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Investigating the neural correlates of successful learning in a classroom environment: the association between course performance and electrophysiological data

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Thesis

INVESTIGATING THE NEURAL CORRELATES OF SUCCESSFUL LEARNING IN A CLASSROOM ENVIRONMENT: THE ASSOCIATION BETWEEN COURSE PERFORMANCE AND ELECTROPHYSIOLOGICAL DATA

by

EDWARD WANG

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Approved by

First Reader ____

Michael Tat, Ph.D.
Post-doctoral Fellow at Center For Translational Cognitive Neuroscience
Instructor, Department of Neurology

Second Reader ____

Gwynneth D. Offner, Ph.D.
Director of M.S. Medical Sciences Program
Associate Professor of Medicine

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ABSTRACT

Despite the vast number of studies that have examined the relationship between human memory and learning, few have examined learning and memory in more realistically valid environments. The current study examines learning memory in a classroom environment, specifically with students enrolled in a medical anatomy course. In addition to behavioral data, this study also uses electroencephalography (EEG) to examine the neural correlates of successful learning in medical students. A total of 37 students over 2 years was recruited from the Boston University School of Medicine to participate in this study. In the study, medical students were tested on a set of anatomical terms that they learned in the anatomy course. Testing occurred in three sessions: prior to the start of the course, immediately after the completion of the course, and 5 months after the completion of the course. In the experiment itself, students were presented with 176 anatomical terms (132 terms learned in the course and 44 terms deemed outdated) and then given three response choices: whether they “Can Define”, are “Familiar” with, or “Don’t Know” the term. While testing, the subject’s scalp EEG was recorded to measure the brain’s neural activity in response to anatomical terms displayed on the computer screen. Resulting EEG waveforms were separated and then averaged based on the response type in order to analyze the difference in amplitude for three neural correlates across distinct scalp sites when the students could define, were familiar with, or did not know the term. Results showed a higher amplitude in ERP readings for “Can Define” and “Familiar” responses for the early frontal effect, which is correlated with memorial familiarity. A higher “Don’t Know” ERP wave was observed for the late parietal effect, which reflects memorial recollection. Lastly, a larger ERP amplitude was detected for “Familiar” and “Don’t Know” responses for the late frontal effect, which is associated with post memory retrieval processing. Both Pearson correlation and multiple linear regression analyses were then run to investigate if any significant relationship between ERP amplitude and grades existed, and if so, the degree to which these electrophysiological responses can predict the course grades received. Final results found that the early frontal effect for the Can Define responses over the Right Posterior Superior scalp region is the best predictor variable, among the ones tested in the study, for student performance in the medical anatomy course. This finding has the potential to determine whether the information learned in a classroom environment has in fact been incorporated into long-term or even semantic memory. Through the findings of this study, we hope to determine if this method of measuring learning through EEG can be used as a useful indicator of long-lasting learning in classroom environments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

BOLD	Blood-Oxygen-Level Dependent
CAI	Central Anterior Inferior
CPI	Central Posterior Inferior
FN400	Early Frontal Effect
EEG	Electroencephalography
EOG	Electrooculogram
ERP	Event Related Potential
fMRI	Functional Magnetic Resonance Imaging
ITI	Inter-trial Interval
LAI	Left Anterior Inferior
LAS	Left Anterior Superior
LFE	Late Frontal Effect
LPC	Late Parietal Effect
LPI	Left Posterior Inferior
LPS	Left Posterior Superior
PFC	Prefrontal Cortex
RAI	Right Anterior Inferior
RAS	Right Anterior Superior
ROI	Regions of Interest
RPI	Right Posterior Inferior
RPS	Right Posterior Superior

INTRODUCTION

Once inaccessible to all but the most esteemed citizens, education has now become an integral part of most of the world's population. One primary goal of education is to help student accumulate knowledge to store and recollect for future references. For example, medical students spends years increasing their knowledge on the human body, so that it could be later applied when treating patients in a clinical setting. However, due to the high volume of information taught by medical schools, students need to develop efficient study habits so that they retain the maximum amount of long-term knowledge within the limited time period given to them.

Countless numbers of experiments have focused on the human memory, in an attempt to better understand the relationship between learning and memory to better understand how these concepts could be applied to the educational system (Roediger, 2013). Many of these experiments have focused on behavioral aspects of memory, such as teaching methodologies employed by teachers. For instance, most teachers attempt to make learning as easy as possible for students, and have employed passive learning techniques (i.e. re-reading the same passages and giving problems similar to one another) (Roediger, 2014). An example of this is giving students homework that focused on addition problems alone, rather than giving problems that alternated randomly between addition, subtraction, and multiplication. While passive methods are relatively economical with respect to time needed to encode the study material, the effects are generally temporary and dependent on the material being studied, and as such is deemed to be much less effective than other teaching methods (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). On the other hand, evidence suggests that active retrieval of information (i.e. self- testing in an attempt to recover information from memory) is often one of the most effective teaching methods due to its broad applicability and efficacy across a wide range of material (Dunlosky et al., 2013). For instance, students would be testing themselves with flashcards with definitions that were shuffled beforehand as opposed to simply reading a list of definitions off of a paper. Studies have shown that subjects who studied by re-reading took longer than those who studied using self-testing to reach similar improvements in long-term retention, leading them to believe that active retrieval is a critical factor in promoting retention of information in long-term memory (Karpicke & Roediger, 2014). A popular theoretical assumption for the benefit of active retrieval may be due, at least in part, to chunking, or the repackaging of study material into smaller units (Zaromb & Roediger, 2010). This subjective organization allows for greater retention and longer memory than restudying material for the same amount of time.

It is generally accepted that memory and learning are associated with one another. Studies often employ electroencephalography (EEG) and event related potentials (ERP) to examine episodic memory in detail, as it offers researchers visualizations of brain activity that underlie cognitive processes. Out all the theories about the inner workings of memory, the one that ERP research support is the “dual process model”. The dual process model of memory proposes that there are two mechanisms that are used for memory retrieval: familiarity and recollection (Rugg & Curran, 2007; Woroch &

Gonsalves, 2010). Jacoby (1991) defined familiarity as the ability to remember information of an item without recalling the specific details or context of that memory, and can reflect memories of earlier events. On the other hand, recollection is the process of retrieving specific contextual details about the encoding episode. As such, familiarity is often described as a faster acting cognitive process, and represents an acontextual sense that an item was seen before. Recollection is deemed a slower recovery of contextual information about the item (Jacoby, 1991). Familiarity is also generally accepted to be a continuous measure that varies in strength depending on the subject's confidence in his or her judgment, while the most common dual- process models consider recollection to be an all-or-none process where retrieval of information occurs when it crosses a certain threshold of memory strength (Yonelinas, 2002). However, several other studies have found recollection to be sensitive to the variations in the memory strength. In one study, memory test ERPs were greater in amplitude for test items that were associated with full rather than partial recollection (Vilberg, Moosavi, & Rugg, 2007). In a recent review, Squire and colleagues (2007) also showed that areas of the hippocampus do not necessarily code recollection as a thresholded process. As such, both familiarity and recollection rely on neural mechanisms that vary depending on the subject's confidence in their memory. In other words, as memory strength of an item increases, the usage of familiarity and recollection also increases (Woroch & Gonsalves, 2010).

Memory studies utilize ERPs due to their ability to record electrophysiological brain activity with millisecond accuracy, giving it higher temporal resolution over functional magnetic imaging (fMRI) experiments that attempt to perform the same task.

ERP's also outline qualitatively distinct scalp topographies that indicate the distribution of neural activity within the brain (Rugg & Curran, 2007). By varying experimental conditions in memory paradigms, topographic dissociations can reveal which distinct neural populations are active during familiarity, recollection, and post-retrieval monitoring processes that occur after the latter two mechanisms (Duarte et al., 2006). However, scalp topographies may be inaccurate due to the skull spreading out the electrical activity along the scalp, which potentially obscures the source of the neural activity. What may be observed as a posterior ERP may actually have been generated in a different region of the cortex. This is why fMRI studies have been employed as an alternative, or even in concert, to ERP studies, as fMRI's measure the hemodynamic response of the brain where an increase in the conversion of oxygenated to deoxygenated blood would signify an increase in neural activity. While fMRIs have by far superior spatial resolution, the sluggishness of the hemodynamic response means that the temporal resolution of event related fMRI signals is inferior to the millisecond-level resolution that can be attained from electrophysiological measures such as the ERP (Rugg & Henson, 2003). Thus, the two methods provides complementary point of views on the same event related brain activity.

