An Evaluation of Left and Right Brain Dominance using Electroencephalogram Signal

Z. Y. Lim, K. S. Sim, and S. C. Tan

Abstract—**The left and right brain dominance theory has been established for decades. Besides, the left and right brain balancing education concept and training have also been developed for years. Currently, the only way to determine a person whether is left or right brain dominance is by making a questionnaire assessment. There is no scientific data that can directly reflect brain activity to prove the left and right brain theory as well as the effectiveness of the left and right brain development training. Hence, in this research, it is aimed to determine whether the electroencephalography (EEG) signal has any correlation with the brain dominance level. The brain dominance level of the subject is determined and benchmarked by using the Hermann Brain Dominance Instrument (HBDI) test, a popular testing tool utilized by innumerable multinational companies to determine employee's brain dominance level. As the captured raw EEG signal is complicated and noisy, several preprocessing methods are utilized to eliminate the unwanted noise and artifacts efficiently from the acquired signal. The techniques are namely baseline correction method, electrical line noise removal, and independent component analysis (ICA). Besides, significant features can be hardly determined from the time-based EEG signal with high complexity. Hence, the EEG Topographical Power Spectral Density Percentage (EEGTPSDP) method is implemented to analyze the EEG signal. By using the results computed by EEGTPSDP method, it proves that there is a strong correlation between the brain dominance level and EEG power spectral density on one hemisphere. Hence, this research is able to validate the left and right brain dominance theory according to the EEG signal. The implemented EEGTPSDP method can be used to classify the dominant brain of a person. In this way, this research is able to contribute to the education field by determining the students' brain dominance level and track their learning progress based on the EEG signal in a scientific approach.**

Index Terms—**brain dominance, correlation, electroencephalogram, topographical, power spectral density**

I. Introduction

THE brain is known as the most complex organ in the human body. The brain basically can be split into two parts, which are the right hemisphere and the left hemisphere. The brain is an unpredictable organ which is also in charge of learning, sensing, body controlling, and memory [1]. The left and right hemispheres are interconnected by the corpus callosum, which is located in the middle between the left and right hemispheres. It enables the information from the left hemisphere to flow to the right hemisphere and vice versa. Both the left hemisphere and right hemisphere serve different functions [2]. The left half movements of the body are in charged by the right hemisphere and vice versa. Since 1981, Roger Sperry found out that both brain hemispheres could carry out different functions. The left hemisphere is majoring in sequential thinking, logical thinking, mathematical problem solving, and analysis. Whilst, the right brain is majoring in creative thinking, imagination, music, art, and emotions [3]. Most people tend to dominantly use one side of the brain, thus usually people are to be determined either left or right brain dominance [4]. A left brain thinker who is left-brain dominant tends to have a better talent in studying science and mathematics that involves analytical and logical thinking. Contrarily, a right brain thinker who is right-brain dominant tends to have a greater ability in art and music that requires a higher level of imagination and creativity.

However, a person can also maximize the usage of both sides of the hemisphere. Thus, the person is known as left and right brain balanced and also called as the whole brain thinker [4]. Several researches show that achieving brain balancing could unleash the potential of brain capability and it is one of the main reasons which leads to successful achievements in one person's life [5]. A few greatest representatives who are whole-brain thinkers are Albert Einstein, Leonardo Da Vinci, Samuel Morse, etc. They made high achievements in scientific research or inventions, along with high attainment in art or music. It is shown that imagination and creativity thinking majoring in the right brain are as important as the scientific and logical thinking majoring in the left brain [6][7]. Besides, in the field of education, researches also show that achieving brain synchronization could aid students in rapid learning. Thus, some popular academicians have innovated education system which can develop the right hemisphere of the brain such as Betty Edwards and Makoto Shicida. Their students' achievements prove the results of their new education concept and approach.

To determine one person's brain dominance level, the Stroop's test and questionnaire-based approach such as the Herrmann Brain Dominance Instrument are employed [8]. Nevertheless, currently there is still no data-driven approach to validate the brain dominance test. There are a few approaches that can acquire the information of the brain activity: positron emission tomography (PET), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), and electroencephalogram (EEG) [9].

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Among these methods, EEG is the most suitable method as it is non-invasive, portable, and high sampling frequency [10].

EEG measures the voltage emitted from the scalp due to the ionic current flows within the neurons in the brain. The voltage obtained from the scalp is around 10 microvolts to 100 microvolts [11]. Thus, a signal amplifier is required to amplify the acquired signal. Besides, the raw EEG waveform is complicated and may be contaminated by different sources of noise. Thus, it requires preprocessing techniques such as baseline removal [12], independent component analysis (ICA) [13], etc. to remove the noise and artifacts from the acquired raw EEG signal [14][15]. In order to analyze the complicated time-based waveform, EEG Topographical Power Spectral Density Percentage (EEGTPSDP) method is implemented based on several techniques such as frequency-based [16][17], power spectral density [18][19], etc. are employed. In this paper, the process involved in the EEG data acquisition, preprocessing techniques, analysis method, and the correlation between the brain dominance level and EEG signal are presented.

II. Implementation

A. Electroencephalogram Signal Acquisition System

The EEG device employed in this research is known as the Ultracortex "Mark IV" EEG Headset developed by OpenBCI as shown in Fig. 1.

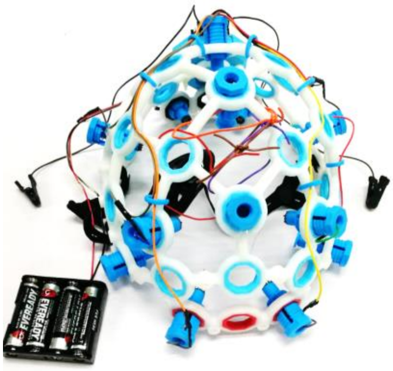


Fig. 1. Open BCI Mark IV EEG headset

It is a 3D printed headset equipped with Cyton Biosensing board which allows the acquired data to transmit wirelessly from the EEG device to the personal computer. The advantage of the headset is that it allows the user to configure the location of the electrode sensors among the 35 node locations as shown in Fig. 2, where the figure is redrawn based on the image indicates the node locations of Ultracortex Mark IV in OpenBCI shop [20].

The 35 node locations are designed according to the International 10/20 system [21]. The numbers '10' and '20' represents the distances between every position of the sensors. They are either 10% or 20% where the total length is based on the length from the front to the back of the head, or left side to the right side of the head. The electrode positions are represented by letter: F, T, C, P and O. 'F' indicates the frontal lobe, 'T' indicates the temporal lobe, 'C' indicates central, 'P' indicates the parietal lobe, and O indicates "Occipital lobe". The letter will be followed by either letter 'z' or numbers. 'z' indicates zero and refers to the location on the centerline which separates the left and right

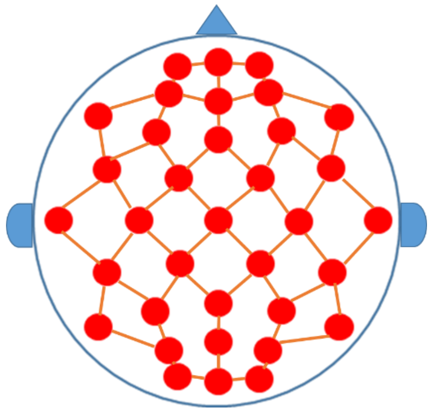


Fig. 2. 35 node locations for positioning electrode sensors (Redrawn based on the image indicates the node locations of Ultracortex Mark IV in OpenBCI shop) [20]

hemisphere. Even numbers refer to the location on the right hemisphere and odd numbers refer to the location on the left hemisphere. Fig. 3 shows the illustration of the International 10/20 system, which is redrawn based on figures and information on page 140 of "Electroencephalography: Basic Principles, Clinical Applications, and Related Fields" by E. Niedermeyer and F. L. d. Silva. [21].

