EEG-BASED BRAIN CONNECTIVITY ANALYSIS OF
WORKING MEMORY AND ATTENTION

MOHAMMAD BASHIRI

ELECTRICAL AND ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
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EEG-based Brain Connectivity Analysis of Working Memory and Attention

by

Mohammad Bashiri

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UniversitiTeknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak DarulRidzuan

Certification of Approval

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Approved by,

_____

AP Dr. Aamir Saeed Malik,
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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Certification of Originality

This is to certify that the author, Mohammad Bashiri, is responsible for the content and work submitted in this project, and this work is originally done by no one but the author, however, where necessary, the content is referenced.

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Mohammad Bashiri

ABSTRACT

Recent research reveal that the Working Memory (WM) is more powerful than IQ as a predictor of academic success. WM is the type of memory in human brain which is responsible for manipulating the input (encoded) data and storing them in a limited manner. As it can be observed from the latter statement, "limited manner", the limitation of WM is the number of items which it can hold, which essentially leave the performance of WM to depend on the type of information that is being held in it (i.e., some information take more space, some less).

However, recent psychological advances show that not only WM performance is affected by the type of information, but also attention can influence WM performance. Although the impact of attention is well documented using ERPs; yet, the underlying brain connectivity of the interaction of these two constructs is not sufficiently understood. In this study, a Delay-Response task and electroencephalography (EEG) data are used to investigate the brain connectivity during two stages of Working Memory: Encoding and Maintenance.

We have presented distraction in both stages, and a secondary task in maintenance stage. Scalp EEG data of 19 participants were recorded. These results not only reveal the underlying brain connectivity of each task, but also highlights the differences between distraction and multitasking. The results show significant brain connectivity changes in the frontal and occipital areas of the brain depending on the WM stage where the distraction is presented.

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Abbreviations

WM	Working Memory
IQ	Intelligence Quotient
ERP	Event-related Potential
EEG	Electroencephalography
STM	Short-term Memory
LTM	Long-term Memory
CDA	Contralateral Delay Activity
BL	Base Line (task)
DE	Distraction in encoding stage (task)
DM	Distraction in maintenance stage (task)
IM	Interruption (secondary task) in maintenance stage (task)

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

In psychology, Memory is concerned with encoding the information from outside world, storing them, and retrieving them when needed. These are the three stages of Memory in an information processing aspect. However, there are three different types of Memory, which has different functionalities and characteristics. These types are Sensory Memory, Short-term Memory (STM), and Long-term Memory (LTM).

One of the main types of human memory (as mentioned above) is Short-term Memory which debatably is same as Working Memory (WM). Working Memory is a type of memory which is able to manipulate and hole a limited amount of information for a limited time. Some researchers believe that STM and WM are the same, while others believe that STM is essentially a part of WM, since it does not have the capabilities of manipulating the encoded information and it only holds the information, for a limited time (< 1 min).

But what is so important about WM? Working Memory is the very first brain construct which processes the encoded (input) information that comes into human brain. And based on that processing, it will be decided whether the information must be discarded or they have to be transferred to Long-term Memory (LTM). The performance of WM is crucial in learning process, in tasks which need high focus, and etc. based on the definition mentioned earlier, the limitations of WM are:

1. The number of items that it can hold
2. The amount of time that they can be held in WM

However, psychological studies revealed that, not only number of items and the time period are determining factors in measuring WM performance, but also attention can significantly influence its performance. The ability to focus on a task and manipulate and

store the relevant information with regards to that task, which entail the interaction of these two brain functions, is one of the most crucial aspects of our cognitive capabilities.

But how attention can influence the performance of WM? The definition of attention in its general form is *to selectively focus on a specific aspect of information while ignoring the other aspects.* To what extend this can be done is a significantly determining factor is WM performance. This is because regardless of the relevancy of the information, they will be held in WM; hence, attention plays a filtering role for the information that being held in WM. The more irrelevant information can be inhibited, the more enhanced the relevant information will be and as a result WM ends up with a better performance since it is filled mostly with task-relevant information.

The mechanism that bridges between these two constructs is top-down modulation. But what is top-down modulation, and why it bridges attention and Working Memory? Top-down modulation is when the processing command comes from higher processing units in brain to sensory parts, that is the case when we selectively (willingly) focus on something, and in the case of interaction between attention and WM we are selectively focusing on a specific task and observe the relevant information from it, that is why top-down modulation is the bridge between these two functionalities of human brain. In contrast, bottom-up mechanism is when something derives our attention towards itself.

1.2.   PROBLEM STATEMENT

Although there is a huge amount of research related to Working Memory from a long time ago, the interaction between Attention and WM is a recent field of interest for researchers from different backgrounds (e.g., psychology, neuroscience, neurophysiology, etc.). Yet this field has a lack of evidence in terms of the underlying neural activities which are responsible for the interaction between WM and Attention.

Hence, this study aims to provide supporting evidences regarding the interaction between Attention and Working Memory and the neural activities which underlies the interaction between these two constructs.

1.3. OBJECTIVES

Based on the problem statement mentioned above, the objective of this study is to analyze influence of attention in neural activities of brain while performing working memory task. This can be examined in two different stages, encoding and maintenance. Hence, the objectives, in a clearer way, can be expressed as:

1. Analyze the influence of attention during encoding stage on WM load
2. Analyze the brain connectivity in maintenance stage while distraction and interruption is introduced

1.4. SCOPE OF STUDY

The research regarding Working Memory is going on in different aspects, such as neuronal sources of different activities related to WM, Linguistics, influence and interconnectivity of different functionalities of human brain with WM. However, the scope of this study is limited to the influence of attention on the WM-related neural activities.

The modality which is mainly used for this study is Electroencephalogram. This study, besides providing information regarding brain connectivity through WM task, provides a Graphical User Interface to enable users to perform similar analysis in a more user-friendly environment.

CHAPTER 2
LITERATURE REVIEW

The term "Working Memory" was first introduced in 1974, by two British psychologists, baddeley and Hitch. They have argued the simplicity of the multi-store model of STM which was believed to be a unitary system at that time, with limited processing and storage capabilities for a limited period of time. In contrast to the multi-store model of the STM, they introduced WM which was not a unitary system and contained three subsystems at that time. You can see the WM model of Baddeley and hitch in Figure 1.
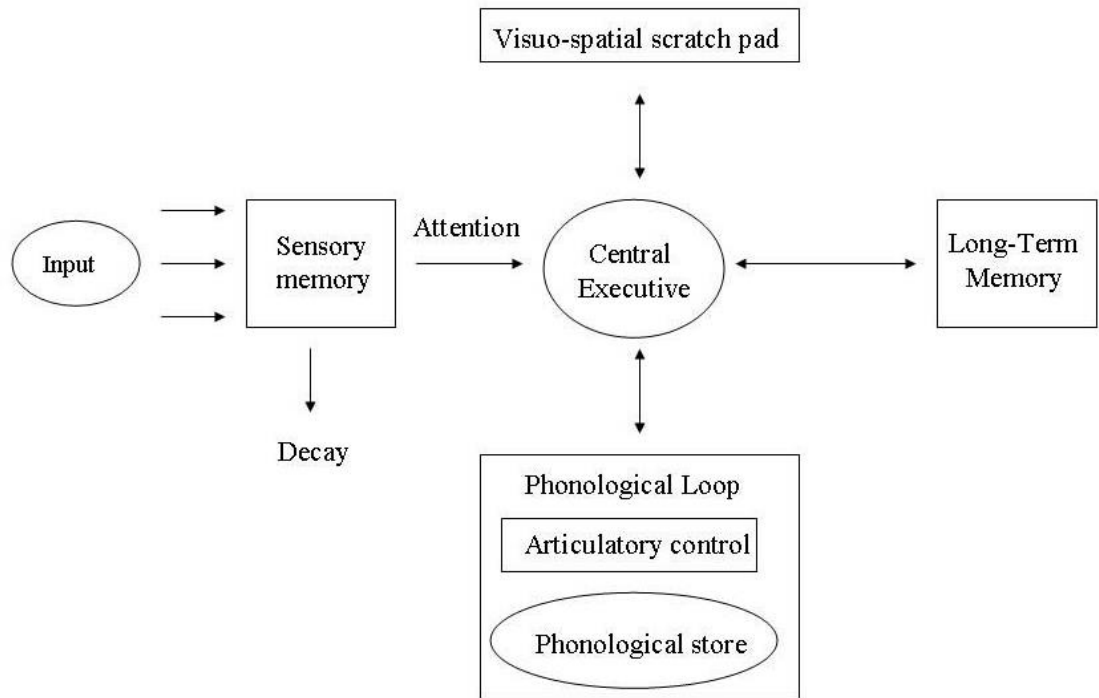
Figure 1: Working Memory Model (Baddeley and Hitch, 1974)

Later in year 2000, baddeley have added another subsystem to the existing model, to overcome its limitations. The modified model is illustrated in Figure 2 (the area covered by the red dotted line).
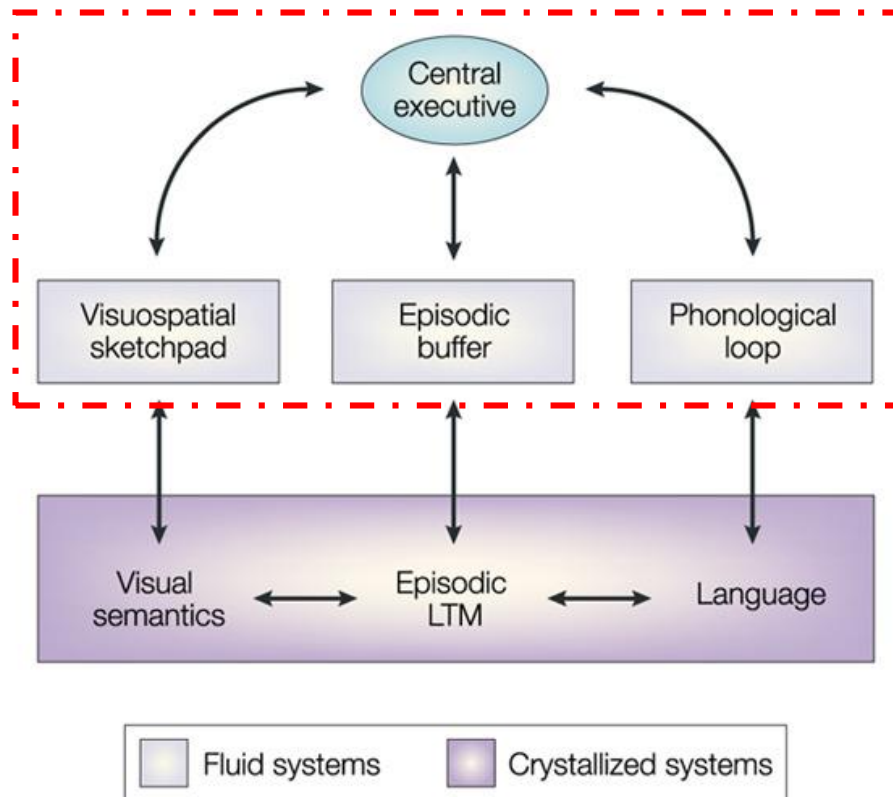
Figure 2 : Baddeley modified Working Memory model with episodic buffer

The Working Memory model contains:

- **Central Executive:** handles the other subsystems and their interconnectivity
- **Visuospatial Sketchpad:** It manipulates and store visual information
- **Phonological Loop:** It manipulates and stores acoustic information
- **Episodic buffer (added in 2000):** It stores information which either are integrated with other subsystems, or information that is not covered by other subsystems.

