The Influence of Emotional States on Short-term Memory Retention by using Electroencephalography (EEG) Measurements: A Case Study

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Abstract: This study explored how emotions can impact short-term memory retention, and thus the process of learning, by analyzing five mental tasks. EEG measurements were used to explore the effects of three emotional states (e.g., neutral, positive, and negative states) on memory retention. The ANT Neuro system with 625Hz sampling frequency was used for EEG recordings. A public-domain library with emotion-annotated images was used to evoke the three emotional states in study participants. EEG recordings were performed while each participant was asked to memorize a list of words and numbers, followed by exposure to images from the library corresponding to each of the three emotional states, and recall of the words and numbers from the list. The ASA software and EEGLab were utilized for the analysis of the data in five EEG bands, which were Alpha, Beta, Delta, Gamma, and Theta. The frequency of recalled event-related words and numbers after emotion arousal were found to be significantly different when compared to those following exposure to neutral emotions. The highest average energy for all tasks was observed in the Delta activity. Alpha, Beta, and Gamma activities were found to be slightly higher during the recall after positive emotion arousal.

1 INTRODUCTION

Neuroscientists and educators have long focused on the role of emotions in the process of learning. This interest in such relationship became evident in neuroscience laboratories and classrooms, nevertheless separate from one another. It was only in recent years that the two camps united to acknowledge the fact that emotion guides the learning process and overall, has a major impact on cognition (Greene et al., 2001; Goswami, 2006; Immordino-Yang and Damasio, 2007). It is well known that positive and negative emotions affect the brain's function (LeDoux, 2000; Damasio, 2005). For instance, positive emotions, such as joy, serenity, happiness, gratitude, and love, have a positive impact on the brain's capacity to learn. These emotions can cause an increased ability to learn and solve problems. On the other hand, negative emotions, such as hate, anger, sadness or fear, can impair the brain's capacity to learn. In consequence, educators can use the neuro-scientific perspective on learning to create emotional climates in the classroom that can be conducive to learning. This case study aims to provide support for such actions by investigating the impact of emotion on memory retention through the analysis of five electroencephalography (EEG) bands.

2 COMPARISON WITH RELATED WORK

Psychological studies have long shown that subjects' emotional states have an influence on their learning and memory. Researchers in psychology have carried out many experimental techniques in order to find a relationship between emotion, learning, and memory. For instance, in an early experiment performed by Bower and collaborators (1978), study participants were asked to recall words from two lists, one list learned while they were happy, and the other learned

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while they were sad. Emotional states (happiness and sadness) were induced via hypnotic suggestions. Highly hypnotizable volunteers performed the experimental task while maintaining their mood (happy or sad) for 5 to 20 minutes. Later they recalled both lists when they were in one mood or the other. People who were found to be in a general sad state recalled more of the list they had learned while being sad from hypnosis, and people who were found to be generally happy recalled more of the list they learned while being happy from hypnosis. Neuro-scientific studies have also shown that emotions exert influences on various behavioral and cognitive processes such as concentration, long-term memory, and decision-making (Bower, Monteiro, and Gilligan, 1978; Bower, Gilligan, and Monteiro, 1981). Emotions cause a change of perception of environmental stimuli, which in turn become more significant, lead to deeper neuronal processing, and affect memory (Clark and Fiske, 1982). Positive emotions have been proven essential for cognitive organization, thought processes, creativity, flexibility in problem solving, and intrinsic motivation (Isen, 2000; Kort, Reilly, and Picard, 2001; Chaffar and Frasson, 2004). It has also been reported that people who are anxious have slow decision latency, deficit in inductive reasoning, and reduced memory capacity (Bower, Gilligan, and Monteiro, 1981).

Electroencephalography (EEG) measurements, as well as positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) techniques, are noninvasive techniques used to detect changes in the brain activity. These changes in large-scale electrical potentials, in the case of EEG, or in regional blood flow in brain regions, in the case of fMRI, can be correlated with various processes that take place in the brain. For example, fMRI measures brain activity by detecting changes associated with blood flow. This technique relies on the fact that increased cerebral blood flow and neuronal activation are coupled.