Most researchers suggest that a mid-frontally distributed component that peaks from 300-500 milliseconds (ms) may be associated with familiarity (Curran & Cleary, 2003). This ERP component is referred to as the "early frontal effect" (FN400) and is distinct from and occurs before neural correlates of recollection (Curran, 2000; Duarte et al., 2004; Friedman & Johnson, 2000). Curran (2000) demonstrated the association between familiarity and the FN400 component when they found that FN400 amplitude was largest when subjects were shown familiar test items that were seen at some point in the experiment versus novel test items. Other experiments that were modeled from previous studies (Gardiner & Java, 1991) had participants respond in a remember/know paradigm as they were observing a mix of previously encountered and new items. Participants were instructed to respond “remember” if they were able to recollect specific associations that occurred at study, and “know” if they couldn’t recollect any specific association but were believed that the item was seen during the study. In other words, the “remember” and “know” judgments reflected the 2 neural processes that occurred during memory retrieval: recollection and familiarity. ERP data from these experiments showed that responses associated with a “know” judgment elicited activity in the brain that matched those shown in studies to be neural correlates associated with familiarity, both temporally (300-500 ms) and topographically (mid-frontal) (Düzel et al., 1997)

The same literature that defined familiarity with respect to ERP also described the neural correlates of recollection (Curran & Cleary, 2003). This ERP component is often referred to as the “later parietal effect” (LPC), as it is localized over the parietal regions of the brain and is generally observed to be elicited 500-800 ms after the stimulus onset (Curran & Cleary, 2003; Duarte et al., 2004; Woroch & Gonsalves, 2010). Although there have been many studies that support the idea that LPC activity is related to memorial recollection, the functional significance of this effect relative to recognition memory is not definitive (Wagner et al., 2005). Wagner hypothesizes that the parietal cortex integrates information about the history of the stimulus, accumulating evidence for or against a memory decision. This theory is appealing because it draws on the observation that the LPC changes in amplitude depending on the strength of the source memory, which raises the possibility that the strength of activation contributes to the eventual memory decision (Wagner et al., 2005; Woroch & Gonsalves, 2010). An alternate hypothesis draws upon the typical notion that memory tasks usually demand attentional shifts from the stimulus item to representations that rely on derived internal information. As such, parietal activity may reflect stimulus-driven attention to internally generated mnemonic representation of the external stimulus (Rugg & Henson, 2003; Vilberg et al., 2007; Wagner et al., 2005).

Functional magnetic resonance imaging (fMRI) studies on human memory have further contributed to the understanding of recollection's role in memory retrieval (Rugg & Henson, 2003). While ERP relies on the measurement of the brain's electrical signals, fMRI uses the blood-oxygen-level dependent (BOLD) signal that monitors brain activity through the change from oxygenated to deoxygenated blood, which is indicative of metabolic activity occurring in the brain. This technique, as stated before, provides better spatial resolution of the cortex compared to the EEG, allowing for the localization of cortical areas of the cortex associated with cognitive mechanisms more accurately. However, fMRI detects changes in blood deoxygenation as a function of seconds as opposed to the millisecond accuracy of ERP, which means that it has worse temporal resolution compared to EEG. Researchers who conducted fMRI recording studies have found that the hippocampus and medial temporal lobe are also involved in recollection (Eichenbaum et al., 2012; Rugg & Henson, 2003). Studies that measured the degree of memory impairment exhibited by patients with hippocampal lesions have confirmed their role in declarative memory when impaired subjects performed worse on recalling test s timuli than control subjects (Eichenbaum et al., 2012; Wixted & Squire, 2010). As such, activity that is seen from parietal site in ERP may represent signals that may have originated from the hippocampus, medial temporal lobe, and parietal lobe.

The final neural correlate relevant to this study is the late frontal effect (LFE) that occurs between 800-1200 ms and is reflected most prominently over the right frontal scalp sites (Curran & Cleary, 2003). This modulation is thought to reflect the engagement of effortful post-retrieval processing, and has been linked to the evaluation of the observed item for source or other item specific features (Goldmann et al., 2003; Wolk et al., 2006). Although ERP studies are unable to pinpoint the neural source due to its inability to generate highly accurate scalp topographies, researchers believe that the LFE may represent prefrontal mediated activity that contributes to recollection based memory decisions and even memory decisions involving weak familiarity cues. There are also studies where the LFE was shown to be elicited despite unsuccessful recollection from the participant, thus suggesting it might serve an additional role as an executive function of the frontal lobes in order to direct subsequent attempts at retrieving information (Ally & Budson, 2007; Budson et al., 2005).

Determining the neural substrates of episodic memory has also been a major focus of research in attempts to understand recognition memory. Contrary to what ERP measures suggest, familiarity and recollection do not function based solely off of the frontal and parietal lobe, respectively. Rather, they involve such wide and varied parts of the brain that researchers are still attempting to determine the association between the brain and memory. For instance, researchers studying prefrontal cortex (PFC) lesions have often found conflicting evidence on whether familiarity or recollection was impaired. Aly and her colleagues (2011) rationalized that lesion location within the PFC is likely critical in determining whether recognition deficits are due to recollection impairments, familiarity impairments, or both. This conjecture is shared by many other researchers, who likewise found deficits in both familiarity and recollection in patients with PFC lesions (Duarte, Ranganath, & Knight, 2005).

In order to better understand the electrophysiological correlates of the brain in regards to recognition memory, a paradigm was designed that measured both ERP memory components and behavioral performance of participants using knowledge they acquired in a classroom environment. These participants, who consisted of 1st year medical students taking a 16-week long medical anatomy course, and would be learning in a classroom environment, being exposed to lectures, going to labs, and reading material that would increase their knowledge base of medical gross anatomy. It was expected that the participants would be capable of learning the course material, and verification of this criteria was determined by a passing grade in the course. Based off this assumption, it was therefore predicted that the students would be able to define, at the very least, the majority of the anatomical terms used in the experiment by the end of the course. Preliminary data from this study is consistent with the idea that participants have little to no knowledge of the medical gross anatomy material during the baseline testing session, choosing to use “Don’t know” responses for the majority of the terms seen. In terms of ERPs, only a frontal effect was expected for terms that the participants indicated that they were familiar with. However, during the session after the end of their course, it was expected that the participants would choose the “Can define” response more frequently, which is indicative of recollection, in addition to a larger percentage of “Familiar” responses, indicative of familiarity. As such, not only would a frontal effect be elicited, but also a LPC effect as well.

The focus of this study was limited to the collection of data from the tests given right after the end of the course in order to determine if ERP served as a potential tool to predict the learning of anatomical terms among subjects. In a behavioral aspect, students who passed the course with higher marks would be expected to respond with “Can define” more often than others due to their retention of a larger amount of information from the anatomy course. It was also hypothesized that students who performed better in the course and achieved a higher grade would display signs in their ERP results a greater indication of recognition memory of the anatomical terms presented. Since both memory components, familiarity and recollection, are found to be sensitive to the variations in the strength of source memory or confidence in judgment (Woroch & Gonsalves, 2010), it seemed likely that the neural correlates for higher performing students will be greater in amplitude compared to those who did not perform as well. An example would be a consistently higher LPC amplitude whenever the participants were able to define the terms shown on screen. Since all the participants would be expected to define at least a portion of the terms presented since the information is still fresh in their minds, both frontal and parietal components would be elicited. However, it may be possible that the frontal and parietal activity seen in higher performing students might be higher than those who did not perform as well due to a broader recruitment of brain activity.

Objectives

The primary goal of the current study is to examine the data collected from ERPs in hopes of finding a potential indicator of successful learning to better future educational endeavors. For this work, it was decided to measure the participant's success in learning the course material as a function of their grade, and to use Pearson Correlation analyses to assess the relationship between ERP amplitudes and course grade. Multiple linear regression was then calculated to predict the grades students received based on the amplitude of their ERP waveforms. It was expected that there would be a significant positive correlation where the ERP amplitudes detected on the scalp would increase alongside with the course grade received because students who were able to successfully retain more information would thus be able to recollect or be familiar with a larger percentile of the terms given to them. Their larger memory base would theoretically be expressed on the ERP data as waveforms of higher amplitude, and as such we expect that the degree of neural correlates is proportional to grades received, and by extension success in retention memory. The assumption in this study that a relationship exists between grade and ERP amplitude also leads to a hypothesis that a student's performance in class can be predicted based on the amplitude of one, if not all, of the neural correlates of memory (FN400, LPC, and LFE). In conclusion, this research aims to determine hallmarks within the brain that serves as an indication of this efficient studying, with the hopes that it can one day be used to prepare competent and confident young minds for their respective careers. If any significant results are found, it can prove useful in not only analyzing long-term memory retention under real life settings, but can potentially also be applied under medical settings to catch and diagnose early symptoms of memory impairments.

METHODS

Participants

37 participants (13 male, 28 female) were recruited from the Boston University School of Medicine who were enrolled in the Medical Gross Anatomy course. Students of the Medical Gross Anatomy course were recruited by sending 2 emails to all students registered to the course, with one notification occurring 1 month prior and another 1 week prior to the experiment. Flyers were also posted around the Boston University Medical Campus. All participants were all right-handed native English speakers with normal or corrected-to-normal vision and hearing. The ages ranged from 20 to 29 years (mean: 22.97 years, SD = 2.34). As compensation for their time, participants were reimbursed $30 for each session.

For the behavioral experiment, data was obtained from 37 participants. Five participants were excluded because they did not complete all three sessions of the study. One participant did not complete the post-test and their post-test data was excluded from data analyses. Eight additional participants were excluded due to excessive artifacts in their ERP data and excessively small bin sizes (<16), which meant that an inadequate amount of clean, stable data were collected for these subjects. Causes of such technical issues include, but are not limited to, issues with recording devices, subject attrition along the several sessions, and computer malfunction. In total, there were data from 15 participants that were used in all analyses.

Stimuli

264 anatomical terms were used for the experiment, with 132 words selected among key terms listed in the syllabus of the Medical Gross Anatomy course (44 Back & Limbs, 44 Thorax, Abdomen, & Pelvis, 44 Head & Neck). Examples include: olecranon (Back & Limbs); omentum (Thorax, Abdomen, & Pelvis); and buccinators (Head & Neck). All students were presented with the same 132 terms, and the terms themselves were not changed across all 3 test sessions. The remaining 132 words were taken out of Fonahn, 1922, and consisted of outdated anatomical terms meant to serve as a baseline for terms which participants were unfamiliar with. Examples include: lisan (tongue), natis (greater trochanter), and poples (popliteal fossa). These terms were labeled as "obscure" terms, and were unchanged across all participants. Obscure terms were divided into thirds, with each set used in Sessions 1, 2, and 3 respectively. There was no overlap in the obscure terms across sessions.