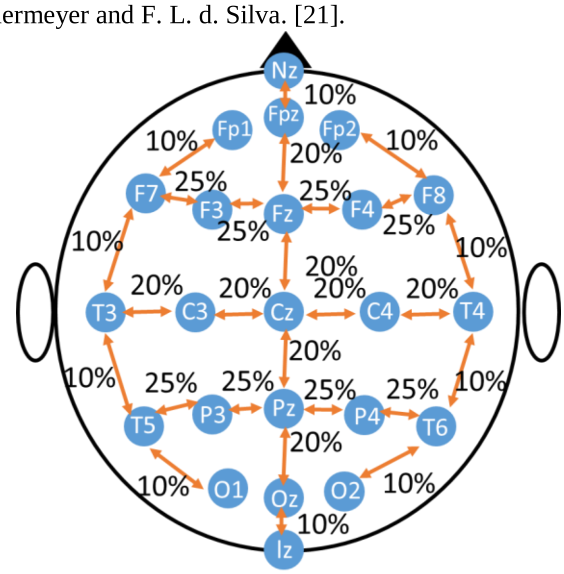


Fig. 3. International 10/20 system (Redrawn based on figures and information in page 140 of "Electroencephalography: Basic Principles, Clinical Applications, and Related Fields" by E. Niedermeyer and F. L. d. Silva) [21]

In order to determine the signal imbalance level between the left and right hemispheres of the brain, the number and position of electrodes should be equal and symmetry for both left and right hemispheres. The frontal lobe of the brain majoring is responsible for concentration and solving complex problems, thus sensor electrodes are placed at the position of Fp1 and Fp2. Since the parietal lobe of the brain majoring is in the task management and working memory, hence sensor electrodes are fixed at the position of F7 and F8. The temporal lobe is responsible for hearing and long term memory, thus two sensor electrodes are placed at the position of P7 and P8. The occipital lobe of the brain mainly functions for vision and sight, thus electrodes are placed at the two positions of O1 and O2.

B. EEG Signal Acquisition Procedure

In this research, there are a total number of 60 samples. The subjects are required to wear the EEG device throughout the signal acquisition process. The procedure of the EEG signal acquisition process is illustrated in Fig. 4.

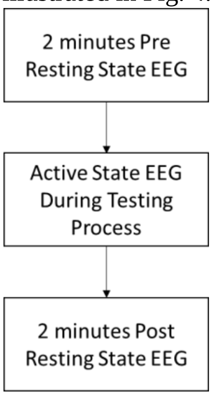


Fig. 4. Procedure of the EEG signal acquisition process

In the beginning, the EEG device is placed onto the subject's head and the contact quality of all the sensors are ensured in good condition. Then, the subject is requested to rest calmly with opening the eyes for 2 minutes when the EEG signals are recorded. After that, the subject is asked to perform the Hermann Brain Dominance Instrument test with a personal computer. The active state EEG of the subject is recorded during the subject performing the test. After the subject has done the test, the subject is requested to rest and relax with opening the eyes again for another 2 minutes. Meanwhile, the post resting state EEG signal is recorded.

C. Hermann Brain Dominance Instrument

Hermann Brain Dominance Instrument is a psychometric assessment developed by William Hermann to determine the strength of each cognitive style represented by the left and right hemispheres of the brain [8]. This test is widely employed by many companies and employers to determine the cognitive ability and personalities of the employees. The concept of HBDI is thinking and can be categorized into four modes which are analytical thinking, sequential thinking, interpersonal thinking, and imaginative thinking. The HBDI test requires the user to answer the questionnaires designed to measure the degree of preference for each of the four modes of thinking. Fig. 5 shows the whole brain model concept of HBDI, the figure is redrawn based on the information of Whole Brain® Model in Think Hermann-How it works [8].

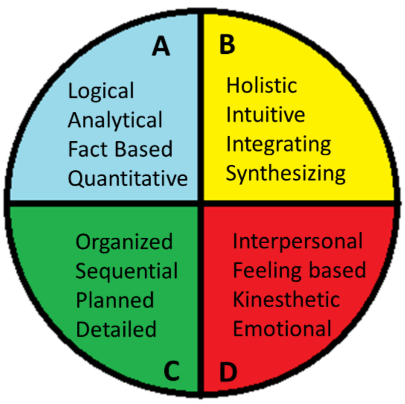


Fig. 5. Whole Brain Model concept of HBDI (Redrawn based on the information of Whole Brain® Model in Think Hermann-How it works) [8]

The results of the test will show the strength of the subject in each quadrant. The quadrant A represents the front left side of the brain indicates the person's strength in analytical thinking which includes logical thinking, mathematics, and evidence-based decision making. The quadrant B represents the rear left side of the brain indicates the person's ability in sequential thinking which includes detailed planning, timing, and scheduling. The quadrant C represents the rear right side of the brain indicates emotional thinking and interpersonal thinking which involves communication and feeling. And the quadrant D represents the front right side indicates the person's imaginative thinking and creativity. According to the results of the test, the strength percentage of each quadrant can figure out the person is left-brain dominance, right-brain dominance, or whole-brain thinker and how balance is their left and right brain hemisphere.

D. EEG Signal Preprocessing

As the original voltage of the EEG signal is extremely low and digital amplifier is employed, the EEG signal is often contaminated by different sources of noise such as electrical line noise, muscular activity, eye blinking, and so on. Thus, signal preprocessing is mandatory to eliminate the unwanted artifacts from the acquired raw signal. Fig. 5 shows the preprocessing techniques to be employed in this research.

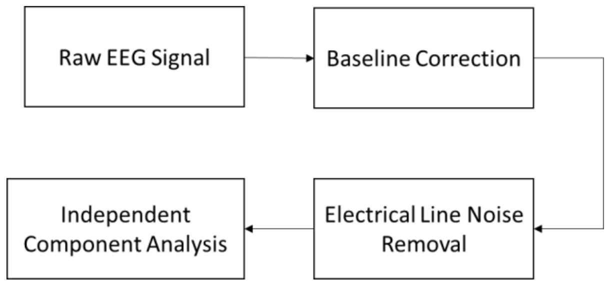


Fig. 6. Block Diagram of EEG Signal Preprocessing Techniques

Generally, the EEG waveform does not oscillate at a baseline voltage such as alternating current (AC) electrical waveform, which oscillates at the voltage value of zero [22]. The baseline voltage where the EEG waveform oscillates will shift time by time as shown in Fig.7., where the black line indicates the baseline of the waveform.

