Brain Behavior in Learning and Memory Recall Process: A High-Resolution EEG Analysis

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Abstract—**Learning is a cognitive process, which leads to create new memory. Today, multimedia contents are commonly used in classroom for learning. This study investigated brain physiological behavior during learning and memory process using multimedia contents and Electroencephalogram (EEG) method. Fifteen healthy subjects voluntarily participated and performed three experimental tasks: i) Intelligence task, ii) learning task, and iii) recall task. EEG was recorded duration learning and memory recall task using 128 channels Hydro Cel Geodesic Net system (EGI Inc., USA) with recommended specifications. EEG source localization showed that deep brain medial temporal region was highly activated during learning task. EEG theta band in frontal and parietal regions and gamma band at left posterior temporal and frontal regions differentiated successful memory recall. This study provide additional understanding of successful memory recall that complements earlier brain mapping studies**

Keywords— **learning, memory recall, intelligence, electroencephalography (EEG), spectral analysis.**

I. INTRODUCTION

Learning and memory are two fundamental inter-related cognitive processes. There are important conceptual differences in learning and memory in the areas of neurosciences and cognitive neuropsychology. Traditionally, learning is the change in behavior because of an experience; while memory is the ability to store and recall learned experience [1]. In other words, learning is considered as the first step for new memory creation and memory is the internal mental records that we maintain in our brain. In neuroscience and neuro-psychology, learning is the process that brings changes in the neurons synaptic levels and leads to create new memory formation while memory is the retention and retrieval of learned information. A process of long-term potentiation (LTP) is used in learning activity to produce changes in the connections (synapses) between neurons that are essential to obtain and store new information [2]. As we gain new information or experience, our brain creates new connections between neurons. By repeatedly recalling or rehearsing, these connections become strengthen.

Dual code theory [3] states that memory performance is enhanced if the information is presented in both visual and auditory modes. Further, research studies on modality effects were shown that multimedia audio-visual contents improves learning performance and leads to lower cognitive load on working memory as compared to presenting information in a single modality [4, 5].

Electroencephalography (EEG) has widely been adopted for investigation of brain behavior in different cognitive tasks e.g. learning, working memory, short-term and long-term memory [6], decision-making, intelligence tests [7], mental arithmetic tasks [8], problem solving under stress, playing video games [9], pattern-matching, and recognition [10]. Changes in EEG measures and features have been associated with these cognitive activities [11]. EEG spectral analysis and source estimations are commonly applied to estimate neuronal changes during different mental tasks.

The aim of this study is to investigate the brain physiological behavior during memory retrieval process after learning from computer animations (audio-visual contents), using EEG spectral analysis. The EEG dynamics during memory recall and the regions that discriminate correct from incorrect memory performance are explored. The paper is organized as follows: section II describes the detail methodology, section III discusses the results and section IV summarizes the conclusion and future work.

II. METHOD

A. Subjects

Sixteen healthy volunteers participated in the experiment. All of them are university students and their age range was 20-30 years. They had normal or corrected to normal vision and free from hearing impairments. The subjects were also free from any medication, neurological disorders that may affect the experimental results.

B. Consent form

All the subjects have signed informed consent documents prior to start experiment. It has a brief description of the research study concerned to human.

J. Goh (ed.), *The 15th International Conference on Biomedical Engineering*, IFMBE Proceedings 43,
DOI: 10.1007/978-3-319-02913-9_174, © Springer International Publishing Switzerland 2014

C. Ethics Approval

This research work was approved by Research Committee of Universiti Teknologi PETRONAS (UTP) and Human Research Ethics Committee of Universiti Sains Malaysia.

D. Tasks

The experiment consists of three main tasks 1) Intelligence task, 2) Learning task, 3) and recall task. In the intelligence task, the Raven's Advance Progressive Matrices test (Raven's APM) was selected to assess the individual general cognitive ability. For detail about Raven's APM, see our previous study [10].

In learning task, three animations of total duration approx. 8 minutes were selected for learning purpose. The animations were repeated twice and were related to science subject. The contents of the animations were 1) Human Skull and its structure, 2) Brain Anatomy and functions, 3) Brain disorders (Alzheimer disease). The selected subjects have no or minimum prior knowledge about the animations' contents. Their background knowledge about the contents was assessed by asking general verbal questions about human skull, brain parts, and brain diseases. The recall task consists of twenty multiple-choice questions (MCQs) related with animations' contents. Each MCQ consist of question of missing information and with four choices, among the four choices only one choice was the correct answer. Thirty seconds time was specified for each MCQ to answer. Numeric keys from 1-4 were specified for the four choices.

