MINDFULNESS MEDITATION IMPROVES BRAIN-COMPUTER INTERFACE (BCI) PERFORMANCE

By

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ABSTRACT

Brain-Computer Interface (BCI) systems enable patients with severe neuromuscular disorders to use their brain signal to control devices and to communicate with others. BCI users need to maintain stable mental states to achieve a higher accuracy rate, while distraction and frustration will degrade it. Previous studies found that long-term mindfulness meditation (MM) practice could regulate the mental state, and thus improve BCI performance. A recent study showed that participants of a 12-week MM programme significantly improved their BCI performance compared to a music training group and a no-treatment control group, indicating effects of MM above and beyond expectancy effects. It would be advantageous to find out whether a shorter 4-week MM programme will promote a similar improvement in BCI performance because it would shorten the MM training period. Thirty eight undergraduate students completed the 4-week randomized controlled trial study consisting of a MM group (19 participants) and a no-treatment control group (19 participants). Participants of the 4-week MM programme showed a significant improvement in BCI performance compared to the nonintervention control group. Ten participants from the main study (5 from the MM group and 5 from the control group) also participated in an fMRI study where they were fMRI scanned before and after the intervention period to compare activation changes in the brain. The fMRI results showed evidence of more focus activation during motor imagery in the fronto-parietal areas of the brain of the MM participants compared with the control group and this was also associated with improved BCI performance.

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APPROVAL SHEET

This dissertation entitled **"MINDFULNESS MEDITATION IMPROVES BRAIN-COMPUTER INTERFACE (BCI) PERFORMANCE"** was prepared by **TAN YIN QING** and submitted as partial fulfillment of the requirements for the degree of Master of Engineering Science at Universiti Tunku Abdul Rahman.

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DECLARATION

I hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

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LIST OF ABBREVIATIONS

ALE	activation likelihood estimation
ALS	amyotrophic lateral sclerosis
ANCOVA	analysis of covariate
BCI	brain-computer interface
BF	both feet
BOLD	blood oxygen level dependant
CB	cerebellum
EEG	electroencephalogram
EMG	electromyogram
EOG	electrooculogram
fMRI	functional magnetic resonance imaging
GUI	graphic user interface
IFG	inferior frontal gyrus
IPL	inferior parietal lobule
LDA	linear discriminant analysis
LH	left hand
MBSR	mindfulness base stress reduction
ME	motor execution
MfG	middle frontal gyrus
MI	motor imagery
MM	mindfulness meditation
NA	no activation
NMD	neuromuscular disease

NR	not-restricted
PcG	precentralgyrus
PcL	paracentral lobule
PreC	precuneus
RA	restricted activation
RH	right hand
SMA	supplementary motor area
SMG	supramarginalgyrus
SPL	superior parietal lobule
SPM	statistical parametric mapping
SWCT	stroop word-colour task
TM	traditional meditation

CHAPTER 1

INTRODUCTION

A Brain-Computer Interface (BCI) system enables users to use their brain signals such as electroencephalogram (EEG) to communicate without using the normal pathways involved in verbal communications. The BCI has rapidly developed in the past few decades, and aimed primarily to help patients with severe neuromuscular disorders (NMD)e.g. amyotrophic lateral sclerosis (ALS), cerebrovascular accident (i.e. stroke), lock-in syndrome, and spinal code injury to regain control over their environments (Birbaumer and Cohen, 2007).

Previous studies showed that EEG signals were significantly affected by mental states (Guger et al., 2003; Mahmoudi and Erfanian, 2006). Therefore, a better BCI performance requires a better controlled mental state with sustainable attention during BCI execution.

A BCI user needs to learn how to control their mental states in order to achieve their goals. Mindfulness meditation (MM) had been shown to be able to improve cognition processes (Zeidan et al., 2010b) and healthcare conditions (Mars and Abbey, 2010). Dr. Kabat-Zinn, founder of Mindfulness-Based Stress Meditation (MBSR) defined mindfulness as “the intentional and non-judgementally paying attention in the present moment” (Kabat-Zinn, 1994).

A recent study (Tan et al., 2014a) showed that the BCI performance of participants who underwent a 12-week MM training programme were improved significantly compared to those who received a music training programme and a no-treatment control group.

The current study investigates whether a shorter 4-week MM training programme will produce a improvement in BCI performance. To examine the biological changes caused by the MM training, functional magnetic resonance imaging (fMRI) was used to identify changes in brain activity.

fMRI studies had been widely used as a non-invasive assessment to observe both the structures and functional activities of the brain (Chen and Li, 2012). By using activation likelihood estimation (ALE) meta-analysis of 75 papers, Hétu et al. (2013) provided the first quantitative map of the activated areas of the brain during motor imagery (MI).

The aim of this study is to investigate the effect of a 4-week MM training programme on the BCI performance. The BCI performance results were also correlated with the changes in brain activity observed from the fMRI scanning.

This thesis consists of six chapters, and is structured as follows:

Chapter 2 is a review of the existing literature regarding BCI, meditation and fMRI.

Chapter 3 provides a description of the methodology for both the BCI and fMRI studies. The details of participant recruitment procedures, design of experimental paradigms and analysis methods are explained in this chapter.

Chapter 4 presents the results of both the BCI and fMRI studies. Statistical analysis and Bayes factor calculator were applied to the BCI study results, while statistical parametric mapping (SPM) method was used to analyse the fMRI study results.

Chapter 5 presents the discussions of the results and explanations of the findings. Limitations of the study are also discussed here.

The conclusion and suggestions for future work are given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 BRAIN-COMPUTER INTERFACE (BCI)

A brain-computer interface (BCI) is a system that detects brain signals, records and processes the signals to produce a command with the aid of a computer, and lastly to use the command to integrate with the surroundings (Wolpaw and Wolpaw, 2012). Naturally, a human relies on neuromuscular pathway to communicate (speaking), control (movement) or interact. However, neuromuscular diseases (NMD) impede the functions of muscle and / or nervous system control. Patients who suffered from NMD such as amyotrophic lateral sclerosis (ALS), cerebrovascular accident (i.e., stroke), spinal muscular atrophy, cerebromedullospinal disconnection have little or no neuromuscular control (Wolpaw et al., 2002). The BCI system does not employ the human natural neuromuscular pathway. Instead, it replaces the non-functioning pathway with a new pathway to help the patients regain their control (Pfurtscheller et al., 2000).

Over the past few decades, BCI systems gained great expansion in research, encouraged by rapid improvements in hardware design, feature extraction and data processing algorithms (Wolpaw et al., 2000; Vaughan et al., 2003; Vaughan and Wolpaw, 2006; Lee, 2014). Novel methods for user training were also introduced to improve the BCI performance (McFarland et al., 2005; Kaiser et al., 2014).

2.1.1 EEG-BASED BCI

This study focused on the EEG-based BCI, which is a non-invasive signal collection method. There are a few types of EEG signals which have been used in the BCI systems, including P300 (Fazel-Rezai et al., 2012), event evoked potential (Xiaorong et al., 2003), and motor imagery (MI) (Pfurtscheller and Neuper, 2001). Each of these methods has its own strengths and weaknesses.

The main advantage of MI is that it is a voluntary natural activity. MI also produces brain activity that is similar to those produced during actual motor execution (ME) (Porro et al., 1996; Pfurtscheller and Lopes da Silva, 1999; Miller et al., 2010). Typically, MI of right hand (RH), left hand (LF) and both feet (BF) movements are used in BCI systems as their activation zone is distinct from one another according to the international 10-20 system (Figure 2.1).

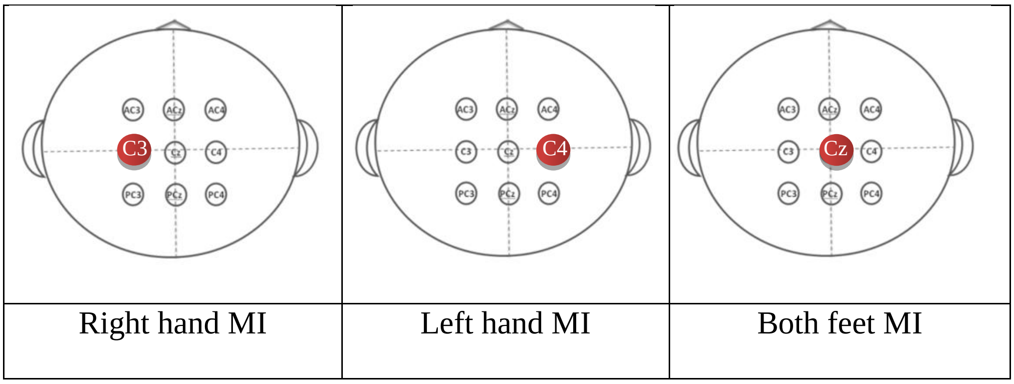


Figure 2.1 Activation regions during MI of (a) RH, (b) LF and (c) BF.

