sims & Hegarty, 1997). Anecdotal research has found that the visuo-spacial sketchpad is likely important in problem solving, and innovation (Sims & Hegarty, 1997). Further research suggests that this component is the temporary storage and manipulation of visual and spatial information, and that these two components can be manipulated separately (Baddeley, 1999). Studies involving participants with lesions would suggest that the visuospatial sketch pad has both dorsal and ventral streams. (Müller & Knight, 2006). The ventral stream is suggested to have a role object recognition, and spans from the occipital lobe to the temporal cortex (Müller & Knight, 2006). While the dorsal stream spans from the occipital lobe to the parietal cortex and is involved in spatial operations (Müller & Knight, 2006).

The episodic buffer is the newest addition to the working memory model (Baddeley, 2010). Baddeley proposes that the episodic buffer is capable of holding several multidimensional chunks of information at a time (Baddeley, 2010). This potentially includes the ability to hold and combine visual and auditory information (Baddeley, 2010). This component of the working memory model is an important link in describing how long-term memory relates to short term memory (Baddeley, 2000). Anatomically, the episodic buffer is more difficult to locate than other portions of the working memory model, however, it is suggested that the frontal lobe plays a role in controlling the episodic buffer (Baddeley, 2000).

The central executive is proposed to be primarily functional in the frontal lobe, and is likely the main component of working memory that determines the functional differences in a working memory digit-span task (Baddeley, 2003). It has been shown that working memory can be described as a consistent elevation in neural firing during a delay, as the information is being kept in one's mind (Klingberg, 2010). Further, it has been suggested that an increase in working memory may potentially be linked to an increase in connectivity between the frontal and parietal cortices (Klingberg, 2010).

Baddeley proposes that working memory is often an indicator of further cognitive function and can predict performance on more complex tasks (Baddeley, 2003). Other research has found initial working memory in older adults to be a predictive measurement of cognitive performance and future improvements in memory through an n-back training task (Matysiak, 2019). This study presents evidence that working memory can be improved upon with training, and improvements in working memory can correlate to improvements in other areas of cognitive function. This concept directly correlates with the current understanding of plasticity within the brain. Recent research suggests that working memory can be improved upon with training that specifically targets the frontal lobe, basal ganglia, and parietal cortex (Klingberg, 2010). Working memory training can be completed through repetitive working memory tasks, such as the Stroop task (Klingberg, 2010). This suggests that there is a basis for plasticity of working memory centers of the brain through training.

It is proposed that cognitive performance in examination settings is directly related to the performance of working memory in an individual (Alloway, 2010). A literature review found that, although complex, there are significant correlations between working memory and intelligence (Ackerman, 2005). Previous research would also suggest that working memory is often a strong indicator of learning potential and intelligence (Alloway, 2010). If participants are able to increase working memory load through neurofeedback, I would suspect to see many educational benefits. For this reason, I am utilizing a test of working memory to determine cognitive performance with and without neurofeedback training.

Uses for Neurofeedback Training

NFT is currently most popular in attention deficit-hyperactivity disorder, ADHD, research, as several studies have found positive results for participants with ADHD that practiced NFT. One study found that positive results after NFT in children with ADHD lasted 6 months after the training occurred (Steiner et al, 2014). Another study designed to test the efficacy of NFT for ADHD used biofeedback as a control, and used multiple sources to diagnose the ADHD. This study also found that the group using NFT outperformed the biofeedback group in all areas, with large to medium effects (Bakhshayesh, 2011). Other studies have found a weak correlation between NFT and sports performance (Xiang, 2018). Suggesting that NFT may be useful for changing EEG power in a way that can affect an individual beyond the classroom. Other studies have noted the implications for NFT in depression. NFT has shown positive results for depression symptoms, and asymmetrical NFT has shown positive results in improving functions of the right frontal lobe. These results have correlated to a decrease in depression symptoms (Choi, 2011). These studies all show a common ground between how changing the biological EEG response, we are able to change the affected behaviors. Neurofeedback training relies on the interpersonal relationship between biology and behavior. We can conclude from this previous research that manipulating one aspect will demonstrate a responsive change in the other.