In Figure 2, the interaction between WM and LTM is illustrated. The Crystallized system represents the LTM where the information is permanently stored and they are very clear.

Based on the explanation above, one can observe that WM performance through two different types of information, visual and auditory. Throughout the past few years, researchers have developed and examined different approaches to discover and define WM further. In this study we are focusing on visual aspect of WM.

One of the frequently used tasks to examine WM is called Delay-response task, which covers all of the WM stages. These stages include Expectation (optional), Encoding, Maintenance, and retrieval [2]. These stages are illustrated in Figure 3. In the following parts we will explain these stages further.

Figure 3 : Working Memory stages

Expectation

The existence of this stage is optional, since the purpose of the expectation stage is only to improve the perceptual performance by generating predictive cues. These predictive cues increase the accuracy and speed of stimulus detection an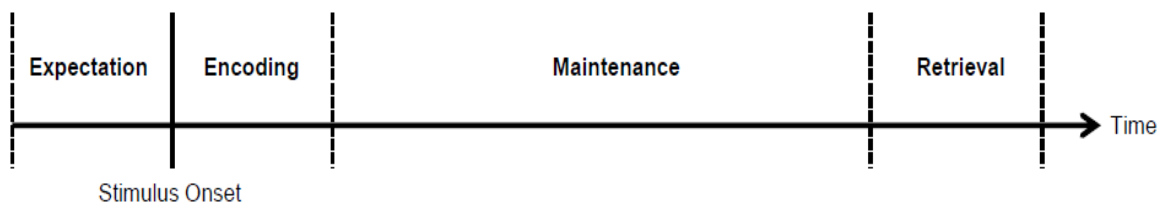d discrimination [3]. In this stage the participant will be guided about the relevant information in the stimuli and the perception will be modulated further (top-down) before stimulus presentation.

The neural activities of brain in this stage are called pre-encoding activities of the brain (since it is before encoding) and EEG analysis has shown that, existence of predictive cues that modulate the spatial attention results in higher pre-encoding activities. And there is a correlation between these activities and the WM performance

[4]. A study using fMRI analysis has revealed that the origins of these pre-encoding activities are Prefrontal Cortex (Middle Frontal Gyrus) and the left basal ganglia [5].

Encoding

Encoding stage is one of the frequently studied stages of WM task for the influence of attention. This is the stage where the stimulus will be presented to the participant. In this stage attention can be distracted in different ways, either by altering the objects (e.g., face and scene) which are presented as stimulus, or the features (e.g., color, orientation, movement) of the same object. fMRI studies has revealed the activity of Prefrontal Cortex (PFC) for both processing the relevant information and ignoring the distractions.

Brain functional connectivity analysis in an object-delayed response task showed that the connectivity between PFC (left MFG) and the regions of visual cortex which are responsible for detection of a specific object (e.g., scene) have stronger connectivity when the participant is instructed to remember the scene and weak connectivity when the instruction is to ignore the scene [6].

Maintenance

Traditionally, it was believed that attention can only influence the performance of WM up to encoding stage and that is the end point for selective attention. However, studies have shown that the neural activities related to selective attention in WM task continue to operate during maintenance stage as well. In fact, how effective the encoded information can be maintained is a significant determining factor in WM performance.

The efficiency of WM maintenance capability can be influence by attention mainly in two stages, encoding and maintenance. Studies has shown that inefficient filtering of irrelevant information during encoding stage results in lower performance of WM since the WM capacity would be filled with irrelevant information. This has been proved by

measuring the amplitude of modulation indexes such as P1 and N1 to find out how much the participant was focusing on relevant versus irrelevant information [7].

The number of items which are being held in WM can be indexed by Contralateral Delay Activity (CDA). It is believed that the amplitude of CDA linearly increases with the number of items which are stored in WM [1,8]. In fact, The result of [7] was complemented by another study which measured the amplitude of Contralateral Delay Activity while presenting distraction in encoding stage, and correlated that with the overall performance of WM [1].

Another study analyzed the influence of attention on WM by introducing distraction or interruption (secondary task) in maintenance stage. By analyzing P100 and N170 modulation, it was revealed that while presenting the distracting stimuli, the items are maintained in WM, however, while the participant was required to perform a secondary task (interruption presentation) in the maintenance stage, the items were not maintained but rather reactivated after the interruption [9]. The conclusion is that the more focused the participant is on the relevant information, the better the performance of WM [10].

Retrieval

The Final stage of WM is retrieval. Indeed, this is the stage where the performance of WM is measured. The research in this stage is not as advanced as the other stages, and that is a result of its complexity and involvement of almost all other stages. The process of retrieval necessarily contains the encoding of the Testing Array (or the Probe) and also the maintenance of the previously encoded information to be compared with the Testing Array. This complexity makes it hard to discover the neural activities that underlie this stage. Hence the information about this stage is rather limited compared to the other stages.

You can see an example of an object Delay-Response Task in Figure 4. And Figure 5 illustrates how the brain signal (CDA) looks like during a feature delay-response task.
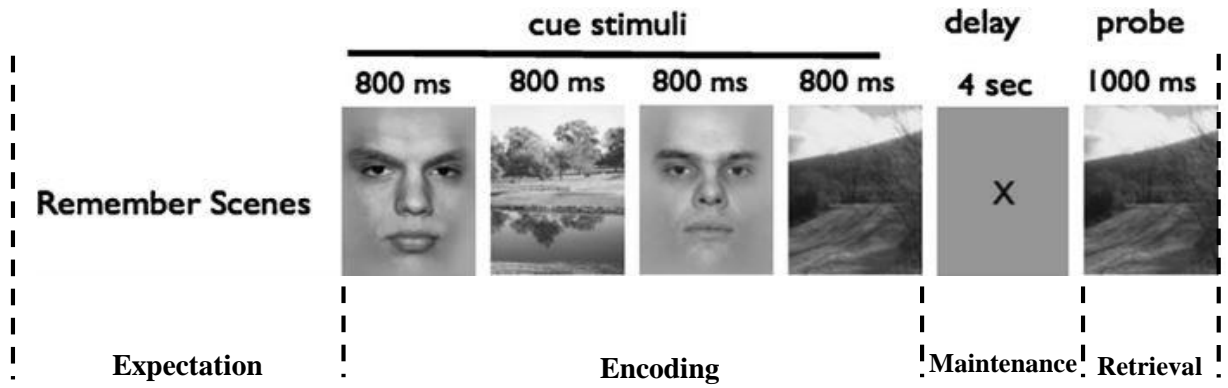
Figure 5: Example of Delay-Response Task
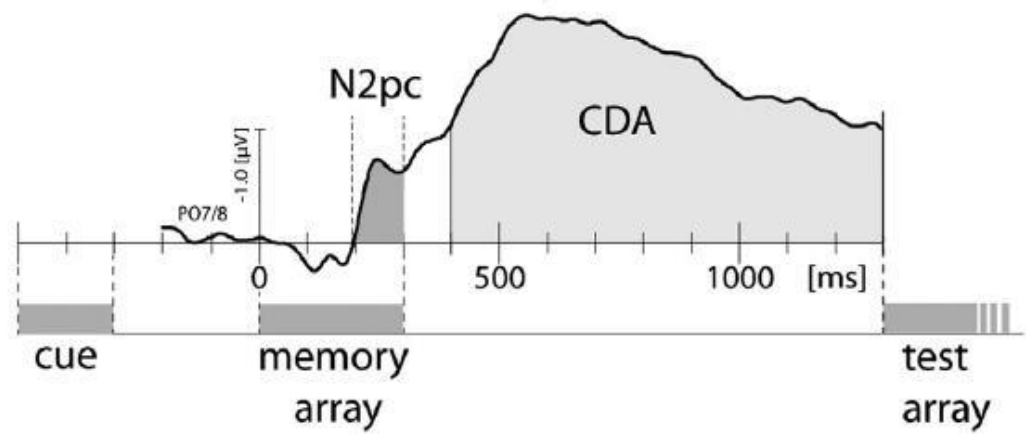
Figure 4: Contralateral Delay Activity during feature delay-response task

CHAPTER 3

METHODOLOGY

In general, this research contains several activities which the most important ones are Experimental Design/Paradigm, Data Acquisition, and Data Processing. In the following sections the Experimental Design, which is the approach to discover the influence of attention on the underlying neural activities of WM, will be explained in detail. Figure 5 illustrates the flow chart of the research.

3.1. Participants

EEG data were recorded involving 23 healthy participants (19-30 years, mean=23, 21 males). The study participants were prescreened to have normal vision and no use of drugs or any psychological treatments that effects the cognitive state. The experiment design was approved by the local ethics committee of Universiti Teknologi PETRONAS (UTP). The participation was voluntarily and the participants were compensated for their participation. The approved ethics form and the documents which were supposed to be prepared for this purpose are available in **Appendix A**. Moreover, a website was made to promote the experiment through social networks. To go to the website please click on the link: https://sites.google.com/site/bashiriexperiment/

Figure 6: Research Flow Chart

3.2. Experimental Paradigm

As mentioned before, the whole objective of this project is to analyze influence of attention in neural activities of brain while performing working memory task. This can be examined in two different stages, encoding and maintenance. This can be divided into two scenarios:

3. Analyze the influence of attention during encoding stage on WM load
4. Analyze the brain connectivity in maintenance stage while distraction and interruption is introduced

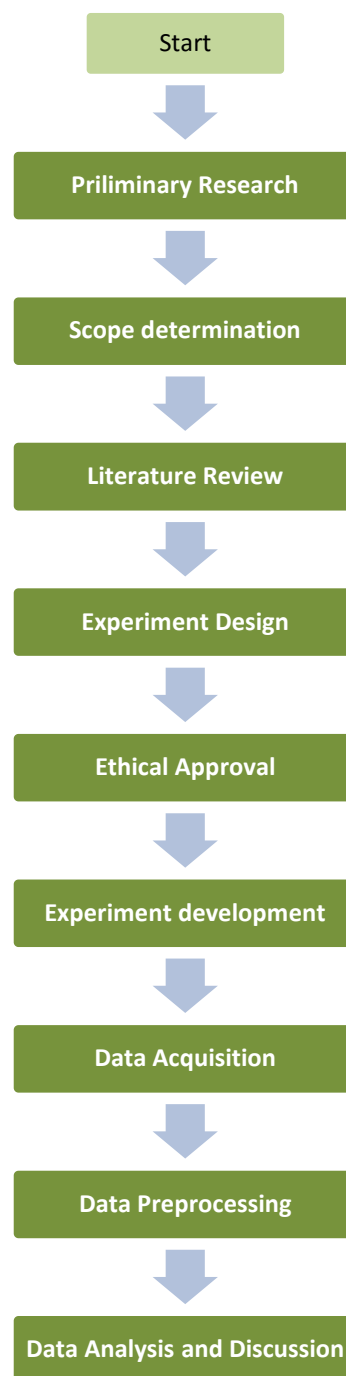In order to achieve the objectives of this research, we are using a feature delayed-response task which is explained in detail in the coming sections.

