Effect of Eye-Closure on Working Memory: An Analysis of Theta Wave Forms

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ABSTRACT

Several studies have shown a correlation between working memory and theta wave activity, specifically theta wave amplitude. Based on this premise, the hypothesis for this study is as follows: does eye closure increase theta wave amplitude and performance level during a working memory task, and also decrease heart rate and blood pressure in comparison to the task being completed with eyes open? This hypothesis was tested using an n-back auditory working memory task with two trials, eyes opened and eyes closed, to see if this affected all variables of the hypothesis. The results indicate no difference in heart rate or blood pressure between the eyes open or eyes closed tests. The EEG data analysis indicates no significant correlation between increased theta wave amplitude and eyes opened and eyes closed tasks.

INTRODUCTION

Many studies have shown that the prefrontal cortex (PFC) is vital in the performance of working memory (Levy and Goldman-Rakic, 2000). Working memory is defined as the process by which the brain temporarily stores and integrates information from external stimuli with the use of higher cognitive function, such as learning and reasoning (A. Baddeley). Simple working memory tasks have been shown to activate brain wave activity in many areas of the brain. However, the prefrontal cortex region has been shown to have significant activity in the form of high-amplitude theta waves that can be measured via EEG (electroencephalography) during mental tasks (Yamaguchi 1981). Working memory and other neurological functions can be closely studied employing EEG, because it has been found that brain wave oscillations are at the center of the neurophysiological theory of memory (von Stein and Sarnthein, 2000).

The prefrontal cortex receives inputs from nearly all cortical structures; visual inputs from the occipital lobe, and auditory inputs from the temporal lobe, etc. (Barbas and Pandya 1989). The several connections within the prefrontal cortex can intermix to provide a wide array of possible integrations responsible for more complex behaviors, such as those needed in working memory tasks (Miller and Cohen, 2001).

Furthermore, heart rate and blood pressure have been shown in several previous studies to be affected by anxiety, specifically in the case of test performance, as heart rate and blood pressure will increase via an autonomic response of the sympathetic nervous system (Holroyd et al. 1978). This study tested if eye closure reduced anxiety during performance, and thus would decrease heart rate and blood pressure in the eyes closed task versus eyes opened task. This study also examined if an increase in heart rate relates to an individual's performance. Some people are more predisposed to being anxious, so this may have a noticeable affect on their performance, heart rate and blood pressure.

This current study set out to validate the relationship between working memory and theta wave activity in the prefrontal cortex of the brain. Since the prefrontal cortex receives inputs from several cortical and sub-cortical structures, this study tested if eye closure during a working memory auditory task would make a difference in theta wave activity, specifically theta wave amplitude. This experiment measured if there was change in the theta wave activity during an auditory working memory task, between the task being completed with subject's eyes opened and then with subject's eyes closed. Secondly, the physiological effects of blood pressure and heart rate between the eyes open and eyes closed forms of the working memory tests were explored. These physiological factors might elucidate additional information as to the conditions under which working memory best performs. The ultimate goal is to determine if the additional visual stimuli with eyes open during the task interferes with the ability of working memory to perform at a high success rate, while also affecting the heart rate and blood pressure of the subjects.

METHODS AND MATERIALS

This study included twelve healthy college-aged subjects (6 male, 6 female), who are currently enrolled at the University of Wisconsin-Madison. All subjects gave formed consent to participate in the experiment.