E. Procedure

All the subjects performed the experiment individually. They were seated in partially sound-attenuated EEG experiment room and briefed about the experiment tasks. First, they were performed Raven's APM for intelligence assessment. They twice watched three selected animations of duration eight (8) minutes each. There were five minutes break between the second and third repetition. After completion of learning task, the subjects were given thirty minutes retention time for recall task. During the retention period EEG cap was set as per recommended procedure and baseline EEG was recorded (eye open and eye closed). Immediately, after the retention period, the subjects were performed the recall task. Subjects were instructed to response a correct answer by pressing a button from 1-4. Both animations and recall task were presented on 41-inch TV screen, which was kept at a distance of 1.5 meter away from subject's eyes.

F. EEG Recording

EEG data were recorded with a sampling rate of 250 samples per seconds using 128-channels Hydro Cel Geodesic Net (Fig.1). The impedance of all the electrodes was kept below 50KΩ and Cz was used as a reference. Data conditions were 1) Eye closed for 5 minutes, 2) Eye Open for 5 minutes, 3) and Recall Task for 10 minutes (maximum). Recall task was implemented in E-prime to stamp EEG data for MCQ appear on screen and subjects response by pressing button.

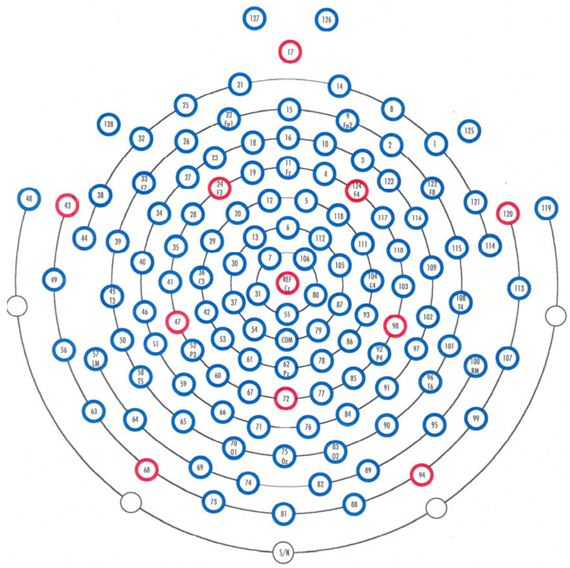

Fig. 1 Electrodes Placement (EGI sensor net)

G. Data Analysis

EEG Preprocessing: A band pass filter (1-48Hz) was on raw EEG data, artifacts were detected and exported data into .mat files format using Netstation software of EGI. Ocular artifacts were removed by using Gratton & Coles method [12] and visual inspection.

Power Spectral Analysis: EEG data of memory recall task was divided into twenty segments (20 MCQs) for each subject. A Fast Fourier Transform (FFT) was applied on successive 2 seconds segments (500 points) with 50% overlapping (250 points) to compute the power spectrum. Theta and gamma bands power was extracted and separated as per correct and incorrect responses for each subject. EEG power of theta and gamma power for correct and incorrect recall was averaged within subjects and grand averaged across subjects.

EEG Source Estimation: Standardized low resolution brain electromagnetic tomography (sLORETA) was applied from *netstation* software (EGI Inc, USA) to estimate the sources in the learning task.

III. Results & Discussion

The intelligence test was performed to avoid an individual with exceptionally high or low cognitive abilities which may affect the experimental results as an outlier. However, all the subjects were scored 66.85±13.5% in the intelligence test. There was no such subject found to exclude from analysis.

In the learning task, medial temporal lobe was found active. The deep brain temporal lobe (limbic region) activation for a single subject is presented in Fig 2. This result was common in the rest of the subjects. Comparable results were reported in previous fMRI studies about medial temporal lobe activation during learning contents [13] and connection with frontal lobe in memory performance [14].

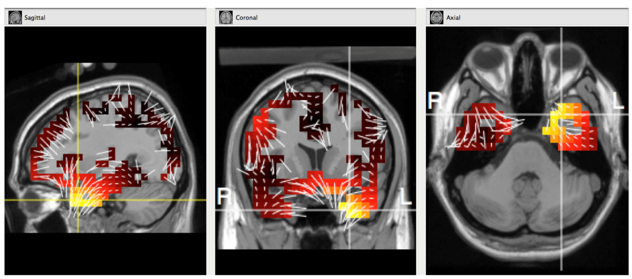

Fig. 2 Temporal lobe activation during learning task

In the memory recall task, 15 subjects recalled 79.66±10.92% of the studied contents. Theta mean power was high at frontal and parietal cortical regions in correct memory recall (Fig. 3) then incorrect recall (Fig. 4). In the incorrect recall there is more theta activation in the temporal side than correct recall (Fig. 5).