In the first task, for first objective, the distraction is introduced in encoding stage (DE task). The participant must remember the position of the red cubes relative to each other. The cubes to be remembered are the red color cubes. The color/number of distracting cubes might change. The cubes can be position in 18 different places in each visual hemifield (VH). We limit the number of red cubes to 6, since it is believed that WM can hold items in the range of 4 to 8, depending on the content.

The number of red cubes would not be altered throughout the experiment, only their position will. The attention of the participant is altered by adding different color cubes. As mentioned each side can accommodate 18 cubes, since 6 of that is filled with red cubes, there are 12 empty places left which can contain the distracting cubes with different colors. The colors of the distracting cubes vary between 7 colors (Black, Blue, Lime, Aqua, Magenta, Yellow, and White). With respect to the above description the steps of the experiment can be described as follow:

1. **Stimuli with no distraction** – This task is a pure WM task, hence the EEG data recorded in this task are used a base line to be compared with data recorded during the other tasks. 6 cubes in different positions will be placed in each VH (12 in total image). The result of this experiment is used as the baseline/reference to compare the changes when distraction is introduced.

2. **Stimuli with distraction – 4 (<6)** – in this step the distracting cubes will be added to the stimuli. The reason of choosing 4 is because we want to examine the brain activity when there are distracting cubes, but the number of them is less than the red cubes. In other words in this case the level of distraction is low!

3. **Stimuli with distraction – 8 (>6)** – In this step we introduce more distraction as compared both to previous step and also the number of red cubes.

Please note that the number of red cubes is the same throughout the experiment. Only their position (relative to each other) is changed. The participants are supposed to remember the position of the red cubes relative to each other as a whole pattern. In the testing array, the distractions would not appear, the reason is that the participants are asked to remember the position of red cubes and that is what they are going to be tested for. The point of introducing distraction is to alter the attention while encoding new information, not to alter attention while retrieval.

In the second task which is to achieve the second objective, there is no distraction or alteration of attention in encoding stage; rather we alter the attention during maintenance stage through a combination of distraction (DM task) and interruption (IM task). Interruption is a secondary task which requires participant's attention; the purpose of this task is to resemble the ability of multitasking. Participants will be shown pictures containing re cubes and in case of distraction the must ignore, and in case of interruption they must perform a secondary task (explained below). In this task, as well as task 1, we will have three (3) different levels. With respect to the above explanation, the tasks are:

1. **No distraction, no interruption** – in this case there will not be any distraction throughout the experiment, the result of this shall be used as a baseline/reference to enable comparison and analysis of the result of other situations.

2. **With distraction only** – The participants will be presented with stimulus containing cubes (same color with the cubes presented earlier in encoding stage), and they are supposed to ignore it.

3. **With interruption only** – The participants will be presented with a stimulus containing cubes (same color), and they are asked to distinguish whether the number of cubes (in the VH which was cued in the beginning of experiment) is more or less than 6. We choose 6 because that is the number of cubes presented in the encoding stage and it is a critical number in this case (at least more critical than other numbers).

The explanation above is the theoretical part of the experimental design. The visual presentation of the design is illustrated in Figure 6.

(a)

(b)
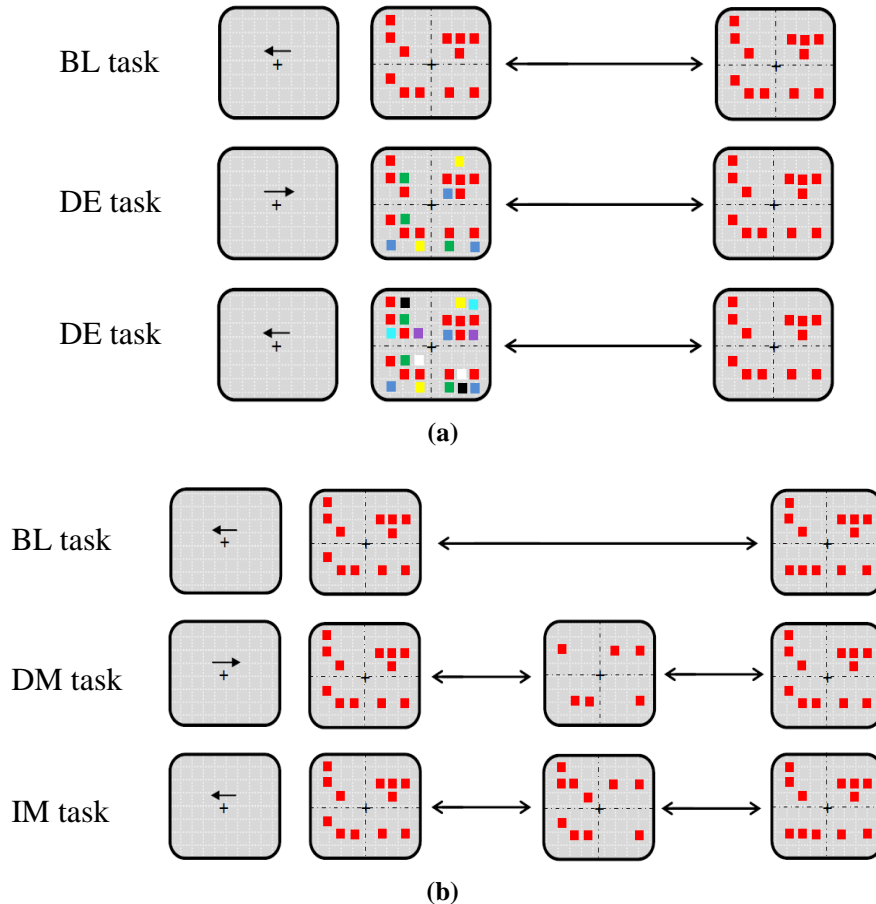
Figure 7: Experimental Design representation. (a) Design for first scenario. (b) Design for second scenario.

The above explanation is considered a theoretical explanation of the experiment design, however, timing is a crucial matter in psychological experiment. Hence, below there are some information about the timing and number of trials per level to clarify and complete the whole picture of the experiment.

Task 1 timing:
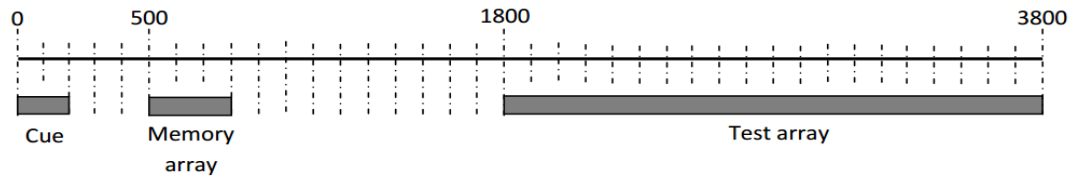
Total time for one trial = 3800 ms

Inter-trial Interval (ITI) = 2000 ms

Total time for one level (50 trials) = 3800 x 50 + 2000 x 49 = almost 5 min

Total time for task 1 = 5 x 3 = 15min (exclusive of breaks between levels)

Task 2 timing:
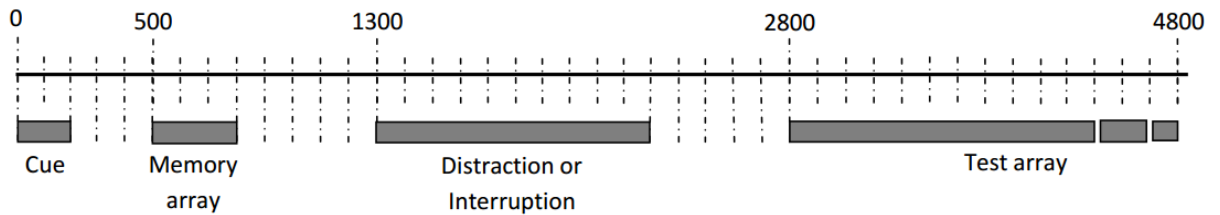
Total time for one trial = 4800 ms

Inter-trial Interval (ITI) = 2000 ms

Total time for one level (50 trials) = 4800 x 50 + 2000 x 49 = almost 6 min

Total time for task 1 = 6 x 3 = 18min (exclusive of breaks between levels)

3.3. Modality

The modality which is mainly being used for this study is Electroencephalogram (EEG). EEG data were recorded with a sampling rate of 256 Hz with a 21–channel EEG acquisition system (BrainMaster Discovery 24E) with link-ear (LE) reference. The electrode placements follow the international 10-20 electrode placement standard. The equipment which was used is BrainMaster Discovery 24E for EEG data acquisition. The equipment and 10-20 system electrode map are illustrated in Figure 7 and Figure 8, respectively.

Figure 8: BrainMaster Discovery 24E
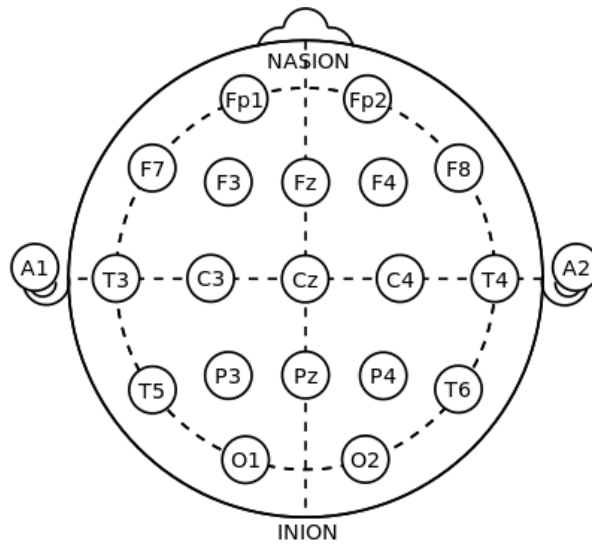
Figure 9: International 10-20 electrode map standard

3.4. Software

There are two software used in this experiment:

1. BrainMaster, for data acquisition
2. E-Prime, to design and conduct the experiment

Figure 10: E-prime software, logo

The software used to construct the experiment design is called E-Prime. E-Prime is a suite of application used for psychological experiments. The experiment design exactly looks like the pictures in figure 7.

E-Prime software, as expected, provides precise timing as required by the specifications of the experiment, and also it provides feedback, based on timing, to the BrainMaster software on the second PC to enable the researcher to keep track of time according to the stimulus presentation in the experiment. BrainMaster software was installed in PC1 and the E-prime on PC2.
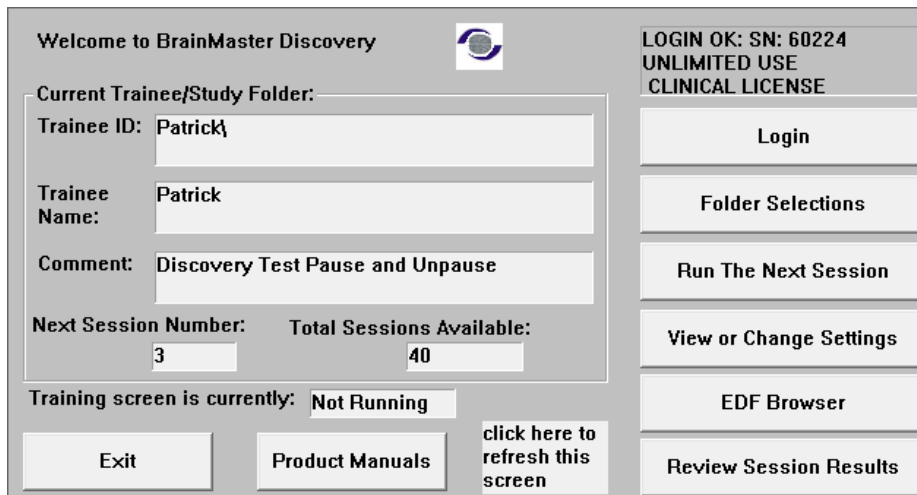
Figure 11: BrainMaster software

3.5. Sample Size

One of the most important steps of this experiment or any clinical experiment is the calculation of sample size, the number of subjects for the experiment must be chosen in such a manner that it is not too small to make the result of the study unreliable and not too big to waste resources (i.e., money). In this part, the necessary calculations for the sample size of this study is explained.

