The 9th International Conference on Cognitive Science

Asymmetry pattern of resting EEG for different IQ levels

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Abstract

The aim of this work is to analyze asymmetry pattern of resting brainwave for different intelligence levels. EEG signals were measured from fifty samples and three IQ levels were established from Raven’s Progressive Matrices. Asymmetry scores for alpha and beta waves were computed by subtracting ln-transformed ESD of the left from right hemisphere. The study elucidate that individuals in high IQ level exhibit a balanced brain with smaller asymmetry score for alpha and beta waves compared to medium and low IQ levels. Meanwhile, the medium and low IQ levels exhibit unbalanced brain alpha and beta activity with greater asymmetry values.

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Keywords: Electroencephalogram (EEG); intelligence quotient (IQ); brain asymmetry; Raven’s Progressive Matrices

1. Introduction

Intelligence encompasses a human ability to comprehend complex ideas, to adapt effectively with the environment, to learn from experience, to engage forms of reasoning, and to overcome obstacles by taking thoughts. The ability differs between individuals [1] and can be gauged via conventional psychometric tests such as the Wechsler Intelligence Scale [2] and Raven’s Progressive Matrices (RPM) [3] and mental rotation tasks [4]. A mainstream study suggests that the brain is less mentally active in brighter individuals compared to the lesser intelligent people [5]. This leads to the hypothesis of neural efficiency and is supported by higher alpha, but lower beta power in the prefrontal region of brighter individuals [6].

Apart from an efficient brain, other related studies have also related specific functioning of the brain hemispheres with intelligence [7-9]. These have been studied in conjunction with other behavioural and cognitive-related parameters such as attentiveness [10] and information processing strategies [11]. For that purpose, the electroencephalogram (EEG) has been employed to observe the brain’s electrical activities, while being stimulated with a defined cognitive task. The left hemisphere is involved in sequential processes [12], analogic reasoning [13], non-verbal semantic-categorical processing [14] and linguistic [15]. Meanwhile, the right hemisphere is involved in visuo-spatial processing [16].

Hence, lateralization of hemispheric functioning results in brain asymmetry with specific hemisphere dominating the other in a defined cognitive task. These have been observed in terms of alpha and beta band power, and have also extended into a relational asymmetry index between both hemispheres. A related study shows that brain activation is

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symmetrical when solving simple arithmetic operations, but is left dominant when solving complex mathematical problems [17]. Recent finding also suggests that activation asymmetry to left be related to high motivation [18]. Frontal asymmetry to left has also been associated with verbal fluency [19]. These however, contradict with findings that relate asymmetry characteristics with giftedness, where gifted individuals are right dominant. The phenomenon may be contributed by the creative ability that is much contributed by the right hemisphere [20].

This paper elaborates on the brain asymmetry pattern in relation to different intelligence level. The uniqueness of the finding is defined through the analysis of resting EEG and non-verbal reasoning task to cluster subjects into different levels of intelligence quotient (IQ).

2. Methods

As shown in Fig. 1, several procedures were performed to accomplish the research work. These involve EEG measurement, signal pre-processing and filtering, extraction of normalized energy spectral density (ESD), and calculating the brain asymmetry score (AS). Detailed explanation is described in the following sub-sections and the patterns of AS among the different IQ levels are elaborated in Section 3.

![Flow chart for assessment of resting asymmetry](image)

**2.1. EEG recording and establishment of IQ levels**

50 healthy postgraduate and undergraduate students; mean age = 23.9 and standard deviation (SD) = 3.5 from various disciplines have volunteered in this research work. Real-time EEG signal was recorded using G-MobiLAB. Fp1 (left hemisphere-LHS) and Fp2 (right hemisphere-RHS) are connected to the prefrontal area with Fpz as the reference. Both ear lobes were used for grounding and the electrode placements conform with the 10-20 international system. The EEG is sampled at a frequency of 256 Hz.

