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Analysis on Visual Signal based on the Effect of Eye Massaging Device using Wavelet Transform

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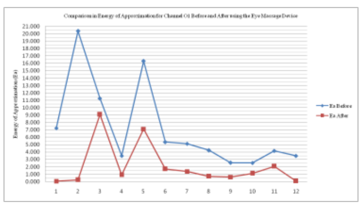
Graphical abstract



Abstract

This study has been conducted to examine the effectiveness of the eye massaging device to reduce massive amount of eyesight problem. The electrical activity of the muscles surrounding the eyes is recorded by using Neurofax EEG-9200 machine. Electroencephalography (EEG) is a process to determine the brain signal, while Electrooculography (EOG) is used to measure the biopotential produced by the changes in eye position and eye movement occurred. The conventional electrode setting (also called 10-20) system is applied on the scalp electrodes for EEG to record the brain signals. While five electrodes on the forehead is used to record EOG signals. Channel O_1 and O_2 that act as visual processing is selected in order to record EEG signals. The signal is analyzed using Wavelet Transform and the useful parameter, Energy of Approximation (E_a) was extracted. In this study, *t*-test analysis is used to validate the differences of data produced before and after using eye massaging device. Based on the results, the average value collected for EEG signals before using the eye massaging device has been decreased for both channel with the different (O_1: 5.083, O_2: 3.385). Thus, it is proved that the eye massaging device exhibit difference for each movement tested.

Keywords: Eye massaging device; electroencephalography; electrooculography; energy of approximation; *t*-test analysis

Abstrak

Kajian ini telah dijalankan untuk mengkaji keberkesanan alat mengurut mata untuk mengurangkan jumlah masalah penglihatan yang sangat banyak. Aktiviti elektrik sekitar otot mata direkodkan dengan menggunakan mesin Neurofax EEG-9200. Elektroensefalografi (EEG) adalah satu proses untuk menentukan isyarat otak, manakala Elektrookulografi (EOG) digunakan untuk mengukur biokeupayaan yang dihasilkan oleh perubahan dalam kedudukan dan gerakan yang berlaku dalam mata. Tetapan elektrod konvensional (juga dipanggil 10-20) digunakan dalam EEG untuk merakamkan isyarat otak. Sementara itu, lima elektrod pada dahi digunakan untuk merakam isyarat EOG. Saluran O_1 dan O_2 yang bertindak sebagai pemprosesan visual, dipilih untuk merakam isyarat EEG. Isyarat ini dianalisis dengan menggunakan Wavelet Mengubah dan parameter yang berguna, Tenaga Penghampiran (E_a) ditentukan. Dalam kajian ini, analisis ujian-*t* digunakan untuk mengesahkan perbezaan data sebelum dan selepas menggunakan alat mengurut mata. Dari keputusan yang diperolehi, purata tenaga yang dikumpul untuk isyarat EEG sebelum menggunakan alat mengurut mata menunjukkan penurunan untuk kedua-dua saluran yang digunakan dengan perbezaan (O_1: 5.083, O_2: 3.385). Oleh itu, dapat dibuktikan bahawa alat mengurut mata memberi perbezaan bagi setiap pergerakan mata yang diuji.

Kata kunci: Alat mengurut mata; elektroensefalografi; elektrookulografi; tenaga penghampiran; analisis ujian-*t*

■1.0 INTRODUCTION

Eye is one of the most important senses in all living humans and animals. Some of conceptual explanation will describe eye as the ability to collect visual [1]. It is found that biopotential energy is produced every time the eye is move from one point to another. One of the well-known methods to collect this energy is using EOG [2].