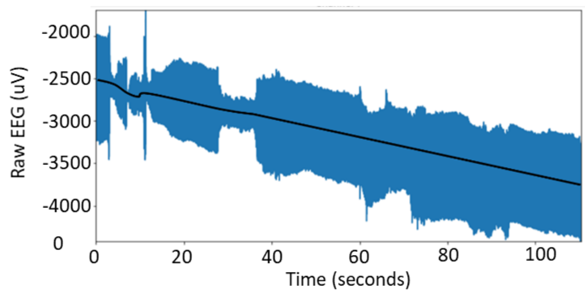


Fig.7. Raw EEG Waveform Plot

The baseline correction is performed by using the equation as shown in (1) to (5).

$$f_n[x] = \begin{cases} f_n^R[x] + C_n^L \,, 0 \leq x < W_n - 1 \\ \frac{1}{2} * (f_n^R[x] + f_n^L[x]) \,,\ W_n - 1 \leq x \leq k - W_n \\ f_n^L[x] + C_n^R \,,\ k - W_n < x \leq k - 1 \end{cases} \quad (1)$$

where

$$f_n^L[x] = \frac{1}{W_n}\sum_{v=x-W_n+1}^{x} f_{n-1}[x]\ ,\ W_n - 1 \le x \le k - 1 \quad (2)$$

$$f_n^L[x] = \frac{1}{W_n}\sum_{v=x}^{x+W_n-1} f_{n-1}[x]\ ,\ 0 \le x \le k - W_n \quad (3)$$

$$C_n^L = \frac{1}{2}[[f_n^L[W_n - 1] - f_n^L[W_n - 1]] \quad (4)$$

$$C_n^R = \frac{1}{2}[[f_n^R[k - 1] - f_n^L[k - W_n]] \quad (5)$$

where $f_n[x]$ is the output value, $f_{n-1}[x]$ is the input value, $f_n^R[x]$ is right moving average, $f_n^L[x]$ is left moving average, C_n^L is compensation value for the left moving average, C_n^R is compensation value for right moving average, W_n is window length, n is the number of order for moving average filter.

Next, the electrical line noise is removed by using a notch filter as implemented using (6).

$$G(z) = \frac{1-2\cos(50)z^{-1}+z^{-2}}{1-2r\cos(50)z^{-1}+r^2z^{-2}} \quad (6)$$

where z is the z-transform of the signal.

Next, independent component analysis is employed to eliminate the unwanted noise caused by eye blinking, muscular action, etc. The input signal is modeled as (7).

$$Y = B \cdot S \quad (7)$$

where Y is matrix represents input signal, B is the matrix that represents source values and S is the matrix to represents the number of sources. Equations (8) to (13) are used to estimate out the value of the sources.

$$B = P\gamma^{-1}Q^T \quad (8)$$

where

$$Q^T = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \quad (9)$$

$$\delta_1 = \sum_{j=1}^{N} Y(j)cos\theta \quad (10)$$

$$\delta_2 = \sum_{j=1}^{N} Y(j)\cos(\theta + \frac{\pi}{2}) \quad (11)$$

$$\gamma^{-1} = \begin{bmatrix} \frac{1}{\sqrt{\delta_1}} & 0 \\ 0 & \frac{1}{\sqrt{\delta_2}} \end{bmatrix} \quad (12)$$

$$P = \begin{bmatrix} cos\emptyset & sin\emptyset \\ -sin\emptyset & cos\emptyset \end{bmatrix} \quad (13)$$

where N is the number of sources, θ is the angle of rotation matrix and $\emptyset$ is the angle value at the minimum value of normalized kurtosis. Then, the final reconstructed signal is expressed as (14).

$$\tilde{S} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{\sqrt{\delta_1}} & 0 \\ 0 & \frac{1}{\sqrt{\delta_2}} \end{bmatrix} \cdot \begin{bmatrix} cos\emptyset & sin\emptyset \\ -sin\emptyset & cos\emptyset \end{bmatrix} \quad (14)$$

E. EEG Topographical Power Spectral Density Percentage (EEGTPSDP)

As time-based EEG waveform is complicated and significant features are unable to be identified from the complicated time-based EEG waveform, several processing techniques are applied to the EEG waveform to ease the process of analysis and feature extraction. The first technique employed is the Continuous Wavelet Transform (CWT) that converts the complicated time-based waveform into a frequency-based waveform. The technique is implemented by using equation (15).

$$F(x,y) = \frac{1}{\sqrt{|x|}}\int_{-\infty}^{+\infty} f(t)\varphi\left(\frac{t-y}{x}\right)dt \quad (15)$$

where φ(t) is known as the defined wavelet function, x is the dilation scaling parameter and y is the translation scaling parameter. In this way, the time-based waveform will be converted into a frequency-based waveform.

Next, power spectral density is obtained based on the frequency-based waveform. It is obtained by using equation (16) and (17).

$$P = \int_{-\infty}^{+\infty} |\tilde{x}(f)|^2 df \quad (16)$$

$$\tilde{x}(f) = \int_{-\infty}^{\infty} e^{2\pi ft}x(t)^2 dt \quad (17)$$

where f is frequency-based and t is time-based.

Based on the results of the power spectral density, a 2D topographical interpolation plot can be constructed by defining a set of grid points based on the 10/20 system with the value of power spectral density. Fig 8 shows the grid points defined on the 2D head plot top view.

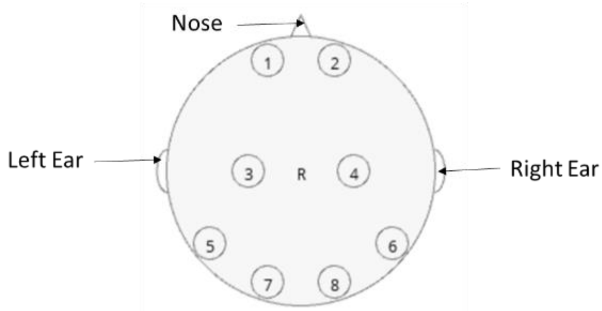


Fig. 8 Grid points defined on the 2D head plot (top view)

Color intensity is used to represent and differentiate the correlative strength of the power spectral density. The radius of the color which represents the maximum value is computed based on the normalized value of the power spectral density and predefined maximum radius size as shown in equation (18).

$$R_n = \frac{\max(\tilde{x}_n(f))}{\max(\forall\tilde{x}_n(f))} * r_s \quad (18)$$

where R_n is the radius size for the maximum intensity, $\max(\tilde{x}_n(f)$ is the maximum value of power spectral intensity for the channel n, where $n \in (1,2,3,4,5,6,7,8)$ and r_s is the predefined maximum radius size for each grid, wherein this case is 6 cm. Except for the color that represents the maximum intensity, the other colors are diffuse evenly until reaching the predefined maximum size. After that, color interpolation is employed in between the grids where they intersect to smoothen the topographical view.