Design and Procedure

The entire experiment was divided into 3 test sessions, but only the sessions that occurred the week before and within 12 days after the Medical Gross Anatomy course began is relevant for the current study. Each session lasted approximately 2 hours. The anatomy course itself was divided into 3 blocks, with anatomical terms associated with the Back & Limbs; Thorax, Abdomen, & Pelvis; and Head & Neck taught in the 1st, 2nd, and 3rd blocks respectively. The course was 16 weeks in length, so there was an estimated 18 to 19 weeks between each experimental session. The test sessions were identical across all aspects, with the exception of having a different set of obscure terms as noted above.

The participants were tested individually. Each session was split into 3 different parts. For each part, students were shown the stimuli on a 22 inch computer using the E-Prime v.2.0 (Schneider, Eschman, & Zuccolotto, 2002). The first part involved the observation and recognition of terms while observing the participant's EEG. The second part involved the observation and recognition of images while using Gaze-tracking software. The third part involved the observation and recognition of images using both EEG and Gaze-tracking software. The article will focus only on the first part, which is expanded on below.

Prior to the start of the experiment, participants were calibrated on a Biosemi ActiveTwo 128-electrode high density electroencephalography (EEG) system (see ERP procedure below). Following calibration, they were asked to complete the first part (noted above) on a computer, in which 176 anatomical terms were presented one at a time on the computer screen. The number of terms presented were to ensure that sufficient bin sizes (> 15) would be available for analysis. Anatomical terms were presented in a random order. Upon presentation of the word, the participants were then asked to press, on a keyboard, the numbers "1", "2", or "3" to indicate whether they "Could Define", were " Familiar" with, or "Don't Know" the word, respectively.

Before the presentation of each word stimuli, a 1000ms fixation cross ("+") was shown on the computer screen. The anatomical term would then remain on the screen until the participant responded with one of three choices. Following participant response, an inter-trial interval (ITI) lasting 1500ms was displayed, after which the process would then repeat itself for the entirety of the experiment. The task itself lasted an average of 20 minutes across all students.

Once the experiment was completed, the EEG equipment was removed from the participant, who would then be given a post-experimental test. Terms that the participant marked as “Can Define” were filtered from the 176 terms and randomized using Microsoft Office Excel. The first 20 terms were then presented to the participant on one column of the Excel sheet, while the remaining words were deleted. The participants were asked to define the term to the best of their ability, which were then compared to definitions derived from 2 sources: Stedman’s medical dictionary or Merriam-Webster’s medical dictionary. The purpose of the post test was to verify the accuracy of participant’s responses towards “Can Define” terms, and determined whether they were asked to participate in further sessions.

Event-Related Potential Procedure

Participants were seated and fitted with an Active Two electrode cap (Behavioral Brain Sciences Center, Birmingham, UK) that best conformed to their head shape. Conductive gel was then injected into each of the electrode wells in the cap to help promote scalp electrical conductivity to a full array of 128 Ag-AgCl BioSemi (Amsterdam, The Netherlands) “active” electrodes. Before placement of the electrodes, they were soaked in a warm sodium chloride (NaCl) solution to further promote conductivity. These electrodes were then connected to the cap in a pre-configured pattern that placed each electrode in equidistant concentric circles (Fig. 1).

In addition to the scalp electrodes, 2 mini-biopotential electrodes were placed on each mastoid process. Bipolar electrodes were also placed below the left eye and outer canthus of each eye to measure vertical and horizontal electrooculogram (EOG) activity.

EEG and EOG activity was amplified with a 0.03-30 hertz bandwidth (3 decibel points) and digitized at a 2048 hertz sampling rate. Recordings were referenced to a vertex reference point, but were later changed to reference a common average reference. This was done to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields (Tim Curran, DeBuse, Woroch, & Hirshman, 2006; Dien, 1998).

In each task, the sampling epoch for each individual test trial lasted 2000 ms, including a 200 ms pre-stimulus baseline period. The pre-stimulus period was used to baseline correct averaged ERP epochs lasting 1800 ms. ERPs were later averaged and corrected using EMSE Software Suite (Source Signal Imaging, San Diego, CA, USA). Trials were corrected for excessive EOG artifact activity using empirical EMSE Ocular Artifact Correction Tool, in which artifact data and clean data was manually identified from the data by investigators. The Ocular Artifact Tool then produces a logarithmic ratio of artifact data to clean data, subtracting artifact data from all channels where it is detected. Individual channels that were deemed poor in recording were later corrected with the EMSE spatial interpolation filter.

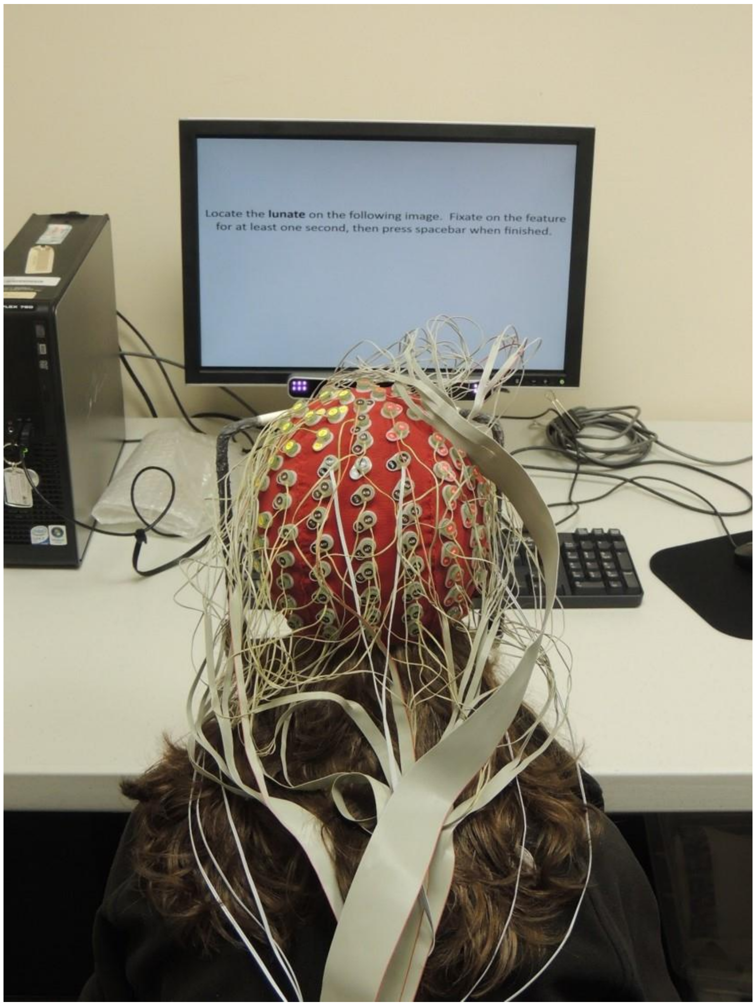
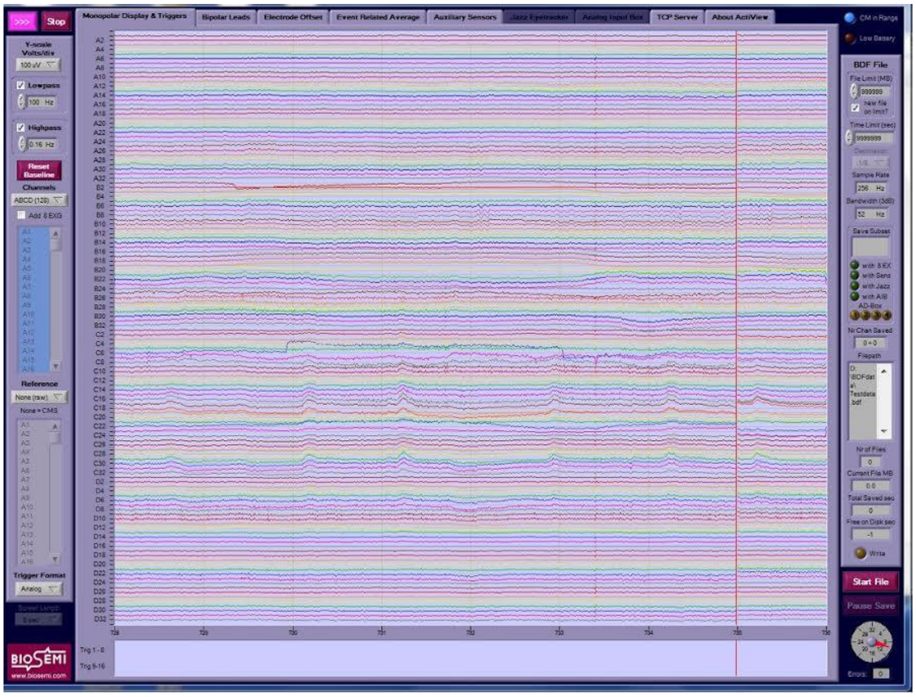


Figure 1: Actual Representation of Electrode Cap on a Subject



Y-scale Volts/div: 100 uV
☑ Lowpass: 100 Hz
☑ Highpass: 0.16 Hz
Channels: ABCD (128)
☐ Add 8 EXG
Reference: None (raw)
None = CMS
BDF File
File Limit (MB): 999999
☑ new file on limit?
Time Limit (sec): 9999999
Sample Rate: 256 Hz
Bandwidth (3dB): 52 Hz
Nr Chan Saved: 0 + 0
Filepath: D:\BDFdata\Testdata.bdf
Nr of Files: 0
Current File MB: 0.0
Total Saved sec: 0
Free on Disk sec: -1
Errors: 0