EEG were recorded in two sessions; relax closed eyes for 3 minutes during the first session and with the brain stimulated with IQ test for 10 min in the second session. A non-verbal reasoning-based IQ test, adopted from RPM has been employed in the study. The IQ test has been set up in a user-friendly graphical user interface (GUI) to reduce body motion. The focus of study will be on resting EEG, hence further analysis on the second recording session will not be discussed further. The scores obtained from the IQ test are used to group the samples into different IQ levels [8, 9, 21].
2.2. Signal pre-processing, filtering and feature extraction

The EEG was pre-processed offline using MATLAB 2010b. The trials which were affected by noise; characterized by amplitudes exceeding ±100 μV, has been rejected. As no EOG (EMG) signal was recorded during data collection, automatic rejection approach [22] on the EEG has been employed. The EEG is then filtered into alpha (8 –13 Hz) and beta (13–30 Hz) waves by means of bandpass filter. The spectral characteristics of the artifact-free EEG signals are computed via Fast Fourier Transform (FFT) algorithm.

The power spectral density (PSD) has been calculated by means of Welch’s averaged periodogram method. The signal was divided into 50% overlapping epochs with a window size of 256. The length of FFT is 1024 and extracted using a Hamming window. Then, the ESD which covers the entire energy distribution for each range of the frequency band is calculated.

2.3. Brain asymmetry score in resting alpha and beta waves

Initially, the normalized ESD of alpha and beta waves for both hemispheres have been computed via In-transformation method and plotted to observe the pattern in RHS and LHS. As mathematically expressed by Eq. 1, the AS is then derived from the difference of normalized magnitude between both hemispheres.

\[
\text{AS}_j = \ln(ESD_{j, R}) - \ln(ESD_{j, L})
\]  

where \( j \) represent brainwave frequency bands. Positive scores of AS indicate right dominance while negative scores refer to left dominance.

3. Results and Discussion

3.1. Establishment of IQ levels

The IQ scores based RPM range from 0 to 150 and were statistically analyzed to group the samples into different IQ levels. The population of scores (N=50) is in normal distribution with the mean (96.9) and SD (24.8). Therefore, three distinct IQ levels have been established with the corresponding number of samples as shown in Fig. 2. Due to the existing outliers, one sample each has been removed from the low and medium IQ levels; ending up with a total of 48 samples.

Fig. 2 Number of samples among IQ levels
3.2. Assessment on alpha and beta asymmetry

The ln-transformed ESD of LHS and RHS with respect to low, medium and high IQ groups are as shown in Fig. 3. It is observed that the normalized ESD for alpha wave in RHS is higher compared to LHS in medium and high IQ levels. In contrast, the normalized ESD for alpha wave in RHS is less than LHS for low IQ level. An inversed pattern can be observed in high IQ level for beta wave where the normalized ESD in RHS is lower than LHS. The medium and low IQ levels however attained similar pattern as the normalized ESD for alpha wave.

Subsequently, Fig. 4 shows the mean of \( AS \) for alpha and beta waves. The high IQ level tends to be more balanced with smaller asymmetry value for alpha and beta waves. A high IQ level is characterized by a right dominant alpha activity. In contrast, beta activity is left dominant. Meanwhile, medium and low IQ levels indicate unbalanced brain activity with greater asymmetry values. It can be observed that alpha and beta activities are right dominant for medium IQ level. However, low IQ level exhibit brain activities that are left dominant. The findings support previous evidence, where the low asymmetry indicates efficient attention shifting between both hemispheres and is associated with higher intelligence [23]. Furthermore, deviation from symmetrical brain activities in less intelligent individuals is associated with less efficient network configuration in the brain [24].

![Fig. 3. Normalized ESD for alpha (on the left) and beta waves (on the right) for LHS and RHS among different IQ levels](image)

![Fig. 4. Resting alpha and beta asymmetry in distinct IQ levels](image)
4. Conclusion

Significant pattern of resting alpha and beta waves can be observed from the asymmetry score with varying IQ levels. EEG activity in relaxed state may reflect the relationship between balanced brain and intelligence. As a conclusion, findings show that the highly intelligent individuals are able to maintain relatively balanced attention between the two hemispheres, as compared to the medium and low IQ groups.

Acknowledgements

This work was supported by the Ministry of Higher Education (Grant No.: 600-RMI/FRGS 5/3 (72/2012)), as well as Research Management Institute (Grant No: 600-RMI/DANA 5/3/RIF (121/2012)) and Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia. The corresponding author is sponsored through the Malaysian MyPhD scholarship programme.

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