Note: RH activated region C3, LF activated opposite hemisphere at region C4, BF activated region Cz.

There is a drawback of MI-based BCI system. Training is required for the users to produce consistent and reliable EEG signals. Unstable mental states as a result of anxiety, fatigue, frustration and loss of concentration can reduce BCI performance (Pfurtscheller and Neuper, 2001). Some studies showed that with the help of meditation practice, users were able to improve their mind controllability and thus improve the BCI performance (Lo et al., 2004; Mahmoudi and Erfanian, 2006; Eskandari and Erfanian, 2008; Lakey et al., 2011).

2.2 MINDFULNESS MEDITATION

Meditation, an ancient mental exercise that has been practised by various civilizations and religions for thousands of years, refers to a practice to create awareness and self-regulation (Braboszcz et al., 2010). Generally, meditation can be categorized into two major groups, which are traditional meditation (TM) and mindfulness meditation (MM) (Cahn and Polich, 2006). TM captured much attention in early years, but MM proven more popular in scientific research more recently (Murphy et al., 1997; Cahn and Polich, 2006).

Mindfulness is a state of consciousness in which the practitioner maintains a single pointed awareness focused on mental, interoceptive and exteroceptive senses(Mars and Abbey, 2010).

Previous studies reported that meditation led to physical and psychological changes in practitioners (Murphy et al., 1997). Experienced meditators showed physical changes such as increase in grey matter densities

(Luders et al., 2009; Vestergaard-Poulsen et al., 2009), white matter densities (Luders et al., 2011; Tang et al., 2012) and regional cortical thickness (Lazar et al., 2005). Meditation also led to changes in brain function (Davidson et al., 2003; Jang et al., 2011). Some clinical studies suggested meditation as an alternative therapy for emotion regulation (Braboszcz et al., 2010), pain reduction (Kabat-Zinn et al., 1985) as well as anxiety disorder treatment (Miller et al., 1995). In addition, studies based on engineering perspective confirmed that meditation resulted in changes in brain signals, such as increased P300 amplitude (Lakey et al., 2011), increase in the power of brain signals (Mason et al., 1997), enhanced phase consistency of brain signals (Lutz et al., 2009) as well as improved classification rate of EEG signals which directly affect the performance of a EEG-based BCI (Mahmoudi and Erfanian, 2006).

Traditionally, meditation requires a long learning and practicing period to master the skill. The MBSR programme introduced by Dr. Kabat-Zinn consists of 26 hours of lessons over 8 weeks (Kabat-Zinn et al., 1990). Lengthy programme normally demands higher commitment in terms of finance and time. It is therefore advantageous to find out whether a short-term meditation programme is able to show the same benefits as a long-term meditation programme. Several studies have been conducted to determine the effects of short-term meditation with varying practicing hours: a 3-day MM training effectively reduced pain rating (Zeidan et al., 2010a), 4-day (Zeidan et al., 2010b) and 5-day (Tang et al., 2007) meditation training helped in sustaining attention, and a week of meditation practicing induced changes in the resting EEG signals (Xue et al., 2014) and improved creativity performance (Ding et al., 2014).

However, none of the above studies focuses on investigating the effect of short-term MM on BCI performance. A recent study (Tan et al., 2014a)showed that a 12-week MM training significantly improved the BCI performance.

This current study is an extension of the above study. In the study by Tan et al., the total MM training time was 12 hours carried out over 12 weeks, one session per week, one hour per session. In the current study, the same 12 hours of training was completed in 4 weeks, one session per week, 3 hours per session.

2.3 FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI)

The first successful functional magnetic resonance map of human task activation was constructed in early 1990s (Belliveau et al., 1991). Over the past 20 years, fMRI technology and research has grown rapidly and played an important role in human cognitive neuroscience. Functional magnetic resonance imaging (fMRI) is a non-invasive functional neuroimaging method used to assess the functional changes in the brain (Huettel et al., 2004).

Modern fMRI technique uses a standard clinical MR scanner to create images based on the changes in blood oxygenation level-dependent (BOLD) contrast, and thus provide an indirect measurement of neuronal activity

(Huettel, 2000).

Oxygen is required by cell metabolism. When there is an increase in neural activity in certain brain areas, the requirement of oxygen is also increased, which in turn increases the blood flow to fulfill the oxygen demand of the cells. Oxygen is carried by haemoglobin in red blood cells. The haemoglobin that carries oxygen to the cells is known as oxyhaemoglobin, whereas deoxyhaemoglobin are the ones leaving the cells. The intrinsic magnetic property of haemoglobin depends on the amount of oxygen carried, and oxyhaemoglobin is diamagnetic while deoxyhaemoglobin is paramagnetic (Pauling and Coryell, 1936).

fMRI scanning images are generated based on the strength of the magnetic field responses. When there is brain activity, the increase of blood flow will cause the concentration of oxyhaemoglobin to increase, producing images of lighter shade. On the other hand, image scanned during the resting periods when there is no stimulation is of darker shade (Figure 2.2) (Gore, 2003).

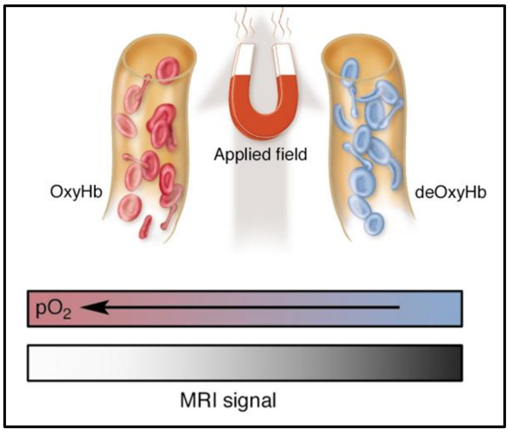


Figure 2.2 Schematic illustration of the BOLD effect in fMRI.

Note: Oxyhaemoglobin (OxyHb) with higher level of oxygen is diamagnetic and thus produce lighter shade of MRI signal. Deoxyhaemoblobin (deOxyHb) which is lacking of oxygen is paramagnetic and thus produce darker shade of MRI signal.
Figure adapted from (Gore, 2003).

2.3.1 FMRI AND MOTOR IMAGERY

An fMRI study looking at the activation of motor-related areas during motor execution (ME) and motor imagery (MI) revealed that common cortex regions were activated during both ME and MI (Hanakawa et al., 2003).

The ALE meta-analysis revealed that the upper and lower limb MIs showed consistent activation~~s~~ in similar cortex region than other MI (Hétu et al., 2013).

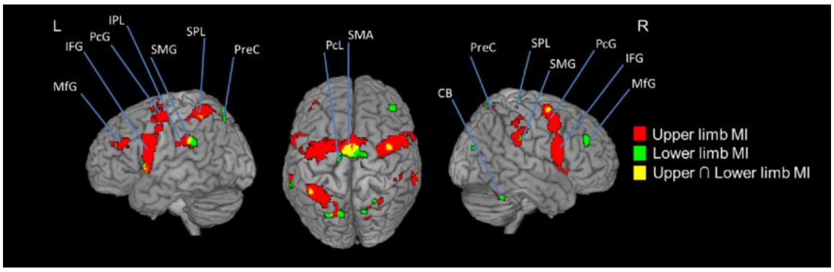


Figure 2.3 Consistently activated cortex regions during motor imagery of upper limbs and lower limbs.

CB: cerebellum, IFG: inferior frontal gyrus, IPL: inferior parietal lobule, MfG: middle frontal gyrus, PcG: precentralgyrus, PcL: paracentral lobule, PreC: precuneus, SMA: supplementary motor area, SMG: supramarginalgyrus, SPL: superior parietal lobule.
Adapted from (Hétu et al., 2013)

MI of upper limb consistently showed bilateral activation within inferior frontal gyrus (IFG), including precentralgyrus (PcG), middle frontal gyrus (MfG) and supplementary motor are (SMA). On the other hand, MI of lower limb showed consistent activation in SMA, cerebellum (CB), right MfG, preceneus (PreC), and superior parietal lobule (SPL). Comparison of both upper and lower limb MIs revealed consistent activation in the SMA, supramarginalgyrus (SMG), SPL, inferior parietal lobule (IPL) and CB. Most of the activation regions during MI of upper and lower limbs were located within frontal and parietal cortices. For this reason, the fMRI analysis carried out in this study mainly focused on the fronto-parietal cortex.

2.3.2 FMRI AND MEDITATION

While the fMRI technology is gaining popularity, studies of the effects of meditation with fMRI scanning have also increased.

