Brain Behavior during Reasoning and Problem Solving Task: An EEG Study

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***Abstract*-The capacity of relational reasoning is to find relationship, comprehend implications, analyze novel problems and draw conclusion. This study investigated brain behavior and dynamic neural activity during Raven's Advance Progressive Matrices (RAPM), which requires strong cognitive reasoning and thinking to select a solution, by using electroencephalogram (EEG). EEG was recorded all over the scalp of eight healthy volunteers using 128-channel Hydro-Cel Geodesic (EGI Inc., system). Brain activation was dominant duration reasoning and problem solving process in pre-frontal lobe and parietal lobe as compared to baseline condition in all the subjects consistently. Theta band (3.5-7.5Hz) was significantly (p<0.025) high in reasoning process at frontal lobe as compared to eye closed and eye open conditions. Results showed high frontal theta activity in problem solving, which requires substantial reasoning and thinking skills.**

Keywords: brain behavior, reasoning and problem solving, Electroencephalography

I. INTRODUCTION

Reasoning and problem solving are inter-related processes and have deep involvement in our daily lives. These processes may have effect on individual as well as on other people. Problem solving refers to the process of choosing one among alternative several available options based on some comparison or matching of the characteristics of the existing options with expected reward or loss. The comparison or matching among several possible alternatives leads to the reasoning process. Several disciplines like neurosciences, neuro-psychology, cognitive and behavioral psychology are involved in the research on human reasoning and decision-making. Extensive research work has recently been done in several disciplines like neurosciences, neuro-psychology, cognitive and behavioral psychology to understand the neurological and neuro-functional mechanism of these processes.

In modern research, two brains mapping techniques — Electroencephalography (EEG) and Functional magnetic resonance imaging (fMRI) have been widely adopted. The former is famous for its high temporal resolution, which is helpful to study the brain dynamics. Conversely, the latter allows direct estimation of neuronal activation with high spatial resolution that assists to study deep brain activation. Additionally, researchers implemented several mental tasks during experiments to stimulate the brain and make an environment of reasoning, thinking, and problem solving, which actually helps in these processes. These tasks include stimulus like digits, letters, pattern matching, images, figures, colors, and geometrical objects etc.

Recent research studies associated EEG bands in different brain regions with complex intelligence test, arithmetic task, and other mental load demanded tasks. Prefrontal [1] and parietal brain regions [2] linked with higher cognitive information processing, and linked the connection between reasoning and problem-solving ability and complex cognitive performance [3]. Right lateral prefrontal cortex activation was reported in individuals' overall selection performance in a dynamic decision task [4]. Another study reported that right hemisphere anterior superior temporal gyrus involved and high gamma activity in problem solving task [5].

EEG power analysis and entropy are frequently applied features in previous studies for investigation of brain neuronal activity in cognitive tasks [6, 7]. EEG mean power and complexity analysis was investigated in IQ task and reported high complexity in IQ task than rest condition [8]. Scalp potential and autonomic nerve activity was simultaneously studied in intelligence test [9] and reported high heart rate variability as compared to eye-closed condition. Theta and alpha bands are mostly associated with performance in mental tasks and individual variation assessment [10]. Strong correlation between sub-bands of alpha activity and performance in intelligence task was reported by [11]. Another study investigated high alpha activity in problem solving and intelligence tasks [12]. Alpha and theta even-related synchronization/de-synchronization (ERS/ERD) was related with cognitive performance [7]. However, there are some studies, who reported reverse results [13].

The aim of this study is to investigate the relationship of brain behavior during reasoning and complex problem solving process using EEG spectral analysis. We emphasize the relationship of brain activation in reasoning and problem-solving task. The following sections of the paper as, section-II describes the methodology, section-III discusses the results and section-IV provides conclusion.

II. METHODOLOGY

A. *Subjects:*

Eight right-handed adult volunteers (all male) participated in this study. All participants had normal or corrected to normal vision and free from any neurological disorder. Their age range was between 20 and 30 years. They signed subject informed consent form before prior to start experiment as per procedure of the Research Ethics committee of Universiti Teknologi PETRONAS (UTP).