Next, the EEG Topographical Power Spectral Density Percentage (EEGTPSDP) value is computed according to the resultant interpolated intensity value on the topographical plot. The value indicates the percentage of power spectral density which is contributed by each hemisphere of the brain. The EEGTPSDP value for the left and right hemisphere are calculated using (19) and (20).

$$EEGTPSDP_L = \frac{(2\sum R_l)+\sum B_l}{(2\sum R_w)+\sum B_w} * 100\% \quad (19)$$

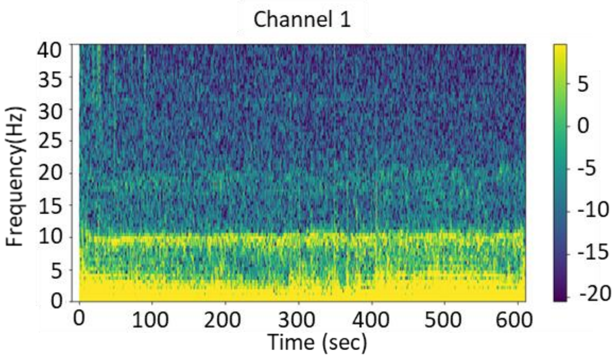
$$EEGTPSDP_R = \frac{(2\sum R_r)+\sum B_r}{(2\sum R_w)+\sum B_w} * 100\% \quad (20)$$

where $\sum R_l$ is the total value of red pixels on the left hemisphere, $\sum B_l$ is the total value of blue pixels on the left hemisphere, $\sum R_r$ is the total value of red pixels on the right hemisphere, $\sum B_r$ is the total value of blue pixels on the right hemisphere, $\sum R_w$ is the total value of red pixels on the whole brain topography, and $\sum B_w$ is the total value of blue pixels on the whole brain topography.

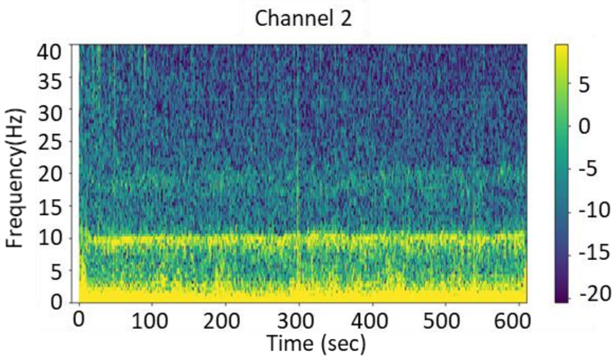
III. Results and Discussion

A. *Frequency-based analysis*

By using the CWT, a 3-axes time-frequency plot is constructed based on the time-based waveform. The time-frequency plot represents the strength of the respective frequency against time by using color intensity. Fig. 9 shows the example of the generated time-frequency plot from channel 1 to channel 8 from a left-brain dominant subject.



(a)



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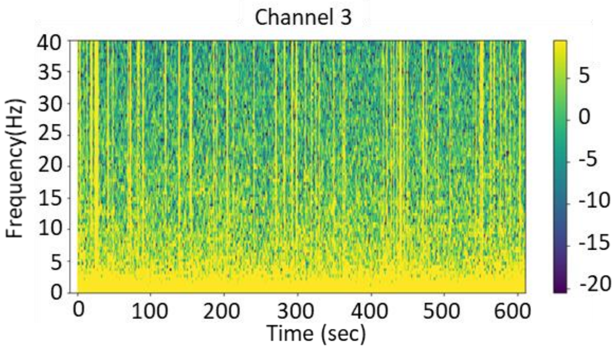

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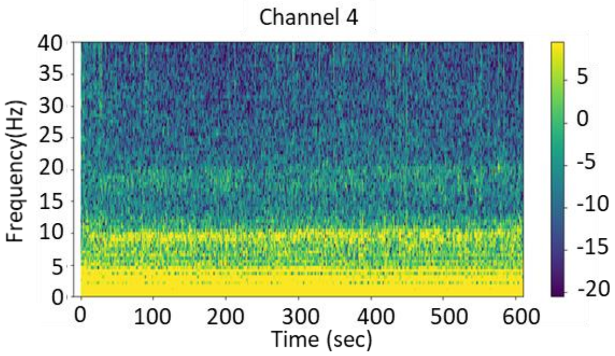
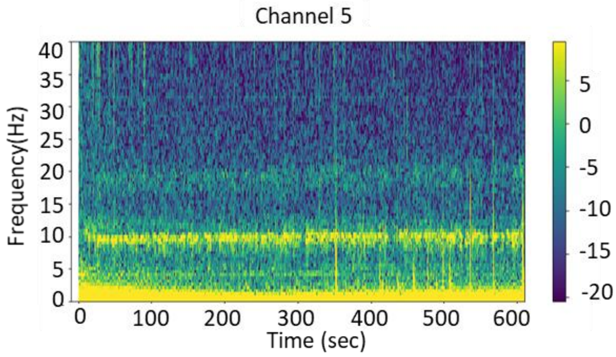
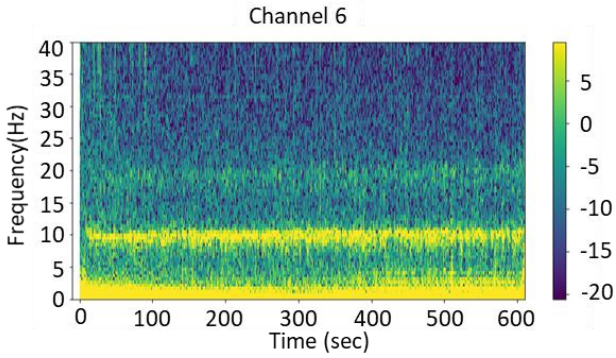


(d)

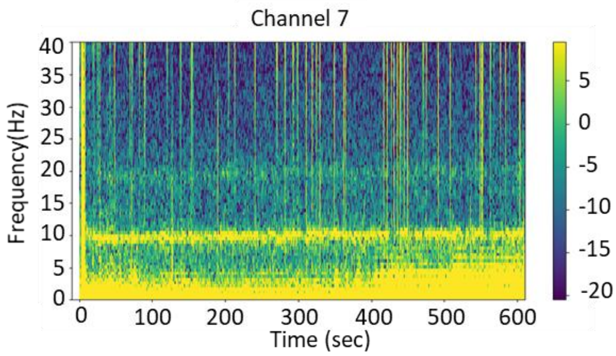
As shown in Fig.3, the odd number channels are located on the left hemisphere and the even number channels are located



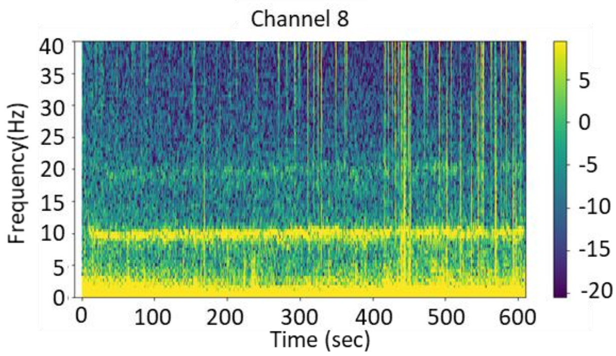
(e)



(f)



(g)