Previous studies with fMRI suggested differences in the brain activation regions during meditation and non-meditation periods (Lazar et al., 2000; Guleria et al., 2013). On the other hand, participants who attended short-term meditation training were found to have an increased network efficiency in the anterior cingulate cortex, when compared to participants in the control group (Xue et al., 2011). Regular meditators also showed more activation in their brain cortex during Stroop Word-Colour Task (SWCT) (Kozasa et al., 2012).

The author is not aware of any previous fMRI study on meditators and non-meditators while performing MI.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The present work consists of two parts -- a BCI study and an fMRI study. The purpose of the BCI study was to investigate the effects of MM training on a group of BCI users. The study was carried out at a local university. The fMRI study was conducted to investigate the changes in brain activities during motor imagery (MI) as the result of MM training. The study took place at the radiology department of University Malaya Medical Centre (UMMC).

3.2 BRAIN-COMPUTER INTERFACE (BCI) STUDY

3.2.1 INTRODUCTION

The experimental protocol of the current study was designed based on a previous study(Tan et al., 2014a). The schedule for the tests was arranged according to the study semester of the participants. Recruitment was started at the beginning of the semester and tests were completed at the end of the same semester.

Participants were to complete a pre-intervention test, followed by intervention training and finally a post-intervention test. The process flow of the study is shown in Figure 3.1. The duration of the intervention training applied in the current study was 4 weeks.

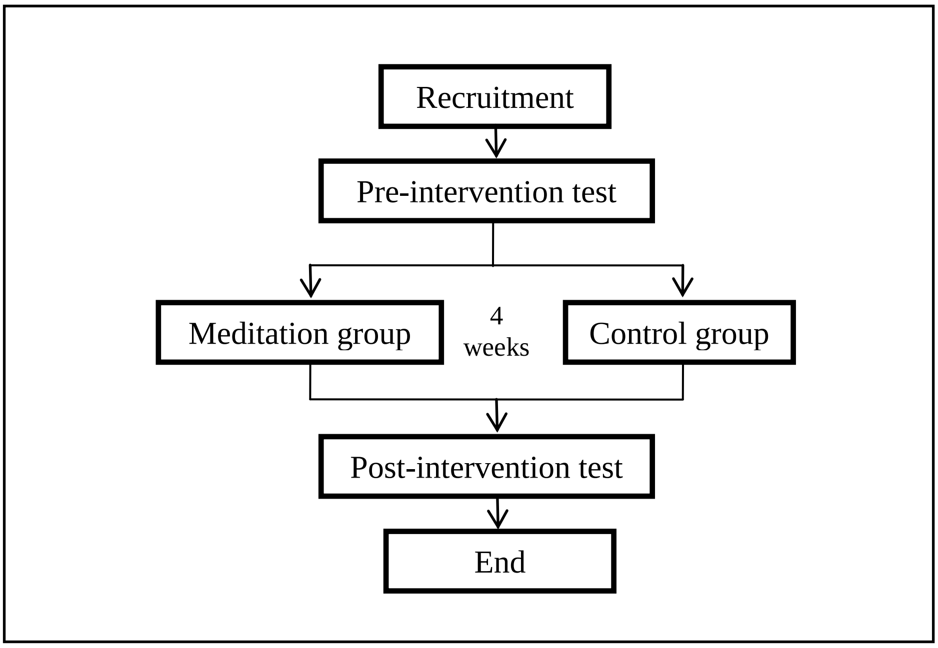


Figure 3.1 The process flow of a complete BCI study.

Two experiments were conducted during the pre-intervention test, i.e. the EEG experiment and the BCI performance test. Each participant underwent the two experiments on two different days. Upon completion of the pre-intervention test, all participants were randomly assigned to join either the meditation group or the control group by using computer-generated random numbers. The meditation group was required to follow a 4-week intervention training programme. The study was completed with a post-intervention test after the intervention period. The same experiments and procedures as pre-intervention test were repeated to assess changes in the BCI performance. This was not a blind study as all the participants and the experimenter were aware of the group allocation.

3.2.2 PARTICIPANTS

All participants were recruited from a local university. Publicity for recruitment was held through posters, leaflets, and announcements made in lecture halls.

Students who were interested to participate in the study submitted an application form consisting of a self-reported questionnaire (see Appendix A for details). Those with a history of neurological diseases or with previous experience in any form of meditation training or BCI systems were excluded from the study.

All participants were given detailed explanations on the procedures of the study and completed a written informed consent form (Appendix B). Each participant was given a monetary reward of RM100 (approximately USD28) upon the completion of the study.

3.2.3 EEG EXPERIMENT

The choice of motor imagery (MI) tasks and placement of the bipolar EEG electrodes are subject dependent and optimized for best BCI accuracy.

Prior to the BCI performance test, an EEG experiment was conducted to determine the most optimum MI tasks and locations for the bipolar EEG channels.

The experiment was held in a quiet room to avoid ambient noise and disturbance. Participants were seated comfortably in an arm chair. Instruction was given to the participants through a laptop computer placed on a table in front of them. The distance between the participants and the computer screen was about 0.5 m. The computer screen was adjusted to the eye level of the participants.

The EEG signals produced from motor execution (ME) and motor imagery (MI) tasks of both feet (BF), right hand (RH) and left hand (LH) movements were recorded over the sensory-motor cortices region of the subjects with an EEG cap (Figure 3.2), which was connected to a Nicolet 64-channel EEG acquisition system. The electrodes of the EEG cap were referenced at mastoids and grounded at forehead. The sampling rate was set as 256Hz.

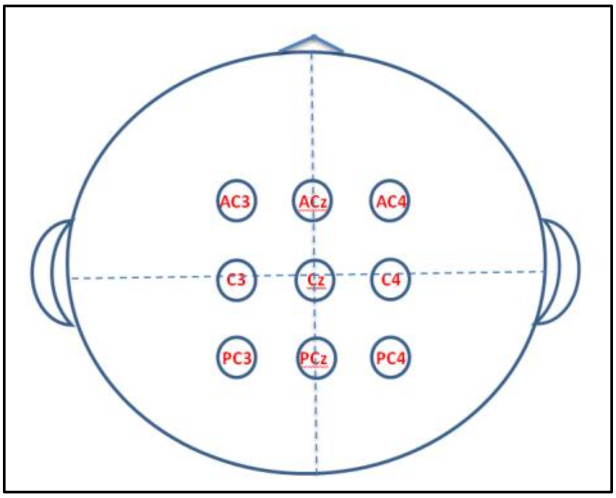


Figure 3.2 Montage used in EEG experiment.

The process flow of the experiment is shown in Figure 3.3. The experiment consisted of 6 sessions lasting for a total duration of about 2 hours.

Participants were allowed to rest for 2 minutes or longer between 2 consecutive sessions. Each participant was required to perform a total of 20 real movement trials and 60 mental imagery trials for each of the motor tasks. The participants were asked to get a feeling of kinesthetic imagery through the real movement trials. The EEG signals collected from the real movement trials were not included in the analysis. A clear explanation on how to perform the motor tasks was given to the participants before the start of the experiment. The hand movement was gripping of the fist with a frequency of 2Hz. The feet movement was flexing the toes with a frequency of 1Hz. Participants were told to perform / imagine the same motor movements throughout the scanning. They were asked to concentrate to perform / imagine the particular movement while at the same time avoid eye blinking or any other body movements.

A pre-set timing Microsoft Power Point presentation was used to give commands to the participants. The duration for each trial was 15 second. The trial started with 7 seconds of “REST” followed by 3 seconds of “READY” to allow the participants to get prepared for the particular movement. The command of RIGHT/ LEFT/ FOOT followed and persisted for 5 seconds. The EEG signals recorded during these 5 seconds were extracted and processed offline. Samples of screenshot of the instructions are shown in Figure 3.4.