B. *Reasoning Task:*

A Raven's Advance Progressive Matric (Raven's APM) was used in this experiment for assessment of brain behavior in reasoning and problem solving process [14]. It consists of two modules 1) one having 12 patterns, which was used for practice and 2) another one consists of 36 patterns, used for assessment. Each pattern/question consists of 3x3 cells structure, in which each cell contains a pattern of geometric features except the blank cell (bottom-right). There are eight possible options for the blank cell given below the pattern. Each correct answer had score '1' and score '0' for 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). The subject's task is to judge the available information in the given pattern and select one best answer among the given eight options.

C. *Procedure*

Participants were brief about the experiment and asked to sign 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.3). Cz was used as a reference and impedance was kept below 50kΩ. EEG was recorded at rest condition, and then during performing reasoning task with sampling rate 250 samples per second.

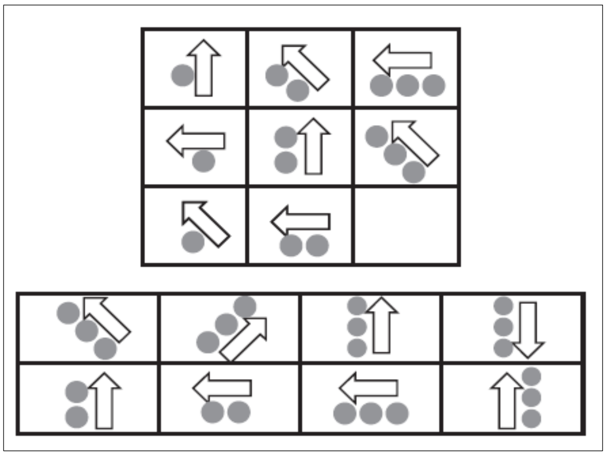

Figure 1. A simple Raven's style pattern [15].

D. *EEG Data Analysis*

The EEG was analyzed over frontal regions as shown in Fig 3. EEG data were filtered using 0.5-48Hz band pass filter. Eye blinks, eye movement, and muscles artifacts were removed using Independent Component Analysis (ICA) of matlab free toolbox (EEGLAB). Region wise spectral analysis was performed. Power spectral density was computed using p-welch method on two seconds segment (500 points) with 50% overlapping for each electrode, and then averaged the value of all the electrodes in each selected region.

For selecting one option, the data of two seconds duration were analyzed before response, and for reasoning and thinking process, data were analyzed from onset to two seconds before response (see Fig. 2).

E. *Statistical Analysis*

As the sample size was small and EEG was recorded in three different conditions 1) RAPM 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. Further, most significant condition was determined by employing Wilcoxon signed ranked test as post-hoc analysis.