The electroencephalogram (EEG) is a test that records the electrical activity of the brain as wave patterns generated by various brain structures. The electrical activity of an alternating type is recorded from the scalp surface after being picked up by metal electrodes (small metal discs) and conductive media. EEG reading is a completely non-invasive procedure that can be applied repeatedly to normal adults and children with virtually no risk or limitation. EEG measurements are frequently used in medicine for the detection of problems associated with certain brain disorders (i.e., seizure disorders, stroke, brain tumors, dementia, etc.). Research and clinical applications of the EEG in humans and animals are used to monitor alertness, coma and brain death; locate areas of damage following head injury, stroke, tumor, etc.; test afferent pathways (by evoked potentials); monitor cognitive engagement (alpha rhythm); produce biofeedback situations, alpha, etc.; control anesthesia depth ("servo anesthesia"); investigate epilepsy and locate seizure origin; test epilepsy drug effects; assist in experimental cortical excision of epileptic focus; monitor human and animal brain development; test drugs for convulsive effects; investigate sleep disorder and physiology; human-computer interaction, and much more (Bickford, 1987). No studies to date have been reported in the literature to use EEG data in order to investigate the impact of emotional states on memory, thus on the process of learning.

Computer applications that can detect the emotional state of the user are still in demand in an effort to copy human communication. Facial expressions and voice signals have been heavily studied to detect emotions, especially in the last two decades (Fox et al., 2000; Bartlett, Littlewort, Fasel, and Movellan, 2003; Hudlicka, 2003). Emotion classification accuracies lie between 80-90% in such studies. From a physiological standpoint, there is a net separation between physiological arousal, behavioral expression, and the conscious experience of an emotion. Additionally, physiological studies indicate that face and voice can represent emotional states which can be adapted and therefore, their interpretation is not objective. For example, one can smile while feeling sad. In this case, emotion recognition systems by using facial expression will not be able to detect the true emotion.

In contrast, EEG measurements have been shown to correlate with emotional states (Sammler, Grigutsch, Fritz, and Koelsch, 2007; Mauss and Robinson, 2009). Currently, the sensitivity of EEG-based recognition of artificially evoked emotion has been reported around 60% (Bos, 2006). Although there are many studies in the field of EEG-based emotion recognition, there is much to be done to understand and improve current EEG-based emotion recognition systems. In addition, no studies have been carried out to directly investigate the effects of emotion on memory retention, and thus the learning process, by using EEG measurements. Some of the studies indirectly related to this research are mentioned below.

A review of the research literature performed by Banich and colleagues (2009) revealed that working memory and long-term memory can influence, and in turn are influenced by, emotional processes. They concluded that lateral prefrontal regions and the anterior cingulate cortex are recognized as playing a large role in the cognitive control and emotional information in both working memory and long-term memory. EEG data was not utilized in their work. Nonetheless, Klimesch (1999) presented evidence that EEG oscillations in the alpha and theta bands reflected cognitive and memory performance, which were related to two types of EEG phenomena: a tonic increase in alpha, but a decrease in theta power, and a large event-related decrease in alpha but increase in theta, depending on the type of memory demands. Additionally, Berka and collaborators (2007) studied task engagement and mental workload in vigilance, learning, and memory tasks using EEG data. They showed that EEG workload increased with increased working memory load and during problem solving, integration of information, and analytical reasoning, leading to the fact that EEG engagement reflected information-gathering, visual processing, and allocation of attention.

In order to get a better understanding of the effects of various emotions on our capacity to memorize and learn, this work employed EEG measurements to investigate the relationship between emotion and memory. More specifically, our study compared event-related potentials (ERP) measured by EEG when triggered by emotions (sadness, happiness, neutral emotion) and engagement in several tasks (memorization of words and numbers). The outcome of such research in the field of education can shed light on how emotions impact memory retention. In addition to the education field, this study's findings can also provide valuable information to the field of affective computing, an emerging topic in human-computer interaction that tries to satisfy the need of the user.