There are three theories that valuable for understanding about this visual signal or also known as EOG signals. The first is the cornea-retinal dipole theory [2]. It states that the cornea is positively charged and retina is negatively charged, hence an electric dipole is formed through the eye. The dipoles create electric field that can be measured by using EOG. Every time the eyes move from one position to another, the dipoles also move. Similar to the first theory, the second theory states that instead of having the electric dipole, there is a potential difference across the retina itself [2]. Basically, between the cornea and retina, there is steady electric dipole of approximately 0.4 mV to 1 mV for the normal eye [2]. This dipole is not created from the muscle movement, but it is strongly believed comes from the higher metabolism rate of the retina. It will lead to the increment in formation of free ions in the back of the eye, hence creating different voltage between them. A third theory states that the movement of eyelid will create a sliding potential source [2]. However, the first theory (corneal-retinal theory) is most widely accepted. This potential difference can be measured by placing several electrodes on the forehead. Ag-AgCl is one of the best electrodes to collect the EOG since their half-cell potential is nearly zero. The position of electrode is place based on the required data for the analysis [3]. Every time an eye is focus onto something, all eye muscle is forced to work hard to obtain continuously clear visual. In a normal extraocular muscles system, there are six muscles include superior rectus, superior oblique, medial rectus, inferior rectus, inferior oblique and lateral rectus [4] (see Figure 1) that are used to control the movement of the eye. While another muscle, levator palpebrea is responsible to control the eyelid elevation [4].

Basically, all the extraocular muscles are formed from three different pair of muscles with different controlling area. The lateral rectus and medial rectus is a pair of muscle to control the movement of eye in horizontal direction, while superior rectus and inferior rectus is used to control the movement in vertical direction [4]. The last pair is superior oblique and inferior oblique that is used to control the rotation of the eye [4]. There are three nerves that connect to these entire muscles which are simply oculomotor nerve, trochlear nerve, and abducens nerve [4].

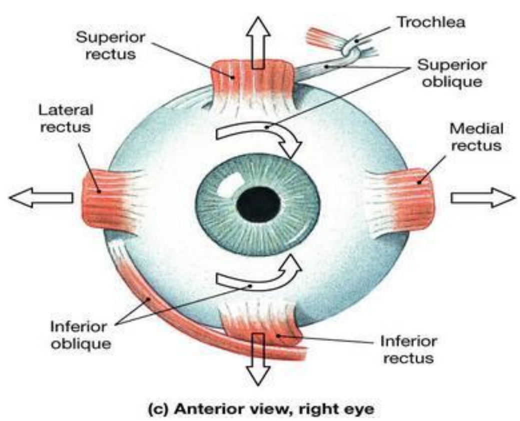


Figure 1 Six muscles in a normal extraocular muscles system are superior rectus, superior oblique, medial rectus, inferior rectus, inferior oblique and lateral rectus [5]

Combination of several muscles will lead to a movement of the eye. Basically, there are so many type of eye movement such as saccades, fixation, blinks, pursuit, vestibular ocular eye, vergence and optokinetic [6]. The eyes will not exactly remain still during visualize a scene, but they have to constantly move to capture all the visual data to make a complete scene. To get the overall scene, the process of collecting data needs to be repeated to several interesting point continuously.

Predomination of innovation and technology recently forced people to work or stay in front of laptop, computer or smart phone most of the time. This issue is not only referred to working adult since this technology is also used as gaming device to the children [7]. Excessive use of this technology exposed to less clear eyesight. Since the muscle is working hard while visualizing a static scene, with the current usage of the technology, the muscles tend to over-stressed. For a long period of time, this eyesight problem may results in blindness without proper control and treatment [8].

It is not impossible to see the increment of people suffering from the eyesight problem. One of the well known methods to overcome this problem that already produced is using the eye massaging device. The concept of massaging in this device is quite similar with the massaging chairs that use vibration to move the virtual ‘hand’ to massage the user. This device has seven different type of vibration with three modes for timer; 3, 5, and 10 minutes for each full cycle of usage. This study is conducted to detect the effect of this device to the electrical electivity of muscle surrounding the eye and the signal of visual processing from the brain signal.