Several studies have found positive results with alpha training, increasing the 8-12Hz alpha amplitude through neurofeedback training. Increases in alpha amplitude have been shown to enhance both working and episodic memory after alpha training (Hsueh, 2016). Studies have also found a positive correlation between increased upper alpha amplitude after multiple neurofeedback sessions and short-term memory performance. Interestingly, alpha improvement was seen the most when participants were thinking positively (Nan, 2012). This may correlate to the decrease in depression symptoms after alpha training. Upper alpha training showed the most improvements with short-term working memory (Nan, 2012). This leads us to a similar method of neurofeedback training, alpha-theta training. Alpha-theta training has proven to be useful in positively changing mood, making participants more confident, energetic, and elevated (Raymond, 2005). Alpha-theta training has also shown to be effective in addiction counseling and relaxation (Egner, 2004). When attempting to maximize the alpha/theta ratio through neurofeedback, studies have found improvements in music performance, creativity, mood, depressive symptoms, and executive cognitive performance (Gruzelier, 2008). Theta research has found that theta plays an important role in coordinating information in the hippocampus. Gruezelier concludes that theta is profoundly involved in two main networks, both the mesencephalic-cortical arousal system and the limbic system. These systems allow theta to have both cognitive and emotional importance, as well as a role in coordinating the two (Gruzelier, 2008).

Successful increases in theta from theta training have suggested that increasing theta could potentially increase alpha, which results in increases in working memory (Reis, 2016). For this reason, the focus of my neurofeedback training protocol will use alpha training, where I aim to increase alpha frequency in participants. Working memory has been found to be a predictor of cognitive performance (Matysiak, 2019) and increasing working memory has been found to directly correlate to increase in cognitive performance in other areas. The n-back task has been found to be a measure of cognitive function, and not just a working memory task (Miller, 2009). Increases in upper alpha have also been found to occur during the retrieval process, which is hypothesized to be related to an increase in cortical inhibition (Sauseng, 2005). Due to the relationship between working memory and cognitive performance increases relating to increases in alpha frequency, my study will focus on using alpha neurofeedback training to increase performance in the n-back task, a task which measures cognitive performance as well as potentially working memory.

Aim of This Study

In this study I aim to determine whether a single session of neurofeedback training is successful in increasing cognitive performance so that, if I am successful, future studies may search to see if neurofeedback training is a useful mechanism for increasing classroom performance. This study may also provide the psychology and neuroscience fields with further understanding into the plasticity of working memory and how to manipulate the mind. If my results find a significant positive relationship between scores and speeds in a working memory task and NFT, it would suggest the possibility that cognitive performance can be manipulated and increased with a single session of NFT. For this study I hypothesized that the experimental group would show a significant increase in change scores greater than the increase in change scores of the sham group.

CHAPTER TWO

Methods

Participants

42 volunteers were obtained for the study using SONA to inform them of the study. Participants began the experiment after signing written informed consent. Demographics were not collected, as they were not seen to be important for the study. Handedness was not important for the results, as this study used symmetric bilateral electrode placement.

Procedure

The participants were randomly split into two groups, the sham group and the experimental group. Participants were blind to the groups. Researchers assisted participants in placing electrodes on Fp1, Fp2, and on each mastoid bone, for each participant in both groups. Both groups started by completing an instructional block followed by block one of the n-back testing to determine their individual baseline scores. N-back testing was completed on PEBL software. Each block consisted of 25 trials, where 10 of the 25 trials were correct for each block. Each stimulus was shown for 3000 ms. The n-back training consisted of a 1-back and 2-back task to demonstrate how the task is to be performed. The first block of n-back testing consisted of a single 1-back, single 2-back, and single 3-back testing sequence. For a 2-back test, if the participant thought the stimulus was the same stimulus as 2 back, they were to press the left shift key. If the stimuli did not match, they were to avoid pressing the key. If the participant pressed the key when the stimulus did not match 2-back, the trial was marked as incorrect. If the participant did not answer, and the stimulus did match 2-back, the trial was recorded as incorrect. Both accuracy and speed of the blocks was collected for both groups. After the first block of n-back testing, the sham group was shown a 20-minute recording of a previous alpha training activity. All sham group participants were shown the same recording for consistency. After the first block of n-back testing, the experimental group participated in 20 minutes of alpha training as described below. Following experimental or sham neurofeedback training, all participants completed blocks 2 and 3 of n-back testing. All blocks used the same parameters as described previously. See figure I for a visual representation of the order of n-back task blocks and NFT.