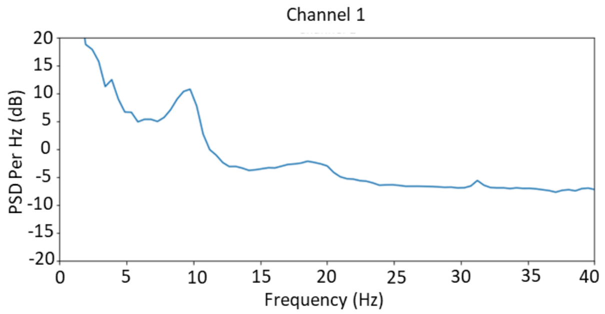
(h)

Fig. 9 Time-frequency plot for (a) channel 1, FP1 (b) channel 2, FP2 (c) channel 3. F7 (d) channel 4, F8 (e) channel 5, P7 (f) channel 6, P8 (g) channel 7, O1 (h) channel 8, O2

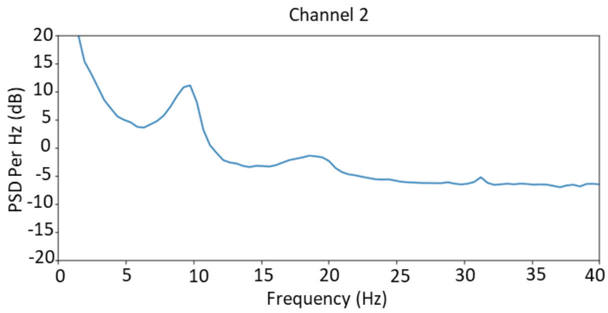
on the right hemisphere. The position of the odd number channel is symmetrical to the next even number. For instance, the position of channel 1 (FP1) on the left hemisphere is symmetrical to the position of channel 2 (FP2) on the right hemisphere, position of channel 3 (F7) on the left hemisphere is symmetrical to the position of channel 4 (F8), and so on. Hence, the results of the channels can be compared in pairs (e.g. channel 1 compared to channel 2, channel 3 compared to channel 4, and so on) to determine the difference between the left and right hemispheres of the brain.

The results generated and shown in Fig.9(a) to Fig.9(h) are from a subject who is a left-brain dominant. The time-frequency plots show a major difference where the odd channels have a larger distribution area of high amplitudes signal in the range of 10Hz to 40Hz compared to channel 2. This indicates the region on the left hemisphere is more active compared to the right hemisphere.

Next, in order to analyze in terms of the average power in each frequency, the power spectral density (PSD) graph is generated according to the value from the time-frequency plot. Fig.10 shows the generated power spectral density graph for channel 1 and channel 2.



(a)



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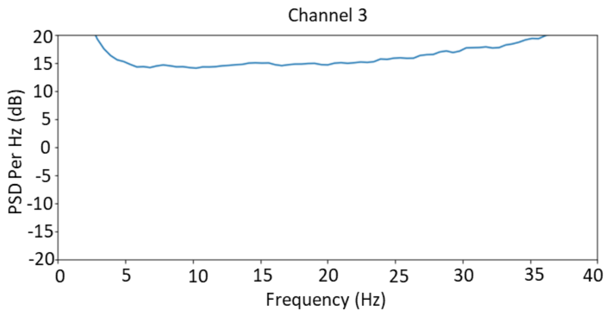

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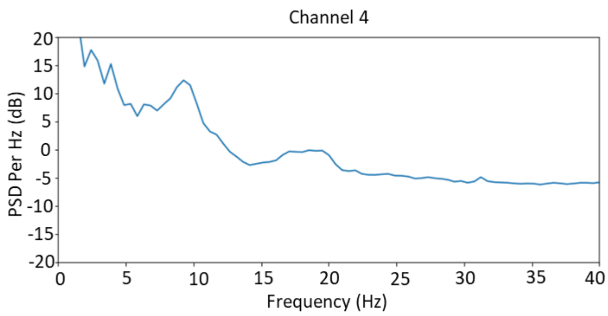

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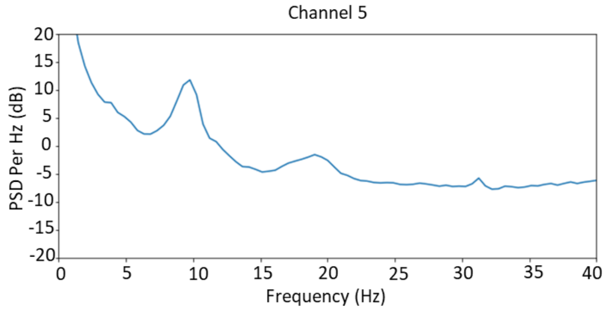

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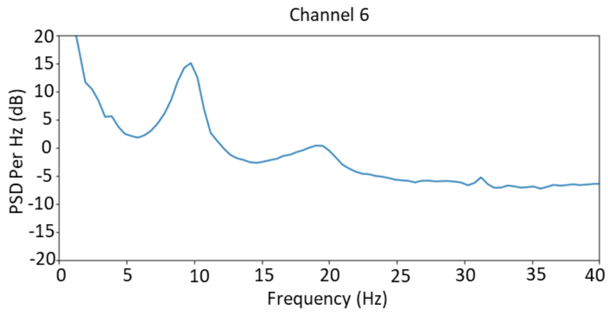

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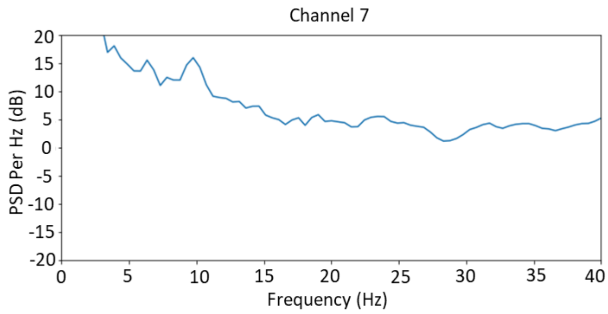

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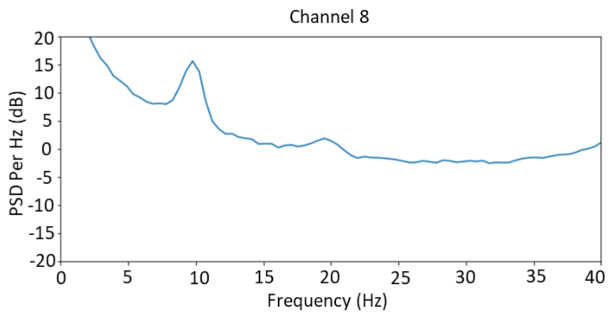
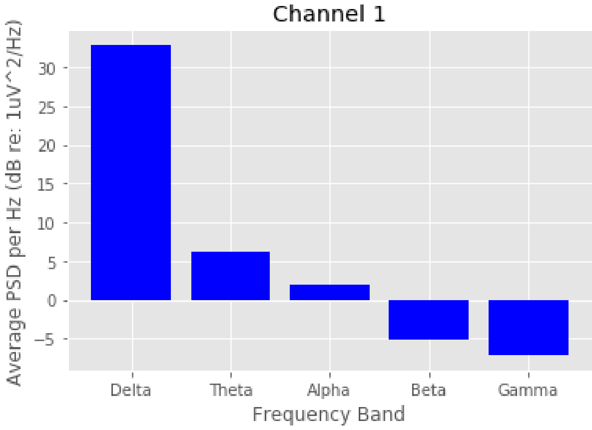