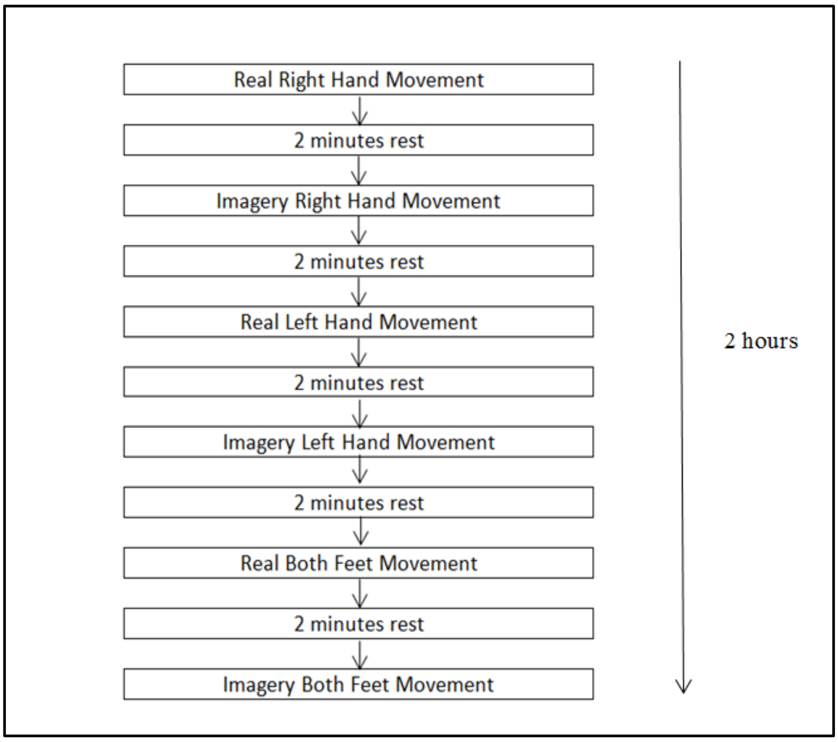


Figure 3.3 The process flow of the EEG experiment.

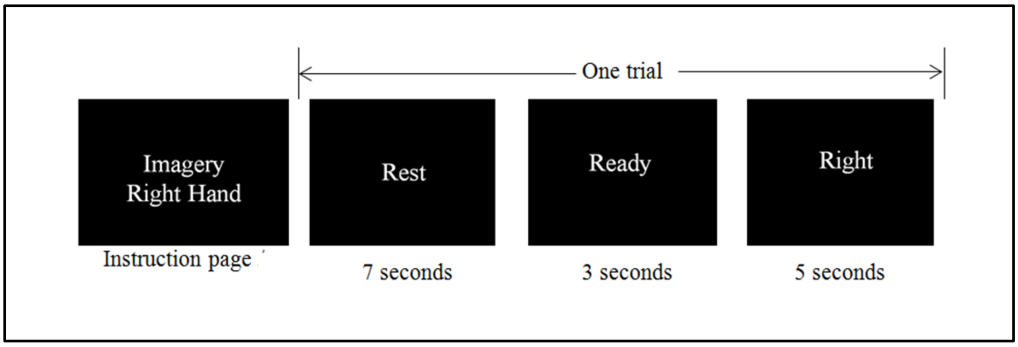


Figure 3.4 Samples of screenshot of instruction for one trial.

EEG signals from 9 electrodes placed over the sensory-motor cortices area (Figure 3.2) were analyzed offline. The analysis was performed on 3 combinations of MI tasks (RH and BF, LH and BF or RH and LH) and 36 combinations of bipolar EEG channels, as shown in Appendix C (Yong, 2005). The combination that gave the highest accuracy in linear discriminant analysis (LDA) 10 x 10 fold cross validation was selected to be used in the following

BCI performance test.

3.2.4 BCI PERFORMANCE TEST

The BCI performance test was conducted in the same experiment room used for the EEG experiment. The experimental setup and the procedure of the test were adapted from an earlier study (Tan et al., 2014a). Two pairs of EEG electrodes were placed on the sensory-motor region of the participants. The locations of the recording electrodes were pre-selected from the EEG experiment conducted earlier (see Section 3.2.3). Electrodes were also placed around the eye and chin areas to record electrooculogram (EOG) and electromyogram (EMG) signals, respectively. Analog signals recorded were amplified and converted into digital signals through a 16-bit analog-to-digital converter, with sampling rate set at 256 Hz. The digital data was sent to a laptop via a RS-232 interface for processing. The graphical user interface (GUI) for the BCI performance test and the signal processing tasks were handled by a visual C++ program.

The BCI test was started with a training phase, followed by a testing phase and an application phase. The GUI of the training phase is shown in Figure 3.5. Instructions were displayed on the top of the screen while alphabets “A”, “B”, “C” and “D” appeared in the middle. A feedback cursor bar was provided at the bottom of the screen.

There were altogether 3 training sessions. Each session consists of 20 trials for each of the selected MI tasks. The paradigm of the trials was similar to the ones in the EEG experiment. Each trial started with the instruction "REST" for 7 seconds, followed by "READY RIGHT" / "READY LEFT" / "READY FOOT" for 3 seconds, and "RIGHT" / "LEFT" / "FOOT" for another 5 seconds. The participants were allowed to rest for two minutes or longer between two consecutive sessions.

Figure 3.5 shows an example of the GUI for the training phase for right hand (RH) and both feet (BF) combination. "REST" was first displayed for 7 seconds, the cursor remained at the center of the feedback bar during this period (Figure 3.5a). Subsequently, "READY RIGHT" (Figure 3.5b) or "READY FOOT" (Figure. 3.5c) was displayed for 3 seconds, and the participant gets ready to perform the MI task. When the instruction of RIGHT was given for 5 seconds, the cursor moved to the right of the bar as shown in Fig. 3.5d. If the instruction of FOOT was given, the cursor would move to the left (Figure 3.5e). Details of the cursor movement for each MI task combination are shown in Table 3.1.

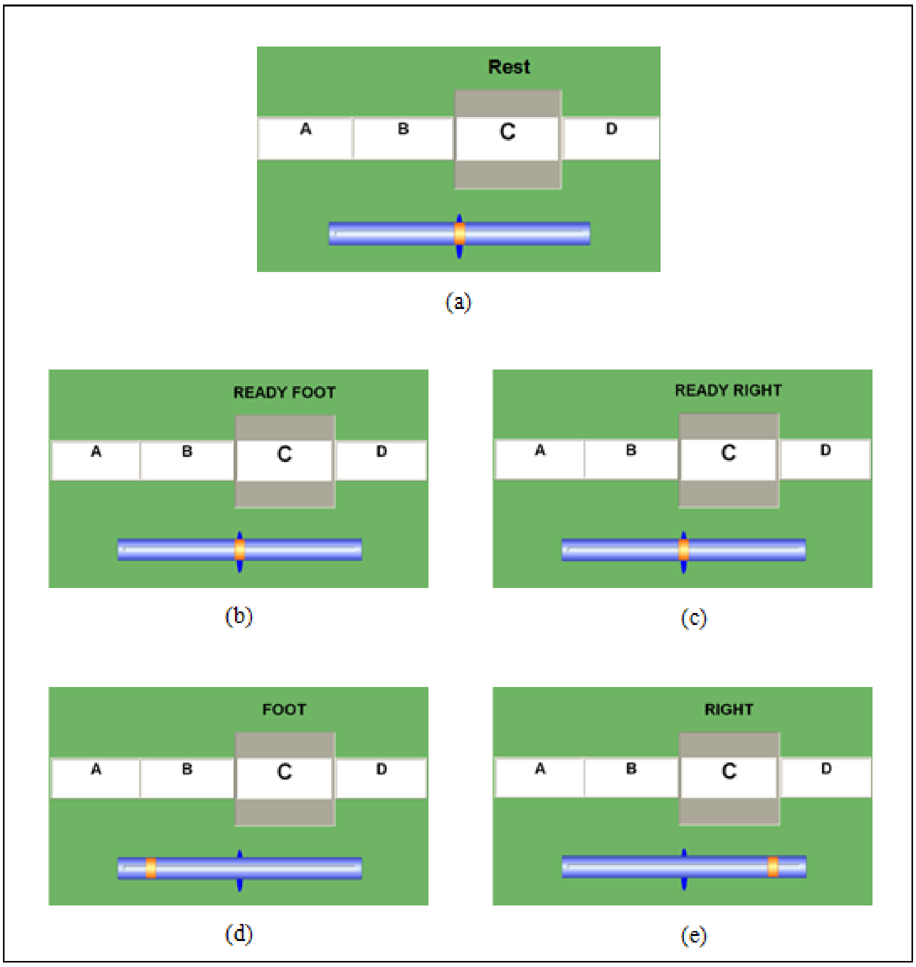


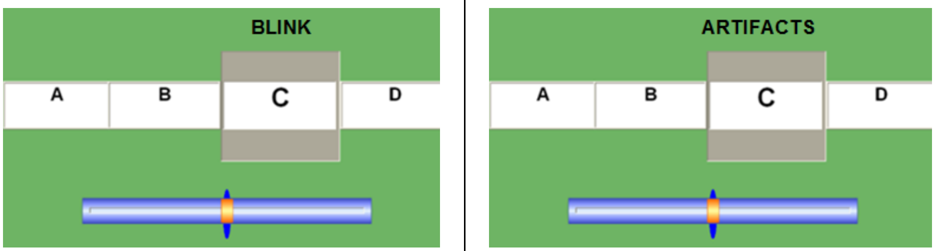
Figure 3.5 Example of GUI training phase, with MI task of right hand (RH) and both feet (BF) combination.