EEG method is used to record brain electrical activity before and after using the eye massaging device. EEG is a process of capturing brain signal in the form of electrical waveform at various interest points on the head. The waveform is easily described as voltage fluctuations for every ionic current flow within the neurons and the brain [9]. The analogy of process collecting data is similar to the EOG but the main difference is, in the EEG, the electrodes is replace by the scalp which have multiple electrode at specific location.

The International Federation of Societies for Electroencephalography and Clinical Neurophysiology has recommended the conventional electrode setting (also called 10-20) for 21 electrodes [10]. Figure 2 shows the details of every point on the standard 21 point of interest in the EEG scalp. Each and every part of the point determines the different area of response from the brain.

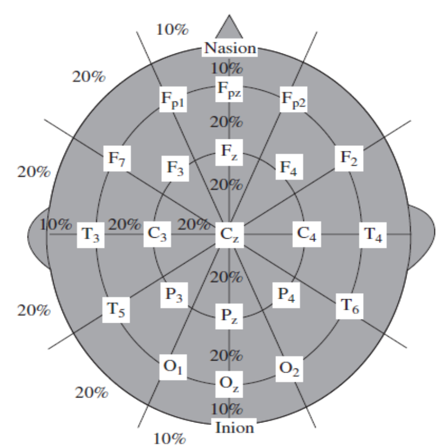


Figure 2 Position of electrode on the EEG scalp with point labeled [11]

The brain is composed of three parts; the brainstem, cerebellum and cerebrum. While the cerebrum is divided into four lobes; frontal, parietal, temporal and occipital [12] (see

Figure 3). Visual information is processed in the occipital lobe, motor planning is performed in the frontal lobe, and the temporal lobe is responsible for processing auditory information [12]. Therefore, this study used Channel O_1 and O_2 that are more familiar with visual processing function as it is placed on the occipital lobe.

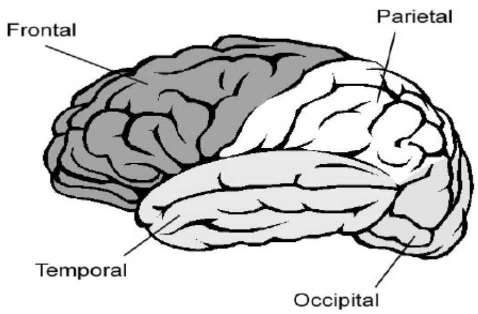


Figure 3 Four lobes in the brain are frontal, parietal, temporal and occipital [12]

2.0 EXPERIMENTAL SETUP

2.1 Experimental Procedure

Firstly, the EEG signals acquired by using Neurofax EEG-9200 machine is converted to ASCII format in order to make it readable and easy to use in the analysis. For filtering part, second order of Butterworth band pass filter with range of frequency between 1-50 Hz is used to cut the unwanted signal with irrelevant frequency, meanwhile denoising part is used to remove the noise recorded along with the signal. Figure 4 shows the flowchart of this study.

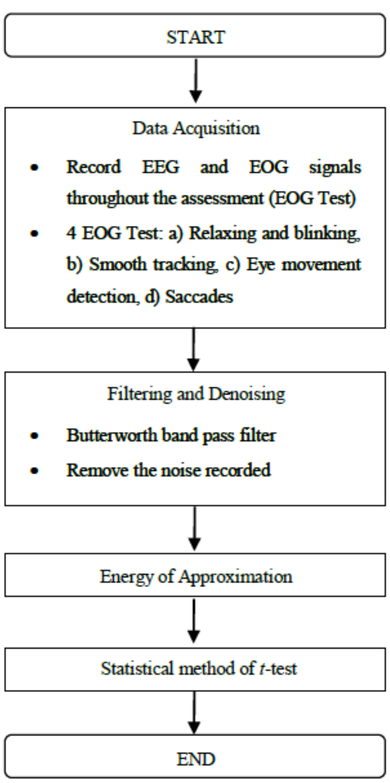


Figure 4 Flowchart of the study

MATLAB software is used to analyze and extracting significant parameters such as Energy of Approximation of the signals before and after using the eye massaging device. A *t*-test statistical method is used in order to validate the results obtained.