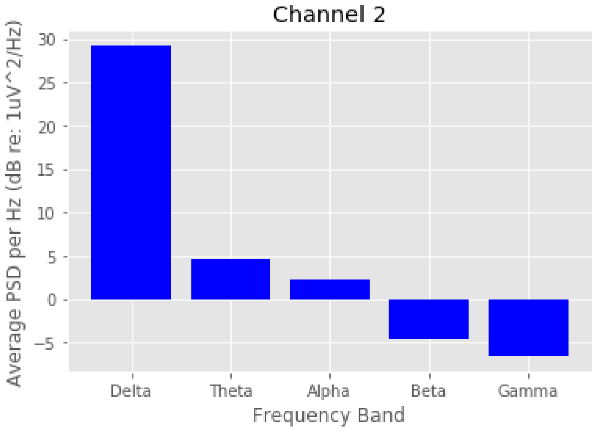
(h)

Fig. 10 Power spectral density chart for (a) channel 1, FP1 (b) channel 2, FP2 (c) channel 3. F7 (d) channel 4, F8 (e) channel 5, P7 (f) channel 6, P8 (g) channel 7, O1 (h) channel 8, O2

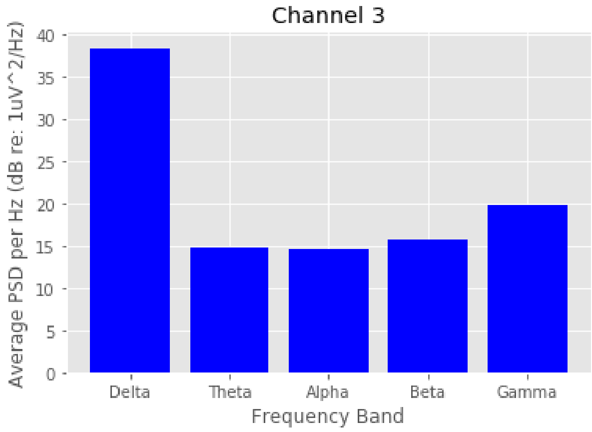
From the generated results shown in Figure 10, they show that the PSD values of odd channels (Channel 1, 3, 5, and 7) are higher compared to even channels (Channel 2, 4, 6, and 8) especially in the range of 3Hz to 40Hz. This indicates that the average power spectral density in every frequency is higher in the dominant brain hemisphere in contrast with another brain hemisphere. Hence, results show that the left brain dominant person tends to have a higher average PSD value on the left brain hemisphere, whereas the right brain dominant person tends to have a higher average PSD value on the right brain hemisphere. As the EEG signal is commonly analyzed in term of the frequency band, the data from the PSD chart is quantified according to the frequency bands: Delta (0.5Hz to 4Hz), Theta (4Hz to 8Hz), Alpha (8Hz to 13Hz), Beta (13Hz to 30Hz) and Gamma (above 30Hz). Figure 11 shows the average power spectral density in each frequency band for 8 channels.



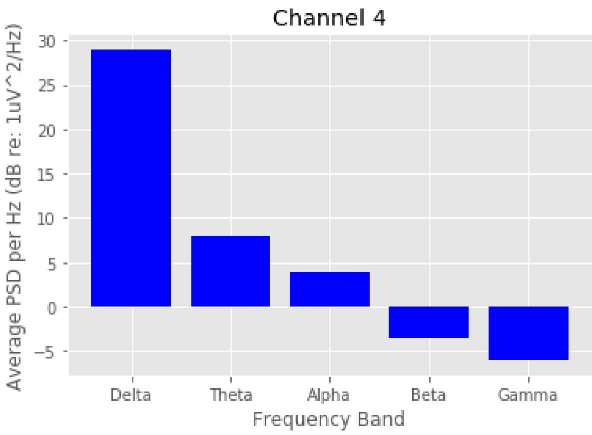
(a)



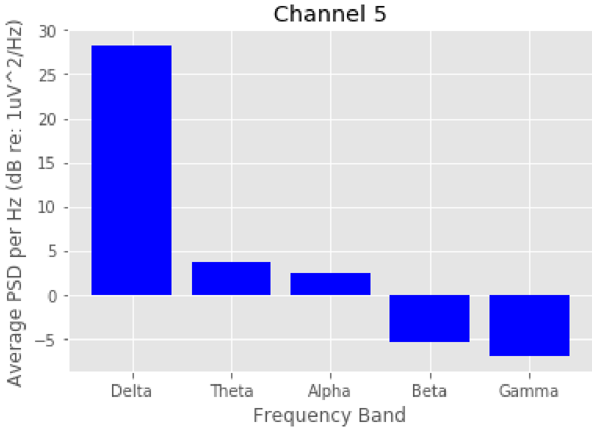
(b)



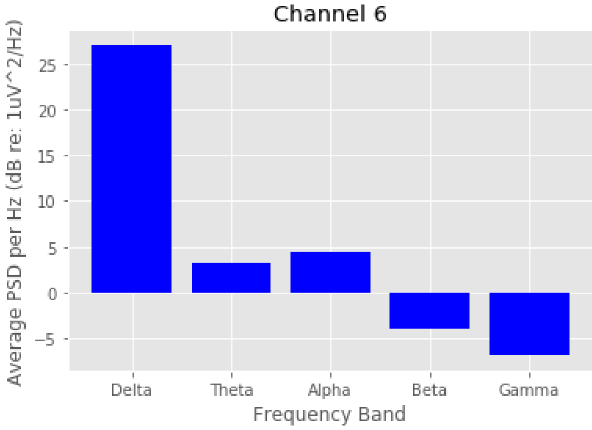
(c)



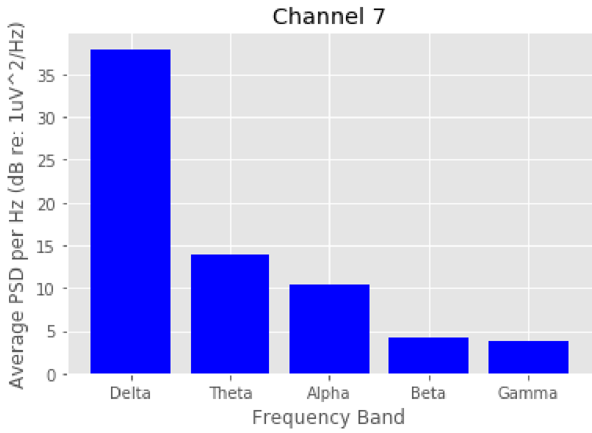
(d)