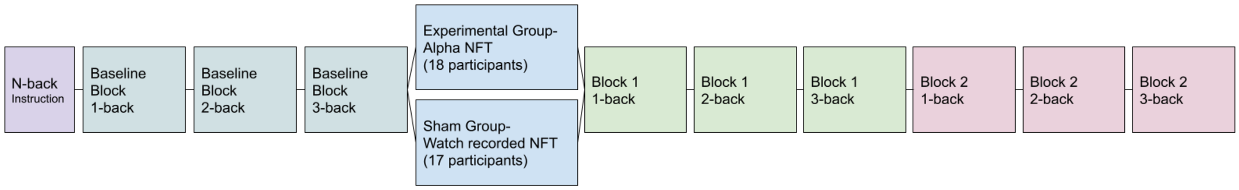

Figure 1. Outline of research design for each group.

Alpha Training Protocol

An OpenBCI Cyton was used as the source device for the EEG measurements. Alpha neurofeedback training was conducted on BrainBay software. Alpha frequency was set to 8-12 Hz. Activity was monitored from Fp1 and Fp2 on the international 10-20 electrode system, reference and ground electrodes were placed on the left and right mastoid. Smoothing was kept at .5 seconds. A 256 Hz sampling rate with <.01 Hz resolution was used. Data was amplified by a gain of 10.00%. Participants were asked to keep their eyes open and relax, but not sleep, during the training. During the first two minutes, BrainBay measured the participants' individual alpha frequency levels. After the average IAF was measured, BrainBay would offer the sound of beach waves whenever the participant would reach the goal of keeping alpha > 30% of the average IAF value.

Participants were encouraged to keep this sound going for as long as possible. Participants were also able to watch a meter graph that represented their alpha frequency. Participants were encouraged to raise the bar graph, or their alpha frequencies, as high as they could, for as long as they could. Neurofeedback training was completed after 20 minutes.

CHAPTER THREE

Results

42 subjects participated in this research study. Of the 42 subjects, 7 data sets were removed. 4 of these were not complete data sets, 1 of which was a participant that left while in the middle of the study, 3 of which the data was saved incorrectly. 2 subjects were removed as they asked for clarification on the n-back task after completing the baseline testing. Their results did not reflect an accurate measurement, as they did not understand the task at baseline testing. The final one was removed as that participant had selected the shift key for each trial, suggesting that they did not understand the task.

All data was analyzed with several repeated groups ANOVA using Jamovi software. Data includes N= 35 participant data sets, with 25 possible correct answers in each testing difficulty level. Difficulty is defined as either a 1-back, 2-back, or 3-back test. Blocks are defined chronologically as baseline, block 1, and block 2. See figure 1 for further description of block set up. Treatment is defined as either the sham or experimental group.

My first analysis was done to determine any difference in the baseline scores between the experimental and the sham groups. I predict that there would be no significant difference between baseline scores in the groups, as neither group had received any treatment at this point. Using a repeated measures between-subjects ANOVA test to examine the effects of difficulty and number correct in the baseline test, I found a significant difference in difficulty, $F(2,66)=26.8$ and $p= <.001$. No further significant findings were noted with this analysis.

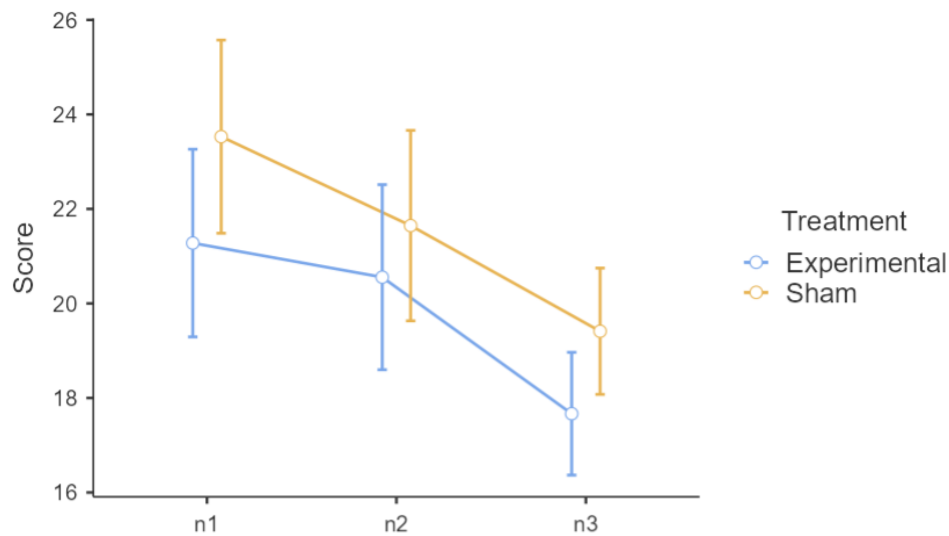

Figure 2. Comparison of Sham vs. Experimental for raw scores in baseline condition by difficulty.