2.2 Signal Data Acquisition

12 subjects have been selected randomly from male and female genders for this research. They need to answer a questionnaire form that included their basic personal information; visual problem, body mass index (BMI), daily activities as well as their sleep cycles. This is important in order to detect if there is any criteria that could affect the data collected such as eye fatigue due to less sleep and any heavy activities that may affects their eye muscles before undergoing the experiment.

Several precautions have been taken to minimize the noises that could affect the signal processing such as body movement and room environment. The experiment is conducted in a dark room and the subject is advised to remain still while collecting the data. The distance between the chair placed in front of the screen is 1 meter and is marked by the 'X' spotted on the floor (see Figure 5).

Figure 5 Distance of 1 meter is marked by the 'X' spotted on the floor

The materials and tools used are fixed throughout the experiment. Both position and distance of all equipment used in this experiment are labeled and placed at the exact position for the whole time to minimize parallax error. Both instructor and subject are not allowed to interact with each other and all electronic devices such as phone or tablet must remain switched off at all time to minimize interference.

The subject is required to seat comfortably on the chair with the scalp electrodes and five electrodes are connected to Neurofax EEG-9200 machine. The position of the electrode will determine the group of data collected either vertical or horizontal [3]. Figure 6 shows the electrodes placement on the forehead and position of scalp electrodes on the head used to obtain both EOG and EEG signals.

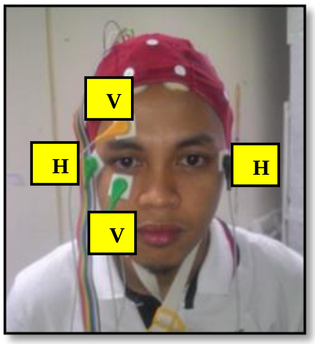


Figure 6 Electrodes placement on the forehead and position of scalp electrodes and to obtain both EOG and EEG signals. 'H' and 'V' denoted as horizontal and vertical channel respectively

Firstly, the experimental procedure for this experiment is displayed on the screen. The subject needs to close their eyes for 60 seconds in order to acquire EEG signals before using the eye massaging device. Then, subject must complete all of EOG tests procedures designed to create eye tiredness also known as asthenopia. After that, they were required to wear the eye massaging device for 15 minutes in relaxation mode. After eye massage treatment, the EEG signals are recorded for 60 seconds to investigate if there are any differences in Energy of Approximation before and after using the eye massaging device.

2.2.1 EOG Tests Procedure

A. Relaxing and Blinking

This test was designed in order to distinguish between the actual signals and signals artefacts (blinking artifact) produced by the placement of electrodes on the skin surface. For this test, subject is required to blink on each 5 seconds interval and it is repeated for five times throughout the total time duration of 30 seconds.

B. Smooth Tracking

Subject is required to concentrate at the pen movement that is displayed at the centre of the screen as a reference point. Then, the pen will move slowly to the right side for 30 seconds, and coming back to its reference point before it goes to left side of the screen for another 30 seconds (see Figure 7). This test was conducted for the total time duration of 60 seconds.

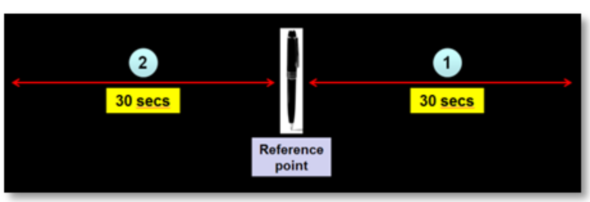


Figure 7 Reference point and the direction of the pen for smooth tracking test

C. Eye Movement Detection

This test was designed to look for another four eye movements; looking up right, looking up left, looking down right and looking down left.

At the first moment, a red point appears at the centre of the screen. The static eye movement at this moment is referred as the reference point. The point then disappears for 3 seconds and it consecutively appears at different position randomly for another 3 seconds (see Figure 8). After the 8th point, the red point reappears at the reference point. For this test, subject is asked to look at the direction of the red point without moving their head or giving any body movement for 60 seconds.