Note: Instruction REST display for 7 seconds (a). Figure (b) and (c) shows the instruction for READY FOOT and READY RIGHT respectively for 3 seconds. Instruction of FOOT display for BF imagery and the cursor will move to left as shown in (d). On the contrary, cursor moves to the right if the instruction RIGHT display for RH imagery (e).

Table 3.1 Detail of cursor movement for each MI task combination.

Combination of mental tasks	Command	Direction of cursor movement
RH and BF	RIGHT FOOT	Right Left
LH and BF	LEFT FOOT	Left Right
LH and RH	LEFT RIGHT	Left Right

Signal processing for the training phase included artifact detection algorithm. If EOG signals were detected during the training phase, “BLINK” would be displayed on the screen (Figure 3.6a). If an EMG signals were detected, “ARTIFACTS” would be displayed (Figure 3.6b). Whenever artifacts were detected, that particular trial would be excluded. At the end of the training phase, all non-contaminated EEG signals were used to setup the classifier for use in the test and application phases using LDA method. The LDA output generated acted as the command to control feedback cursor. The detailed LDA classifications were explained in the study by Yong (Yong, 2005).



(a) (b)

Figure 3.6 Screenshot of GUI when artifacts of EOG signals (a) and EMG signals (b) were detected.

After completing the training phase, the participant proceeded to the testing phase. Participants were requested to rest for 2 minutes with eyes opened when the LDA classifier was classifying the recorded EEG samples. If more EEG samples were classified as MI task 1 than MI task 2, the LDA was then considered biased to MI task 1, or vice versa. Results of this testing phase were used to determine the MI task to be used to make selections in the application phase. If the LDA is biased to MI task 1, then the MI task 2 will be used for the selection time, and MI task 1 will be used for the non-selection time, to minimize the percentage of false positive. Selection of MI tasks in application phase shown in Table 3.2. If there is no bias between MI tasks, then either of the tasks can be used for the selection time.

Table 3.2 Selection of MI tasks in application phase.

Bias class	MI task for selection time	MI task for non-selection time
MI task 1	MI task 2	MI task 1
MI task 2	MI task 1	MI task 2
None	Either of the MI task	The alternative MI task

The GUI of the application phase is shown in Figure 3.7. Similar to the training phase, a grey colour selection box was located at the center of the screen. Instruction was given at the top left corner and a feedback bar with cursor was displayed at the bottom of the screen. The four options “A”, “B”, “C” and “D” scrolled from left to right. Each alphabet appeared in the selection box for 5 seconds. By performing the appropriate MI task, participant moved the feedback cursor to the right (or left, depending on the tasks) to perform the selection.

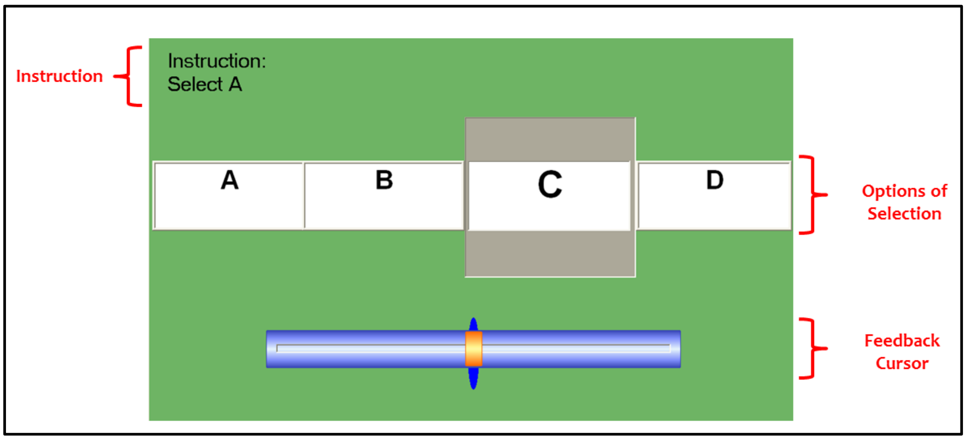


Figure 3.7 GUI of BCI performance test

For example, if the MI task combination was RH and BF, and the bias class was RH, then the participant should use the MI task of BF to select the alphabet that appeared in the grey colour selection box. The cursor was required to be maintained at the left side of the feedback bar for 5 consecutive seconds for selection and repeated for another 5 consecutive seconds to confirm and activate the selection. Otherwise, the participant performed the MI task of RH to maintain the cursor at the middle or right side of the feedback bar if he did not wish to select that particular alphabet.

Table 3.3 shows the possible circumstances during BCI performance test. Participants should perform the proper MI task that was selected and classified to execute the selection.

Table 3.3 Possible circumstances for selection time and non-selection time during BCI performance test.

Instruction	Text displayed in the selection box	Selection time	Non-selection time
Select alphabet “A”	A	✓	
	B / C / D		✓
Select alphabet “B”	B	✓	
	A / C / D		✓
Select alphabet “C”	C	✓	
	A / B / D		✓
Select alphabet “D”	D	✓	
	A / B / C		✓
RESET	RESET	✓	
Rest for 30 seconds	RESET		✓

For participants who used BF for selection and RH for non-selection, if the system classified the selection of BF during selection time represented a correct selection (true positive), while a classification of RH represented a wrong selection (false negative). During non-selection time, classification of RH represented a correct selection (true negative), and classification of BF represented a wrong selection (false positive), as shown in Table 3.4.

Table 3.4 Classification of BCI test.

	Selection time	Non-selection Time
Correct Response	True Positive (TP)	True Negative (TN)
Incorrect Response	False Negative (FN)	False Positive (FP)

When selection was made, the GUI will change to the “RESET” window. Participants were required to reset the GUI with the selected MI task in order to proceed to the next alphabet selection. If the participant selected the wrong alphabet, he would be required to re-select the alphabet after resetting the window. After every 4 correct selections, participants were given a 30-second resting period. The cursor was required to be maintained at the non-selection side of the feedback bar during the resting period. If the cursor moved to the selection side for 5 consecutive seconds, the system would be classified as “wrong selection” and returned to the previous selection step. A complete BCI performance test consists of 12 alphabets selection (“A”, “B”, “C”, or “D”, in randomised order). The minimum possible time to finish the selections is 7 minutes, however each participant was provided 30 minutes to complete as many selections as possible. An example of the selection sequence is shown in Figure 3.8.

