EEG Feature Extraction with Fast Fourier Transform for Investigating different Brain regions in Cognitive and Reasoning Activity

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Abstract— **In this study, cortical brain activity during a pattern matching task (PMT) was measured by employing electroencephalography (EEG). The EEG data were recorded from 128 scalp locations during a pattern-matching task and in rest conditions (eyes open and eyes closed). Spectral Analysis of EEG frequency bands reflected a significant (*p*<0.025) difference between baseline and PMT task. The EEG activity in slow waves (delta: 0.5 to 3 Hz and theta: 4 to 7 Hz) was high during PMT in frontal regions, while EEG activity in fast waves (Beta: 14 to 20 Hz and Gamma: 21 to 30 Hz) was reduced in parietal and occipital regions as compared to the frontal region. The changes in EEG medium waves (alpha: 8 to 13 Hz) was high in frontal, central, and temporal regions, while depressed in parietal, parieto-occipital and occipital regions. The results show high cortical activations in different brain regions during solving pattern-matching task as compared to baseline resting conditions. The study has implications for thinking and decision-making situation, such as object recognition, visual comparison, and consumer choice.**

Keywords—EEG Signals, Feature Extraction, Fast Fourier Transform (FFT), Power Spectral Density, Cognitive and Reasoning Task

I. Introduction

Electroencephalography (EEG) is a well-known brain imaging modality used for diagnostics of various brain disorders in clinics and for investigating brain processes in research labs. EEG has potential advantages, including low cost, high temporal resolution, direct recording of electrical potentials, easy to use, and user-friendly, over other neuroimaging methods such as fMRI, MEG, or fNIR [1]. EEG acquisition is a sensitive procedure and needs expertise and care to capture good EEG data for reliable diagnostics or analysis for research. It is very sensitive to physical events and the external environment, which can induce unwanted changes in the data recordings. EEG is widely adopted for investigation of brain behavior in different cognitive and attention-demanding tasks, such as problem-solving, decision-making, intelligence test, mental arithmetic task, recognition and pattern-matching. The fluctuations in the voltage potentials elicited by the neuronal networks in the form of EEG activity have been associated with different cognitive activities [2]. Several EEG studies investigated brain behavior in cognitive tasks [3], working memory [4], mental arithmetic tasks [5] and intelligence [6]. Previous studies had reported the linkages of EEG signals with certain cognitive activities. The trend of changes in EEG signals concerning the cognitive activities is varies in different cortical regions of the brain. Recent research studies have reported the connections of EEG signals and its frequency waves in numerous cognitive tasks, such as creative thinking [7], fluid intelligence ability [8], decision-making [9], and complex mental reasoning tasks [10]. In the previous studies, various techniques have been adopted for analysis of EEG data and mining useful information. The standard and common method of EEG signals analysis is the EEG power spectrum, in which the time series data is transformed into frequency domain and reflect the strength of the EEG activity in certain frequency, measured in hertz (Hz) as a unit. The power spectrum is widely adopted EEG measure, which has dimensions of power or energy per unit in EEG signal. It reflects the strength of synchronous neural activity in brain cortical areas, which have associations with cognitive activities. For instance, Reference [11] reported that power of low frequency EEG waves discriminated between low ability and high ability of fluid intelligence. Similarly, it is investigated that EEG energy in low frequency successfully classified the cognitive activity from resting state EEG [12]. In another study [9], it is examined that EEG theta power was significantly high in reasoning task as compared to resting state in the pre-frontal and frontal regions. It is reported that EEG power in alpha and gamma frequency bands are strongly associated with visual learners in a multimedia learning and memory tasks [13].

This study aims to investigate the brain behavior in three experimental conditions: pattern-matching task (PMT) and resting states, eyes open (EO) and eyes closed (EC). EEG acquisition was done over 128 scalp locations and then analyzed at different brain regions. The EEG power measure was used to observe the changes in the brain electrical activities at different regions. Fast Fourier Transform was adopted as a method for analysis and extracting features from EEG data. Extracted feature values were verified by using statistical tests for detecting differences in the experimental conditions.

The remaining paper is organized as: Section II describes the methodology adopted in this study, section-III presents the results and section-IV gives the conclusion.

II. Methodology

A. EEG Data and Participants

The EEG data utilized in this analysis is a part of a previous research study [14] which was approved by the Human Research Ethics Committee Hospital Univerisiti Sains Malaysia (HUSM). The data includes six participants who joined the experiment voluntarily. All participants had normal or corrected to normal vision and were free from any neurological disorder. Their age range was between 18 and 28 years. They signed the subject's informed consent form prior to starting the experiment.