3 RESEARCH IDEAS AND RESULTS

This study investigates the influence of emotional states on memory retention by evaluating the effects of five mental tasks in EEG bands. The study outline is depicted in Figure 1. The five mental tasks were: 1) the baseline task, for which the subjects were asked to relax as much as possible; 2) the letter task, for which the subjects were asked to memorize ten words; 3) the math task, for which the subjects were asked to memorize ten numbers; 4) the visual task, for which the subjects were asked to watch a set of images; and 5) the recall test, for which the subjects were asked to recall the words and numbers presented them earlier. The visual task was separated into three categories corresponding to the type of images extracted from the IAPS library and the corresponding emotional state assumed to be evoked by them: neutral, sadness, and happiness.

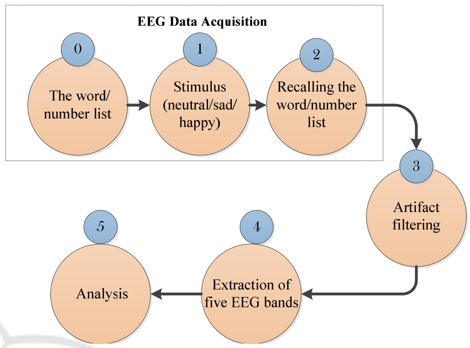

Figure 1: The study outline.

Steps 0-1-2: EEG Data Acquisition.
The impact of three emotions (i.e., neutral /calm, negative/sad, and positive/happy) on memory was analyzed. Each emotion was evoked by a 1-minute exposure to a set of twenty images from the International Affective Picture System (IAPS; Lang, Bradley, and Cuthbert, 2005). Event-related brain potentials (ERPs) were recorded throughout the duration of the test, as explained in Figure 2. An event-related potential (ERP) represents the electrical signal detected by EEG and indicates the effect of the stimulus on the brain, millisecond by millisecond following the stimulus. ERPs are averaged to eliminate the background and provide a 'picture' of the brain activity induced by a stimulus. The rate of these changes may vary from milliseconds to years, depending on what is being learned. Nonetheless, for a simple task such as memorizing 10 numbers/words, it has been shown that ERPs recorded from milliseconds up to 1 minute, would serve as good indicators of the brain changes that took place during the task (Dehaene, 1996). Consequently, this study analyzed short-term ERPs.
Each participant was exposed to each emotional stimulus for 1 minute. Before exposure to a stimulus, a list of words and a list of numbers were presented back to back for 15 s for memorization. The word lists contained ten words as five event-related and five not event-related words. Event-related words include

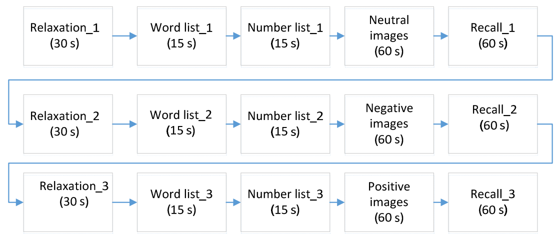

Figure 2: EEG data acquisition setup with five mental tasks.

words that directly relate to the type of emotion triggered. For example, when participants were exposed to negative visual stimuli, such as images of mutilated individuals, the event-related words included 'horror'. For positive visual stimuli, such as images of laughing babies, the event-related words included 'caring'. Immediately after the exposure to each set of emotional stimuli, each participant was asked to recall and write down the words and numbers from the list.

Participants: Participants were informed in advance about the procedure and the topic of research. Each participant signed a consent form after they were informed. A short test was run for 1 minute during which the participant was exposed to 3 neutral visual stimuli in order to prepare the subject for the actual recording. The goal of the short test was to familiarize participants with the recording procedure in order to prevent any anxiety-related EEG measurements. Six male participants (enrolled in a graduate level engineering program at the time of the study) were recruited from the School of Engineering graduate program. All participants had science and engineering education backgrounds and belonged to the same age group (between 20 and 25 years old). The research was approved by the IRB. The fact that no female participants took part in the study is considered as study limitation and is discussed in the conclusion section. Currently, the study has been extended and is ongoing in the hope that investigators would be able to recruit female participants and overall, enlarge the sample size.