The objectives (recap):

Objective 1) Analyze the influence of attention during encoding stage on working memory load.

Objective 2) Analyze the influence of attention during WM maintenance stage by introducing distraction and interruption.

But what is to be achieved at the end of this experiment? And how the data is going to be analyzed?

In case of the first objective, the outcome of the study is to analyze the WM performance with respect to filtering efficiency of the WM. This can be achieved by looking at the changes in EEG signal amplitude with respect to amount of distraction which is present in the stimuli, and at the same time we will measure the WM performance by keeping track of the number of times the participant responds correctly.

Based on literature, the amplitude of EEG signal (i.e., CDA) for stimuli with and without distraction are different. The result of the amplitude in two different situations is:

Without distraction: 1.02 +/- 0.2865 μV

With distraction: 1.4344 +/- 0.4358 μV

$\delta = 0.4144, \sigma = 0.4358$

In case of the second objective, the outcome of the research is to explore the brain connectivity when distraction or interruption is presented while the encoded items are being maintained in WM. At the same time the brain connectivity can be correlated with the performance of working memory which is pretty close in these two cases. Hence, in this case we will use these percentages of WM performance as the basis to calculate the

sample size. A sample size that can be reliable to compare the performance of working memory in these two different situations can be reliable to analyze the neural behavior of the brain as well. Hence we have:

1. No Interruption, No Distraction: 94.2% +/- 3%

2. with Distraction only: 91.6% +/- 2%

3. with Interruption only: 90.3% +/- 3%

Between 2 and 1: δ = 2.6, σ = 3

Between 3 and 1: δ = 3.9, σ = 3

The results are always compared with the reference which is no interruption and no distraction condition. Having hat said, the following formula [11] is used to compute the sample size for this experiment:

$$n = \frac{2(Z_\alpha + Z_{1-\beta})^2 \sigma^2}{\delta^2}$$

In both cases, the **significance level is 0.05**, and **power is 0.9**. Since our test is one-tailed, the normal deviation (Z_α) for 0.05 significance level (Alpha) is 1.64, and normal deviation ($Z_{1-\beta}$) for statistical power is 1.28. Putting this information and the previous information in the formula the resulting sample size for each experiment will be:

Objective 1: $n = \frac{2(1.64+1.28)^2 \text{ x } 0.4358^2}{0.4144^2} = 19$

Objective 2: $n = \frac{2(1.64+1.28)^2 \text{ x } 3^2}{2.6^2} = 23$

3.6. Data Processing and Analysis

In the previous sections, we have discussed all the necessary steps which are required before starting the experiment. In the following sections we shall discuss the steps which are related to experiment setup and processing the data (see figure 12).

```
┌─────────────────────┐
│     EEG Data        │
│    Acquisition      │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│  Noise removal and  │
│    Segmentation     │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│   Computation of    │
│    Grand Average    │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│  Feature Extraction │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│  Feature Selection  │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│   Classification    │
└─────────────────────┘
```
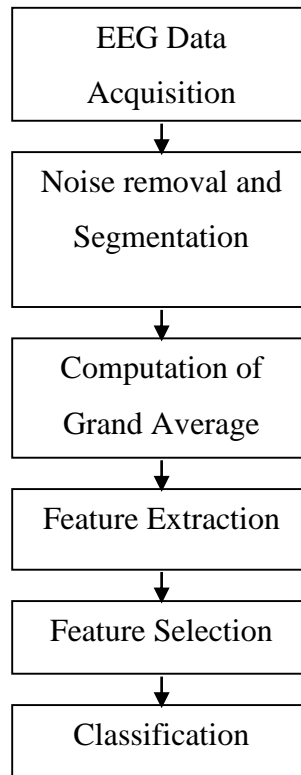
Figure 12: EEG acquisition and Analysis

The experiment was conducted in Universiti Teknologi PETRONAS campus, academic block 22, Center for Intelligent Signal and Imaging Research. Figure 13 shows the experiment setup while the participant is performing the task.

Figure 13: Experiment setup

EEG Data Acquisition

The challenges faced during data acquisition was the availability of the participants, and also interfacing BrainMaster software and E-Prime software to be enable the timing feedback from E-Prime to BrianMaster.

Noise Removal and Segmentation

To process the data, EEGLAB toolbox has been used. EEGLAB is a MATLAB toolbox for processing EEG, MEG and other electrophysiological data incorporating independent component analysis, artifact rejection, time/frequency analysis, event related statistics, and several useful modes of visualization of the averaged and single-trial data. The flow of data processing using EEGLAB to provide a clean data are shown in Figure 10. After cleaning the data, it is saved as .edf file again and that .edf file is then processed, based on the timing information, to perform grand averaging.

For this purpose the researcher had to construct several function in MATLAB, first to perform segmentation of the continuous data based on the timing information. And then perform averaging for the segmented data. These codes are available in **Appendix B**.

```
Import Data (.edf)
        ↓
Apply Filtering
        ↓
Artifact Removal by Visual
Inspection
        ↓
Import channel location (.locs)
        ↓
Independent Component
Analysis
        ↓
Reject component(s)
        ↓
Check and Compare the dataset
with previous one
        ↓
Satisfied?  — No →
        ↓ Yes
Save [clean] Data
```
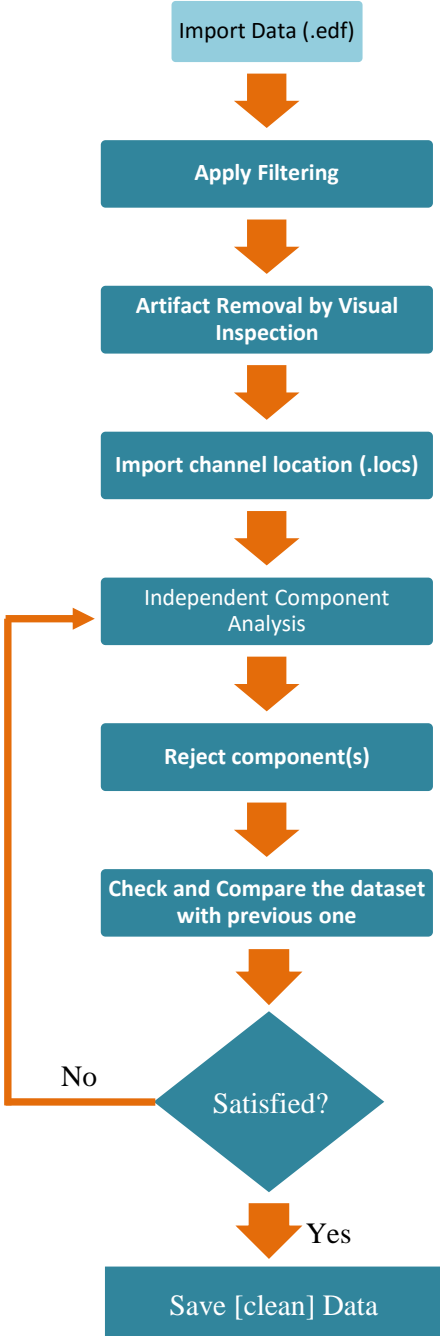
Figure 14: Data Processing Flow Chart

Computation of Grand Average

Noise always exist in EEG data; there are various ways to deal with this noise, however, one of the ways is computing the grand average over the number of trials. As mentioned before, each level of each task of the experiment contains 50 trials. Some of the trials contain artifacts, which are removed by visual inspection, but some of the noises have other sources which are out of our control (i.e., noises related to the data acquisition device). Top deal with the noise, we perform grand averaging which is one of the methods to deal with the existing noises in the data.

Feature Extraction and Selection

EEG features were extracted by computing coherence from the EEG data. It is the most common brain connectivity estimators is Magnitude Squared Coherence (MSC) which measures linear connectivity in the frequency domain [11]. Coherence is sensitive to changes in both power and phase of the signals and provides spatial correlation between the signals in different frequencies. In order to find the magnitude squared coherence *Cxy* of the input signals x and y we have used the modified periodogram, Welch's averaged method. Coherence of signal *x* and *y* is defined as:

$$C_{xy}(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)} \tag{1}$$

Where C_{xy} represents Fourier cross-spectrum of signals *x* and *y*. The estimated MSC ranges from 0 (no coupling) to 1 (maximum linear independence) at a given frequency, which indicates how well x corresponds to y at each frequency.

To select the features, we have used binary classification method to divide the result form behavioral data into "good" and "weak" WM-Attention performance. And the features (i.e., coherence between left electrode and right electrodes) were ranked according to their ability to result in same results as behavioral data.

Classification

After recognizing the best features to resemble the same result as behavioral data with EEG data, we have used logistic regression classifier to classify and, furthermore, we have validated our results by computing the accuracy of our classifier. To validate our results and to find the best classification method, we have assign different number of ranked feature to our classifier and we have computed the accuracy of result for each number of features used, and based on that we have decided how many of features must be used to give us the best accuracy which is closest to the results from behavioral data. These results are explain in the next sections.

Graphical User Interface

For the purpose of this study, a Graphical User Interface (GUI) is also developed, which enables the user to perform all of the steps mentioned in the *data processing* part.

Hence, providing a user-friendly environment to perform WM-related experiment and analyze the data. The output of this GUI is designed in such a way that it is in line with the results from the result of the E-prime software, therefore, it specifies whether the WM capability of the participants as "good" or "weak". The purpose of having this GUI is enable the users to assess WM performance, based on EEG signals (brain connectivity) and not by special software and specific task. The advantage is enabling users to have flexibility of tasks to assess WM performance.
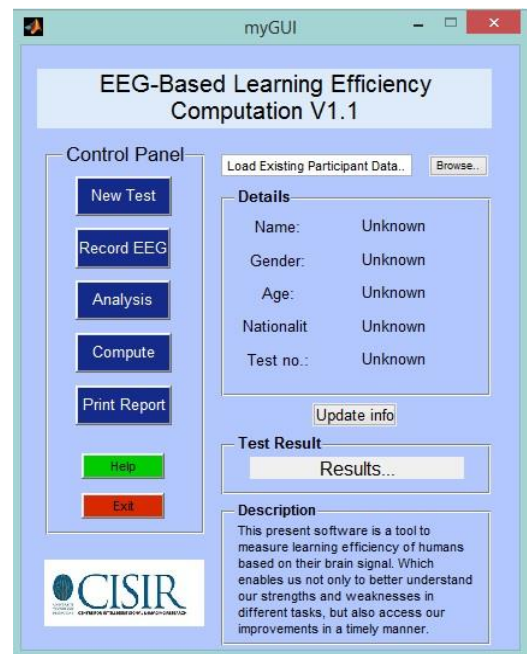
Figure 15: Graphical User Interface

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3.7. Gantt Chart (including milestones)

No.	Detail\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experiment setup	🟥	🟥												
2	data Acquisition			🟥	🟥	🟥	🟥								
3	Data Processing					🟥	🟥	🟥	🟥						
4	Progress Report Submission									😊					
5	Data Analysis									🟥					
6	Pre-SEDEX										😊				
7	Submission of draft final report											😊			
8	Submission of Dissertation												😊		
9	Submission of technical paper												😊		
10	Viva													😊	
11	Submission of Project Dissertation														😊

Figure 16: Gantt chart of Final Year Project 2

CHAPTER 4
RESULT AND DISCUSSION

As studies have shown, attention can have significant influences on WM performance. However, having several stages of WM task, different types of attention, and different types of information which differ in the amount of processing needed for encoding increase the complexity of this topic.