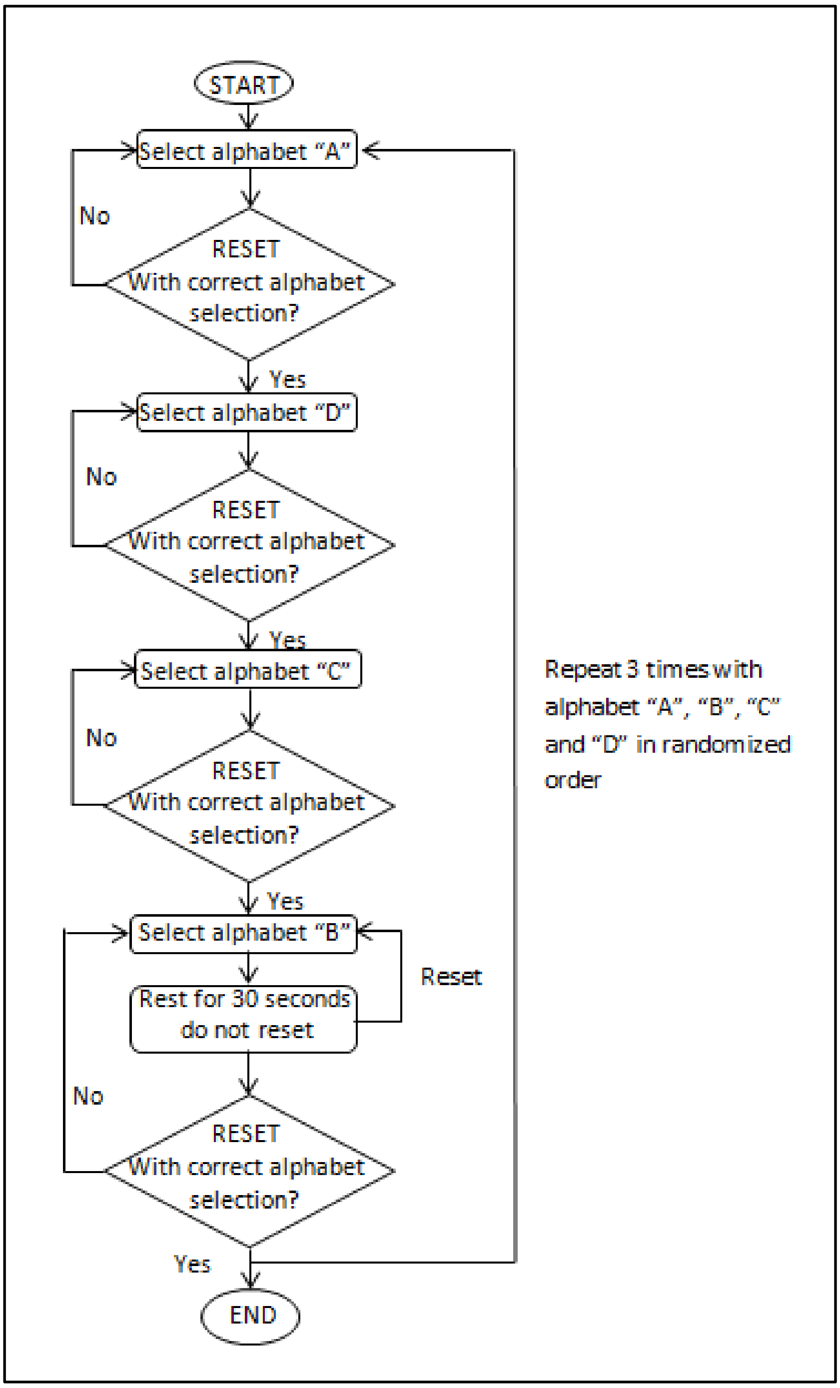


Figure 3.8 Example flow of BCI performance test.

The BCI performance was assessed based on its accuracy percentage, as proposed by Wolpaw and Wolpaw (2012):

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \quad (3.1)$$

3.2.5 MINDFULNESS MEDITATION INTERVENTION

Upon completion of the pre-intervention test, the participants were randomly assigned into either a mindfulness meditation group (MM) or a non-intervention control group (control).

The mindfulness meditation (MM) programme was conducted in English by an experienced meditation instructor. The instructor was blinded to the purpose and the content of the research project. The classes were conducted 3 hours per session, one session per week for 4 consecutive weeks. Participants were required to attend all the classes.

Participants were first introduced to some basic concepts of being non-judgmental in mindfulness meditation. The class started with basic sitting meditation. Participants started to focus on breathing, with eyes closed, and be aware of their thoughts. The basic procedure is: if you notice that your mind has wandered, focus back to your breath and start observing the thoughts again. After that, participants learned how to perform the body scan. Participants were requested to move their attention through their body, feel and be aware of the various sensations in the different parts of their body.

The training in the second class was to increase awareness of body sensations, thoughts and emotions. Participants were taught to observe not only their internal stimuli, but also how their body and mind responsed to the environment. Different meditation poses such as walking, sitting, and lying down meditations were introduced. Participants learned how to practice MM in their daily life, for instance at the moment when they are eating, speaking or relaxing.

Non-judgmental training was the core element of the following class. Participants were taught to focus, observe and accept what is happening, and be aware of the present state by acknowledging it but do not react to it. This skill is important when handling stress. Participants learned how to accept and respond to the pressure and at the same time keep their mental state stable.

During the last class, MM was conducted with distraction. Participants were told to practice MM while the instructor tried to create noise and movements to distract the attention of the participants. Participants should notice the distraction, but react non-judgmentally to it and keep themselves mindful.

Each class consists of a discussion and experience sharing session. Participants shared their experiences and discussed the problems they faced during the meditation practice.

Unlike the front group, participants assigned to the control group were to continue with their normal daily life as usual. They were required to avoid any form of meditation activities during the 4-week intervention period.

3.2.6 STATISTICAL DATA ANALYSIS

Data obtained from the BCI performance test were analysed using Statistical Package for Social Science (SPSS Inc, Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc). Analysis of covariate (ANCOVA) was performed to assess the post-intervention BCI accuracy, using the pre-intervention BCI accuracy as a covariate. A significant level of .05 was used.

The data of the BCI performance test were also assessed with Dienes' online Bayes factor calculator (Dienes, 2008). The Bayes factor calculation requires an experimental hypothesis and a null hypothesis. This calculation provides more information than the conventional statistical analysis because the confidence level of the Bayes factor (as illustrated in Figure 3.9) provide an indication of whether there is substantial evidence to support the experimental hypothesis over null hypothesis or vice versa, or if there is an insensitive result.

			(Substantial)		(Insensitive)		(Substantial)			
Stronger	0.1	<	1/3	<	Bayes factor	<	3	<	10	Stronger
←										→
Support null hypothesis										Support experimental hypothesis

Figure 3.9 Confidence level of Bayes factor, proposed by Jeffery (1961).

3.3 FMRI STUDY

Each participant underwent the first scanning after completing the pre-intervention test of BCI study. The second scanning was performed after the post-intervention test.

3.3.1 PARTICIPANTS

Participants recruited for the BCI study were offered the fMRI scanning on a first-come-first-serve basis. Participants were screened through the magnetic resonance scanning safety eligibility criteria. Those with any metallic implants were excluded from participating in~~to~~ the fMRI study.

The MR machine used for this study is mainly for clinical applications and therefore with only limited slots available for research. As a result, only 18 participants from the BCI study were recruited in this study.

Prior to scanning, participants were given detailed information about the study (see Appendix D for details) and completed a written informed consent form (Appendix E) according to the guidelines of Medical Ethic Committee of University Malaya Medical Center. Participants were given a monetary reward of RM100 (approximately USD28) at the completion of the study.

3.3.2 EXPERIMENTAL PROCEDURES

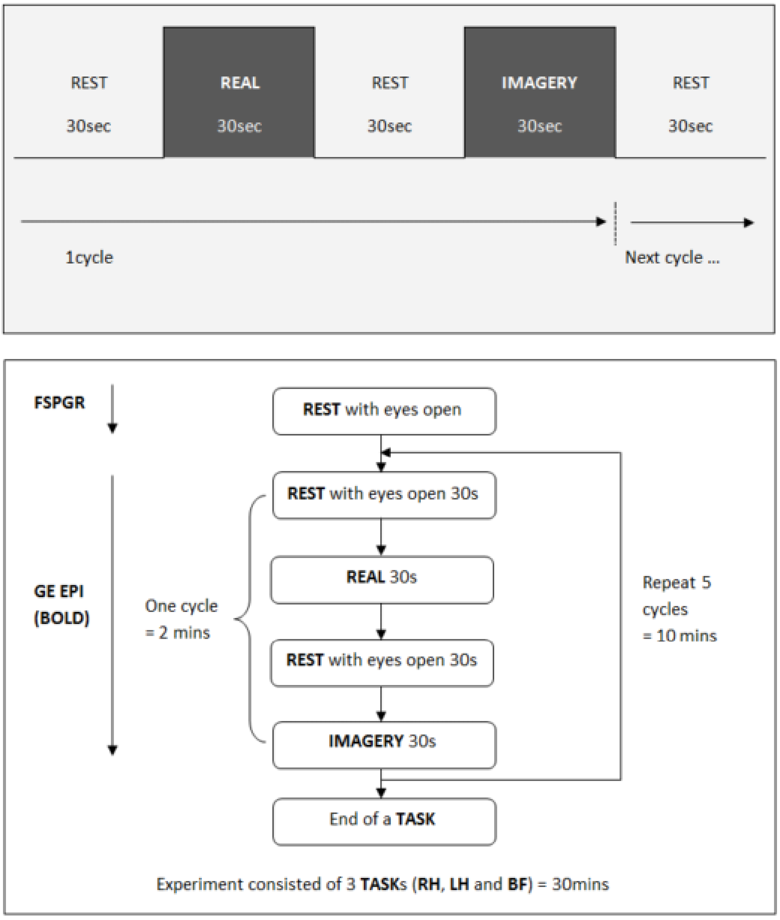
The fMRI scanning was carried out using a clinical 3.0 Tesla Signa® HDx MR system (GE Healthcare, Milwaukee, Wilcousin, USA) equipped with a dedicated 8-channel high definition head coil for radiofrequency signal transmission and reception. The whole scanning process was monitored by an experienced radiographer.

A blood-oxygen-level dependent (BOLD) – gradient echo, sensitive EPI sequence was used for the whole brain (TR 3s, TE 35ms, 90˚ flip angle; acquisition timing – matrix 128 x 128, NEX 1.0, phase FOV 1.0; sampling range – FOV 24cm, slice thickness 3.0mm, spacing 1.0mm).In addition, a sagittal fast spoiled gradient echo (FSPGR) scan was done (TR 7.9 ms, TE 3.0 ms, FOV 25.6cm, matrix 256 x 256, thickness 0.5mm, image scan time 3 min 48 sec) for structural image fusion with the fMRI.