Software/EEG Recording: The ANT Neuro system with 625Hz sampling frequency was used for EEG measurements. The ANT WaveGuard cap, non-magnetic and very comfortable, had 32 Ag/AgCl sintered electrode configuration. Electrode cap with electrodes were placed by following the 10-20 electrode placement system (Klem, LuÈders, Jasper, and Elger, 1999). Contact between the WaveGuard electrodes and the subject's head was made by using conductive gel. Preparation time was about 20-30 minutes.

The ASA software incorporates all recording functions for optimal data acquisition. The interface is intuitive and allows displaying online EEG, spectra and frequency maps, averaging, triggers, and response statistics. In addition to the ASA software, EEG Lab in MATLAB was used for the analysis of the EEG data.

Visual Database: A public-domain library with emotion-annotated images (IAPS) was used in this study (Lang, Bradley, and Cuthbert, 2005; Mikels, Fredrickson, Larkin, Lindberg, Maglio, and Reuter-Lorenz, 2005). Each emotion was evoked by exposure to a set of static images based on a dimensional model of emotion. Neutral pictures included sceneries and household objects; positive pictures included food items, children and happy families; negative pictures included snakes, mutilated bodies and scenes of attack and threat. Every picture was presented on a 17-in computer monitor, situated approximately 0.5 m from the participant, leading to an image presentation with a visible angle of 15 degrees horizontally and 11 degrees vertically. Each picture was presented for 3 s. The IAPS catalog numbers for pictures used in this study are as follows: neutral: 5720, 5725, 7035, 7042, 7057, 7547, 7490, 7545, 7041, 7700, 7500, 7180, 7175, 7090, 7080, 7050, 7030, 7020, 7010, 5500; negative: 2205, 9050, 9075, 9220, 2688, 1300, 1120, 3100, 1070, 3000, 1050, 6370, 1090, 3350, 1930, 9040, 9490, 6260, 6510, 2345.1; positive: 2345, 2332, 2530, 2216, 2091, 1600, 2050, 2070, 7405, 2311, 2340, 2341, 7200, 2347, 2208, 2224, 2306, 2374, 7350, 7330.

Step 3: Artifact Filtering
This step removed the eye movement/blinking (most dominant below 4Hz) from the recorded EEG data. A low-pass filter with a cut-off frequency of 50Hz was used.

Step 4: Five EEG frequency ranges
Band-pass filtering was used to extract five EEG bands for each lobe: Delta (0-3.9Hz), Theta (4-7.9Hz), Alpha (8-12.9Hz), Beta (13-30 Hz), and Gamma (31-50Hz). Brain waves of different frequency range are generally associated with different brain activities. The delta band frequency, or delta activity, is highly dominant in deep sleep of adults and infants. Harmony showed that during concentration on a task, the delta activity increased in mental calculation, and also during semantic tasks (Harmony, 2013). The theta activity is seen in sleep, drowsiness of adults, in infants and children. The high theta activity in adults who were awake suggested

that there were some abnormal pathological conditions (Subha, 2010). The alpha activity is present in learning, light trance and relaxed adults. The beta activity is present in alertness states and during learning. Gamma activity refers to the state of multi-tasking, namely simultaneous processing. In this study we analyzed the influence of three emotional states on memory by analyzing the five EEG frequency bands.

Step 5: Analysis
The extracted five EEG bands were analyzed for each task and corroborated with the three emotional states. Data were evaluated along with the results from memory tests. Average band energy was used as a way to compare neuronal activities in mental tasks and three emotional arousals. The average signal energy was calculated as

$$E = \frac{1}{N}\sum_{i=1}^{N}|x(n)|^2 \quad (1)$$

where x(n) is the signal and N is the signal size, $0<N<\infty$.