Before starting the experiment, baseline readings of the subject were taken at rest. First, the subjects were comfortably seated, and then blood pressure and heart rate measurements were taken. Blood pressure was taken manually using a blood pressure cuff and a stethoscope. Heart rate was taken using a Nonin® Pulse Oximeter/Carbon Dioxide Detector Model: 9843 (Nonin Medical Inc.), and was put on the subjects' left index finger. Subjects were then instructed to do ten vigorous jumping jacks, and upon completion, their blood pressure and heart rate were re-measured to finish the control readings. Once the subject was comfortably seated, two electrodes were placed on their forehead (in the prefrontal cortex region), and one electrode on their neck, behind the ear, ipsilaterally. These three electrodes were secured using a Velcro strap. A baseline EEG reading was performed, while the subject was relaxed. Next, the subject read an excerpt on digestive science from a physiology textbook (Berne et al. 2004), and their EEG during the reading task was recorded to complete control readings. Additional blood pressure and heart rate measurements were taken immediately before beginning the working memory test.

The working memory task was a sound n-back test, created by Brain Workshop©. In this test, subjects needed to remember a series of spoken letters, and remember when the same letter arose that was said n=3 times back. While listening to the audio recording via headphones, when subjects thought they heard a letter that had also been spoken three letters prior, they would press the letter "L" on the keyboard. In each test, there was a forty-four letter sequence, randomized for each trial by the program. Subjects completed the task twice, the first time with eyes open, and the second time with eyes closed. EEG recordings of total brain and theta wave activity were measured throughout the experiment. The EEG monitor was unable to be seen by subjects, since the recording may have been a distracting visual stimulus while subjects were trying to complete the task. Immediately following the completion of each round of testing, blood pressure and heart rate measurements were recorded. Heart rate was also recorded while the subject was in the midst of each test, approximately half way through the task.

Data analysis was performed on the heart rate, blood pressure, and EEG data that was recorded. Analysis of the EEG theta wave data was done in MATLAB®. Reduction of noise in the data was alleviated by normalizing the theta wave data, both for eyes open and eyes closed, with their respective baseline recordings. Microsoft® Excel was used to analyze additional data using the ANOVA tool regarding EEG, heart rate and blood pressure measurements. The alpha value was set at a significance value of 0.05, where a corresponding P-value less than 0.05 is significant.

RESULTS

EEG, heart rate, and blood pressure readings were analyzed in the context of the eyes open versus eyes closed working memory tasks. All data was also compared to overall performance on the working memory tasks.

EEG

The average theta wave amplitude was found for both eyes open and eyes closed parameters. These values were plotted, using (+/-) the standard deviation of 0.4131 for eyes open, and 0.3554 for eyes closed (Figure 1a). The P-value was calculated to equal 0.2235. Theta wave amplitude was also graphed against working memory test score using three representative subjects of the data pool (Figure 1b). Eight out of twelve subjects (66.67%) had increased mean theta wave amplitude during their higher performance trial.