Figure 2: Visual Representation of Electrodes Recording ERP Data from Subjects

RESULTS

ERP results

ERP data was obtained from a total of 37 students and analyzed to detect differences between the amplitude and peak latency of the electric activity after stimulus onset. Three specific points in time: 300-500 ms, 500-800 ms, and 800-1200 ms after stimulus onset were studied. These time intervals are associated with the three components of the old/ new ERP effect: the early frontal, late parietal, and late frontal effects, respectively. The amplitudes of all subjects along these three time intervals were then averaged for all 128 electrodes, giving a total of 128 mean amplitudes. Based on the location of the electrodes, these amplitudes are split and averaged again into ten groups that represent regions of interest (ROIs) across the scalp. Each ROIs was composed of a seven electrode groups and is named the following: the Left Anterior Inferior (LAI), Central Anterior Inferior (CAI), Right Anterior Inferior (RAI), Left Anterior Superior (LAS), Right Anterior Superior (RAS), Left Posterior Inferior (LPI), Central Posterior Inferior (CPI), Right Posterior Inferior (RPI), Left Posterior Superior (LPS), and Right Posterior Superior (RPS). Figure 3 provides a visual representation of the scalp topographies in relation to the ROIs. Frontal ROIs were mainly of interest when observing for the early frontal effect, and as such the LAI, CAI, RAI, LAS, and RAS were focused on in this regard. On the other hand, the ROIs that were more posterior were used for the late parietal affect, and consisted of the LPI, CPI, and RPI. Focus was again directed mainly on the frontal ROIs again when searching for the late frontal effect.

Only significant effects are reported in the subsequent analyses. Figures 4-8 show the ERPs of the LAI, RAS, LPS, CPS and RPS.

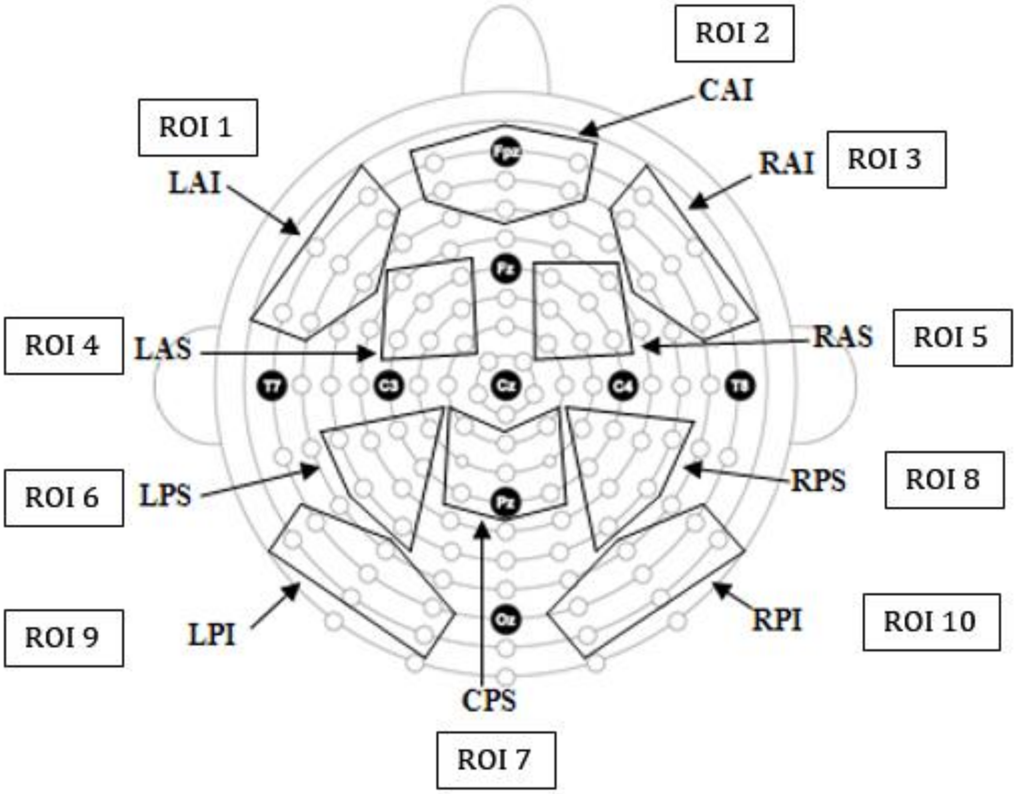


Fig. 3: Regions of Interest (ROI) – 10 scalp regions that consist of one ERP amplitude generated by averaging the waveforms of all the electrode readings within the borders outlined

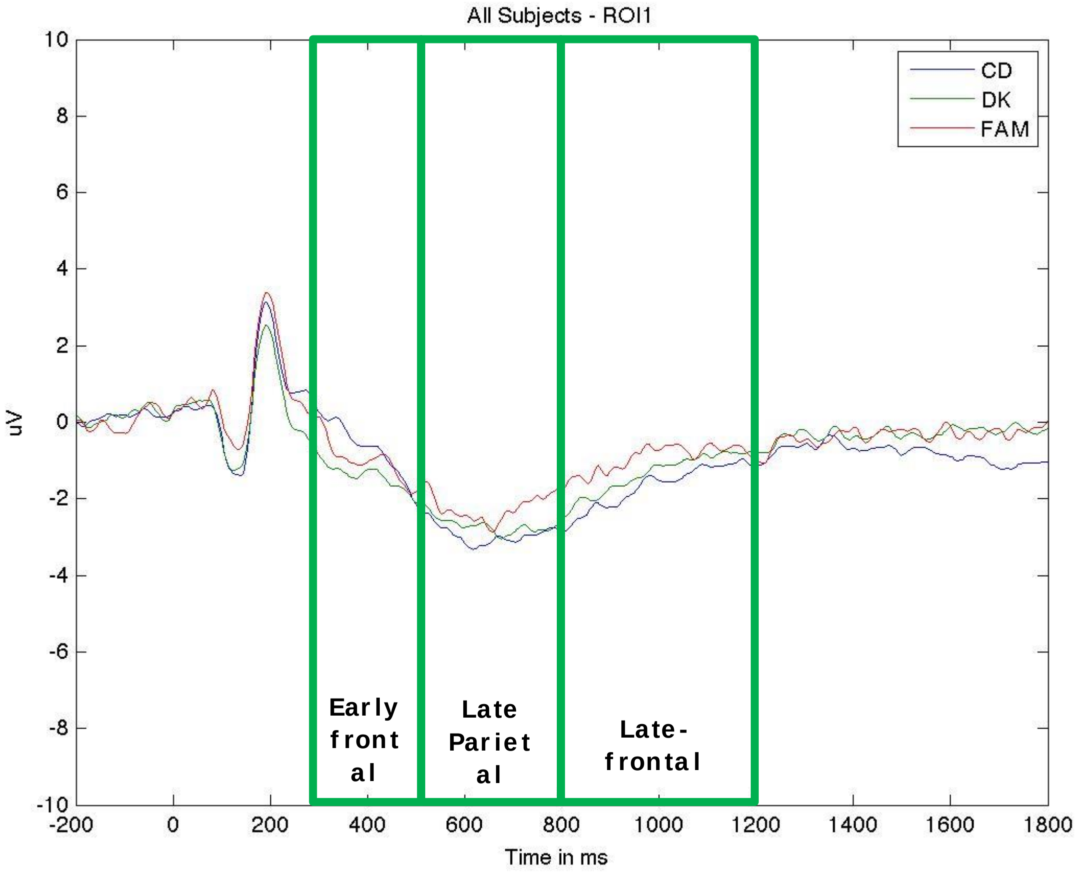


Figure 4: ERP results for all subjects across the LAI (ROI1) with X axis being time after stimulus onset (in milliseconds) and Y axis being ERP amplitude (in microvolts)