4 DATA ANALYSIS

In order to evaluate the level of impact perceived by each participant while viewing emotion-annotated images, a self-assessment sheet was provided to participants after completion of the experiment. Participants were asked to score the emotion-annotated images for emotional arousal as not effective, and effective. 20% of the participants found the neutral images not effective and 80% found them effective. All participants found the negative images (thought of as inducing sadness) effective. Interestingly, only 60% of the participants found the positive images (thought of as inducing happiness) effective while the remainder thought positive images did not arouse positive emotions. We concluded that evoking positive emotions was more difficult than evoking negative emotions in study participants. Nonetheless, these percentages of perceived effectiveness of stimuli are sufficient to make our research findings meaningful.

The capacity to memorize of study participants was evaluated by assessing the percentage of words or numbers recalled from a list. More numbers or words recalled from a list was used as an indicator of increased short-term memory retention, which can be conducive to learning. The memory retention was then corroborated with exposure to various emotional stimuli from the visual library.

Data were analyzed as frequency of recalled words, event-related words, and numbers dependent upon participants' exposure to various emotional stimuli that were categorized as neutral, negative (*i.e.*, sadness), and positive (*i.e.*, happiness). Expected frequencies were considered equal for each evoked emotion and this null hypothesis was tested at 0.05 significance level.

A chi-square test of independence was calculated comparing the frequency of recalled event-related words and evoked emotions. A significant interaction was found ($\chi^2(4) = 10.485$, $p < 0.05$). Participants exposed to negative emotions tended to recall more event-related words (56.25%) than participants exposed to positive emotions (52.94%) or neutral emotions (50%). We can conclude that negative emotions can have a strong effect on memory retention and in consequence, when exposed to words related to such emotions, individuals recall these words better.

A chi-square test of independence was also calculated comparing the frequency of recalled numbers and evoked emotions. A significant interaction was found ($\chi^2(7) = 22.030$, $p < 0.05$). Participants exposed to positive emotions tended to recall more numbers (56%) than participants exposed to negative emotions (42%) or neutral emotions (28 %). We can conclude that participants' capacity to memorize numbers was related to emotion: positive and negative emotions increased memory retention when compared to neutral emotion. Nonetheless, exposure to positive emotions increased individuals' capacity to memorize numbers.

A chi-square test of independence was also calculated comparing the frequency of recalled words (not related to any emotion) and evoked emotions. No significant interaction was found at the 0.05 level.
These preliminary findings suggest that any emotion (positive or negative) can have a considerable effect on the capacity to memorize emotion-related words. This finding comes in contradiction to results reported by Valiente et al. (2012), who found that the highest ability to memorize was associated with neutral emotions, such as being in a calm state. Concerning the short-term memorization of numbers, in average, participants recollected 28% numbers after exposure to neutral stimuli, 42% numbers after

exposure to negative emotional stimuli, and 56% numbers after exposure to positive emotional stimuli. This can indicate that, when memorizing numbers, emotional states can lead to increased memory retention, and in particular positive emotional stimuli increase short-term memory retention.

We therefore conclude that the memorization of words that are related in some way to the visual stimulus or the emotion induced by it, leads to increased memory retention. In other words, connecting the word to be memorized with the visual stimulus or the emotion induced by it increased the memorization capacities of study participants. Context is conducive to learning. Moreover, when memory retention, as percentage of words recollected, was compared according to the type of emotional stimulus, it was found that exposure to negative emotional stimuli led to the highest memory retention capacity. Memory retention after exposure to neutral and positive stimuli were lower that after exposure to negative stimuli, with the memory retention being lowest after exposure to neutral stimuli. This indicates that, for words that are related to the type of stimulus, memory retention increases. Emotional state can play a role on how context is conducive to learning. We were surprised by our findings that suggested an increased memory retention of event-related words after exposure to negative emotional stimuli. We suppose that negative emotions may have a more powerful impact on the short-term memory retention, especially when relating the word to the type of negative emotional stimulus.

Analysis of ERPs in response to all five tasks was performed on the basis that ERPs can serve as indicators of brain changes that take place during engagement in learning, such as the memorization of numbers and/or words (Kelly and Garavan, 2005).