The participant was asked to lie supine on the scanner bed and wear the head coil with cushion inside to avoid any head movement during the scan. A mirror was mounted on the head coil to reflect the projection screen behind the magnetic resonance machine, where instructions were given using black letters on a white background.

Different instructions of ME and MI including RH, LH and BF movements were given to the participants from a pre-set timing power point presentation slide. Participants were requested to perform the real and imagery movements with the same frequency and intensity as in BCI study during the scanning.

The flow of fMRI scanning is shown in Figure 3.10. Each task consists of 5 cycles, each cycle embodied 4 blocks, in the sequence Rest (30 seconds) → Real movement (30 seconds) → Rest (30 seconds) → Imagery movement (30 seconds).



(a) fMRI experiment based on block design. TASK: right hand (RH), left hand (LH) and both feet (BF) movement; REST: without any imagery or motor movement; REAL: real motor movement of hand (grip in a sequence of two movements per second) or both feet (flex toes in a sequence of one movement per second) depending on TASK; IMAGERY: imagine motor movement with same frequency as real movement.

(b) Example of screenshot for fMRI experiment.

Figure 3.10 Sequence of instruction / paradigm of the fMRI experiment.

The total experimental run time for all three motor tasks (RH, LH and BF) was approximately 30 minutes. Participants were required to open their eyes throughout the resting, ME and MI periods. Through the window of the

MR room, the experimenter and operator were able to observe and confirm the movement executed by participants during the period of “REAL movement”, and to confirm no movement was executed during the period of “IMAGERY movement” and “REST”.

3.3.3 DATA PROCESSING AND ANALYSIS

The fMRI data in Digital Imaging and Communication in Medicine (DICOM) format was transferred from the MRI workstation to a computer for processing and analysis using Statistical Parametric Mapping (SPM) 8 software (Wellcome Department of Cognitive Neurology, London, UK) implemented in Matlab 6.5.1 (Mathworks Inc. MA, USA).

The data was first slice-time and motion corrected. Next, the data were spatially normalized to an EPI template in the Montreal Neurological Institute space using the structural images. Subsequently, a Gaussian kernel with a FWHM of 6mm was used to spatially smooth the normalized data, in order to improve the signal-to-noise ratio. Statistical analysis was carried out using a voxelwise least squares estimation via the general linear model for serially auto-correlated observation. All conditions including “Real movement” and “Imagery movement” were modelled using the standard hemodynamic (HDR) function implemented in SPM.

Statistical parametric map were generated to identify regions activated by the respective MI task ($p < 0.5$, family wise error [FEW]), specifically the contrast between MI and the resting condition. According to this experimental design, 150 seconds of neural activation (imagery state) were compared with 300 seconds of normal condition (resting state) for each MI task.

As mentioned in Chapter 2, neural activities during motor imagery were focused around the fronto-parietal cortical region; thus the current fMRI study focused mainly on this region as well. Activated regions on fMRI images were identified and classified with the help of an experienced neuroradiologist who was blinded by the grouping condition and testing phase. The Talairach Atlas (Talairach et al., 1988) was used as anatomy reference for cortical location and classification. The quantitative cortical map of MI by Hétu et al. (2003) was used as reference for activation map during MI tasks of RH, LH and BF.

CHAPTER 4

RESULTS

4.1 INTRODUCTION

This chapter consists of two parts -- results of the BCI study and results of the fMRI study. Demographic data, BCI performance data and analysis, as well as fMRI result and analysis are presented.

4.2 RESULTS OF THE BCI STUDY

4.2.1 DEMOGRAPHIC DATA

A total of 53 neurologically healthy, BCI-naïve and mindfulness meditation-naïve (by self-report) undergraduates were recruited in this study. This study was conducted concurrently with fMRI scanning. Of the total of 53 participants, 8 had to withdraw from the study as the scanning schedule clashed with their lecture hours. Another 7 participants dropped out from the study due to poor attendance to MM classes, poor compliance, or lose of contact after withdrawal from the university.

Thirty-eight participants completed the study (23 males, 15 females); of which 19 of them were from the meditation group and another 19 from the control group. The demographic chart showing the number of participants recruited, withdrawn and completed is presented in Figure 4.1. All the participants were Chinese undergraduates, majoring in various engineering and science courses, aged between 19 and 21 (M = 19.61, SD = 0.75).

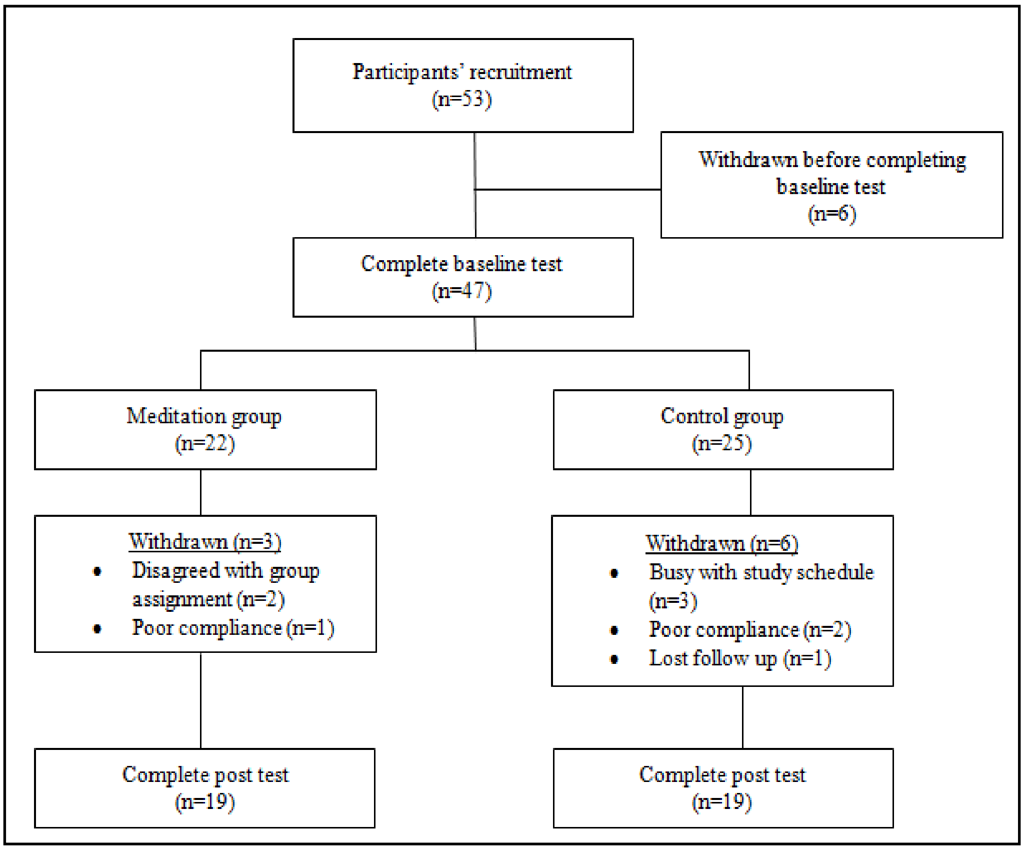


Figure 4.1 Demographic chart showing number of participants recruited, withdrawn and completed.

4.3 BCI PERFORMANCE RESULT

The BCI accuracy measured before and after the intervention period for meditation and control groups are shown in Table 4.1.

Table 4.1 The mean and standard deviation (SD) of BCI accuracy measured pre and post intervention period for meditation and control group.

Group	n	Pre-intervention	Post-intervention
Meditation	19	55.10 (±11.18)	64.29 (±11.49)
Control	19	57.74 (±10.48)	56.35 (±9.47)

A one-way between group analysis of covariance (ANCOVA) was conducted to compare the effects of MM on BCI performance. The results showed that there was a significant effect of MM on BCI accuracy at post-intervention after controlling for the effect of pre-intervention data, ($F(1,35) = 6.372$, $p = .016$, $r = 0.392$). The covariate of the BCI accuracy of pre-intervention test was not significantly related to the BCI accuracy of post-intervention test ($F(1,35) = 2.147$, $p > .05$).

The data were also examined by calculating the Bayes factor (*B*) on the difference between the meditation and the control groups after the 4-week intervention study. As there were no previous results on the effect of 4-week MM training, a uniform distribution was used for the calculation. The experimental hypothesis stated that the difference between meditation and control group will range between 0 and 12, based on the difference of 12-week intervention study. (Tan et al., 2014a). The calculated *B* (experimental / alternative) for a mean sample difference between the meditation and control groups of 8.554 with standard error of 3.389 was 14.37 (Figure 4.2). The Bayes factor of 14.37 is greater than 3 and strong evidence for the experimental over the null. In other words, the results showed that there was strong evidence that the 4-week MM training programme improves BCI accuracy.