Figure 1a

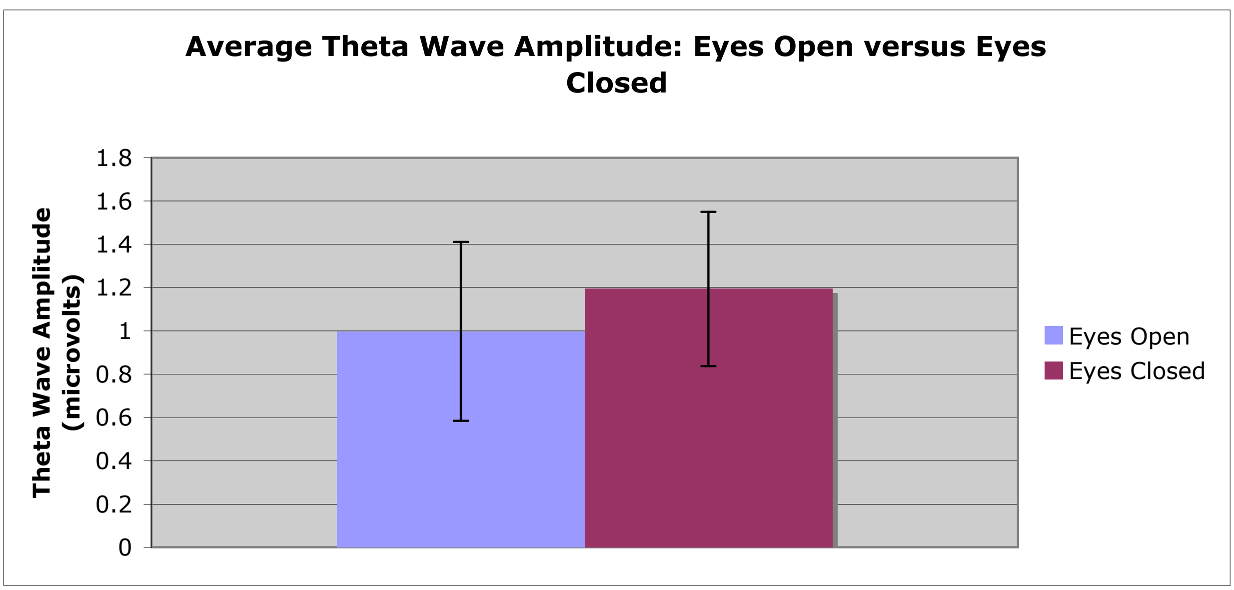

Figure 1a: Average theta wave amplitude (microvolts) for both eyes open and eyes closed was calculated and graphed using the standard deviation (+/-) 0.4131 and 0.3554 for eyes open and eyes closed respectively. The P-value was calculated to equal 0.2235.