In this case, we are analyzing the influence of attention on the neural activities that underlie WM tasks, by altering the attention in two stages of WM, encoding and maintenance. In encoding stage, this is being done by analyzing the amplitude of Contralateral Delay Activity (CDA) whose amplitude is directly proportional with the number of items held in WM. It is believed that inefficient filtering of irrelevant information in encoding stage results is lower WM performance, since the WM capacity will be filled by irrelevant information rather than relevant. Hence, the hypothesis is that as the distraction is introduced, by keeping the amount of relevant information constant, the amplitude of CDA must increase; the more the amplitude increases means the more irrelevant information is being encoded and stored in WM and hence WM performance must decrease.

In case of attentional influence in maintenance stage, it was revealed that our brain behaves differently in case of distraction and interruption (secondary task) during maintenance stage. When a distraction is presented, the encoded items are maintained in WM, as shown by the neural activities (P100 and N170) of brain, are maintained. However in the case of interruption, these neural activities are rather reactivated after the interruption. In this study, this is evaluated by measuring CDA amplitude.

In this study, we have both the behavioral data (from E-prime software) and EEG data. Based on the behavioral data, we have divided the participants into "good" and "weak" categories, and we aim to analyze the brain connectivity through EEG data in such a way that same result as the behavioral data can be computed through EEG data.

Behavioral Data

Behavioral data revealed an adverse effect of distraction and interrupt on WM performance. Participants performed their highest accuracy in BL task (BL = 97%, standard error [SE] = 0.83%). When the distraction was presented in encoding stage, accuracy has significantly dropped (DE = 94%, SE = 1.28%). However, when the distraction was introduced in maintenance stage, the WM turned out to be more accurate then DE task (DM = 95%, SE = 0.96%). And in the final task, when the participants where instruction to perform a secondary task during maintenance stage, WM accuracy has significantly dropped as compared to DE and DM tasks (IM = 84%, SE = 1.8%) (See figure 16)
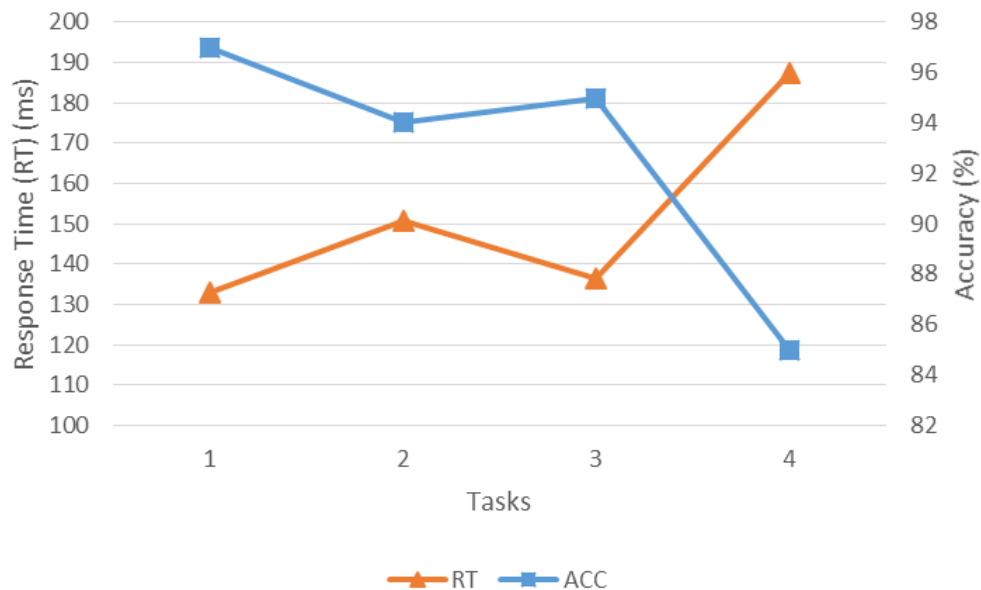
Figure 17: Behavioral performance. WM accuracy. Participants performed best in the BL (1) task, followed by DM (2), DE (3), and IM (4).

As it can be observed, participants have performed best in BL task and worst in IM task. The performance of the participants were almost the same in case of DE and DM tasks, but they have performed in DM task slightly better that DE task and that shows the importance of encoding stage in the accuracy of WM.

EEG Data

EEG analysis focused on brain connectivity using coherence feature between left-side electrodes (Fp1, F7, F3, T3, T5, C3, P3, O1) and right-side electrodes (Fp2, F8, F4, T4, T6, C4, P4, O2). Based on behavioral data, we can distinguish between those participants who have good capability to focus while performing WM task and those who do not. Good performance in both BL task and the other tasks indicates good filtering capabilities, hence by taking the difference between the brain activity of participants during BL task and other tasks (i.e., DE and DM) we can find out what are the underlying brain areas which are responsible for this efficient filtering capability. Moreover, since IM task resembles multitasking capabilities, we have used the same method to analyze the brain connectivity for multitasking capability.

There are 19 participants, 8 electrodes left side, and 8 electrodes right side to be taken into account for connectivity analysis; we monitor the connectivity for frequency range of 0-45 Hz for each pair of electrodes, which results in a 19-by-2880 matrix. This matrix was then fed to the feature selection algorithm to find the best features, among the 2880 features, which distinguishes between a good and weak WM-attention capability, in correspondence with behavioral data.

For the DE task our method resulted in 90% accuracy in distinguishing a good WM-Attention performance. This result was achieved by only taking 5 features into account which means of 5 pairs of electrodes in specific frequency ranging from 0 to 45 Hz. These pairs and their frequency are tabulate in table 1. However, for DM task there are much more features to be taken into account. 35 features must be taken into account for an 80% accurate prediction of good vs weak WM-Attention capability. And finally, for the IM task which resembles multitasking the performance can be predicted with more than 85% accuracy using 35 features.

It is important to note that definition of "good" and "weak" WM-Attention is based on a threshold, which is task-specific factor and it is specified by analyzing the behavioral data. Some tasks might be very difficult and their threshold is lower, on the other hand easier tasks have higher threshold. In our task the threshold was set to accuracy of 98%.

Hence, participants with result of 98% and above were recognized as "good" and the rest as "weak".

Table 1: First 10 electrode pairs (features) for each task.

DE task		DM task		IM task	
Electrode Pair	Frequency (Hz)	Electrode Pair	Frequency (Hz)	Electrode Pair	Frequency (Hz)
F3 – F8	38	F3 – O2	24	F3 – P4	45
F7 – Fp2	43	F3 – T6	33	T5 – P4	18
Fp1 – F8	41	F3 – O2	21	F3 – T6	10
T5 – F8	10	C3 – O2	20	Fp1 – C4	15
T5 – F8	15	O1 – T6	8	C3 – F8	22
T5 – P4	8	O1 – T6	14	O1 – Fp2	19
C3 – F4	39	O1 – O2	40	Fp1 – F4	22
F3 – F4	5	F3 – P4	33	F7 – F4	36
Fp1 – F4	19	T5 – O2	25	F7 – T6	36
F7 – P4	27	C3 – O2	24	F3 – P4	31

(a)

(b)

(c)
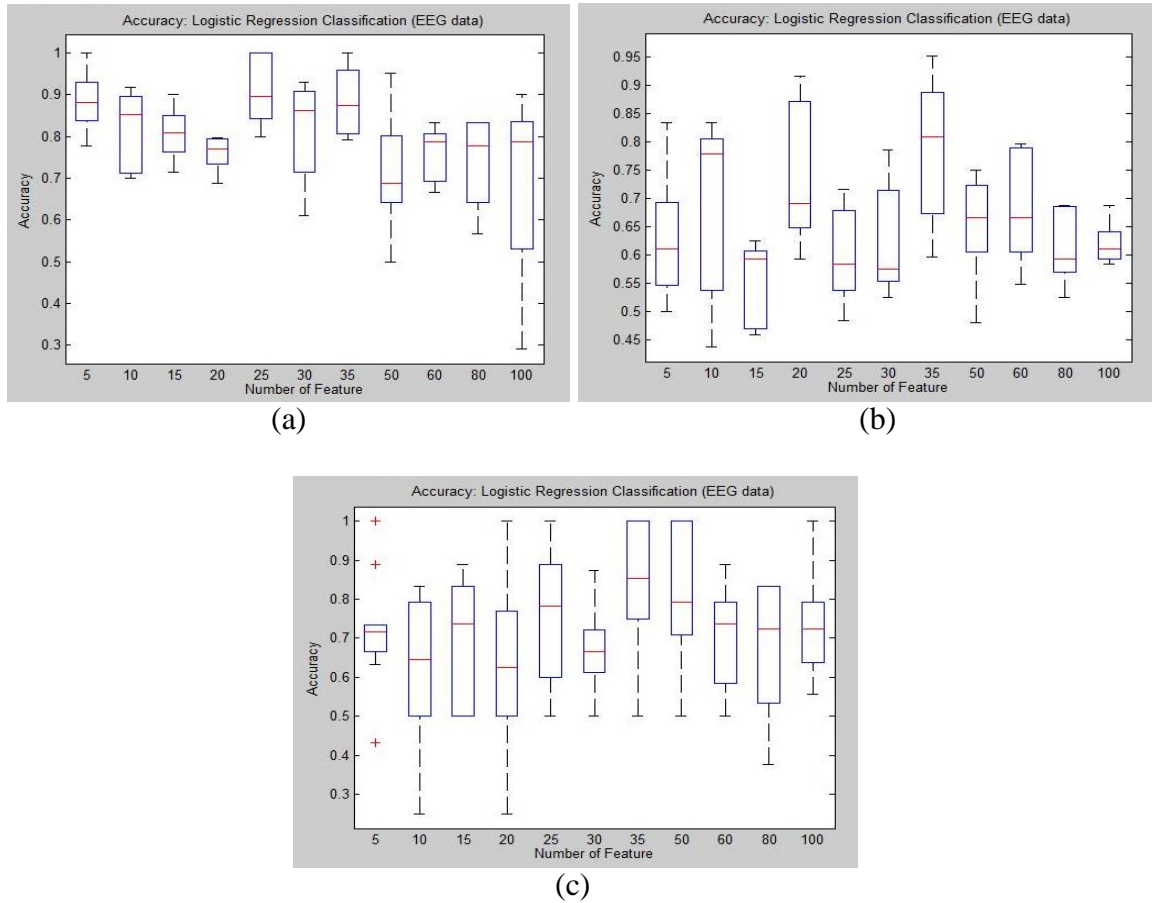
Figure 18: Accuracy of coherence analysis to predict the WM-Attention capability. (a) Accuracy for DE task. (b) Accuracy for DM task. (c) Accuracy for IM task.