B. Pattern Matching Task

Raven's Advance Progressive Matric (Raven's APM) is a standard psychology test, used to assess the fluid intelligence level. The test requires mental reasoning, pattern matching, and decision-making skills. In this analysis, the Raven's APM is used as a pattern-matching task. It consists of two modules 1) one having 12 patterns, which were used for practice and 2) another one consists of 36 patterns, used for assessment. Each pattern/question had score 1 (correct) and score 0 (incorrect answer). The recommended duration for practice is 10 min and for assessment 36 min. Each problem was visually presented on computer screen as a pictorial pattern with a missing element and possible eight solutions (see Fig. 1).

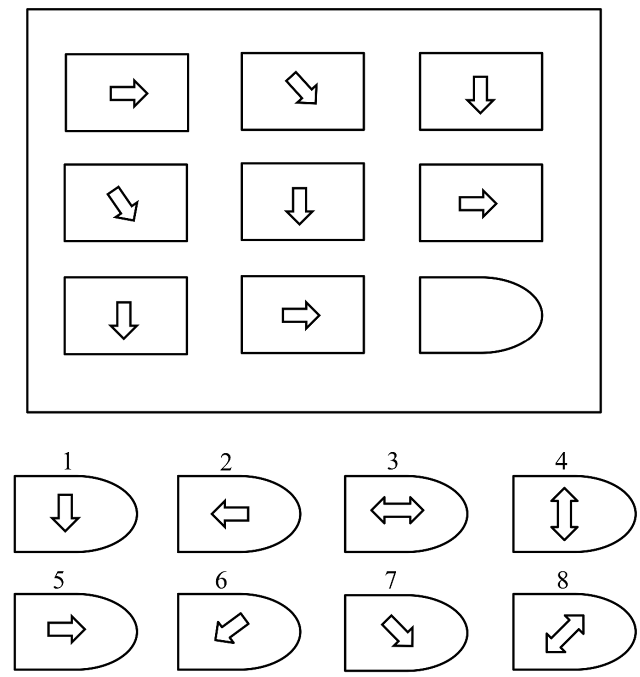

Fig. 1. A Sample of Raven's Advance Progressive Matric Design [8]

C. Procedure

Participants were brief about the experiment and asked to sign the consent form. They were seated in a partially sound attenuated experiment room. Participants performed a task of 36 problems; each problem consists of a pattern with a missing element and corresponding four possible solutions. Participants did practice on twelve similar but easy problems before going to the actual task. EEG was recorded by using EGI 128-channel Hydro Cel Geodesic Net (See Fig.2). Cz was used as a reference and impedance was kept below 50kΩ. EEG was recorded at rest condition, and then during performing pattern-matching task with sampling rate 250 samples per second.

D. EEG Preprocessing and Feature Extraction

The EEG was analyzed over twelve scalp regions, as shown in Fig. 2. EEG data were filtered using 0.5-48Hz bandpass filter. Eye blinks, eye movement, and muscle artifacts were removed using Independent Component Analysis (ICA) of MATLAB free toolbox (EEGLAB). The preprocessed EEG data were then further analyzed for feature extraction using power spectral density. Region wise spectral analysis was performed, and electrodes were grouped region wise using the standard electrode placement. The labels used for twelve regions in the figures were PF: Pre-Frontal, AF: Anterior Frontal, F: Frontal, FT: Fronto-Temporal, FC: Fronto-Central, T:Temporal, C: Central, CP: Centro-Parietal, TP: Tempo-Parietal, P: Parietal, PO: Parieto-Occipital, O: Occipital, EEG spectrum was divided into five frequency bands, including delta: 0.5-3Hz, theta: 4-7Hz), medium waves (alpha: 8-13Hz) and fast waves (Beta: 14-20Hz and Gamma: 21-30Hz frequency bands, see Fig. 3. The range of these frequency bands is not strictly fixed, and slightly varies as reported by different previous studies. Fourier Transform was used on successive 2 seconds data (500 data points) with 50% overlapping (250 data points) and maintained the NFFT greater than the window size, i.e., 512 points in computing the power spectrum. To determine power spectral density of each electrode, the FFT was applied on each electrode and then averaged the values of all the electrodes in each selected region.