Figure 1b

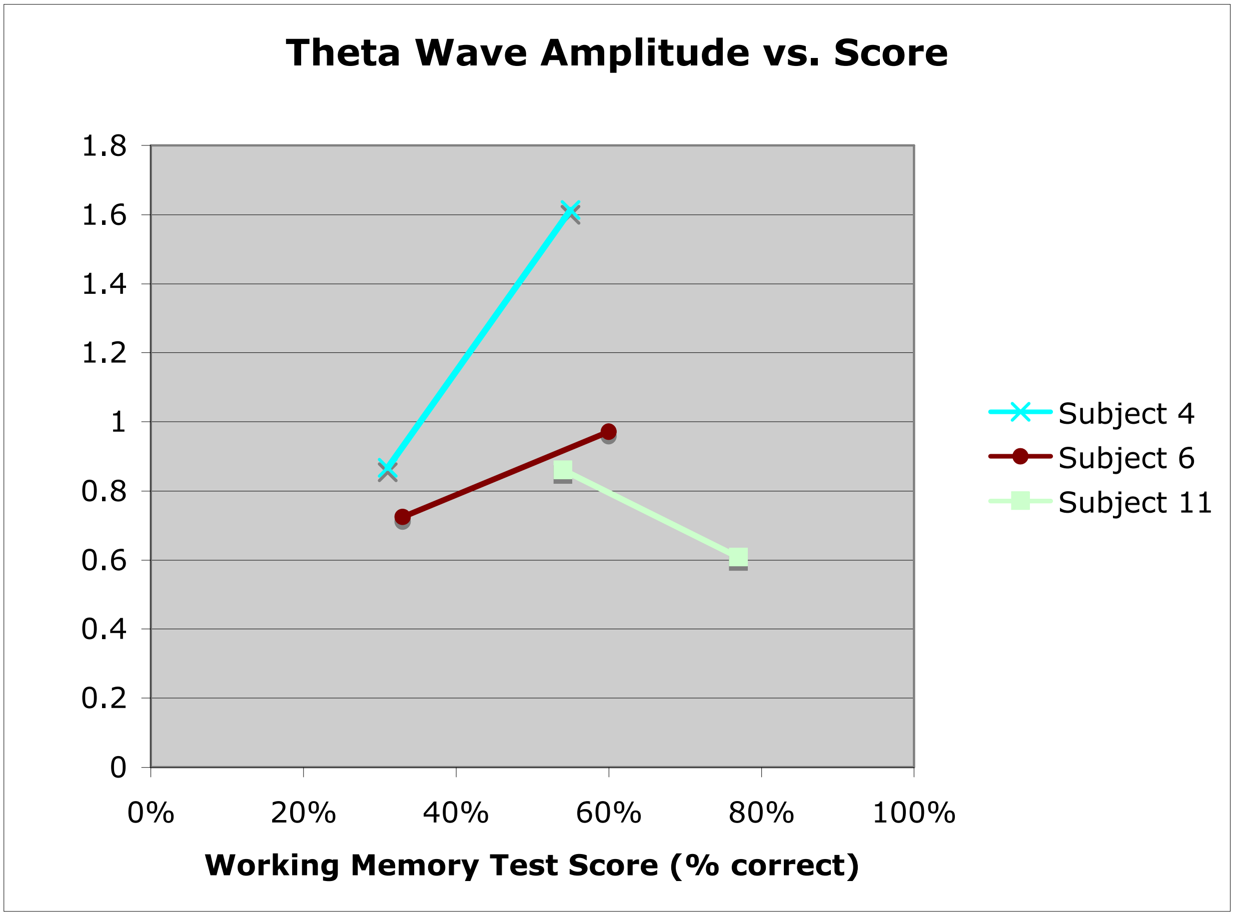

Figure 1b: Correlation between theta wave amplitude and working memory test scores. Reading the graph from left to right, each different subject's data point for the eyes open task is the left of the two points, and eyes closed is the right. These three subjects are representative of the variation within the data.

Performance

Out of 12 subjects, 7 scored higher on the eyes closed portion of the test, 4 on the eyes open portion, and 1 subject had the same test scores for both trials. See Table 2 below for complete summary of results per subject (heart rate data also included in table).

Heart Rate

The heart rate fluctuated throughout the period of the entire task, with varying ranges between subjects. Table 1 includes the starting, middle, and ending heart rate values that were recorded throughout each task. During both tasks, 8 of 12 (66.67%) subjects had an increased heart rate throughout the task (Table 1). A heart rate range was also computed to show the overall increase or decrease throughout the task. These values were then compared to the working memory test scores (Table 2). Absolute value of the average heart rate range was calculated for both eyes opened and eyes closed, and was graphed using the (+/-) standard deviation 3.2322 and 3.8337 for eyes opened and eyes closed respectively (Figure 2a). The P-value was calculated to equal 0.8645. Heart rate range was plotted against working memory test scores using three representative subjects of the data pool (Figure 2b).

Table 1

	Eyes Open				Eyes Closed		
Subject	Before	Midway	After		Before	Midway	After
1	73	77	78		64	67	70
2	81	84	89		78	83	90
3	62	62	66		68	64	67
4	70	65	70		68	69	68
5	83	80	79		83	85	96
6	69	75	76		68	66	69
7	79	87	93		72	79	80
8	83	77	73		80	72	71
9	88	86	78		73	79	81
10	71	75	76		69	79	81
11	67	70	69		67	72	72
12	66	73	74		64	69	68

Table 1: Heart Rates Values through different stages of the working memory task. Highlighted values represent an increase in heart rate throughout the task.

Table 2

Subject	Task Score-Eyes Open	Heart Rate Range	Subject	Task Score-Eyes Closed	Heart Rate Range
1	30%	5	1	66%	6
2	38%	8	2	25%	12
3	35%	4	3	35%	-4
4	31%	-5	4	55%	1
5	41%	-4	5	47%	13
6	33%	7	6	60%	3
7	15%	14	7	40%	8
8	16%	-10	8	26%	-9
9	83%	-10	9	50%	8
10	63%	5	10	20%	12
11	77%	3	11	54%	5
12	45%	8	12	57%	5

Table 2: Displays the working memory task results for the 12 subjects both when completing the task with eyes opened and eyes closed. Also displayed is the heart rate range determined by subtracting the lowest heart rate value that was recorded, from the highest.