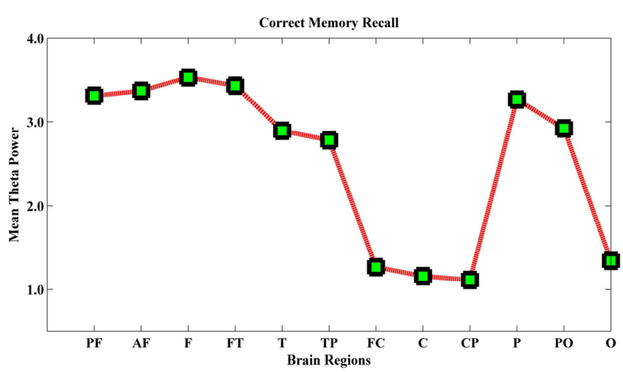

Fig. 3 Region-wise theta mean power (4-7Hz) in correct recall

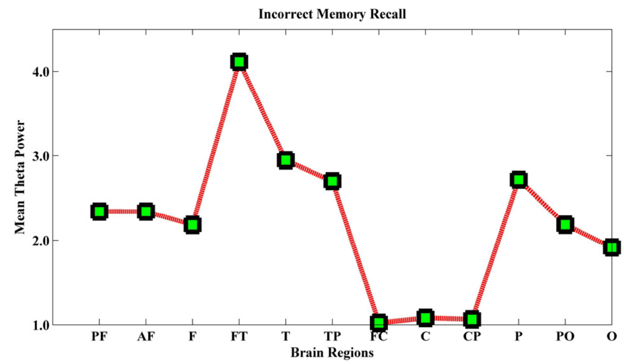

Fig. 4 Region-wise theta mean power (4-7Hz) in incorrect recall

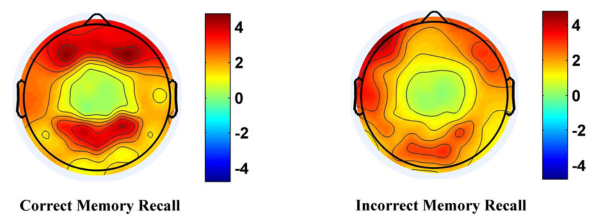

Fig. 5 Grand averaged theta activity (4-7Hz)

Gamma mean power was found very high in left posterior temporal and left frontal region in correct recall. However comparable activation, but lower in incorrect case was observed in the right frontal region in both correct and incorrect recall (see Fig. 6 to Fig. 8). This result was consistent with earlier related intracranial EEG study [15], which discriminated true from false memory by gamma oscillation in temporal lobe.

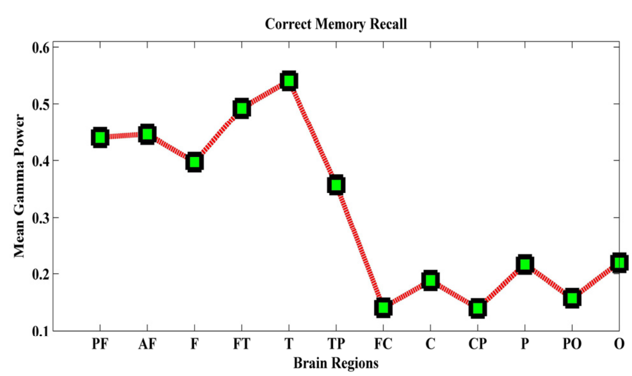

Fig. 6 Region-wise gamma mean power (31-48Hz) in correct recall

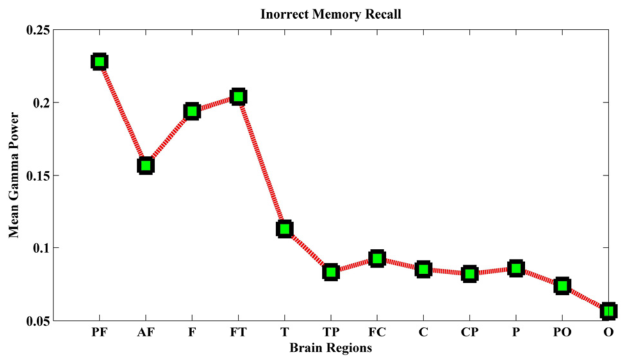

Fig. 7 Region-wise gamma mean power (31-48Hz) in correct recall

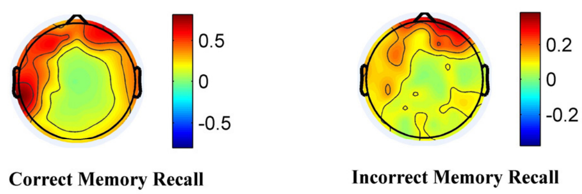

Fig. 8 Grand averaged gamma activity (31-48Hz)

IV. Conclusions

EEG theta band in frontal and parietal region and gamma band at left temporal lobe differentiated successful memory recall. Activated frontal and temporal regions indicated that brain perceived both verbal and visual information during learning from multimedia contents, and brain combined both the modality for learning and creating new memory. EEG high frequency band in temporal and low frequency at frontal and parietal regions reflected successful memory recall. Future work can be implemented with correct vs. incorrect memory recall performance and connection with intelligence score.

Acknowledgment

This research was funded by University Research Internal funding (UREF: 10/2012), Universiti Teknologi PETRONAS, Perak, Malaysia.

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