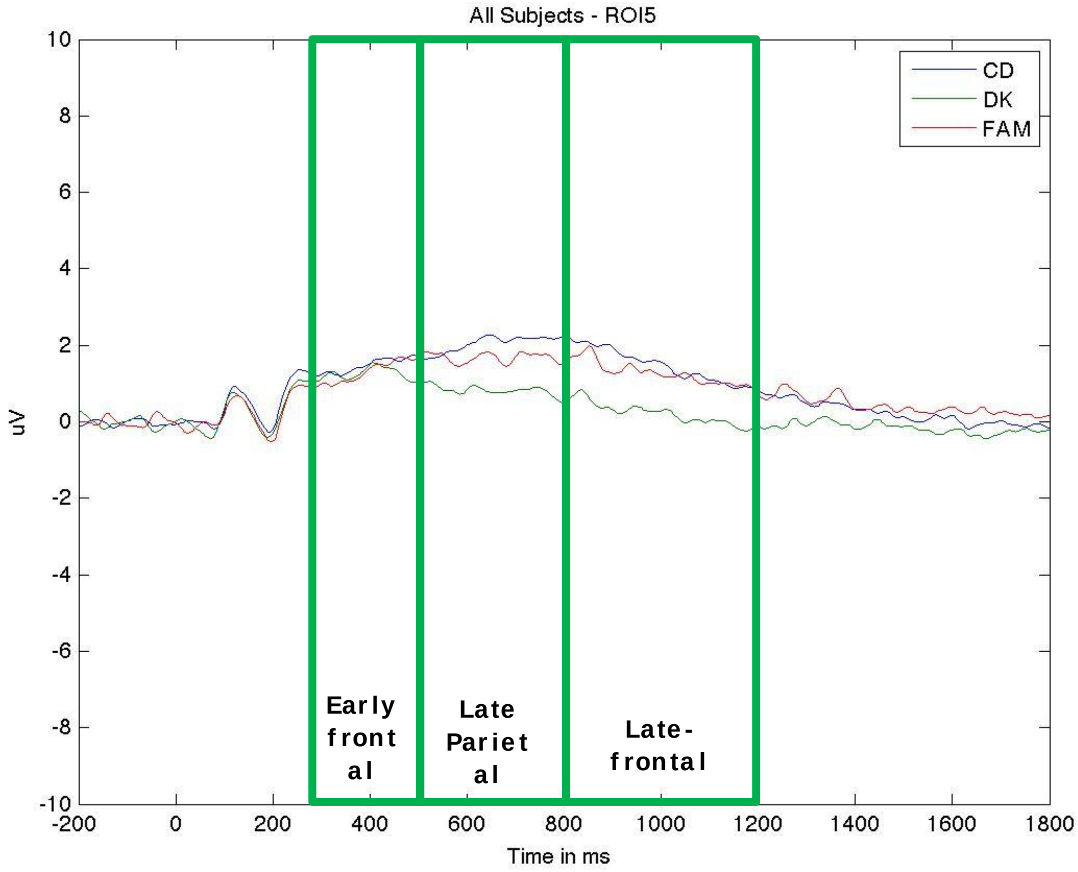


Figure 5: ERP results for all subjects across the RAS (ROI5) with X axis being time after stimulus onset (in milliseconds) and Y axis being ERP amplitude (in microvolts)

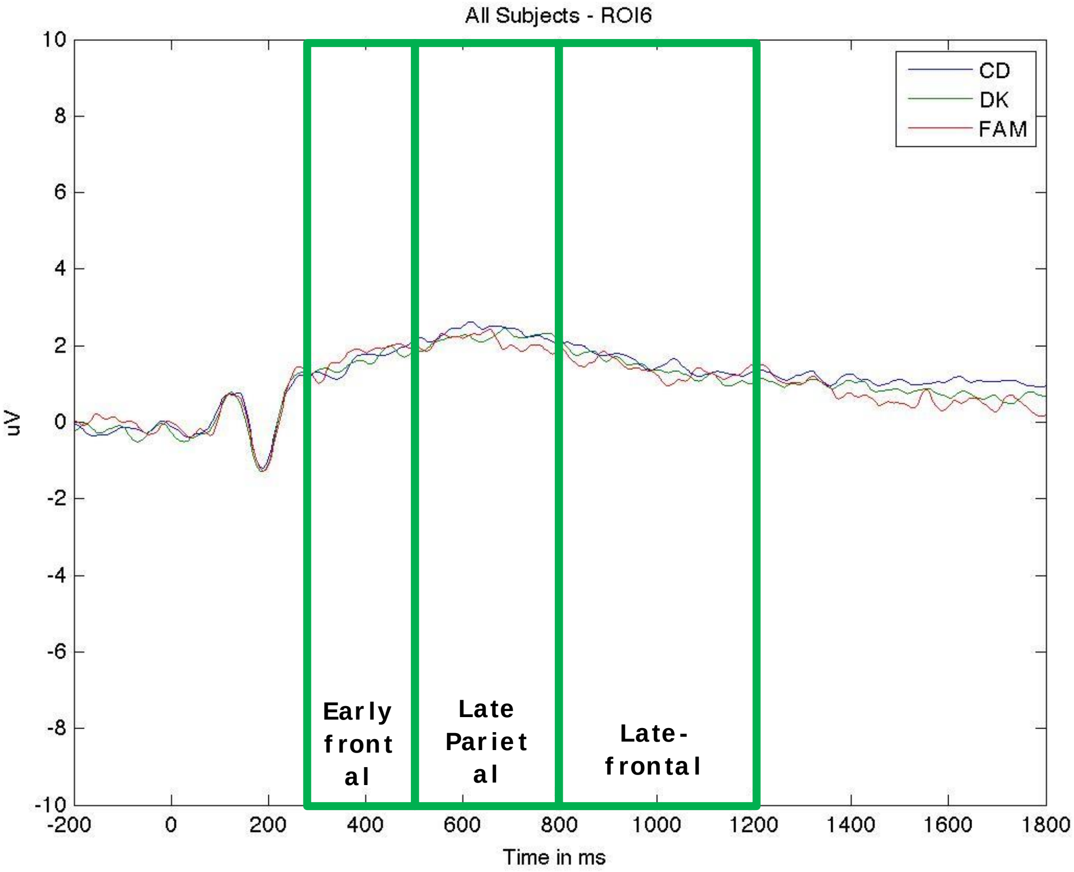


Figure 6: ERP results for all subjects across the LPS (ROI6) with X axis being time after stimulus onset (in milliseconds) and Y axis being ERP amplitude (in microvolts)

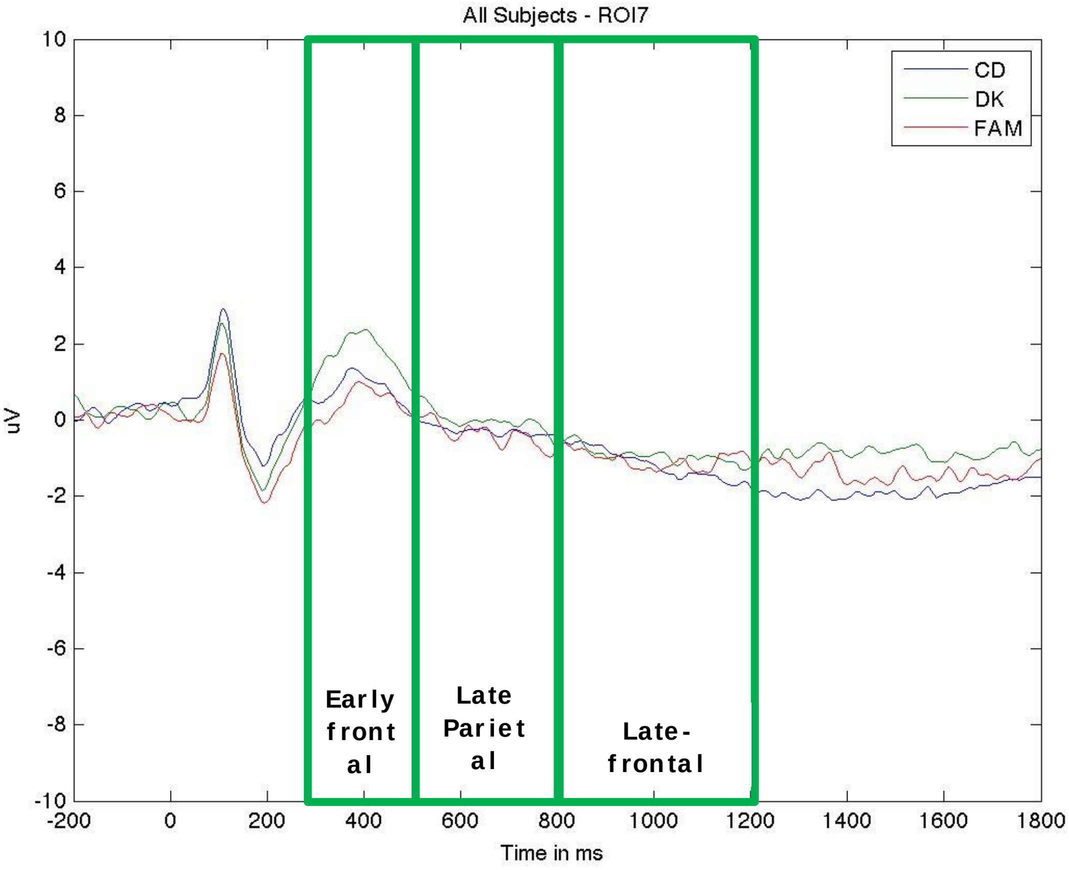


Figure 7: ERP results for all subjects across the CPS (ROI7) with X axis being time after stimulus onset (in milliseconds) and Y axis being ERP amplitude (in microvolts)