Figure 2a

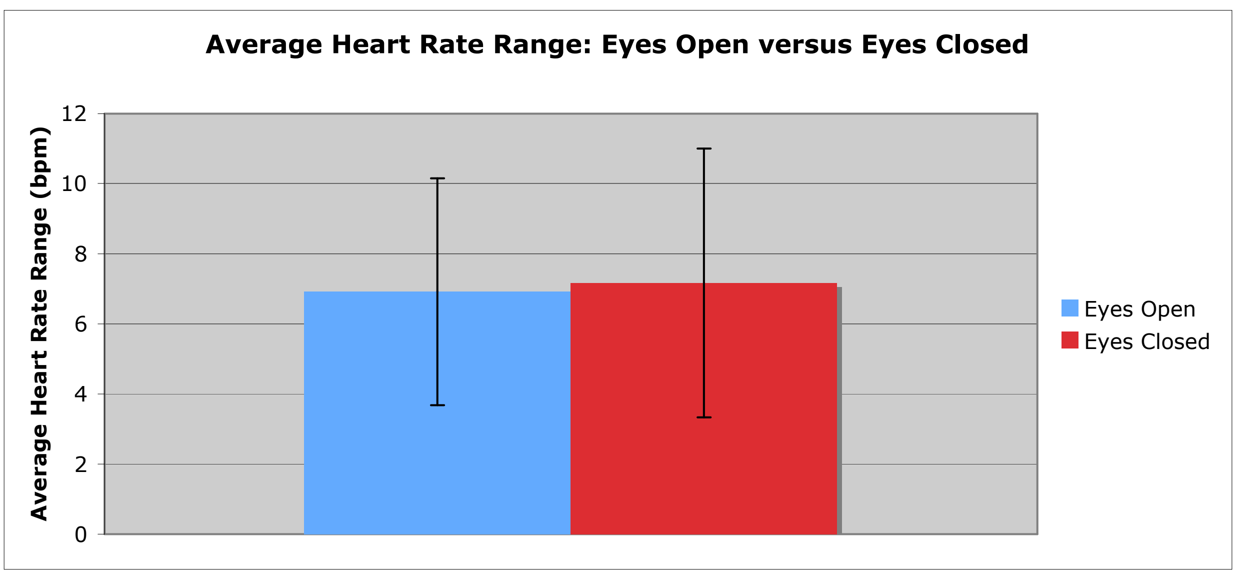

Figure 2a: Average heart rate range for both eyes open and eyes closed was calculated and graphed using the standard deviation (+/-) 3.2322 and 3.8337 for eyes open and eyes closed respectively. The P-value was calculated to equal 0.8645.