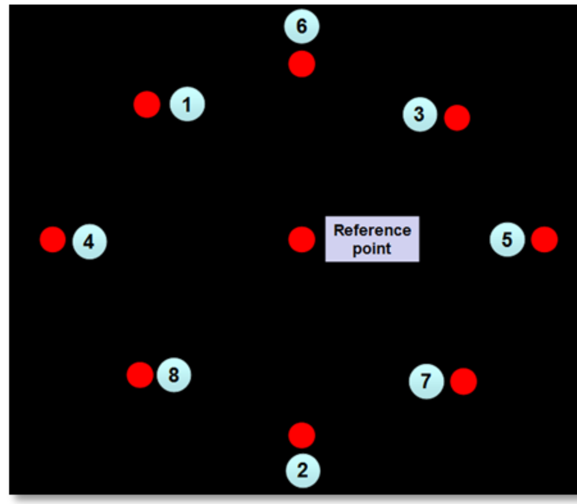


Figure 8 Reference point and the direction of the red point for smooth tracking test

D. Saccades

Saccades is defined as fast and non-smooth tracking movements of the eyes [13]. This test was designed to stress out the eye muscles in order to read the text given based on these specifications designed. One of the easiest ways to observe saccades was when the subject needs to read a text of paragraph which contains of these specifications; small font size text and light grey contrast (see Figure 9).

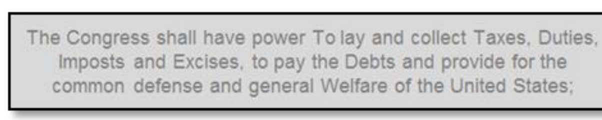

The Congress shall have power To lay and collect Taxes, Duties, Imposts and Excises, to pay the Debts and provide for the common defense and general Welfare of the United States;

Figure 9 Some of the text for saccades test. Specifications are: a) Font type: Arial body, b) Font size: 11, c) Font color: Dark grey, d) Background color: Light grey, e) Spacing: Single

2.3 Signal Processing

MATLAB software and toolbox application is used to analyze the collected signal. Firstly, the data transferred to MATLAB software to be analyzed. The frequency energy distribution for each point in the signal is recorded. The energy can be derived from Equation (1) to Equation (10) [14].

$$\psi_{ab}(t) = \frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right) \tag{1}$$

For Equation (1), $\Psi_{ab}(t)$ is scaled and translated version of $\Psi(t)$ wavelet transform, a is scale, b is translation parameter, and is mother wavelet. For Continuous Wavelet Transform (CWT), the Equation is shown in (2):

$$C_{ab}(t)=\int_{-\infty}^{\infty}s(t)\frac{1}{\sqrt{a}}\Psi^{*}\left(\frac{t-b}{a}\right)\mathrm{d}t \tag{2}$$

where $C_{ab}(t)$ is CWT signal, $s(t)$ is signal in which $s(t) \in L^2(\Re)$, L^2 is space of square integral function, $\Re$ is set of real number. For Discrete Wavelet Transform (DWT), the equations are shown in (3) and (4):

$$\psi_{j,k}(t)=\frac{1}{\sqrt{2^j}}\psi\left(\frac{t-\left(k^{2^j}\right)}{2^j}\right) \tag{3}$$

$$\psi_{j,k}(t)=2^{\frac{-j}{2}}\psi\left(2^{-j}t-k\right) \tag{4}$$

where $a=2^j, b=k2^j$ with $j,k,\in Z$. DWT can also be defined as in equation (5):

$$d_{j,k}=\int_{-\infty}^{\infty}s(t)2^{-j/2}\Psi^{*}(2^{-j}t-k)dt \tag{5}$$

Where $\psi(t)$ is the mother wavelet and $\psi_{j,k}, j,k \in Z$ are the collection functions. Energy in term of DWT concept can be concluded as Equation (6):