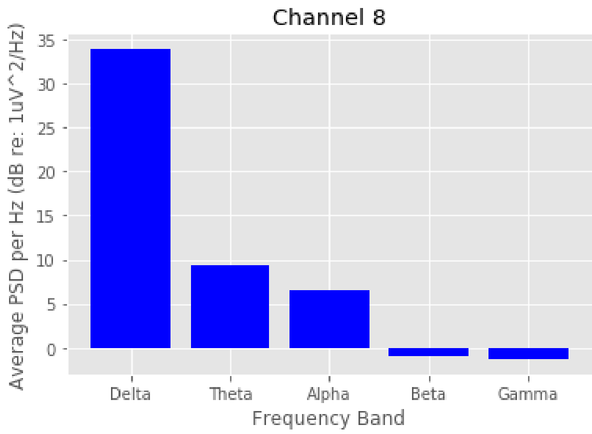
(e)



(f)



(g)



(h)

Fig. 11 Average power spectral density in frequency band chart for (a) channel 1, FP1 (b) channel 2, FP2 (c) channel 3. F7 (d) channel 4, F8 (e) channel 5, P7 (f) channel 6, P8 (g) channel 7, O1 (h) channel 8, O2

From the results shown in Figure 11 in terms of the frequency band, they show a significant difference between the left hemisphere (Channel 1, 3, 5, and 7) and right hemisphere (Channel 2, 4, 6, and 8) especially in the Theta (from 4Hz to 8Hz), Beta frequency band (from 13Hz to 30Hz) and Gamma frequency band (above 30Hz). The EEG signal is collected during resting state with opening eyes. Theta frequency band indicates the resting state, the Beta frequency band indicates the brain is in an active state with eyes opened, and the Gamma frequency band indicates brain activity of information processing such as memory, thinking, and consciousness. The results show that the PSD value is higher on the left hemisphere (odd number channels) compared to the right hemisphere (even number channels) in the Theta, Beta, and Gamma frequency band. Hence, the dominant brain hemisphere of a person can be identified through the comparison of PSD values in the Theta, Beta, and Gamma frequency band between the two hemispheres of the brain.

Although the features of left or right brain dominance can be identified from the comparison of the time-frequency plot and power spectral density chart between the left and right channels, but the process of comparing the charts is tedious. Thus, the topographical view constructed based on the power spectral density can provide better visualization and obvious results.

B. *Topographical plot*

According to the power spectral density of all the 8 channels, topographical plots are constructed according to the PSD and predefined position of channels on the 2D head plot. Fig.12 shows the topographical plot.

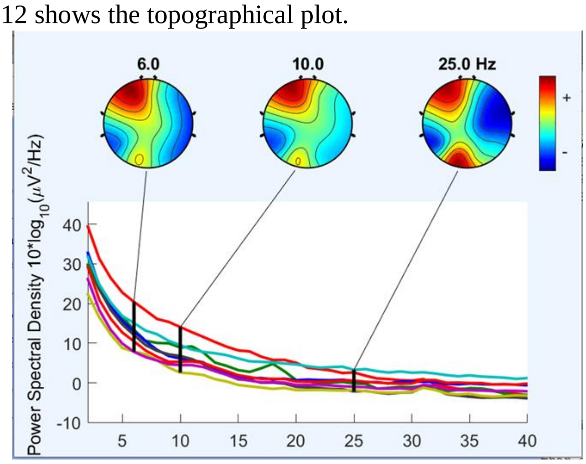


Fig. 12 Topographical plot based on power spectral density

As shown in Fig.12, the topographical plot is able to visualize and compare the PSD which is contributed by a different region of the brain. Thus, the power intensity of the topographical plot is compared with the results obtained through HBDI assessment. Fig. 13 shows some of the topographical results and the left and right hemispheres are separated by the middle dashed line.

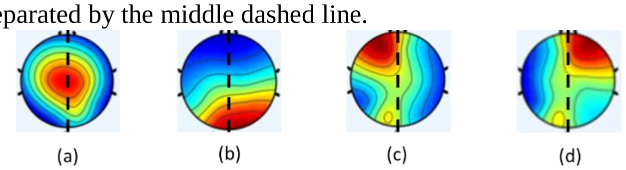


Fig. 13 Topographical plot of (a) subject with left-brain dominant (b) subject with right-brain dominant (c) subject with left-brain dominant (d) subject with right-brain dominant

From the observation in Fig. 13, it shows that the topographical plot based on PSD contributed by the eight channels tends to have higher intensity on the left hemisphere for a left-brain dominant person, and vice versa.

C. *Brain Dominance Level vs EEGTPSDP Value*

As all the subjects are required to undergo the HBDI assessment, the brain dominance level of each brain hemisphere can be obtained through the results of the assessment. The HBDI results act as benchmark data to classify the person is either left- or right-brain dominant.

The brain dominance level results according to the HBDI assessment carried out by the subjects and the respective EEGTPSDP value are computed and tabulated. 18 of the samples are tabulated in the TABLE I and illustrated in scatter plots as shown in Fig. 14 and Fig.15.

By compiling the EEGTPSDP value according to the HBDI results and plotted in the scatter graphs as shown in Fig.14 and Fig.15,

TABLE I
HBDI ASSESSMENT RESULTS AND POWER SPECTRAL DENSITY FOR LEFT AND RIGHT HEMISPHERE OF BRAIN

Sample	HBDI Results (%)		EEGTPSDP (%)	
	Left	Right	Left	Right
1	11.11	88.89	30	70
2	60.71	39.29	55	45
3	30	70	20	80
4	55.56	44.44	80	20
5	60.71	39.29	90	10
6	20	80	40	60
7	44.44	55.56	25	75
8	53.57	46.43	60	40
9	40	60	40	60
10	61.11	38.89	85	15
11	64.29	35.71	65	35
12	50	50	60	40
13	55.56	44.44	85	15
14	53.57	46.43	75	25
15	50	50	45	55
16	44.44	55.56	40	60
17	39.29	60.71	20	80
18	60	40	70	30

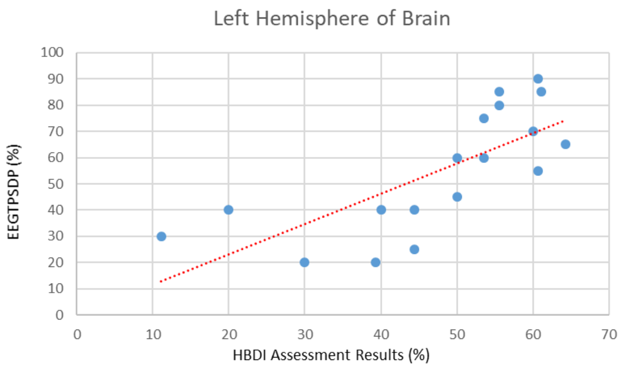


Fig.14 Scatter Plot of EEGTPSDP vs HBDI Assessment Result in Percentage For Left Hemisphere

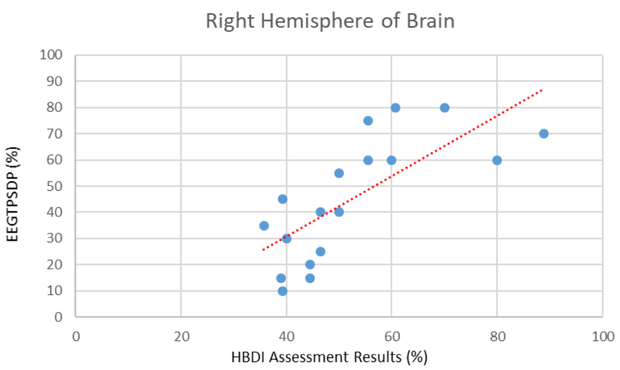


Fig.15 Scatter Plot of EEGTPSDP vs HBDI Assessment Result in Percentage for Right Hemisphere

The simple linear regression line (red line) computed based on the scatter graphs show that the relationship between brain dominance level and EEGTPSDP value is proportional. This indicates that the higher percentage of the left brain dominance level (based on HBDI assessment), the higher the power spectral density is on the left hemisphere and vice versa.