Figure 2b

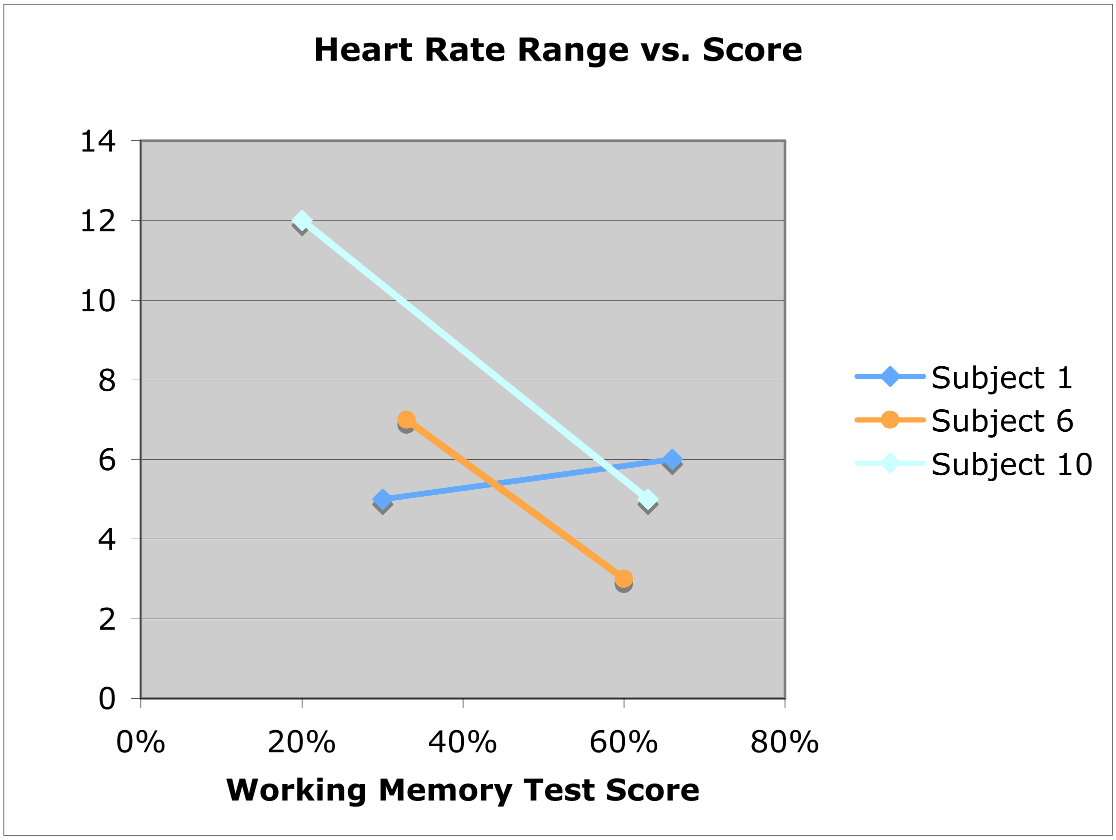

Figure 2b: Correlation between heart rate range and working memory test scores. Reading the graph from left to right, each different subject's data point for the eyes open task is the left of the two points, and eyes closed is the right. These three subjects are representative of the variation within the data.

Blood Pressure

The blood pressure readings were converted to Mean Arterial Pressure (MAP), and results were analyzed. The open eyes task had 8 of 12 (66.67%) subjects with blood pressure that rose during the task, and the closed eye task had 10 of 12 (83.33%) also increase throughout the test. Blood pressure ranges were calculated using the blood pressure measurements from the end of both open and closed eyes tasks, and were both individually compared to the initial baseline blood pressure reading. Average mean arterial blood pressure range was calculated for both eyes opened and eyes closed, and was graphed using the (+/-) standard deviation 2.0597 and 3.1697 for eyes opened and eyes closed respectively (Figure 3a). The P-value was calculated to equal

0.4835. Mean arterial blood pressure range was plotted against working memory test scores using three representative subjects of the data pool (Figure 3b).