I next examined the effects of sham vs experimental in the actual scores of the participants. For each difficulty level of each block, there are a total of 25 possible correct answers. A repeated measures ANOVA found a significant difference for block, $F(2,64) =3.41$, $p=.039$. A significant difference for difficulty was also found, $F(2,64) = 59.9$, $p= <.001$. I hypothesized that the experimental group would have an increase in scores in blocks 1 and 2 compared to the baseline block. To analyze this, I conducted repeated measures ANOVA, and found these resulted in no significant differences, but a p of .081. No further significant results were noted in this analysis.

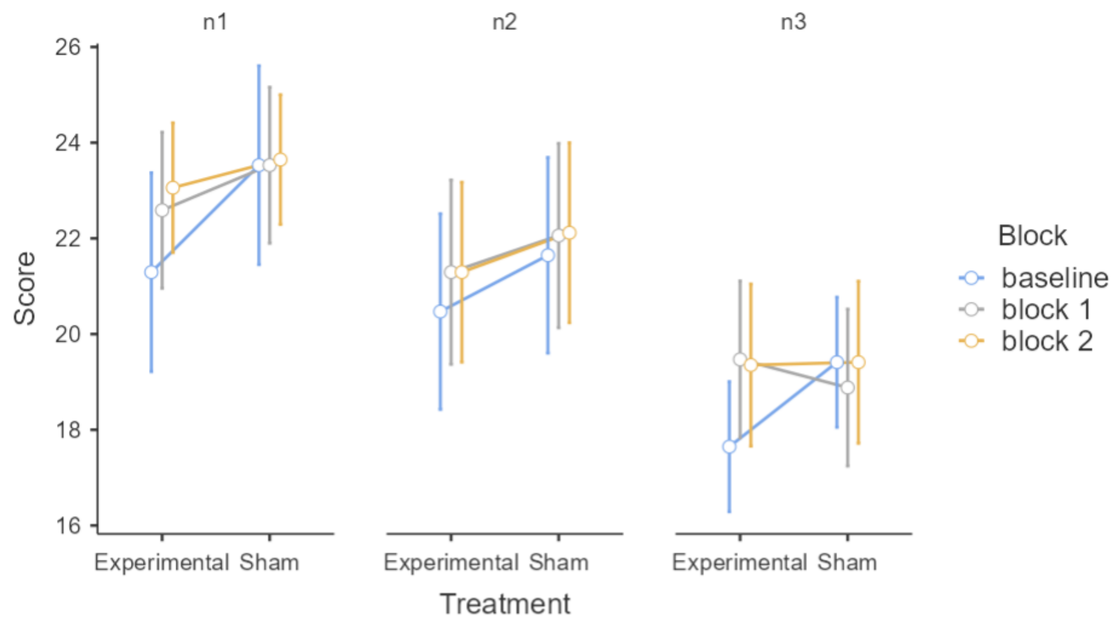

Figure 3. Comparison of treatment vs. block for raw scores by difficulty.

The main hypothesis of this study was to determine if 20 minutes of neurofeedback training had the potential to increase working memory. To examine this, I looked at the change in scores between treatment groups. I used a between-subjects repeated measures ANOVA test to examine this hypothesis. My results found no significant findings in this analysis, but a p-value of .085 for between subjects' analysis of change scores.