$$E_{j,k}=\left|d_{j,k}\right|^2 \tag{6}$$

Overall energy at resolution, j in Equation (7):

$$E_{j,k}=\sum_{k=0}^{2^{m-j}-1}\left|d_{j,k}\right|^2 \tag{7}$$

Total energy for overall signal can be defined as in Equation (8):

$$E_{total}=\sum_{j=1}^{m}\sum_{k=0}^{2^{m-j}-1}\left|d_{j,k}\right|^2 \tag{8}$$

Then, the value of extracted Energy of Approximation has been analyzed using Microsoft Excel. The whole process is repeated to obtain the data after using the eye massaging device.

■3.0 RESULTS AND DISCUSSION

Firstly, the raw EEG data recorded from the machine (see Figure 10) is converted to ASCII format in order to be used in MATLAB. Each and every point in the EEG will record all the signal involves although the value is very small.

There are two main ripple indicates that the movement of the eye is detected. The setting configuration for the machine is 20 µV for sensitivity to ensure that the signal is collected successfully. The data is filtered using Butterworth band pass filter with order of 2 to remove the unwanted signal with irrelevant frequency. Denoising part is used to remove the noise recorded along with the signal. Then, frequency energy distribution for in Channel O_1 and O_2 in EEG are analyzed by wavelet decomposition algorithm with level of 8.

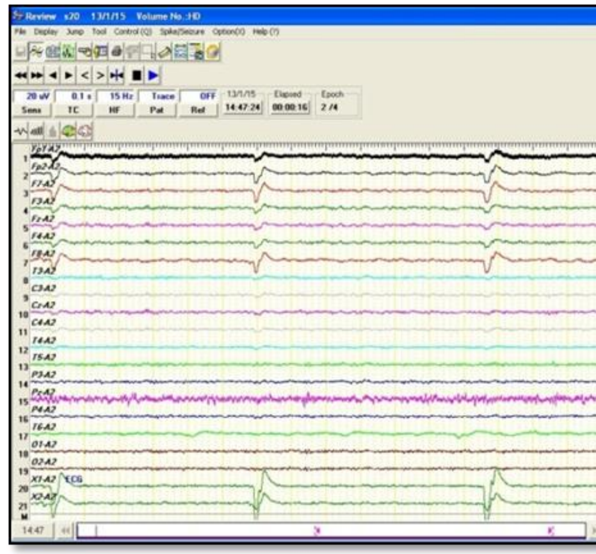


Figure 10 Raw EEG data

Table 1 shows the average of Energy of Approximation collected for 12 different subjects. While Figure 11 and Figure 12 shows the graphical view of the comparison between the energy for Channel O_1 and O_2 respectively. The values of energy in the table indicate the Energy of Approximation in the signal calculated using MATLAB for every required channel in the test conducted.

Table 1 Average of energy of approximation collected for 12 subjects

Subject	Channel O_1		Difference	Channel O_2		Difference
	Before	**After**	**of Energy**	**Before**	**After**	**of Energy**
1	7.237	0.058	7.179	2.127	1.919	0.208
2	20.357	0.240	20.117	7.727	3.506	4.221
3	11.253	9.078	2.175	13.466	5.826	7.640
4	3.483	0.910	2.574	3.049	1.100	1.949
5	16.291	7.116	9.174	15.166	4.975	10.191
6	5.348	1.709	3.639	1.125	0.724	0.401
7	5.111	1.365	3.746	0.129	0.101	0.028
8	4.232	0.712	3.521	8.228	0.880	7.348
9	2.543	0.608	1.935	1.644	0.700	0.943
10	2.527	1.107	1.420	3.918	1.928	1.990
11	4.160	2.071	2.088	4.168	1.903	2.265
12	3.492	0.069	3.423	3.842	0.401	3.440
Avg	**7.169**	**2.087**	**5.083**	**5.382**	**1.997**	**3.385**

It is shown that the values are decreasing between before and after using the eye massaging device. From the result, it is observed that some of the values drop insignificantly, which means the difference between signals before and after is inconsistent for different subjects. From the result, the average of difference between energy between before and after using the eye massaging device in Channel O_1 is 5.083 and for Channel O_2 is 3.385. However, some of the subjects are having high energy signal for Channel O_1 compared to Channel O_2 due to several factors such as the reduced sensitivity in scalp electrodes since it has been used for a long period of time and surrounding noise that occur while conducting the experiment.