Figure 3a

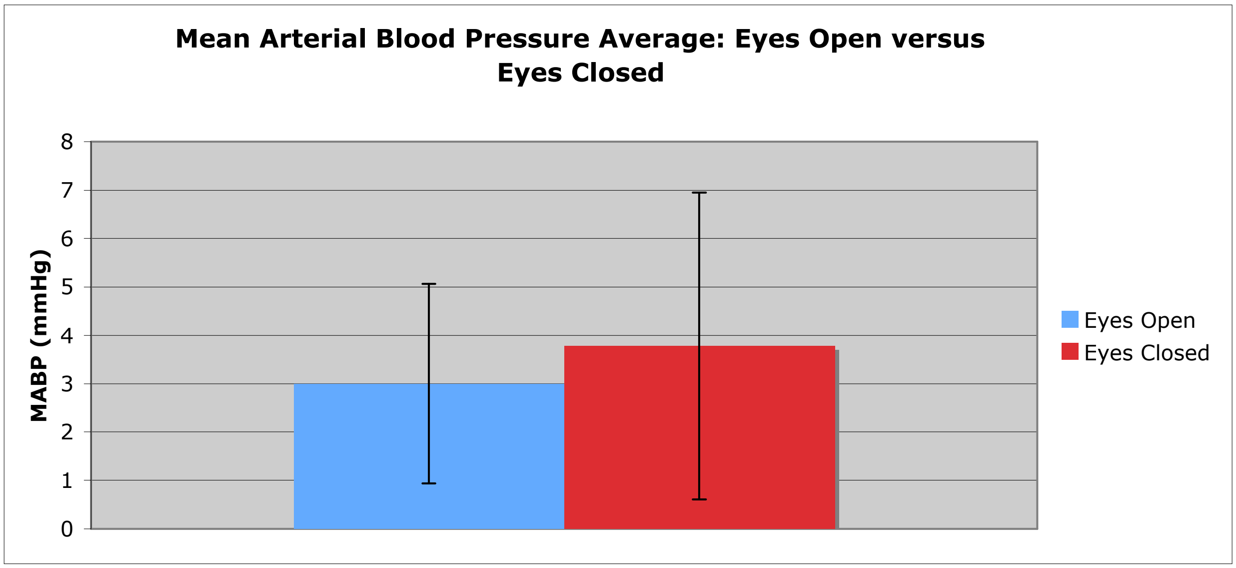

Figure 3a: Mean arterial blood pressure for both eyes open and eyes closed was calculated and graphed using the standard deviation (+/-) 2.0597 and 3.1697 for eyes open and eyes closed respectively. The P-value was calculated to equal 0.4835.

Figure 3b

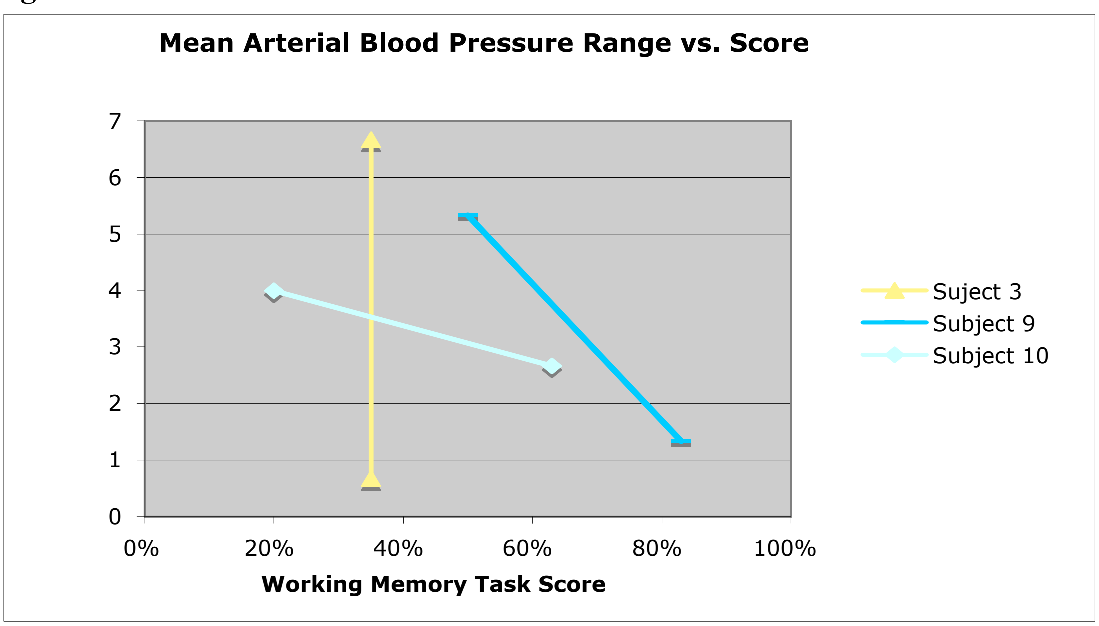

Figure 3b: Correlation between mean arterial blood pressure and working memory test scores. Reading the graph from left to right, each different subject's data point for the eyes open task is the left of the two points, and eyes closed is the right. These three subjects are representative of the variation within the data.