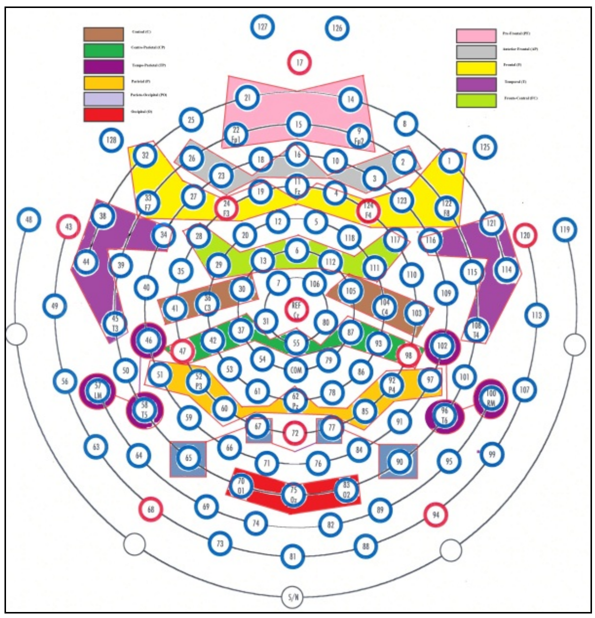

Fig.2. HydroCel Geodesic 128-channel Net

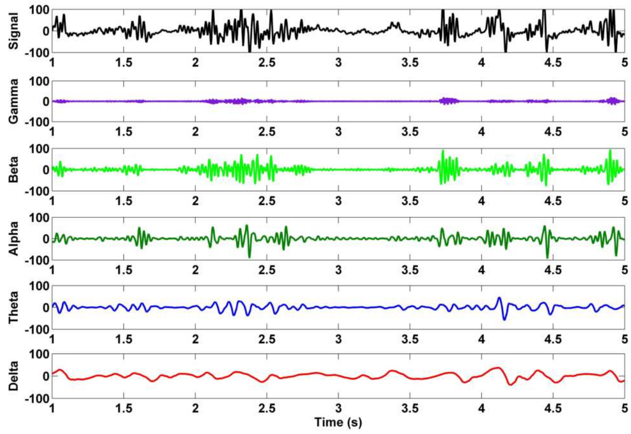

Fig.3. EEG Waves in different Frequency Bands

E. *Statistical Analysis*

The extracted EEG feature values were statistically verified for detecting differences among the three experimental conditions. As the sample size was small and EEG was recorded in three different conditions:1) Pattern-matching Task, 2) Baseline eye closed (EC) condition, and 3) Baseline eye open (EO) condition. Therefore, Freidman non-parametric statistical test was used to determine the significant difference among the three conditions. After detecting a statistically significant difference, the next level of analysis includes further testing to find the most significant condition among the three by employing Wilcoxon signed ranked test as post-hoc analysis.

III. Results and Discussion

Region wise analysis was done by using selected electrodes from the 128 electrodes. The selection of electrodes was based on standard EEG electrodes placements arrangements, such as 10-20 system, and 10-10 system. The spectral analysis of EEG frequency bands slow waves (delta: 0.5-3 Hz and theta: 4-7 Hz), medium waves (alpha: 8-13 Hz) and fast waves (Beta: 14-20 Hz and Gamma: 21-30 Hz) were shown clear difference of EEG activity between PMT and baseline conditions (see Fig. 4 to 8). Significant (*p-value*<0.025) positive mean difference in EEG power value of slow waves at frontal regions and significant (*p-value*<0.025) negative mean difference in EEG power of medium waves at parietal and occipital regions were observed between PMT and conditions.

All frequency bands differentiated the PMT from baseline rest conditions. Logical thinking and reasoning related changes in EEG were observed in slow waves all over the scalp regions, except parieto-occipital (see Fig. 4 and Fig. 5). Further, the changes in EEG were significant in frontal regions during PMT as compared to baseline (EC, EO). EEG changes in medium waves were also shown obvious positive difference in frontal regions and negative difference at parietal, parieto-occipital, and occipital regions (see Fig. 5). Except parieto-occipital region, high EEG activity was observed all over the scalp area in slow, medium, and fast waves (see Fig. 7 and 8). The results show the key differences among the PMT and resting states in multiple regions, and especially more prominent in the frontal regions. In the occipital regions, the resting state eyes closed condition shows high activation in alpha waves (8-13 Hz) as compared to PMT and eyes open conditions (see Fig. 6), which is in line with previous studies [14].