D. Correlation Coefficient of Brain Dominance Level vs EEGTPSDP Value

In order to determine the correlation between the two variables, few correlation coefficients are employed. The first one is the Pearson correlation coefficient, which is calculated based on (21) and (22).

$$r_L = \frac{n(\sum x_L * y_L) - (\sum x_L) * (\sum y_L)}{\sqrt{[(n\sum x_L^2 - (\sum x_L)^2) * (n\sum y_L^2 - (\sum y_L)^2)}} \quad (21)$$

$$r_R = \frac{n(\sum x_R * y_R) - (\sum x_R) * (\sum y_R)}{\sqrt{[(n\sum x_R^2 - (\sum x_R)^2) * (n\sum y_R^2 - (\sum y_R)^2)}} \quad (22)$$

where r_L is the Pearson correlation coefficient for the left hemisphere, r_R is the Pearson correlation coefficient for the right hemisphere, n is the total number of sample, x_L is the left hemisphere dominance level according to HBDI results, y_L is the EEGTPSDP value for the left hemisphere, x_R is the right hemisphere dominance level according to HBDI results, y_R is the EEGTPSDP value for the right hemisphere.

For the Pearson correlation coefficient, -1.0 indicates linearly inverse proportional, 1.0 indicates linearly proportional and 0 indicates no correlation [23]. As the computed value for r_L and r_R are both 0.73, it shows that both the variables which are the HBDI result and power spectral density have a significant proportional relationship.

Another correlation method, namely Spearman rank correlation, is employed to determine the correlation between the EEG PSD percentage and brain dominance level. The coefficient is calculated using (23) and (24).

$$\rho_L = \frac{\frac{1}{n}\sum_{i=1}^{n}[R(x_{L_i}) - \overline{R(x_L)}] \cdot [R(y_{L_i}) - \overline{R(y_L)}]}{\sqrt{(\frac{1}{n}\sum_{i=1}^{n}[R(x_{L_i}) - \overline{R(x_L)}]^2) \cdot (\frac{1}{n}\sum_{i=1}^{n}[R(xL_i) - \overline{R(xL)}]^2)}} \quad (23)$$

$$\rho_R = \frac{\frac{1}{n}\sum_{i=1}^{n}[R(x_{R_i}) - \overline{R(x_R)}] \cdot [R(y_{R_i}) - \overline{R(y_R)}]}{\sqrt{(\frac{1}{n}\sum_{i=1}^{n}[R(x_{R_i}) - \overline{R(x_R)}]^2) \cdot (\frac{1}{n}\sum_{i=1}^{n}[R(y_{R_i}) - \overline{R(y_R)}]^2)}} \quad (24)$$

where ρ_L is the Spearman rank correlation coefficient for the left hemisphere, ρ_R is the Spearman rank correlation coefficient for the right hemisphere, $R(x_L)$ is the rank of the variable x_L , and $\overline{R(x_L)}$ is the mean rank of the variable x_L.

Spearman rank correlation coefficient is similar to the Pearson correlation coefficient, where -1.0 indicates a perfect negative correlation, 1.0 indicates a perfect positive correlation and 0 indicates no correlation [23]. The computed value for ρ_L and ρ_R are both 0.82, it shows that both the EEGTPSDP value in one hemisphere and brain dominance have a significant proportional relationship.

The third correlation coefficient method employed to assess the relationship between EEGTPSDP value and brain dominance level is known as Kendall's Tau correlation coefficient. They are calculated using (25) and (26).

$$\tau_L = \frac{(C_L - D_L)}{(C_L + D_L)} \quad (25)$$

$$\tau_R = \frac{(C_R - D_R)}{(C_R + D_R)} \quad (26)$$

where τ_L is the Kendall's Tau correlation coefficient for the left brain hemisphere, C_L is the number of concordant pairs for the left brain hemisphere, D_L is the number of discordant pairs for the left brain hemisphere, τ_R is the Kendall's Tau correlation coefficient for the right brain hemisphere, C_R is the number of concordant pairs for the right brain hemisphere, D_R is the discordant pairs for the right brain hemisphere. Concordant pair is defined as the pair of variables with proportional relationship and discordant pair is defined as the pair of variables with an inversely proportional relationship.

The computed value for τ_L and τ_R are both 0.97. For Kendall's Tau correlation coefficient, 0 indicates no relationship, and 1.0 indicates a perfect relationship [23]. Hence, this shows the EEGTPSDP value in one hemisphere is highly correlated with the dominant brain hemisphere. The computed values of all the three correlation coefficients are summarized in Table II.

TABLE II
CORRELATION COEFFICIENTS OF BRAIN DOMINANCE LEVEL VS EEGTPSDP VALUE

Correlation coefficient	Left hemisphere	Right hemisphere
Pearson	0.73	0.73
Spearman Rank	0.82	0.82
Kendall's Tau	0.97	0.97

According to the computed results summarized in Table II, where Pearson correlation coefficient value is 0.73, Spearman rank correlation coefficient value is 0.82, and Kendall's Tau correlation coefficient value is 0.97. This validates that the dominant brain hemisphere has a very strong correlation with EEGTPSDP value which is computed from the EEG power spectral density generated by the respective hemisphere. A left-brain dominant person will have a higher EEGTPSDP value on the left hemisphere, whereas a right-brain dominant person will have a higher EEGTPSDP value on the right hemisphere. This also proves that the EEG signal can be utilized to determine one person is either left-brain dominant or right-brain dominant in a scientific manner.

IV. CONCLUSION

In this research, we have implemented several EEG signal preprocessing techniques to eliminate the noise and artifacts from the acquired signal. Besides, the analysis technique implemented in this research namely EEGTPSDP is an efficient method to classify brain dominance. Based on the results of the HBDI assessment carried out by the subject and the computed EEGTPSDP value, it can be concluded that the brain dominance level has a very high correlation with the EEG power spectral density contributed by the respective hemisphere. Thus, this proves that the acquired EEG signal along with the EEGTPSDP method can be used to classify whether the person is left- or right-brain dominant.

By employing the EEG analysis method which reflects the biofeedback information from the brain, this research proves that the left and right dominance theory is no longer a myth. It is believed that the implemented system and the findings in this research are contributing to the first step in revolutionizing the current one-for-all education system. By knowing the brain dominance of the student, the teachers can design appropriate syllabus and training according to their students' brain dominance level. In this way, it will be able to unleash the full brain potential and ability of every student.

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