As predicted, in terms of behavioral analysis, the WM accuracy has diminished as a result of distraction and interruption. However, this result was successfully monitored through brain connectivity analysis during WM-attention task. Our result demonstrates that brain connectivity analysis, as reflected by introducing interference, can predict WM performance.

Based on our result, while the distraction is presented in encoding stage, mostly the activity in frontal part has changed, and that suggests its engagement in directing attention towards the relevant information and filtering out the irrelevant information. However, when the distraction was introduced in maintenance stage most changes of activity were observed in occipital lobe. It identifies the role of occipital region in maintaining visual information efficiently while being distracted during WM task. Finally, the brain activity during multitasking does not highlight a specific area of the brain to be activated more than the other part and that shows the complexity of this cognitive skill, however engagement of frontal lobe is still more than other parts during this task.

CHAPTER 5
CONCLUSION AND RECOMMANDATION

The importance of discovering the influence of attention on WM performance is not only limited to research, but it is even more important in real-life issues. Attention affects the efficiency of WM and efficiency of working memory is determining factor in any task which required encoding of new information, such as learning. Besides learning, it is significant for those jobs that require accurate observation of environment such as security or pilots, drivers and etc.

Although at the present time, research aims to discover the mechanism of WM and its interaction with Attention, but the ultimate goal must be applying this knowledge in making a more efficient living. An efficient leaving by providing mechanisms that enable us to discover everyone's potential in a specific task, or trainings which can enhance our brain performance.

Hopefully this study can contribute in providing and improving the knowledge base about the interaction between Attention and WM.

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Informed Consent Form

This Informed Consent Form is for those male or female participants who are willing to attend the brain-related experiment which is being held in University Technology PETRONAS. The title of our research project is ***Brian connectivity analysis of Attention and Working Memory***.

This document contains two parts:
- Information Sheet (to share information about the research with you)
- Certificate of consent (for signature if you agree to take part)

PART I – Research Information

Researcher's Name: **Mohammad Bashiri**

Supervisor's Name: **AP Dr. Aamir Saeed Malik**

Introduction

In this document you will be given the necessary information about the experiment, and you will be invited to participate in this experiment voluntarily. You can participate in this study between **21st May 2015 and 15th June 2015**. During this period you will take part in two (2) tasks (two experiment sessions). Each session would take around 30 minutes. While performing the tasks your brain activity will be measured mostly from Visual and Prefrontal Cortex (PFC) of your brain.

There may be some words that you do not understand. Please ask me for explanation any time you feel the need. If you have questions later, please do not hesitate to contact me through the communication means which are provided below.

Purpose of the research

Working Memory is a part of our memory system which is able to manipulate and store the information in a limited capacity. The performance of Working Memory is significantly influenced by Attentional derivation in humans. The interaction between Working Memory (WM) and Attention is a one of the most heavily studied field of psychology. In recent years, this topic has gone through research in fields such as neuroscience and neuroimaging which enables scientists to explore the underlying parts of the brain for the interaction between these two cognitive constructs. Until today, the

influence of attention on our working memory performance is being studied through the same type of task which is called delay-response task. This study aims to discover and reconfirm the findings about WM, and attentional influence on it, by utilizing a new experimental design.

Participant Selection

For this project, we are targeting:

- Healthy individuals among university students (19-30 years old)
- Male
- Right-handed

  Who cannot participate in this experiment?
- Individuals who suffered or are suffering from brain related disease and disorders
- Individuals with any drug abuse or those who consumed medication within 5 days prior to the experiment
- Individuals who have any history of psychological or mental problem

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. You may talk about this experiment with anyone that you are willing to, and you can also encourage them to participate.

Procedure and Protocol

The protocols used in this experiment are BrainMaster Discovery E24 which performs the EEG test, and Optical Topography which performs high-quality real-time cerebral-cortex-imaging and measurements. This experiment contains two tasks, which are divided into different difficulty levels and several trials. Participants will be briefed and instructed before each experiment and trial Data are collected while the participants are performing the task. Necessary details of the experiment are listed below:

Type of task: Delay-response match/non-match
No. of tasks in a session: Two (2)
No. of sessions: One (1)
Number of trials per task: 150 (300 trials in a session)
Time Taken for each task: approximately 30 minutes

The step-by-step procedure of the experiment is explained below:

1. **Briefing and Consent**
   - The participant will be briefed amount the experiment and will read and sign the consent form

2. **Practice Session**
   - The participant would be positioned on a particular place to perform the task
   - The participant will go through go through 40 practice trials – 20 left LF and 20 RF.

3. **Equipment Set up**
   - Prior to positioning the BrainMaster Discovery 24E a liquid would be splashed on the electrodes which are used to improve the sensitivity/connectivity of the electrodes.
   - The emotive EEG will be positioned on the participant's head

4. **Experiment and Data Acquisition**
   - Upon the start of each task, data acquisition starts
   - The Participant would be using looking at the monitor and use a keyboard while performing the tasks to respond if necessary

5. **Feedback and Questionnaire**
   - An Appreciate note will be provided to the participant
   - A questionnaire will be provided in order to have the feedback of the participants about the experiment

Duration

The research task takes place over one day. In total there are two (2) sessions and the time of each session is estimated to be two (2) hours. In order to do the task, it is necessary for you to come to the Centre of Intelligent Signal and Imaging Research (CISIR) of UTP at the allocated time.

Side Effects

There is no drug (or any other effective consumable) usage throughout the experiment. Participants would perform the experiment in their normal condition. Hence there is no side effect as a result of this experiment.

Risks

The experiment protocol and equipment used in this study are safe and non-invasive. However, discomfort is likely to occur and the participant may feel uncomfortable during the experiment which might include irritation or slight pain on the forehead region (due to contact of the measuring probes). Besides due to the number or duration of tasks you might be mentally disturbed during the experiment session. In any case, please report your uncomfortable situation (physically or mentally) to the experiment conductor. Upon arising of a concern from either the participant or the person in charge for the experiment, the experiment will be terminated. You may choose to participate in the experiment again (upon approval of the researcher) or withdraw yourself from the study entirely.

Benefits

Your participation in this research would make a contribution to the advancements of our knowledge about human brain. By discovering the behavior of our brain, the recovering methods, as a result of any kind of injury, can be improved, which at the end results in a healthier life for everyone.

Reimbursements

Upon participation and **successfully completion** of this experiment, amount of **RM15 per hour** would be paid to the participant as a sign of appreciation for their time and willingness to help this experiment. Please note that refreshments will also be provided.

Confidentiality

The experiment will be advertised through public communication network (e.g., Facebook, Twitter, etc.). You can share the news for the experiment with anyone you want. The identity of the participants would not be shared by those who are conducting the experiment. But if the participant himself/herself is willing to share, that is his/her decision to make.

Who to Contact

If you have any questions you may ask them now or later, even after the study has started. If you wish to ask questions later, you may contact me through the following communication means:
Hand phone number: 012 259 6853
E-mail address: mohammadbashiri93@gmail.com

PART II: Certificate of Consent

To be a part of this study, you or your legal representative must sign this page.

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Name of Participant_____   I.C number _____

Signature of Participant_____ Date _____
                                                            Day/month/year

To be filled by the researcher

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands the procedure of the experiment.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this ICF has been provided to the participant.

Name of Researcher_____

Signature of Researcher_____   Date _____
                                                            Day/month/year

Name of Witness_____

Signature of Witness_____   Date _____
                                                            Day/month/year

Borang Kebenaran Peserta

Borang Kebenaran Peserta ini disediakan untuk peserta-peserta lelaki dan perempuan yang terlibat dalam aktiviti penyelidikan berkenaan otak yang bakal diadakan di Universiti Teknologi PETRONAS secara sukarela.

Tajuk penyelidikan: ***Brian connectivity analysis of Attention and Working Memory***.

Dokumen ini terbahagi kepada dua bahagian, iaitu:
- Informasi Penyelidikan (mengandungi informasi lanjut berkenaan projek)
- Borang Kebenaran (tandatangan kebenaraan jika bersetuju untuk bekerjasama)

BAHAGIAN I – MAKLUMAT PENYELIDIKAN

Nama Penyelidik: Mohammad Bashiri

Nama Penyelia: Dr. Aamir Saeed Malik

PENDAHULUAN

Maklumat-maklumat berkenaan eksperiment yang akan dijalankan telah disertakan di dalam dokumen ini bagi yang dijemput untuk terlibat dalam aktiviti ini, secara sukarela.

Tarikh penyertaan ialah pada 1 Mei 2015 hingga 13 Mei 2015. Dalam jangkamasa penyertaan, peserta-peserta akan terlibat dalam dua (2) sesi eksperiment dimana setiap sesi akan dijalankan selama satu (1) jam. Semasa aktiviti eksperiment dijalankan, keputusan bacaan aktiviti otak / minda peserta akan diperoleh daripada "Visual and Prefrontal Cortex (PFC)".

Dari maklumat yang disediakan, anda mungkin berhadapan dengan beberapa perkataan atau terma yang sukar difahami. Jika terdapat sebarang pertanyaan, sila hubungi saya pada media komunikasi yang telah disediakan di bawah.

TUJUAN PENYELIDIKAN

"Working Memory (WM)" merupakan sebahagian daripada sistem memori kita dimana ia boleh memanipulasi, dan menyimpan data dalam kapasiti yang terhad. Prestasi "Working Memory" seseorang dipengaruhi oleh asal penumpuan di dalam sistem sedia ada. Interaksi antara Working Memori (WM) dan Perhatian (Attention) merupakan antara

subjek focus yang dititikberatkan dalam bidang psikologi. Sejak beberapa tahun yang lalu, topik ini telah melalui proses penyelidikan dalam bidang neuroscience dan neuroimaging dimana penyelidikan ini telah memberi peluang kepada saintis untuk meneroka bahagian-bahagian otak yang complex dengan lebih mendalam di mana mereka telah melakukan penyelidikan antara dua konstruk kognisi ini.

Sehingga kini, pengaruh perhatian (Attention) terhadap prestasi "Working Memory (WM)" manusia masih melalui proses penyelidikan di bawah jenis aktiviti yang sama iaitu "delay-response task". Penyelidikan ini bertujuan untuk meneroka dan menyetujui penemuan tentang WM, dan pengaruh perhatian terhadapnya, dengan menggunakan konsep penyelidikan yang baharu.

PEMILIHAN PESERTA / KELAYAKAN

Kriteria peserta yang diperlukan:

- Peserta yang tidak mempunyai sebarang isu kesihatan (19-30 tahun)
- Lelaki
- Bukan kidal (tulis mengunakan tangan kanan)
- Tidak merokok

Individu yang **tidak** boleh terlibat?

- Individu yang mempunyai sakit / isu kesihatan yang berkaitan dengan otak / mental
- Individu yang mempunyai masalah berkaitan penggunaan dadah atau terpaksa mengambil medikasi sekurang kurangnya lima (5) hari sebelum aktiviti penyelidikan dijalankan
- Individu yang mempunyai sejarah medik berkaitan sakit / masalah mental

PENYERTAAN SECARA SUKARELA

Penyertaan anda dalam penyelidikan ini adalah 100% dari kehendak sendiri (sukarela). Pilihan terletak sepenuhnya di tangan peserta atas kerelaan masing-masing. Anda boleh mengajak rakan-rakan anda untuk tutur menyertai penyelidikan ini.