In order to validate the result, both results are tested using *t*-test statistical method which is used to compare two different condition (before and after using the eye massaging device) to calculate the significance value between them. Two hypotheses can be applied in this *t*-test analysis:

a) *Null hypothesis, H_0:* There is no difference in Energy of Approximation between before and after using the eye massaging device.

b) *Alternative hypothesis, H_1:* There is a difference in Energy of Approximation between before and after using the eye massaging device.

The null hypothesis will be rejected if both or either one of these conditions is fulfilled:

a) *t*-statistic >*t*-critical two-tail,
b) $P\ (T \leq t)$ two-tails $\leq a$; $a = 0.01$

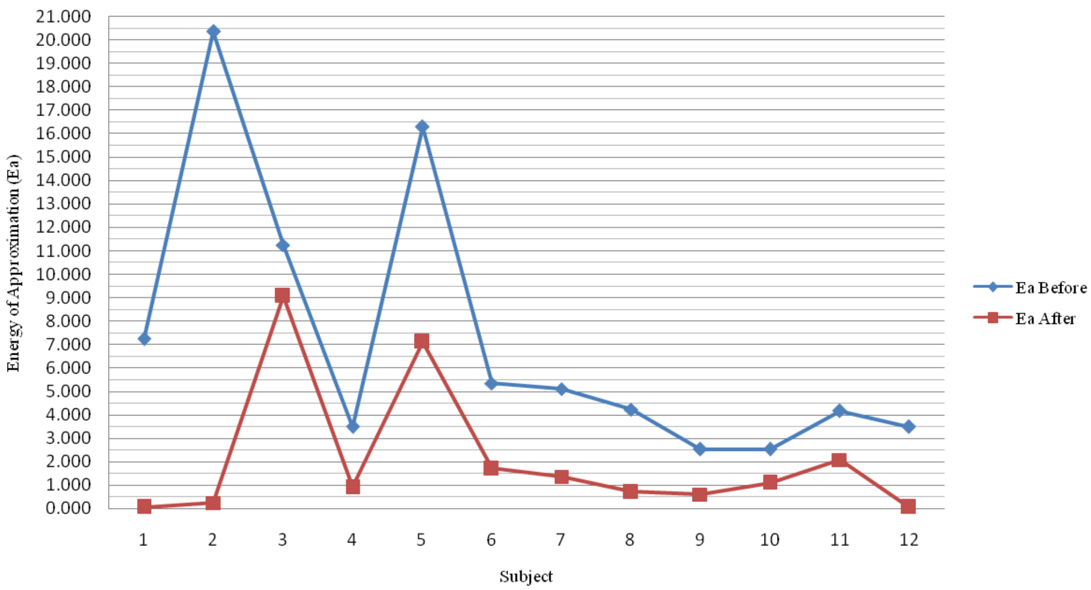


Figure 11 Graph of Energy of Approximation (E_a) for both signals before and after using the eye massaging device for Channel O_1