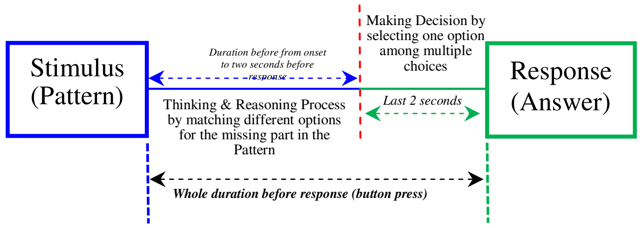

Figure 2. Experiment Design Structure

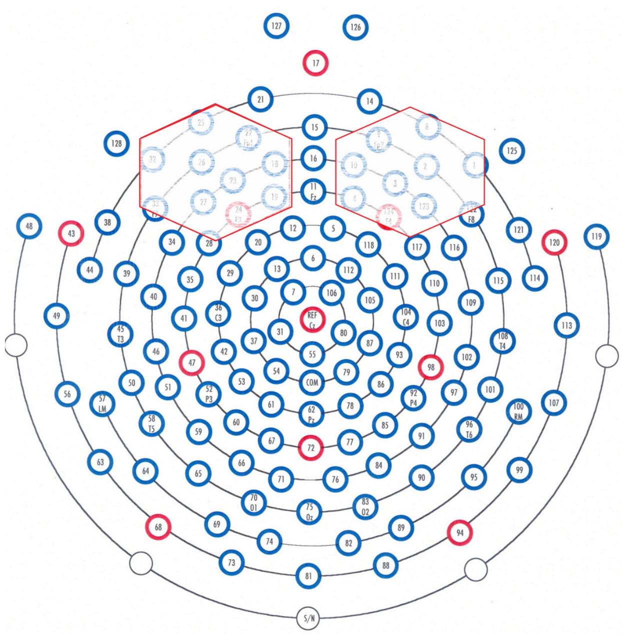

Figure 3. Electrodes Placement (HydroCel Geodesic Net) (regions of interest are under red hexagons)

III. Results & Discussion

The results of EEG mean power in theta band at frontal lobe for RAPM and rest conditions (EC, EO) are shown in Fig. 4. The results indicated significant (p<0.025) mean difference at frontal regions PF, AF, F and FT. Comparison of theta and alpha bands in RAPM task at frontal lobe is presented in Fig. 5. The findings show substantial increase in theta activity than alpha activity. The activation results during reasoning process at the start of question display and during the last two seconds (before response) for a single subject are presented in Fig. 6. The results showed theta activity distribution over whole scalp. From these results, the low theta activity is obvious in centro-parital, and occipital region during the thinking process.

Complex reasoning and problem solving tasks needs a strong cortical network to encode and understand the problem information, working memory operation for comparison of alternative options for solution, and inferring a conclusion. The EEG results presented here finally demonstrated that reasoning and thinking during problem solving task requires the frontal lobe strong involvement. Theta (3.5-7.5 Hz) activity increases in frontal lobe at both hemispheres (see Fig.3) during the reasoning process—searching among several alternative options to choose one option. Highly reduced theta activity was observed at certro-parietal region in reasoning process.

In the selection of best choice among given possible options in RAPM task two seconds before response, the same activity (3.5-7.5Hz) was partially high at frontal lobe (see Fig.7.) and reduced activity over other scalp regions. Overall, we found frontal lobe dominant in RAPM task as compared to resting conditions, which reflects the high theta activity in the thinking and reasoning process.

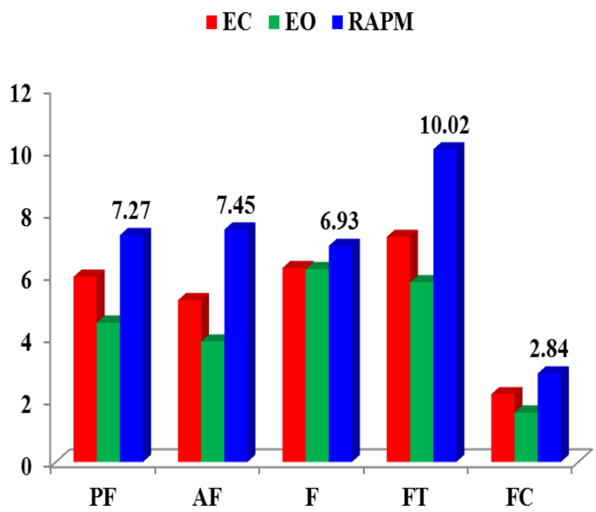

Figure 4. Theta (3.5-7.5Hz) activity in reasoning and rest conditions (PF: Prefrontal, AF: anterior frontal, F: Frontal, FT: Fronto-temporal, FC: Fronto-centaral), y-axis indicates averaged power over region of all the subjects