PROSEDUR DAN PROTOKOL

Protokol yang digunakan dalam penyelidikan ini ialah BrainMaster Discovery E24/**eego**™sports dimana EEG test dilakukan, dan Optical Topography yang melakukan "cerebral-cortex-imaging & measurements" berkualiti tinggi dalam jangkamasa yang singkat. Penyelidikan ini mengandungi dua (2) aktiviti yang terbahagi kepada peringkat kesukaran yang berlainan dalam beberapa cubaan. Para peserta akan diberi taklimat tentang prosedur penyelidikan dan akan diberi arahan oleh penyelidik setiap kali sebelum aktiviti dumulakan. Data akan diambil semasa aktiviti dijalankan. Berikut adalah;

Jenis aktiviti:	Delay-response match/non-match
Aktiviti setiap sesi:	Dua (2)
Jumlah sesi:	Dua (2)
Jumlah percubaan setiap aktiviti:	400 (800 percubaan setiap sesi)
Masa keseluruhan:	Satu (1) jam

LANGKAH-LANGKAH PROSEDUR PENYELIDIKAN:

6. **Taklimat dan Kebenaran**
   - Peserta akan diberi taklimat tentang prosedur-prosedur yang harus diikuti, dan menandatangani borang kebenaran.

7. **Sesi Latihan**
   - Para peserta akan dibawa ke lokasi penyelidikan bagi menjalani sesi latihan.
   - Peserta akan menjalani 40 sesi percubaan – 20 left VF dan 20 RF.

8. **Penyediaan peralatan**
   - Bagi menggunakan BrainMaster Discovery 24E, sejenis cecair akan disapu pada elektrods untuk menambah baikkan prestasi sensitif/sambungan elektrods tersebut.
   - Emotive EEG akan ditampalkan di kepala peserta

9. **Penyelidikan dan Pemerolehan Data (Data Acquisition)**
   - Pemerolehan data (data acquisition) akan dijalankan pada setiap permulaan sesi latihan.
   - Peserta akan melihat monitor yang disediakan semasa sesi dijalankan dan menggunakan papan kekunci jika diperlukan.

10. **Tindakbalas dan Soalan**
    - Para peserta akan diberikan nota penghargaan di akhir sesi.

- Borang tindakbalas tentang sesi penyelidikan disedikan untuk perserta, sebagai penambah baikan.

Jangka masa

Tugas penyelidikan berlaku lebih daripada satu hari. Secara keseluruhannya, terdapat dua (2) sesi dan setiap sesi dianggarkan berlangsung selama dua (2) jam. Bagi menjalankan tugas itu, adalah perlu bagi anda untuk datang ke Centre of Intelligent Signal and Imaging Research (CISIR) (CISIR) UTP pada masa yang diperuntukkan.

Kesan Sampingan

Tidak ada ubat (atau mana-mana ubat yang mendatangkan kesan sampingan yang lain) penggunaan seluruh eksperimen. Para peserta akan melaksanakan eksperimen dalam keadaan normal dan sediakala. Oleh itu tidak ada kesan sampingan hasil daripada eksperimen ini.

Risiko

Protokol eksperimen dan peralatan yang digunakan dalam kajian ini adalah selamat dan bukan-invasif. Walau bagaimanapun, rasa tidak selesa mungkin berlaku semasa eksperimen yang mungkin termasuk kerengsaan / kegatalan atau sakit sedikit di bahagian dahi (kerana hubungan dengan kuar pengukur).

Selain itu, daripada tampoh latihan anda mungkin mengalami gangguan fikiran semasa sesi percubaan. Walau apa pun, sila laporkan keadaan tidak selesa anda (fizikal atau mental) kepada konduktor eksperimen. Jika timbul kebimbangan dari sama ada peserta atau orang yang bertanggungjawab bagi eksperimen, eksperimen itu akan ditamatkan. Anda boleh memilih untuk mengambil bahagian dalam eksperimen lagi (setelah mendapat kelulusan penyelidik) atau menarik balik diri anda daripada kajian penyelidikan sepenuhnya.

Kebaikan

Penyertaan anda dalam kajian ini akan memberi sumbangan kepada kemajuan pengetahuan kami tentang otak manusia. Dengan menemui kelakuan otak kita, kaedah pemulihan, hasil daripada apa-apa jenis kecederaan, boleh diperbaiki yang akan mendatangkan faedah kepada manusia di masa akan datang.

Pembayaran

Jika sesi latihan setiap sesi ini berjaya, setiap peserta akan dibayar RM20 setiap sesi sebagai tanda penghargaan atas penglibatan bersama. Minuman juga disediakan untuk peserta.

Kerahsiaan Identiti

    Program penyelidikan ini akan diwar-warkan melalui media sosial seperti Facebook, Twitter Instagram dan sebagainya. Privasi identiti anda akan dilindungi. Namun begitu, jika peserta secara sukarela ingin berkongsi pengalaman penyelidikan, keputusan sepenuhnya berada di tangan peserta.

Siapa untuk dihubungi

    Jika terdapat sebarang pertanyaan berkenaan aktiviti ini, sebelum mahupun semasa tempoh dijalankan, sila hubungi saya di media kominikasi yang telah disediakan:

Nombor telefon: 012 259 6853

E-mail: mohammadbashiri93@gmail.com

PART II: BORANG KEBENARAN

Untuk menjadi sebahagian daripada kajian ini, anda atau wakil sah anda mesti menandatangani mukasurat ini.

Saya telah membaca maklumat di atas, atau pernyataan telah dibacakan kepada saya. Saya telah berpeluang untuk bertanya soalan tentang hal itu dan soalan yang saya telah tuju dijawab dengan memuaskan. Saya bersetuju secara sukarela untuk mengambil bahagian sebagai peserta dalam kajian ini.

Nama Peserta   _____   No. IC _____

Tandatangan Peserta_____   Tarikh _____

                                                    Day/month/year

Untuk diisi oleh penyelidik

Saya telah membacakan lembaran maklumat untuk peserta yang berpotensi, dan daripada kemampuan, saya telah memastikan bahawa peserta memahami prosedur eksperimen dengan baik.

Saya mengesahkan bahawa peserta telah diberi peluang untuk bertanya soalan mengenai kajian ini, dan semua soalan yang ditanya oleh peserta yang telah dijawab dengan betul dan dijelaskan dengan terbaik daripada kemampuan saya. Saya mengesahkan bahawa individu tidak dipaksa memberikan kebenaran, dan kebenaran yang telah diberikan secara bebas dan sukarela

 Salinan Borang Kebenaran ini telah diberikan kepada peserta.

Nama Penyelidik   _____

Tandatangan Penyelidik _____   Tarikh _____

                                                   hari/bulan/tahun

Nama Saksi   _____

Tandatangan Saksi   _____   Tarikh _____

                                                   hari/bulan/tahun

Volunteer information form

First name:		Last Name:	
E-mail:		Matrix no:	

Personal Information			
Nationality:		NRIC/Passport	
Phone no:		Emergency	Name:
Alternative phone no:		contact	No:
Mailing Address:			
Course of study:		UG/PG	Year/semester:

Research Related Information			
Date of Birth:		Age: ( )	Nationality:
Gender:		Native Language:	
Dominant hand:		English fluency level:	
Smoking?		Highest Education level:	

Health Condition	
Any Physical Problem? ☐Yes ☐No	Any Mental Problem? ☐Yes ☐No
If Yes please explain	If Yes please explain
Drug abuse or consuming any medicine? ☐Yes ☐No	

I hereby declare that are the mentioned information above are filled by me, and they are true and accurate as to the best of my knowledge. I understand that the researchers will do their best to maintain the confidentiality of my personal information and solely use it for information purposes only.

Name: _____   Signature and date: _____

To be filled by researcher					
Information completed?	Yes	No	Suitable for experiment?	Yes	No
Date of Experiment:			Start and End time:		
Data Acquisition Check List					
Task\Modality	EEG	OT	Remarks:		
Task 1:					
Task 2:					

Feedback form

1. How difficult was task #1:   Very easy   ① ② ③ ④ ⑤   very difficult
2. How difficult was task #2:   Very easy   ① ② ③ ④ ⑤   very difficult

3. How satisfied are you with your performance?

    Not satisfied at all   ① ② ③ ④ ⑤   very satisfied

4. Was any part of the equipment setup painful? Please explain.   Yes ☐   No ☐

----

5. Is there any part of the experiment you are dissatisfied with?   Yes ☐   No ☐
   Please explain.

----

6. If you have any other comment or concern that you wish to share with us, please write
   below.

Thank you for your co-operation

Appendix B - Codes

Segmentation (MATLAB)

```matlab
function [ seg ] = segmentizeTask1( fname )

[info, data] = edfread(fname); % get the edf file
a = size(data);
for i=1:a(2)
   if (abs(data(a(1)-2,i))>20)
   point = i;
   sprintf('%d',point)
   break;
   end
end
point = point-1;
record = data(:,1:point);
a = size(record);
sprintf('%d\n%d',size(record),size(data))
t=1:a(2);
b=a(1)-2;
plot(t,record(b,:));
limit = input('What is limit you would like to set? ');
peak = zeros(1,151);
trialStart = zeros(1,150);
trialEnd = zeros(1,150);
v=0;
n_old=0;
a = size(record);
seg = cell(3,50);
max = 0;

for i=1:a(1)
   sprintf('Channel %d => %s\n',i,info.label{i})
end

for n=1:a(2)
     if (n_old==0)
                if ((record(a(1)-2,n)>limit) || (record(a(1)-2,n)<-limit))
                        v=v+1;
                        peak(v)=n;
                        n_old = n;
                end
     else
                if ((record(a(1)-2,n)>limit) || (record(a(1)-2,n)<-limit)) && (n-n_old > 500)
                        v=v+1;
                        peak(v)=n;
                        n_old = n;
                end
     end
end
sprintf('%d',v)
trialStart(1) = peak(1);
trialEnd(1) = peak(2)-(256/(1000/2500));

for i=2:150
   trialStart(i) = peak(i)-(256/(1000/500));
   trialEnd(i) = peak(i+1)-(256/(1000/2500));
   if(max<(trialEnd(i)-trialStart(i))) && ((trialEnd(i)-trialStart(i))<1000)
     max = 975;
   end
end

for i=1:150
   trialEnd(i) = trialStart(i)+max;
end
```

```matlab
sampleCtr = 1;
for taskCtr=1:3
    for trialCtr=1:50
        if (trialCtr==1)
        seg{taskCtr,trialCtr}=zeros(23,peak(sampleCtr+1)-peak(sampleCtr)-(2*256));
        else
        seg{taskCtr,trialCtr}=zeros(23,max);
        end
        sampleCtr = sampleCtr+1;
    end
end

% storing values in elements
ctr = 1;
i = 1;
recordCtr = 1;
unavailable=input('please specify the electrode numbers\nthat are not available in this data: ');
ignore=input('please specify the electrode numbers\nthat are are noisy and you want to ignore: ');
for taskCtr=1:3
    for trialCtr=1:50
        for channelCtr=1:23
            check = ismember(channelCtr,unavailable);
            if(~check)
                if(i==1)
                    for sampleCtr=trialStart(i):trialEnd(i)
                        seg{taskCtr,trialCtr}(channelCtr,ctr)=record(recordCtr,sampleCtr);
                        ctr = ctr+1;
                    end
                else
                    for sampleCtr=trialStart(i):trialStart(i)+max
                        seg{taskCtr,trialCtr}(channelCtr,ctr)=record(recordCtr,sampleCtr);
                        ctr = ctr+1;
                    end
                end
            recordCtr = recordCtr+1;
            end
            ctr = 1;
        end
        recordCtr = 1;
        i=i+1;
    end
end

for i=1:3
    for o=1:50
        for p=1:23
            check = ismember(p,ignore);
            if(check)
                seg{i,o}(p,:)=0;
            end
        end
    end
end


%% Display the segments
flag1 = 1;
while(flag1)
answer = input('Do you want to display any portion of data? (y/n) ', 's');
if(answer=='n')
    sprintf('Great, Thanks')
    flag1=0;

elseif(answer=='y')
    level = input('What level are you interested in? (0/1/2)');
    trial = input('Which trial? ', 's');
```

```
channel = input('What Channel? (1-23)');

t= 1:max+1;
xmarker1 = 256*(500/1000);          % place markers at these x-values
xmarker2 = 256*(800/1000);          % place markers at these x-values
xmarker3 = 256*(1800/1000);         % place markers at these x-values
ymarker = -60:60;
if (strcmp(trial,'all'))
    for i=1:49
       str = sprintf('Level %d , trial %d, Channel %s',level,i,info.label{channel});
       figure(i+1);
       plot(t,seg{level+1,i+1}(channel,:),'b',xmarker1,ymarker,'r',xmarker2,ymarker,'r',xmarker3,ymarker,'r')
       title(str);
       axis([0 max -50 50])
    end
else
       trial = str2double(trial);
       str = sprintf('level %d, trial %d, and Channel %s',level,trial,info.label{channel});
       plot(t,seg{level+1,trial+1}(channel,:),'b',xmarker1,ymarker,'r',xmarker2,ymarker,'r',xmarker3,ymarker,'r')
       title(str);
       axis([0 max -50 50])
  end
  flag1=1;
end
end
end
```