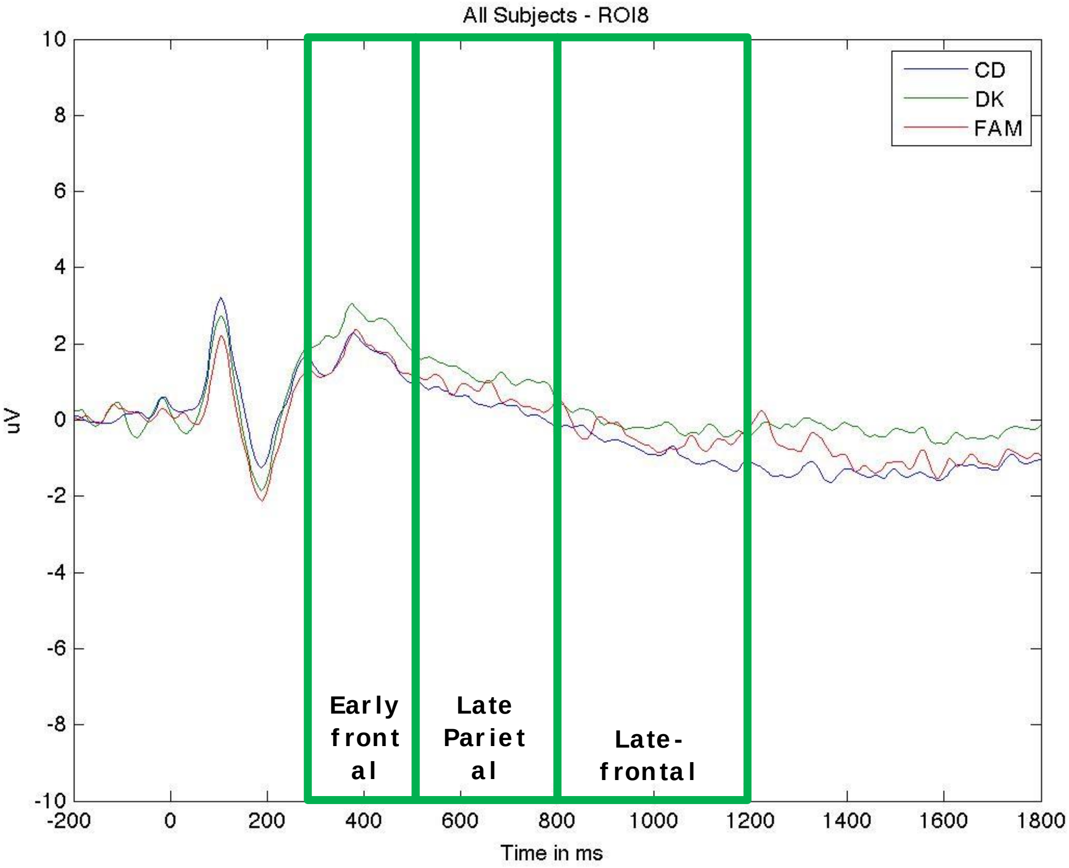


Figure 8: ERP results for all subjects across the RPS (ROI8) with X axis being time after stimulus onset (in milliseconds) and Y axis being ERP amplitude (in microvolts)

Regarding ERP results for the LAI and RAS regions of interest, it was expected that the amplitude for Can Define responses would be highest during the epoch representing the FN400 effect (300-500 ms) followed by the Familiar responses and lastly the Don’t Know responses. The LAI and RAS regions were of special interest in order to detect neural correlates of familiarity because the FN400 has been observed in the frontal regions in prior studies (Curran & Cleary, 2003; Duarte et al., 2004; Friedman & Johnson, 2000). On the other hand, it was hypothesized that the Can Define responses elicit the greatest changes in neural activity due to the fact that these responses suggest that students both are familiar with and can recollect the term displayed to them on the computer screen. The trend for early frontal effect data generally showed a greater positivity for Can Define and Familiar responses over Don’t Know responses. Statistics have not been used to verify this effect yet, but if true, this would be consistent with the study’s hypothesis

For the late parietal effect (the LPC), analyses focused on more posterior located sites (LPS, CPS, and RPS) because neural associates of recollection are localized over the parietal regions of the brain and is elicited 500-800 ms after the stimulus onset (Curran & Cleary, 2003; Duarte et al., 2004; Woroch & Gonsalves, 2010). It was again expected that Can Define responses would have the highest amplitude, followed by Familiar and Don’t Know responses. This was not seen in the ERP data, as the amplitude of Don’t Know responses was just as high (seen in LPS), or even noticeably higher (seen in CPS and RPS) than that of Can Define responses. While the lack of statistical calculations means that no definitive conclusion can be drawn, the trend presented in this ROI suggests that this finding is inconsistent with the study's hypothesis.

Last but not least, the LAI scalp region was studied in order to observe the late frontal effect that is commonly seen 800-1200 ms after the stimulus onset. A more prominent ERP amplitude was expected for both Familiar and Don't Know responses because the participants would engaging in effortful attempts at retrieving information in an attempt to link any features in memory, whether from the stimulus item itself or another item from the past, to the source item (Goldmann et al., 2003; Wolk et al., 2006). This, in turn, would reflect the effortful search of the anatomical term by the subjects as they determine whether they can, or cannot, define the term. Event-related potential data obtained for LAI displayed wave amplitudes with Familiar and Don't Know responses are higher than that of Can Define responses. Just like the trends observed for the FN400 and LFC effect, statistics were not run on these data sets. However, if confirmed, it would be consistent with the study's hypothesis

Session 2 Analyses

This analysis compared the early frontal (300-500 ms), parietal (500-800 ms), and late frontal effects (1000-1800 ms) of all participants and was based on the response type and final grade the student received in the Medical Anatomy course. The participants were asked during the experiment to pick one of three choices when determining whether they had any knowledge of the anatomical terms presented: Can Define, Familiar, and Don't Know. These choices represented the student having recollection of the term, being familiar with the term, and having no knowledge of the term respectively. Multiple bivariate Pearson correlations were then conducted to detect any significant relationship between the amplitude of the electrical activity detected on the scalp and the final grade, which is indicative of successful memory encoding. The response types around five ROIs in particular (LAI, RAS, LPS, CPS, and RPS) were analyzed because they were the regions where the neural correlates were elicited the strongest (See Figure 3). Out of the forty-five different combinations possible that were analyzed (Response Type_ Neural Correlate_ ROI), there was a significant positive correlation between ERP amplitude and **□=.375 , □=37 , □=.022**, and Can Define Late Parietal Effect Responses over RPS . This meant that a higher amount of brain activity detected in CPS and RPS resulted in a higher grade received in the medical anatomy course. Scatterplots for each are provided in Figures 9-12.

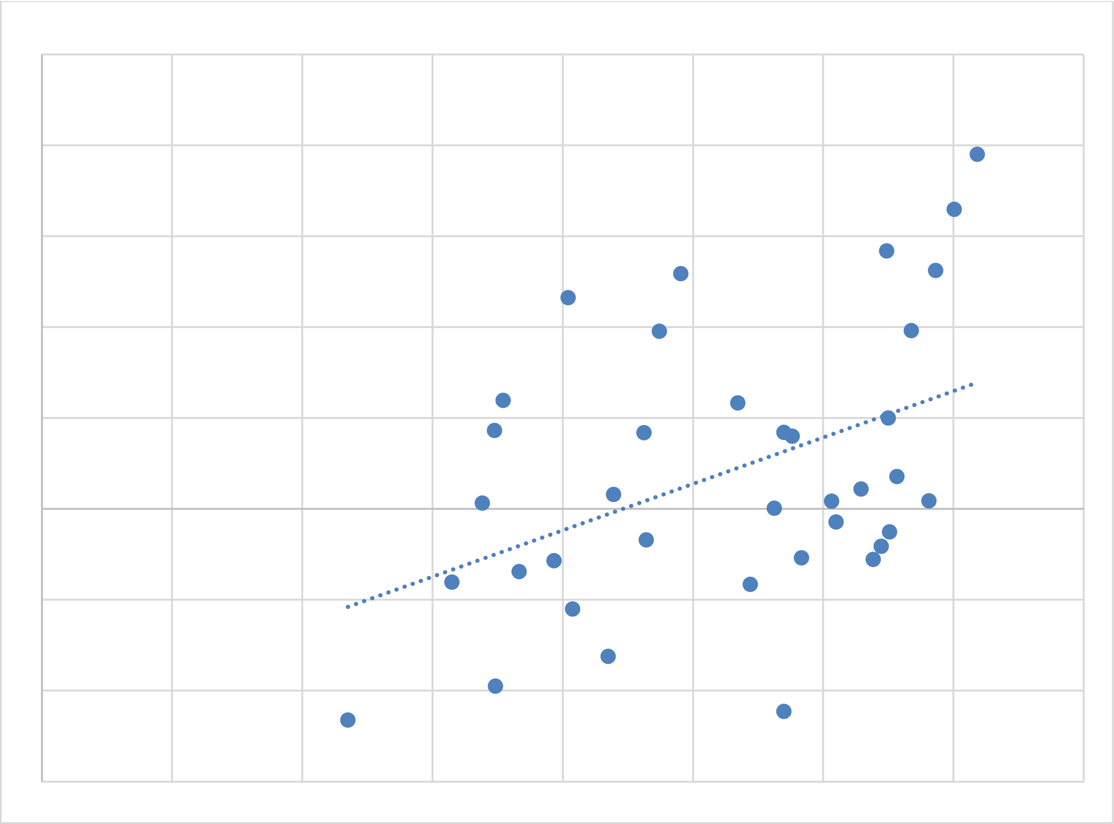


Figure 9: Scatter Plot for Can Define FN400 Responses over the CPS electrodes with Student’s Grades (X-Axis) plotted over ERP amplitude (Y-Axis)