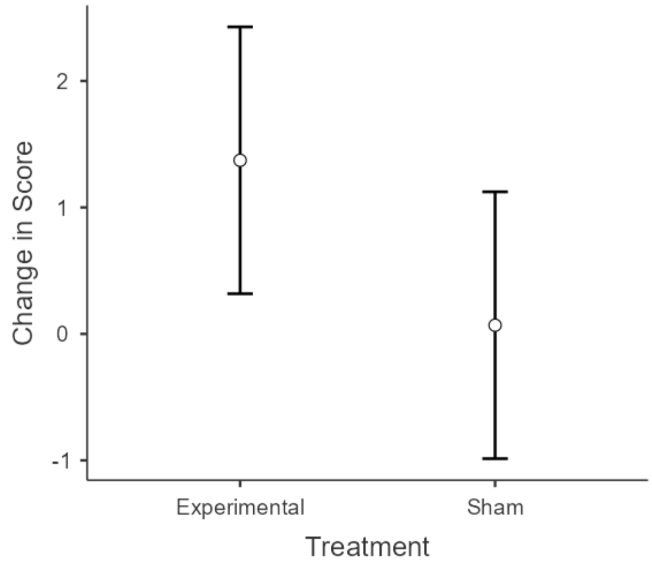

Figure 4. Comparison of Experimental vs. Sham for total change scores between baseline and blocks 1 and 2.

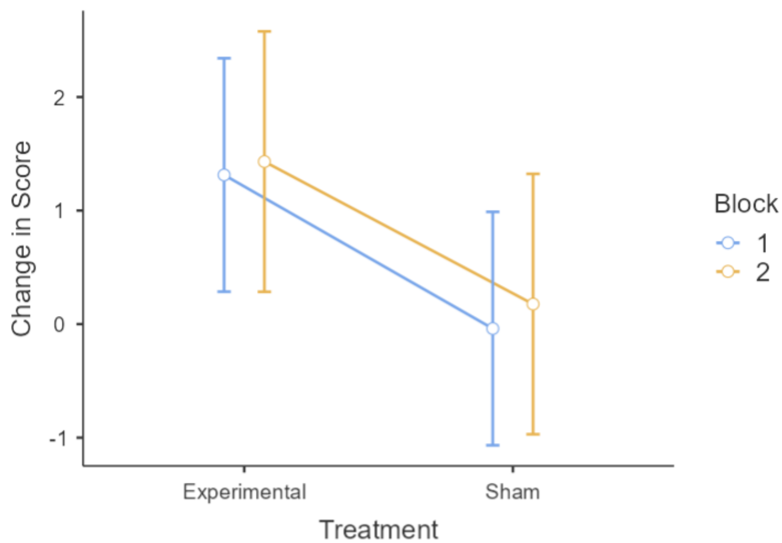

Figure 5. Comparison of Sham vs. Experimental for change scores between the baseline condition, and blocks 1, and block 2, shown separately.

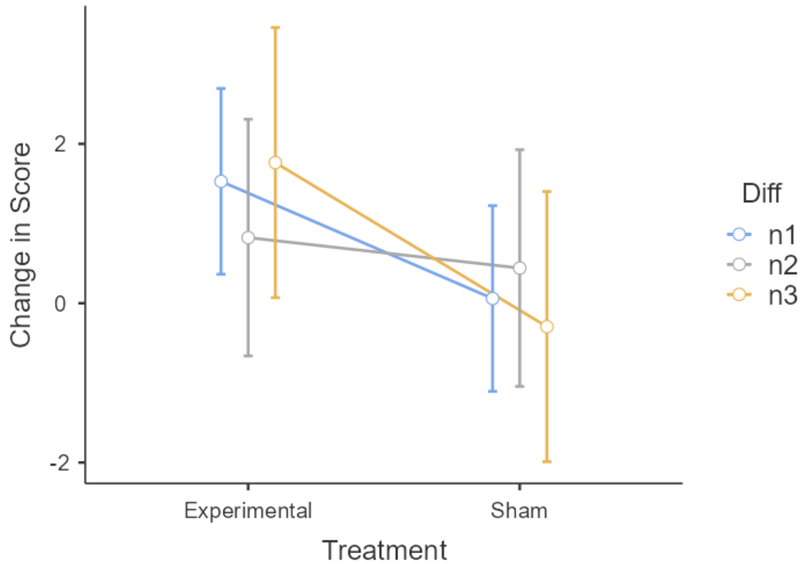

Figure 6. Comparison of Sham vs. Experimental for change scores separated by difficulty.

To determine if changes in score were a result of slower response time, I ran a repeated measures ANOVA test on the average response times for when the correct answer was given. For this analysis I looked at a repeated measures between-subjects ANOVA to find if there was a significant difference in response time. I found no significant differences in this analysis.