Appendix B - Codes

Averaging (MATLAB)

```matlab
function [ DataAvgAll ] = AverageIt( Data )

ignore0 = input('Specify the ignored trial numbers for level 0 between two brackets: ');
num0 = size(ignore0);

ignore1 = input('Specify the ignored trial numbers for level 1 between two brackets: ');
num1 = size(ignore1);

ignore2 = input('Specify the ignored trial numbers for level 2 between two brackets: ');
num2 = size(ignore2);

Data0 = cell(1,49);
Data1 = cell(1,49);
Data2 = cell(1,49);

DataAvgTask0 = cell(1,1);
DataAvgTask1 = cell(1,1);
DataAvgTask2 = cell(1,1);
DataAvgAll = cell(3,1);

for i=2:50
  Data0{1,i-1}=Data{1,i};
end
a = size(Data0);
sprintf('%d',a(2))
b = size(Data0{1,1});
DataAvgTask0{1,1} = zeros(b(1),b(2));
for i=1:a(2)
   check = ismember(i,ignore0);
   if(~check)
      DataAvgTask0{1,1} = DataAvgTask0{1,1}+Data0{1,i};
   end
end
DataAvgTask0{1,1} = DataAvgTask0{1,1}/(a(2)-num0(2));
for i=2:50
  Data1{1,i-1}=Data{2,i};
end
a = size(Data1);
b = size(Data1{1,1});
DataAvgTask1{1,1} = zeros(b(1),b(2));
for i=2:a(2)
   check = ismember(i,ignore1);
   if(~check)
      DataAvgTask1{1,1} = DataAvgTask1{1,1}+Data1{1,i};
   end
end
DataAvgTask1{1,1} = DataAvgTask1{1,1}/(a(2)-num1(2));

for i=2:50
  Data2{1,i-1}=Data{3,i};
end
a = size(Data2);
b = size(Data2{1,1});
DataAvgTask2{1,1} = zeros(b(1),b(2));
for i=2:a(2)
   check = ismember(i,ignore2);
   if(~check)
      DataAvgTask2{1,1} = DataAvgTask2{1,1}+Data2{1,i};
   end
end
DataAvgTask2{1,1} = DataAvgTask2{1,1}/(a(2)-num2(2));

% Now combine them again in a single cell, DataAvgAll...
```

```matlab
DataAvgAll{1,1} = DataAvgTask0{1,1};
DataAvgAll{2,1} = DataAvgTask1{1,1};
DataAvgAll{3,1} = DataAvgTask2{1,1};

a = size(DataAvgAll{1,1});
t = 1:a(2);
answer = input('Which channel are u interested in? ', 's');
b=1;
c=0;
xmarker1 = 256*(500/1000); % place markers at these x-values
xmarker2 = 256*(800/1000);
xmarker3 = 256*(1800/1000);
ymarker = -50:50;
    if(strcmp(answer,'all'))
        for n=1:a(1)-3
            for i=1:3
                figure(n)
                x = DataAvgAll{i,1}(n,128:204);
                meanEnc = mean(x);
                % Instantaneous power of each sample:
                ins_pwr = x .^ 2;
                %Average power of signal:
                avg_pwr = sum(ins_pwr)/length(x);
                %meanMain = mean(DataAvgAll{i,1}(n,204:461));
                str = sprintf('channel %d for level %d\nEncoding Mean = %d\nMaintenance Mean = %d',n,i,meanEnc,avg_pwr);%,meanMain);
                subplot(1,3,i);
                plot(t,DataAvgAll{i,1}(n,:),'b',xmarker1,ymarker,'r',xmarker2,ymarker,'r',xmarker3,ymarker,'r')
                title(str);
                axis([0 a(2) -50 50]);
                %b = b+1;
            end
        end
    else
        for i=1:3;
            if(c == 0)
            answer = str2double(answer);
            c = c+1;
            end
            figure(1);
            x = DataAvgAll{i,1}(answer,128:204);
            meanEnc = mean(x);
            % Instantaneous power of each sample:
            ins_pwr = x .^ 2;
            % Average power of signal:
            avg_pwr = sum(ins_pwr)/length(x);
            %meanMain = mean(DataAvgAll{i,1}(answer,204:461));
            str = sprintf('channel %d for level %d\nEncoding Mean = %d\nAverage Power = %d',answer,i,meanEnc,avg_pwr);%,meanMain);
            subplot(1,3,i);
            plot(t,DataAvgAll{i,1}(answer,:),'b',xmarker1,ymarker,'r',xmarker2,ymarker,'r',xmarker3,ymarker,'r')
            title(str);
            axis([0 a(2) -50 50]);
            %hold;
        end
    end
end
```

Appendix B - Codes

Computing Coherence (MATLAB)

```
function [ DataFeature ] = ComputeCohere( DataAvg )

%% Initializations
num_shuffles = 5; % 100 Monte-Carlo iterations
num_folds = 10; % 10-folds cross validation
feature_sel_criterion = 'roc'; % Ranking the feature according to this criterion.
numb_feat = [5,10,15,20,25,30,35,50,60,80,100]; % Number of features in 11 subsets
%numb_feat = [5,10,15,20,25,30];
%numb_feat = [5,10];

avg_AUC =[];final_values=[];%buffer=[];
buffer_accuracy=[];
buffer_sen =   [];buffer_spec =  [];avg_sen =[];
avg_spec =[];final_sen =[];final_spec= [];%Avg_numb_feat = [];
o=0;
fs = 256;
nfft = 256;
noverlap = 128;
OddChan = [1, 6, 2, 7, 8, 3, 4, 5]; %Odd side scalp locations
EvenChan= [10, 15, 11, 16, 17, 12, 13, 14]; %Even side scalp locations

%% Feature Extraction - Replace this part fot other features
for z = 1:19 %19
   for i= 1: length(OddChan)
      for j = 1: length(EvenChan)
        [C,~] = mscohere(DataAvg{z}(OddChan(i),:),DataAvg{z}(EvenChan(j),:),hanning(nfft),noverlap,nfft, fs); % Plot estimate.
        for p=1:45 %Change this if you wanna cover a larger frequency range (in this case 1-30)
           DataFeature(z,o+p) = C(p);
        end
        o=o+45; %Change this according to the frequency range
      end
   end
   o=0;
end

X1 = DataFeature;
%X1 = rand(19, 100);
%% Normalization
%X=zscore(X1);
%%
TargetMatrix ={
  'G','G','G','G','G','B','G','G','B','B' ...
  'B','B','G','B','B','B','G','B','G'}'; %

groups = ismember(TargetMatrix,'G');

[feature_index,z1] = rankfeatures(X1',groups','NumberOfIndices',100,'Criterion', feature_sel_criterion);
Labels = groups;

for w = 1: length(numb_feat)
    %[feature_index,z1] = rankfeatures(X',groups','NumberOfIndices',numb_feat(w),'Criterion', feature_sel_criterion);

  % Logistic Regression Classification and Validation
  for j = 1 : num_shuffles

    for i = 1:num_folds
       indices = crossvalind('kfold', Labels, num_folds);
       test = (indices == i); train = ~test;

       [b, dev, stats] = glmfit(X1(train,feature_index),Labels(train),'binomial','logit'); % logistic regression

       % logistic regression
       Fit = glmval(b,X1(test,feature_index),'logit');
```

```
    % Accuracy calculation
    [z,cm]=confusionmat((Fit>0.5),Labels(test));
    if numel(z) == 1
        continue;
    end
    accuracy = (z(1,1)+z(2,2))/(z(1,1)+z(2,2)+z(1,2)+z(2,1)); % calculating accuracy
    sen = z(1,1)/(z(1,1)+z(2,1));% calculating sensitivity
    spec = z(2,2)/(z(1,2)+z(2,2));% calculating specificity
    %[X1,Y1,T,AUC] = perfcurve(TargetMatrix(test),Fit,'R');
    buffer_accuracy =[buffer_accuracy accuracy]; % buffering
    buffer_sen =    [buffer_sen sen];% buffering
    buffer_spec =   [buffer_spec spec];% buffering
   end
   avg_AUC = [avg_AUC mean(buffer_accuracy)]; % computing average of the 100 values fo accuracies.
   buffer_accuracy =[];
   avg_sen = [avg_sen mean(buffer_sen)]; % computing average of the 100 values fo sensitivity.
   buffer_sen =[];
   avg_spec = [avg_spec mean(buffer_spec)]; % computing average of the 100 values fo specificity.
   buffer_spec =[];
 end
 final_values = [final_values; avg_AUC];
 avg_AUC = [];
 final_sen = [final_sen; avg_sen];
 avg_sen = [];
 final_spec = [final_spec; avg_spec];
 avg_spec = [];
 %waitbar(w/length(numb_feat),h);
end


boxplot(final_values',numb_feat);
title('Accuracy: Logistic Regression Classification (EEG data)');
xlabel('Number of Feature');
ylabel('Accuracy');
figure
boxplot(final_sen',numb_feat);
title('Sensitivity: Logistic Regression Classification (EEG data)');
xlabel('Number of Feature');
ylabel('Sensitivity');
figure
boxplot(final_spec',numb_feat);
title('Specificity: Logistic Regression Classification (EEG data)')
xlabel('Number of Feature');
ylabel('Specificity');

end
```