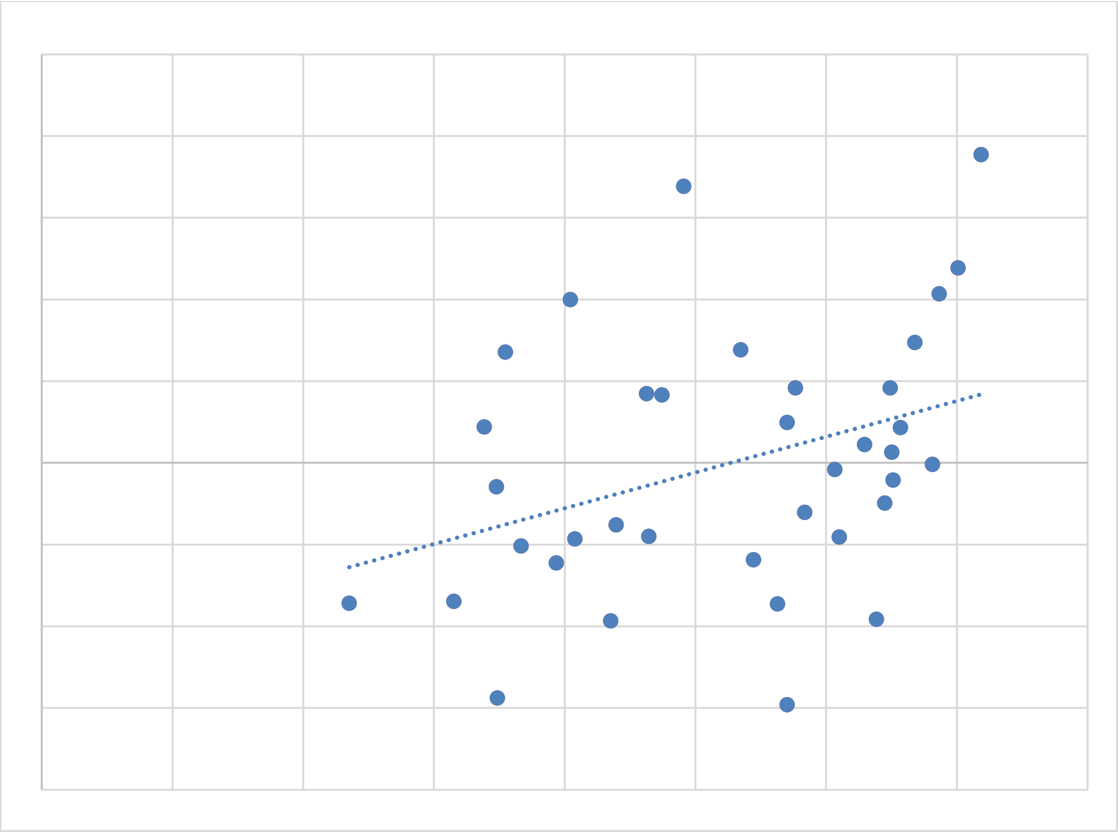


Figure 10: Scatter Plot for Can Define Late Parietal Effect Responses over the CPS electrodes with Student's Grades (X-Axis) plotted over ERP amplitude (Y-Axis)

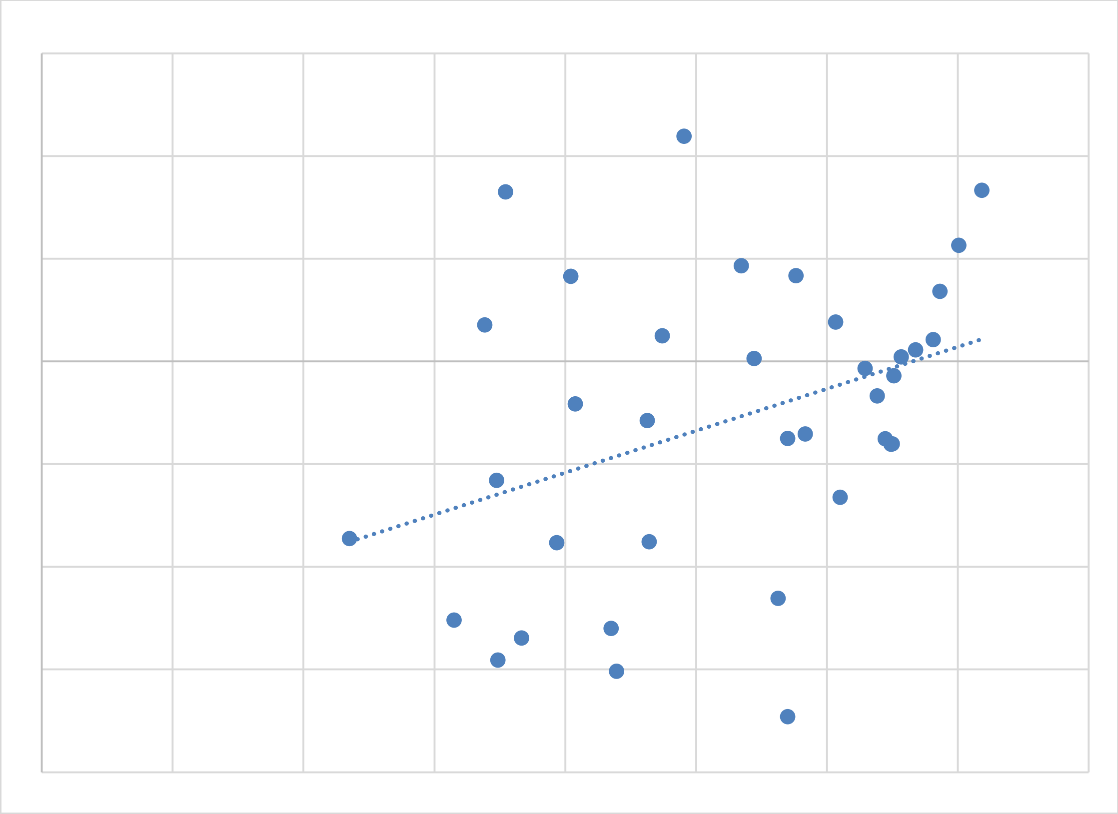


Figure 11: Scatter Plot for Can Define Late Frontal Effect Responses over the CPS electrodes with Student’s Grades (X-Axis) plotted over ERP amplitude (Y-Axis)

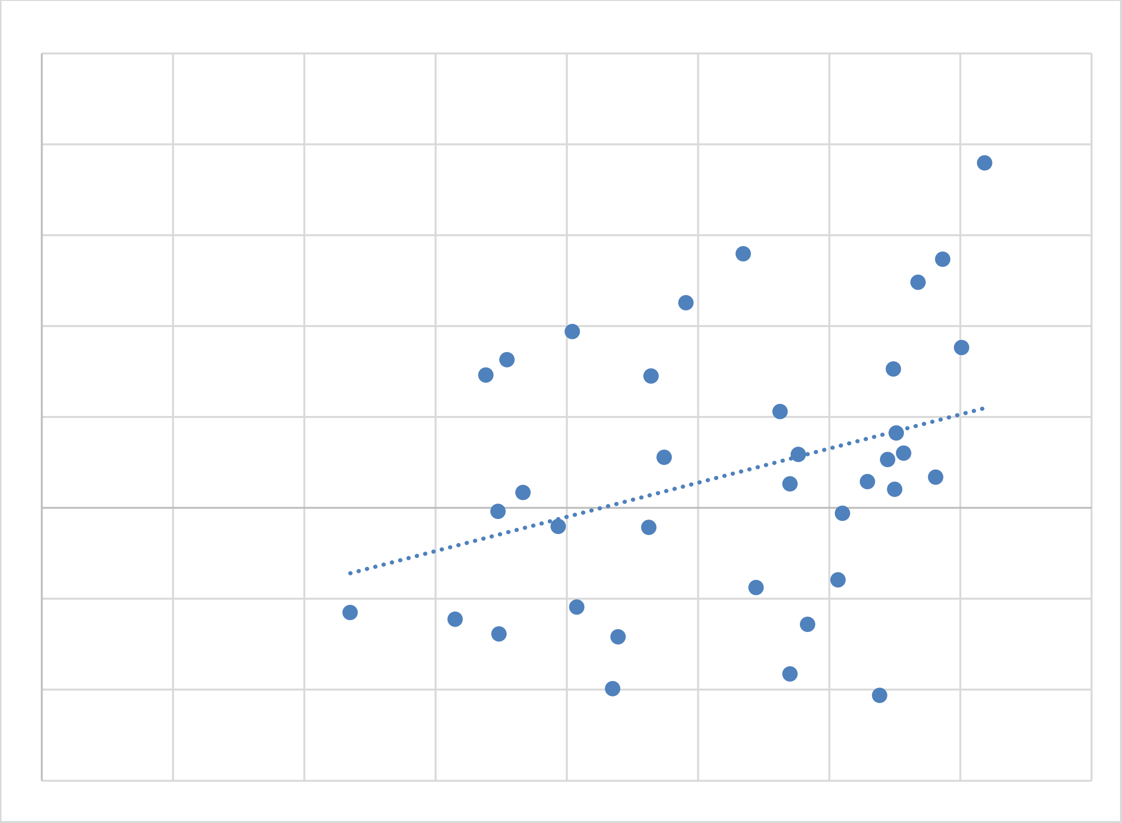


Figure 12: Scatter Plot for Can Define Late Parietal Effect Responses over the RPS electrodes with Student’s Grades (X-Axis) plotted over ERP amplitude (Y-Axis)

Linear Regression Results

After determining the ERP amplitudes that were significantly correlated with the subject’s course grades, investigates were conducted to determine the degree to which these electrophysiological responses predicted final grades, and by extension successful memory encoding. Multiple linear regression was used to predict anatomy grades based on the four ERPs deduced from the Pearson Correlation (Can Define FN400 Responses over the CPS electrodes, Can Define Late Parietal Effect Responses over the CPS electrodes, Can Define Late Frontal Effect Responses over the CPS electrodes, and Can Define Late Parietal Effect Responses over the RPS electrodes). Out of the four available predictor variables, only the amplitude wave for Can Define FN400 Responses over the correlation with the final GPA. A significant regression equation was established for the ERP amplitude of Can Define FN400 Responses over the CPS electrodes [F(4,32) = □**2** of .179]. The conclusion, based on the statistics, was that the Can Define FN400 Responses over the CPS electrodes served as the best predictor of the final grades the participants received in the medical anatomy course (Beta Coefficient = .973, Sig. = .030).