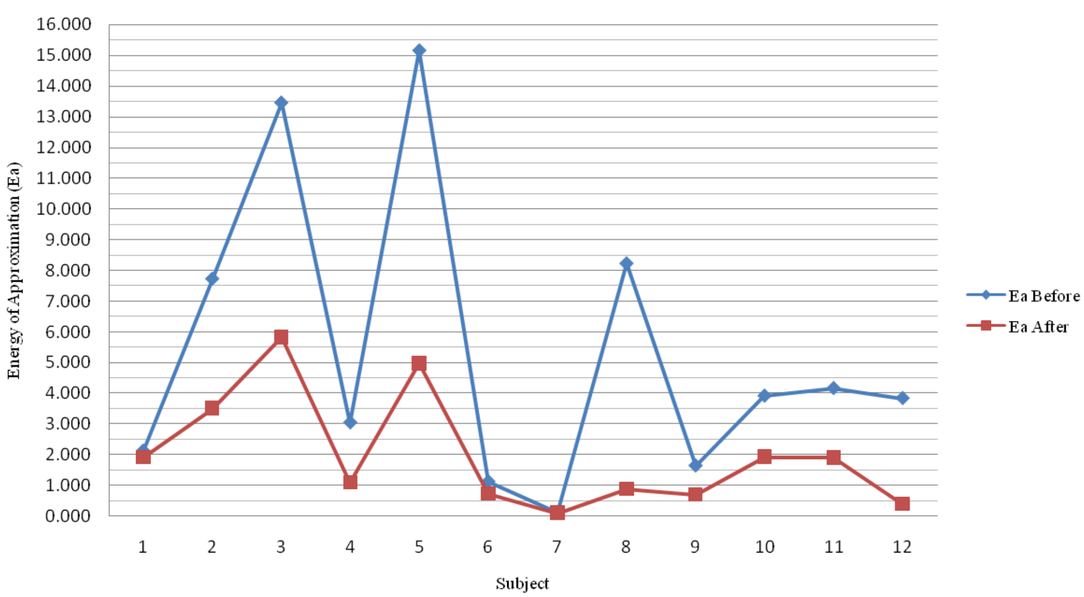


Figure 12 Graph of Energy of Approximation (E_a) for both signals before and after using the eye massaging device for Channel O_2

The output from the test from Channel O_1 and O_2 are displayed as in Table 2 and Table 3 respectively. The probability value (*P* value) two-tail for Channel O_1 is approximately 0.0064 which is less than the alpha value (*a*) 0.01 used in the test. The *t*-statistic value obtained is 3.353, meanwhile the *t*-critical two-tail value is 3.106. Hence, it can be concluded that the null hypothesis for the test suggested that there is no difference between both signal before and after is rejected. *P* value recorded for Channel O_2 is 0.0048 which is less than the alpha value in the test. The *t*-statistic value is 3.517, meanwhile the *t*-critical two-tail value is 3.106. Both situations have fulfilled the conditions to reject the null hypothesis. Thus, it can be concluded that there is a significant difference in both signal; before and after using the eye massaging device.

Table 2 *t*-test: paired two sample for means in channel O_1

Parameter	Before	After
Mean	7.1695	2.0868
Variance	33.5553	8.4414
Observations	12	12
t Stat	*3.3531*	
P(T≤t) one-tail	0.0032	
t Critical one-tail	2.7181	
P(T≤t) two-tail	*0.0064*	
t Critical two-tail	*3.1058*	

Table 3 *t*-test: paired two sample for means in channel O_2

Parameter	Before	After
Mean	5.3822	1.9970
Variance	23.3093	3.3929
Observations	12	12
t Stat	3.5165	
P(T≤t) one-tail	0.0024	
t Critical one-tail	2.7181	
P(T≤t) two-tail	0.0048	
t Critical two-tail	3.1058	

■4.0 CONCLUSION

Based on the results, the average value of Energy of Approximation collected for the EEG signals before using the eye massaging device has been decreased for both channels used (O_1: 5.083, O_2: 3.385). The *t*-test analysis proved that the data is significant between the energy before and after using the eye massaging device for both visual processing point, Channel O_1 and O_2. Therefore, it is proved that the eye massaging device exhibit difference for each of eye movement tested.

For future study, it is highly recommended that the signal collected depends more on the regular eye movement in human nature. The analysis should been done including several testing to compare the signal with highly attention to the surrounding factor to avoid noise since the signal is small.

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