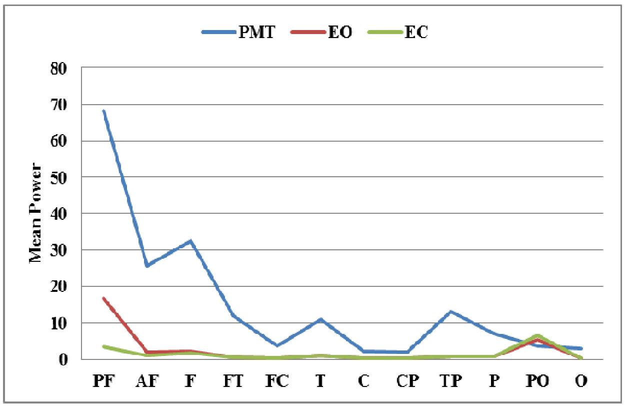

Fig. 4. EEG slow waves (delta: 0.5-3 Hz)

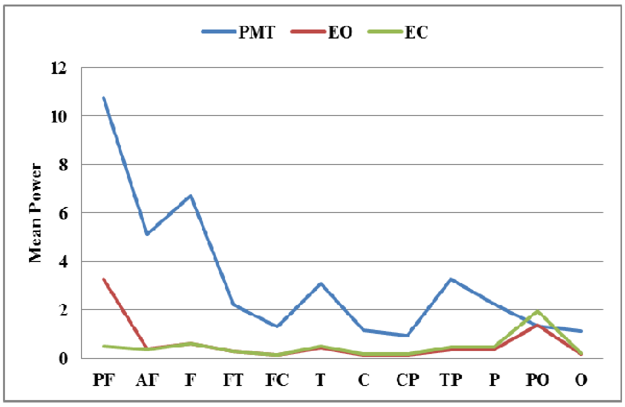

Fig. 5. EEG slow waves (theta: 4-7 Hz)

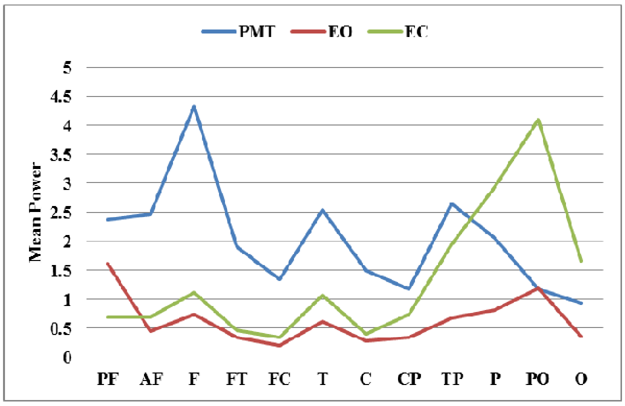

Fig. 6. EEG medium waves (alpha: 8-13 Hz)

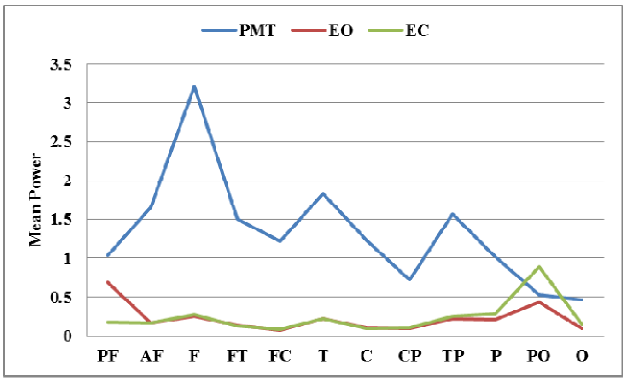

Fig. 7. EEG fast waves (beta: 14-20 Hz)

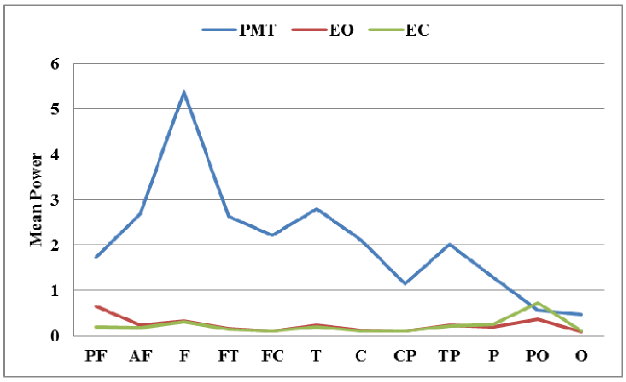

Fig. 8. EEG fast waves (gamma: 20-30 Hz)

IV. Conclusion

The analysis concludes that EEG spectral analysis using FFT techniques clearly differentiated the cognitive condition from the resting states, eyes open and eyes closed conditions. The reasons of such differences could be that in the PMT, the participants were involved in a high level of thinking, reasoning, recognition of patterns, and decision-making processes; while in the resting conditions, the participants were relaxed, and no cognitive activity was performed. During PMT, high EEG activity in slow waves at frontal regions and suppressed EEG activity in medium and fast waves at parietal and occipital regions reflected logical and analytical reasoning and use of working memory for pattern-matching task (PMT) as compared to baseline rest conditions. Further research can be carried out on a large enough sample size for more detailed analysis and to generalize the results of this study.

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