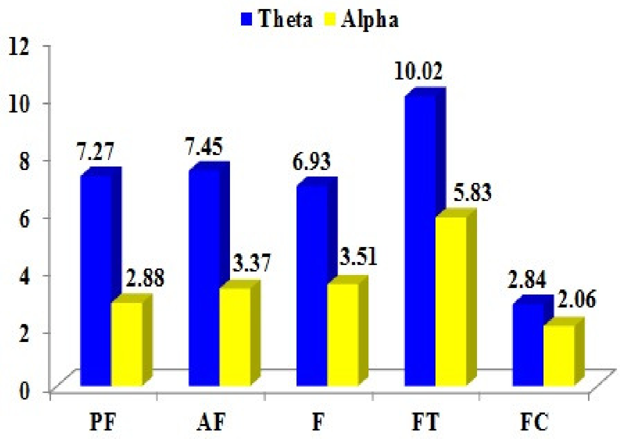

Figure 5. Theta (3.5-7.5Hz) and Alpha (8-13Hz) activity in reasoning process at frontal regions (PF: Prefrontal, AF: anterior frontal, F: Frontal, FT: Fronto-temporal, FC: Fronto-centaral), y-axis indicates averaged power over region of all the subjects

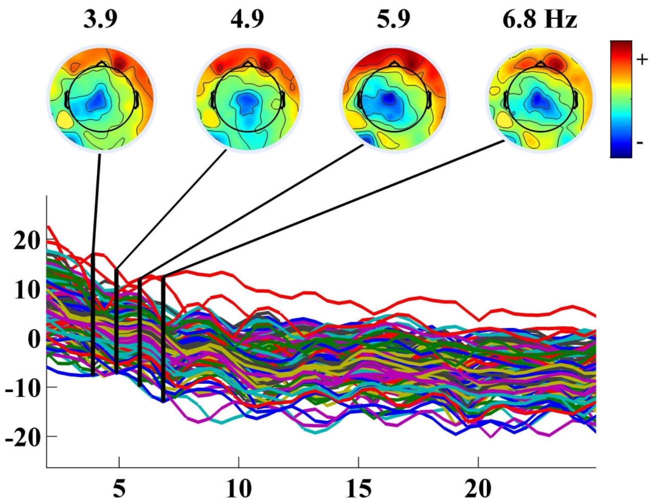

Figure 6. Theta (3.5-7.5Hz) activity during reasoning and thinking process (a single subject's theta activity distribution over whole scalp). The x-axis shows frequency and y-axis indicates signal power in 10*log $_{10}(\mu V^2/Hz)$

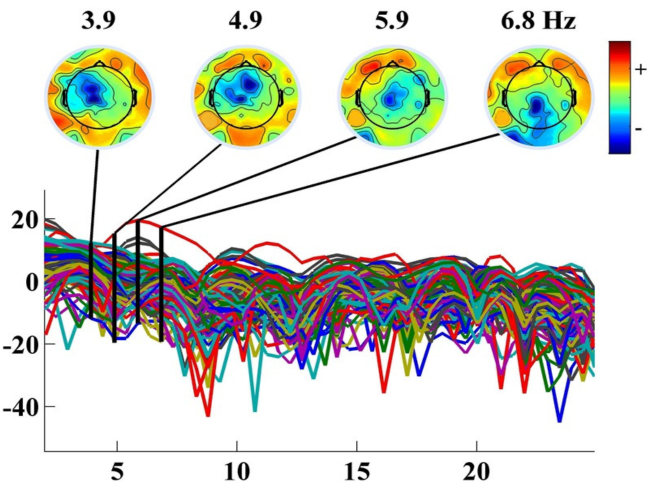

Figure 7. Theta (3.5-7.5Hz) activity in decision-making (a single subject's theta activity distribution over whole scalp 2 seconds before response).The x-axis shows frequency and y-axis indicates signal power in 10*log $_{10}(\mu V^2/Hz)$

IV. Conclusion

Increase in theta and decrease in alpha activity at frontal regions distinguished mental thinking and reasoning process from rest brain states. Further, high frontal activity in RAPM task was due to working memory involvement during matching and evaluating the given options and inferring the best answer. EEG has the capability to separate the involvement of diverse neural mechanisms in reasoning and problem solving situation. Future work can be done with large sample size and other standard analytical tests.

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