DISCUSSION

In this study we set out to determine if eye closure had a significant effect on the performance of a working memory test along with theta wave activity. In addition, we wanted to see if eye closure would have an effect on blood pressure and heart rate, due to a more relaxed, and less distracted state of mind.

The results stated above indicate that there is no significant difference in theta wave amplitude when performing the task in either setting. A P-value of 0.2235 further indicates that the average amplitude of the theta waves with eyes opened and with eyes closed are not significantly different from one another. Therefore, we need to accept our null hypothesis, in that there is no significant change. Although the theta wave amplitude analysis has led to the conclusion that there is no significant difference in brain wave activity, our data show that 7 out of 12 subjects had their best performance with their eyes closed, one person had the same score on both trials, and the remaining 4 scored lower with their eyes closed. Although this was not the main focus of our study, this seems to be interesting data that leans towards a trend of better performance with eyes closed, which could be further analyzed with a larger subject pool.

The heart rate data results were especially inconclusive pertaining to our study. For both open and closed eyes, 66.67% of subjects had an increase in heart rate while performing the task, indicating that the body was responding to the stress of taking the working memory test. Clearly, having eyes closed had no significant affect of alleviating the stress of the test. When determining the range of change in heart rate throughout the task, and if it corresponds to the ability to perform a working memory task, the corresponding P-value indicates that the data was insignificant. The standard deviations further emphasized the wide range of variation within our data (Figure 2a). These inconclusive findings may also be due to the unreliable nature of the equipment used to determine heart rate.

There was no effect on blood pressure between the opened and closed eye tests as we had originally hypothesized. In both trials, over 60% of subject's blood pressure increased throughout the course of completing the task. This may be due to the stressful nature of the test as similarly seen in the heart rate measurements. The correlating P-value of 0.4835 further indicates that performing the task with your eyes closed had no effect.

In conclusion, given the P-values we calculated, we have to accept the null hypothesis for theta wave amplitude, heart rate, and blood pressure. Figures 1b, 2b, and 3b all exemplify the extreme variation found in our data between subjects. Despite the small trends that were observed in each measurement, the variability on either end of the averages was too large, and the sample size was too small, for the data to hold any significance. Although we found inconclusive results, we suspect that more significant data could be collected using the same parameters in our experiment, but given more time and a larger subject pool.

Problems Encountered

The variability of subjects' performance in the working memory tasks is considerable and limits what can be inferred from an individual subject's task result. There are several factors that can influence the subjects' performance (success rate). First, the background noise, such as conversations, movements, etc. can affect the subject's concentration on the task at hand. Second, knowing the results of each task when the subject finished the task for the first time can have an influence on subjects' confidence. Since our experiment called for subjects to complete a working memory task twice; knowing their score on the first task could either increase or decrease their confidence for the second time completing the task. We solved this problem by concealing answers after each task was completed, therefore, subjects can go into both tasks blind. Additionally, there were subjects who expressed their frustration with their perceived performance during the task with excessive movement or by verbalizing these frustrations. This ultimately created more noise on the EEG recording. Because we are not experts in dealing with this type of equipment, we had an especially difficult time analyzing our data and being sure that our results were purely the desired brain wave readings, and not noise.

At the forefront of our suggestions to future physiology lab groups, is to be sure that they have access to an expert on EEG if they plan on using this as the main focus of their research. Due to the nature of the EEG, we would also suggest practicing on member of your lab group before an actual subject. Also, it is important to do a preliminary analysis on the practice data that was recorded, to make sure that you can collect data that can be used to support your hypothesis, and that there are noticeable changes in the wave forms.

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