Figure 3 shows the average energy distribution for each EEG band (alpha, beta, delta, gamma, and theta) after each of the five tasks (relaxation, memorization of words, memorization of numbers, exposure to visual emotional stimuli, and recall of words and numbers).

Alpha, Beta, Delta, and Gamma activities are related to learning, alertness, mental calculation, and simultaneous processing, respectively (Harmony, 2013; Subha, 2010). The highest average energy for all tasks was observed in the Delta band. When the participants were recalling words and numbers, Alpha, Beta, and Gamma activities appeared slightly higher after the positive emotion arousal compared to

Table 1: Recall percentages according to exposure to various emotional events.

Event / Recall	Neutral emotion	Negative emotion	Positive emotion
Nonevent-related words	40%	32%	34%
Event-related words	50%	56.25%	52.94%
Numbers	28%	42%	56%

neutral and negative emotion arousals. We also observed that activities in all EEG bands were the highest while the participants were memorizing words. This is shown in Figure 4.

Our interpretation of this finding takes into account the participants' strong background in mathematics. As engineering graduate students, participants have had extensive exposure to tasks involving numbers and master mathematical concepts on a daily basis. As such, we conclude that dealing with numbers appears as an easy task to them and in consequence, such task does not require increased brain activity, as assessed by EEG measurements.

5 CONCLUSIONS AND FUTURE WORK

To date, no other studies have been reported to use EEG measurements in the evaluation of the influence of emotional states on short-term memory retention. Participants were engaged in five mental tasks, namely relaxation, memorization of a list of 10 words, memorization of a list of 10 numbers, exposure to neutral/negative/positive visual stimuli, and recall of words/numbers from the lists. ERPs were recorded with the ANT Neuro system with 625Hz sampling frequency, and processed by using the ASA software and EEG Lab in MATLAB. Preliminary results are presented herewith. Based on participants' perception of the test, evoking positive emotions was more difficult than evoking negative emotions. Moreover, study participants recalled more event-related words after exposure to negative emotional stimuli. Participants may find more emotional relevance in words. Memorizing and recalling numbers may be processes more sensitive to the influence of emotional states. That said, percentage of recalled numbers was higher after exposure to positive emotional stimuli. So, there is an evidence that positive emotions can lead to increased memory retention.