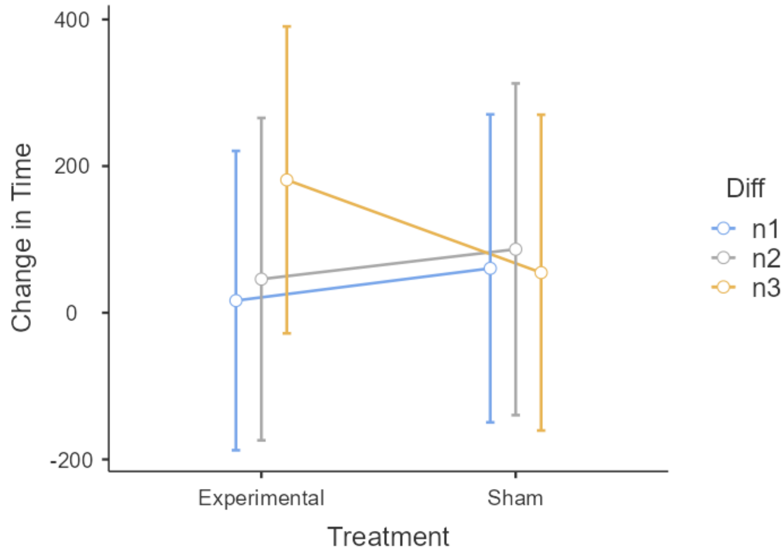

Figure 7. Comparison of Sham vs. Experimental for change in time separated by difficulty.

CHAPTER FOUR

Discussion

There was no significant difference in either the difference in baseline scores for the treatment groups, or the change in response time. This provided us with evidence to conclude that the participants were not doing better or worse than the other group prior to treatment. Both treatment groups decreased in baseline scores with an increase in difficulty in the baseline condition (Figure 2). The experimental group was not responding slower as a result of increased scores. There is no correlation between treatment group and change in response time from baseline to block 1 and block 2 (Figure 7).

The actual scores of each treatment group note no significant difference between the raw scores of the sham vs the raw scores of the experimental group. However, as the difficulty of the task increased from 1-back to 3-back, the scores of the participants in both groups decreased (Figure 3).

For the main hypothesis of the study, I aimed to find if there was a significant difference between the change in scores of the treatment groups. There was no significant difference in the change in scores from baseline and the treatment group (p= 0.085). However, while not significant, the participants in the experimental group had an average increase of 1 more correct answer in the post-treatment task than they did in the baseline task (Figure 4). The sham group, however, had relatively no change in score overall. The greatest difference between the change scores in the treatment groups occurs with the most difficult task (Figure 6). The 2-back task had little difference in the change scores between the groups, while the 3-back task showed a greater difference in the scores of the sham group from the treatment group. Both treatment groups had similar changes in scores between blocks 1 and block 2, where the experimental group had a slightly higher change in score than the sham group for both blocks (Figure 5).

While none of the analyses resulted in significant differences between the treatment groups, this study suggests that there may be a benefit to a single session of increased alpha neurofeedback training with a longer training time. This study provides evidence that 20 minutes of a single session of alpha neurofeedback is likely not lengthy enough to provide significant improvements in working memory or cognitive memory. This could mean that individuals wishing to use neurofeedback training to improve working memory will need to use this for a longer period of time.

This study was limited by the number of participants I was able to gather. Increasing the sample size may lead to different results. The sample size of N=35 was not sufficiently large enough to accurately represent the analyses. A larger sample size is necessary to come to any conclusions. All participants were college students, and this study cannot extrapolate results to individuals beyond university students. Older individuals may have greater or lesser improvements in cognitive performance following neurofeedback training.

I suggest that future studies focus on increasing the length of the single session of alpha neurofeedback training. This may result in more significant differences between treatment groups. Future studies should also consider utilizing different tasks as a measurement for working memory or cognitive performance. A digit span task may allow for a better measure of working memory before and after NFT. Utilizing several different tasks may also allow for a broader understanding of the effects of NFT. Future studies may also consider using tasks that test other components of working memory, such as the visuospatial sketch pad. One task that may test this better could be a dual n-back task. I also believe that it may be beneficial to record and analyze EEG data from all participants. This may allow us to better find if sham participants are improving due to a placebo effect. This could also help us better understand how well the neurofeedback training is working. From that information we may be able to determine if participants that improve their alpha frequencies more during the NFT, also see a greater increase in scores in the n-back task.

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