DISCUSSION

The purpose of this study was to investigate if there was a physiological correlate of learning in a classroom environment, and if so, if it can be used as an indicator of learning. The neural correlates of learning in first year medical students were examined through the use of EEGs / ERP methods, while they made one of three choices to identify the anatomical terms presented to them by the computer monitor. They either answered that they “Can Define” the term, were “Familiar” with the term, or “Don’t Know” the term. ERP data for all three response options were then reviewed for Session 2 results, which was obtained after the end of the 16 week medical anatomy course. Session 1 and 3 data, which was obtained before the start of the course and five months after the end of the course, respectively, were excluded from the study because they were not relevant to the research questions associated with this thesis. The different ERP components that were correlated with recognition memory were measured with a focus on the ROIs on the scalp that were known to elicit the greatest change in electrophysiological activity (LAI, RAS, LPS, CPS, and RPS). Figures 4-8 depict the ERP data obtained from LAI, RAS, LPS, CPS and RPS.

ERP results for the LAI and RAS regions of interest for the FN400 and late frontal effects displayed trends that supported their respective hypotheses, as data showed a greater positivity for Can Define and Familiar responses over Don’t Know responses for the FN400 effect, while also displaying higher amplitudes for Familiar and Don’t Know responses over that of Can Define responses for the LFE effect. However, ERP waveforms over the posterior sites (LPS, CPS, and RPS) displayed a higher amplitude for

Don't Know response rather than Can Define responses, which is contrary to the hypothesis due to previous studies showing Can Define responses as the waveform with the highest amplitude for the LPC effect. It is unclear what this may reflect, as most memory studies associate the LPC effect to the subject actively retrieving contextual information about the test item, and as such a Don't know response that indicates the inability to retrieve any information about the stimulus shouldn't display such a high ERP amplitude. However, it is possible that the participants are actively retrieving knowledge about other items in the hopes that it would help them remember information about the test stimulus. This assumption is based on the popular theory of chunking, or the subjective organization of study material into smaller units to facilitate greater memory retention (Zaromb & Roediger, 2010). It may be entirely possible that the participant may recall that the stimulus item is associated with another item that he does remember, and is actively recollecting information about that different item to facilitate problem solving. Further investigation would be needed to pursue this theory.

Multiple bivariate Pearson correlations were performed in order to determine if any significant relationship could be drawn between the ERP neural correlates of recognition memory that could be detect on the scalp and the performance of the 1st year medical anatomy students. It was hypothesized that if any significant correlation existed between electrophysiological activity and participant grades, then it would be a positive linear correlation. This is because students who performed better in the medical anatomy course would be able to recall, and if not be familiar with, a greater number of the terms presented during the experiment. The student's ability to retain more information over his anatomy course would then be reflected in the ERP data as neural correlates with a higher amplitude. A total of forty-five correlations were run, consisting of participant response type, neural correlate, and ROI (with $p < .05$ as an indicator of a significant correlation). Out of all potential combinations, four correlations turned out to be significant: Can Define FN400 Responses over CPS electrodes, Can Define Late Parietal Effect Responses over CPS electrodes, Can Define Late Frontal Effect Responses over CPS electrodes, and Can Define Late Parietal Effect Responses over RPS electrodes. All four combinations showed a positive linear correlation, which meant that as the amplitude of the FN400, LPC, and LFE effects in the CPS and RPS regions increased, the performance of the students also increased. The scatterplots of each subject's individual amplitude as a function of their grade was consistent with the statistics, as there was a noticeable increase in peak amplitude as the grades increased. However, the scatterplots also showed that the positive correlation was not particularly strong, as the individual points that represent each student did not follow any noticeable trend. This could be due to multiple reasons, with one being the simple individual variation of responses in the experiment. It is not uncommon for one student's distinction between being able to define the term and only being familiar with it to differ from another person's, and as such it is difficult to conduct experiments similar to ours that holds every participant to the same standards when obtaining data. Another reason is that the electrical activity elicited by the brain, and by extension detected by the scalp, for each person may differ in terms of maximum and minimum amplitude. If this were the case, then it could account for the seemingly inconsistent trend seen on the scatterplots, for one student who received a high grade may fire fewer neurons than another student who performed worse. One final consideration is that there was not a huge spread in terms of course grades, as most students performed well in the anatomy course. As such, a ceiling effect was observed such that many students scored higher rather than seeing an equal number of students receiving an E, D, C, B, or A. Further investigation is needed, however, before any conclusive remarks can be made.

Lastly, a multiple linear regression was calculated to predict course grade based on the four ERP amplitudes found to be significant by the Pearson correlation. A significant regression equation was found for Can Define FN400 Responses over the CPS electrodes. This research has thus found the ERP amplitude of Can Define FN400 Responses over the CPS electrodes to be the best predictor of a student's performance in the medical anatomy course. This is puzzling for a variety of reasons, with the chief among them being that the FN400 effect is featured most prominently over frontal scalp sites (LAI and RAS) and is associated with the familiarity mechanism rather than recollection. One possible reason for the discrepancy between response type, neural correlate, and ROI can be attributed to the poor spatial resolution of the EEG. For this experiment, a ERP paradigm was preferable to the study because of the need to visualize brain activity that underlie cognitive processes. However, while EEG's allow for a superior temporal resolution, it is inferior in localizing of neural activity within the brain (Rugg & Curran, 2007). Electrical signals of the ERP picked up by the electrodes are known to disperse as it travels from the brain though the skull and scalp, and often the signals detected in one region of the brain originated from an entirely separate area. We thus believe that it is entirely possible for an FN400 effect to exist in other regions of the brain, although it is most often seen in the frontal lobes. It may be helpful to conduct future experiments with fMRI studies to supplement existing data, as it offers superior spatial resolution compared to EEG studies.

In conclusion, this study has portrayed the usefulness of analyzing the components of learning and memory in a classroom environment. Significant strides were taken towards the primary goal of this study, which was to find a potential indicator of successful learning. However, the results cannot be called definitive, and more testing is required before it can be firmly established that the hypothesis is valid. The result of this experiment suggests that ERP markers can be utilized to increase knowledge of long-term learning under real life settings. It would be especially useful if such experiments were applied along with existing teaching methodologies employed by instructors so that the contribution of each method to long-lasting memory could be derived. Although most behavioral studies have shown active retrieval learning to be most effect in promoting retention of information, there is a scarcity of physiological studies that supports these assertions. One potential step our research could thus take is asking future subjects of their personal study habits, and separating them into groups based on whether they employ passive of active study habits. By comparing the ERP amplitudes as a function of grades for both groups, it might be possible to support existing behavioral data on the benefits of one type of learning over another in long term memory recollection.

Another step that could be taken is to compare the ERP amplitudes of the same medical anatomy students five months after the completion of the course in continuation of the search for a potential indicator of long-term retention memory. It seems likely that results from the current study will assist in predicting the outcome of any future studies conducted for the third session, with the ultimate goal of obtaining a physiological tool able of identifying effective learning strategies and proof of successful information retention. Finally, this research could eventually extend to not only the classroom environment, but also to groups with learning and memory disabilities such as mild cognitive impairments and Alzheimer’s disease. If it is possible to detect when those affected begin to suffer in memory retention, then intervention at an earlier time could offer the individual treatment and care before it begins to adversely affect his or her livelihood.

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CURRICULUM VITAE

Edward Wang

Year of Birth: 1991
Contact Information:
35 Bay State Rd. Unit BR, Boston, MA 02215
(626)807-1326

Education

University of California, San Diego; General Biology Major - Psychology Minor **Sept 2009- June 2013**
cGPA: 3.23 Upper sGPA: 3.49; Received Provost Honors

Boston University; Masters of Science in Medical Sciences **Sept 2013- Present**

Student Involvement

American Medical Student Association Member **Sept 2011-Jan 2013**
University of California, San Diego
- *Communicated with those in the legal profession to gain insight on the medical field*
- *Participated in fundraisers and other events*

Volunteer Experience

UCSD Medical Center- Hillcrest **Feb 2012- Nov 2012**
Pulmonology Department
- *Organized and maintained patient files*
- *Prepared packages used for operations*
- *Learned and witnessed operations performed by specialists (e.g. flexible bronchoscopy, balloon dilation, etc)*
- *Greeted and communicated with patients*

UCSD Medical Center- Thornton
Rehabilitation/ Physical Therapy Department **Nov 2012- Aug 2013**
- *Made, organized, & maintained patient files*
- *Learned about & witness diagnoses and treatments performed by physical therapists*
- *Communicated with patients about their ailments and the circumstances in which it came about*

Boston Medical Center- Yawkey

Bwell Program in the Pediatrics Department

Jan 2014-May 2014

- *Provided health and non-health related information to patients in a casual, non-clinical setting*
- *Engaged with pediatric patients through interactive physical & non-physical activities that promote healthy living (such as obstacle courses, fruit puppets, and yoga)*
- *Administrate the Jump Rope Clinic, where patients are referred by their doctors to participate in a 8 to 10 week program, which promoted a more active lifestyle through jump roping*

Lab Experience

Mark Tuszynski Student Researcher at Biomedical Science Building in the University of California, San Diego

Sept 2012-Sept 2013

Neurosciences Oriented Research Department

- *Learned through medical articles the problems linked to spinal cord injury and repair.*
- *Observed mice behavior after lesioning/treating spinal cord for signs of improvement.*
- *Prepared and stained spinal cords after sciatic nerve crush to observe for signs of neuron growth.*

Andrew Budson Assistant Researcher at the Center for Translational Cognitive Neuroscience Laboratory in the Veterans Affair Hospital in Boston, MA

Aug 2014-Present

Neuroscience Oriented Research Department

- *Learned through research articles and peers about the cognitive processes that underlie recognition memory.*
- *Participate in weekly clinical cases that present real life patients with memory impairments (patients remain anonymous), which provide valuable insight on the intricacies of neural processes affecting central nervous function.*
- *Administrate experiments to participants of various ages, including young healthy adults and older adults with cognitive impairments.*