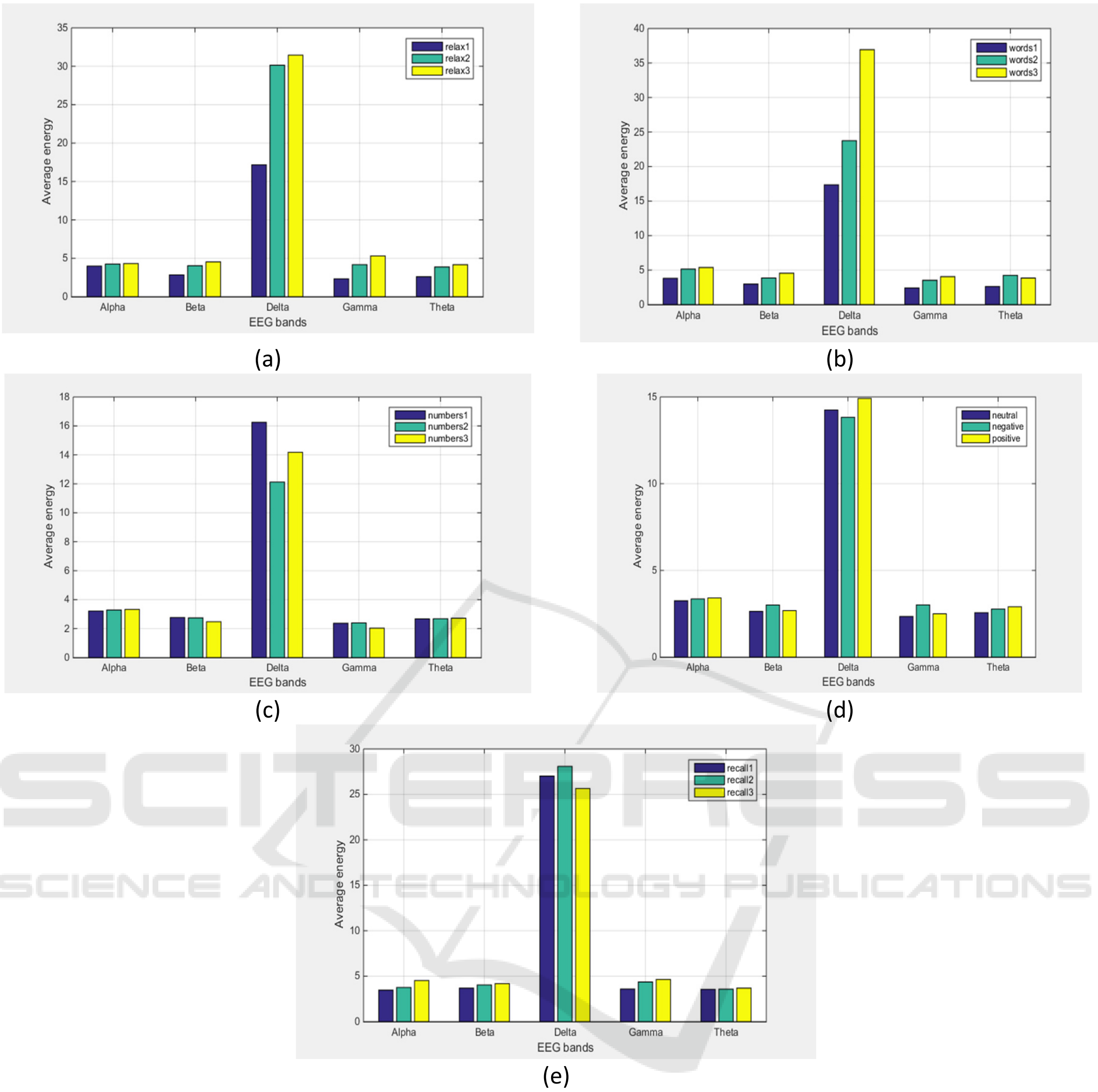

Figure 3: Average energy (E) distribution for events and EEG bands. (a) Relaxation; (b) Memorization of words; (c) Memorization of numbers; (d) Emotional arousal; (e) Recall of words and numbers. Blue bars indicate average energy levels of corresponding ERPs after exposure to neutral visual stimuli; green bars indicate average energy levels of ERPs after exposure to negative visual stimuli; yellow bars indicate average energy levels of ERPs after exposure to positive visual stimuli.

Another important finding is that participants recalled more event-related words from the list when exposed to emotional stimuli related to the words. For example, words such as ‘caring’ tended to be recalled easier when exposed to positive emotional stimuli, such as images of families. We can conclude that context is conducive to learning.

Although we collected valuable evidence of the influence of emotional states on short-term memory retention, our interpretation of the data is limited due to the small number of participants included, their background (graduate students in engineering), and gender (six male participants). In the future, we plan to extend the study to include more participants, in particular females and individuals from different academic backgrounds, such as humanities and social sciences.

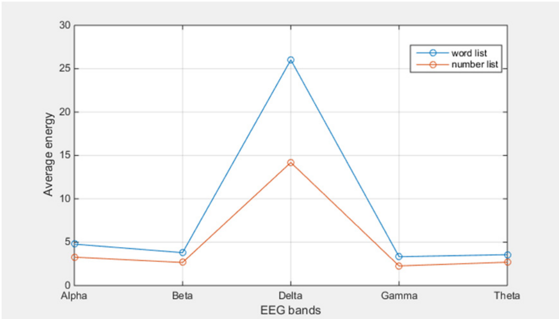

Figure 4: Average energy for EEG bands recorded during the memorization of words and numbers. The blue line corresponds to the memorization of words, and the red line corresponds to the memorization of numbers.

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