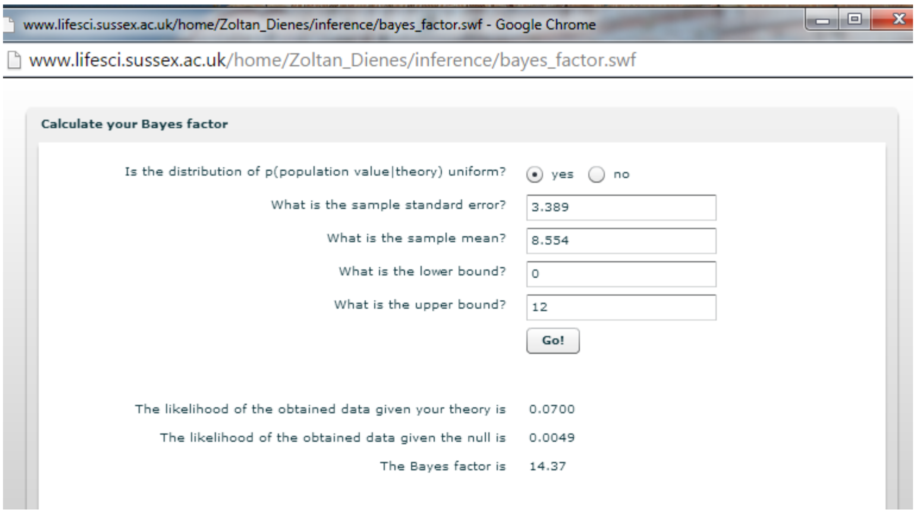


Figure 4.2 Bayes factor calculation for the difference between the meditation group and the control group after 4-week intervention.

4.4 RESULTS OF FMRI STUDY

4.4.1 DEMOGRAPHIC DATA

Eighteen undergraduate volunteers from randomized controlled trial study were recruited into the fMRI study. However, only ten of them completed the test. Two participants who used different MI tasks (LH and BF) from the rest of the participants (whose MI tasks were RH and BF) were not included in the analysis. This exclusion criteria is commonly applied in neuroscience study to reduce the variance in the data (Willems et al., 2014). The 8 participants consisted of 4 from meditation group and 4 from control group. They were 5 males and 3 females, with age ranging from 19 to 21 (M = 19.75, SD = 0.71).

4.4.2 FMRI ACTIVATION MAPS FOR MOTOR IMAGERY

Because of the small size of study population (n=8), no statistical comparison of the fMRI results between the two groups was carried out. To compare the individual results of the 8 participants who completed the fMRI tests, the cortical activation region map for each participant during each MI task compared to the resting period is generated.

The activated regions were classified into restricted (RA), non-restricted (NR) and no-activation (NA), as illustrated in Figure 4.3. The region is classified as RA if activation was found confluent to one region of the fronto-parietal cortex. The region is NR if activation was found scattered across different regions of the fronto-parietal cortex. If there is no change in BOLD signals, the regions were classified as NA.

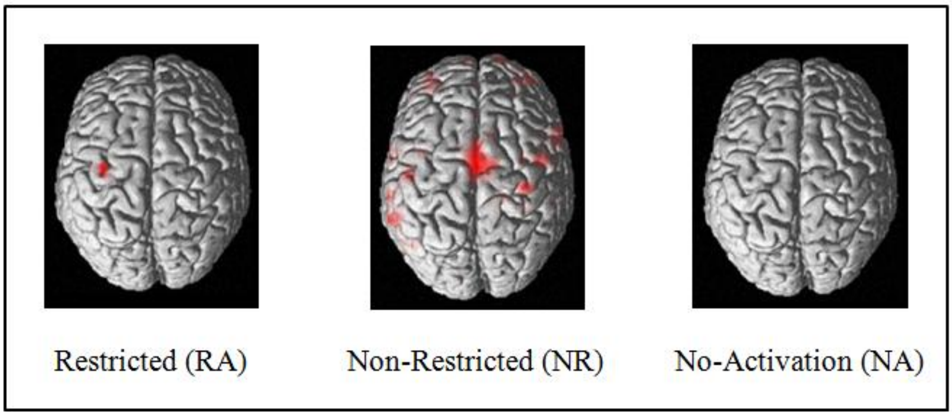
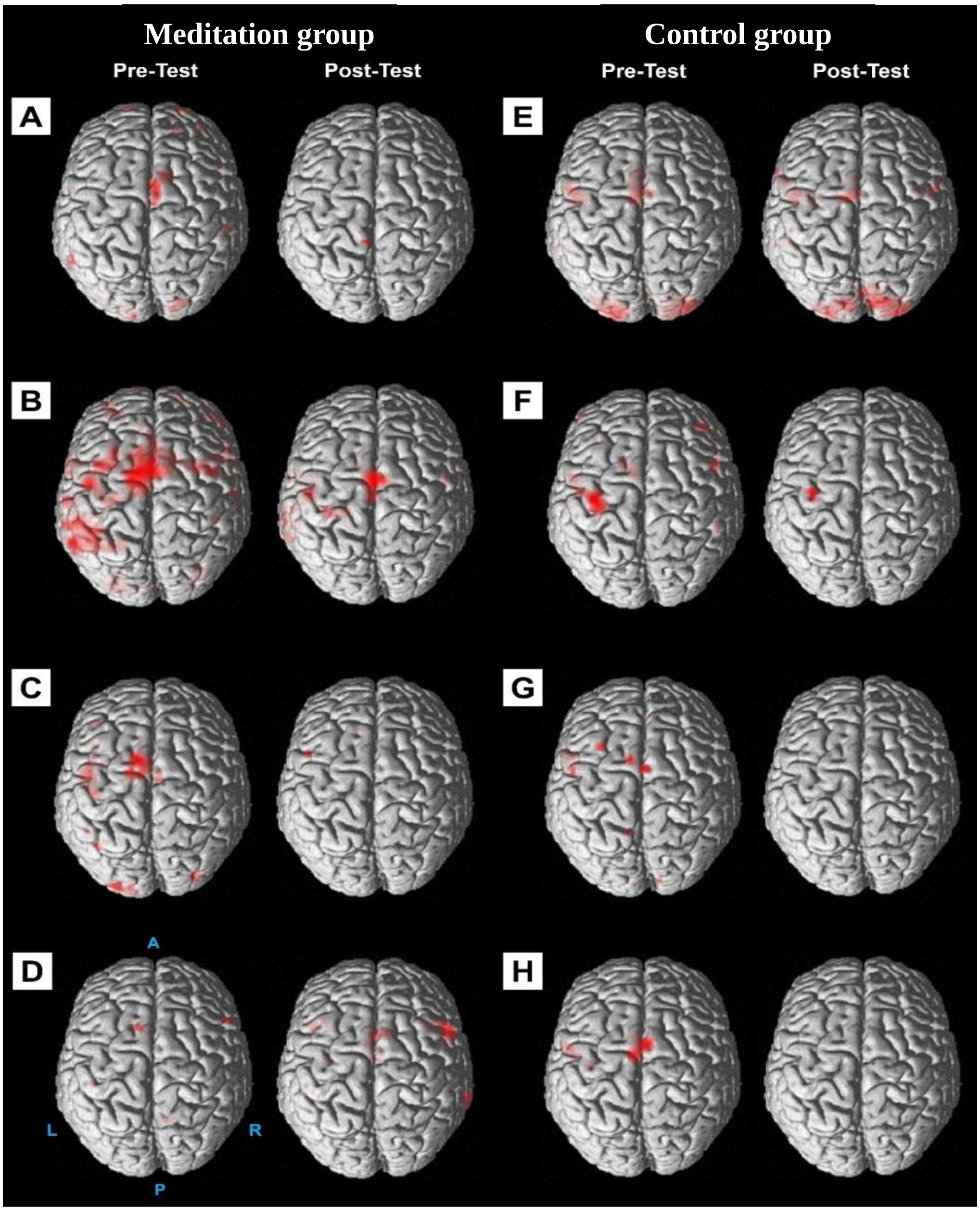


Figure 4.3 Classification of activated region: Restricted (RA), Non-Restricted (NR) and No-Activation (NA).

4.4.2.1 RIGHT HAND MOTOR IMAGERY

Figure 4.4 shows the activation maps of right hand motor imagery for each of the participant before and after intervention.

During the pre-intervention test, all participants showed NR activation during MI. Restricted activation was found in most participants from the meditation group (participant A, B and C) during the post- intervention test. Similar changes were observed only in participant F from the control group. No activation was found in participants G and H during the post-intervention test. Participants D and E showed little or no change in their activation patterns before and after the intervention.



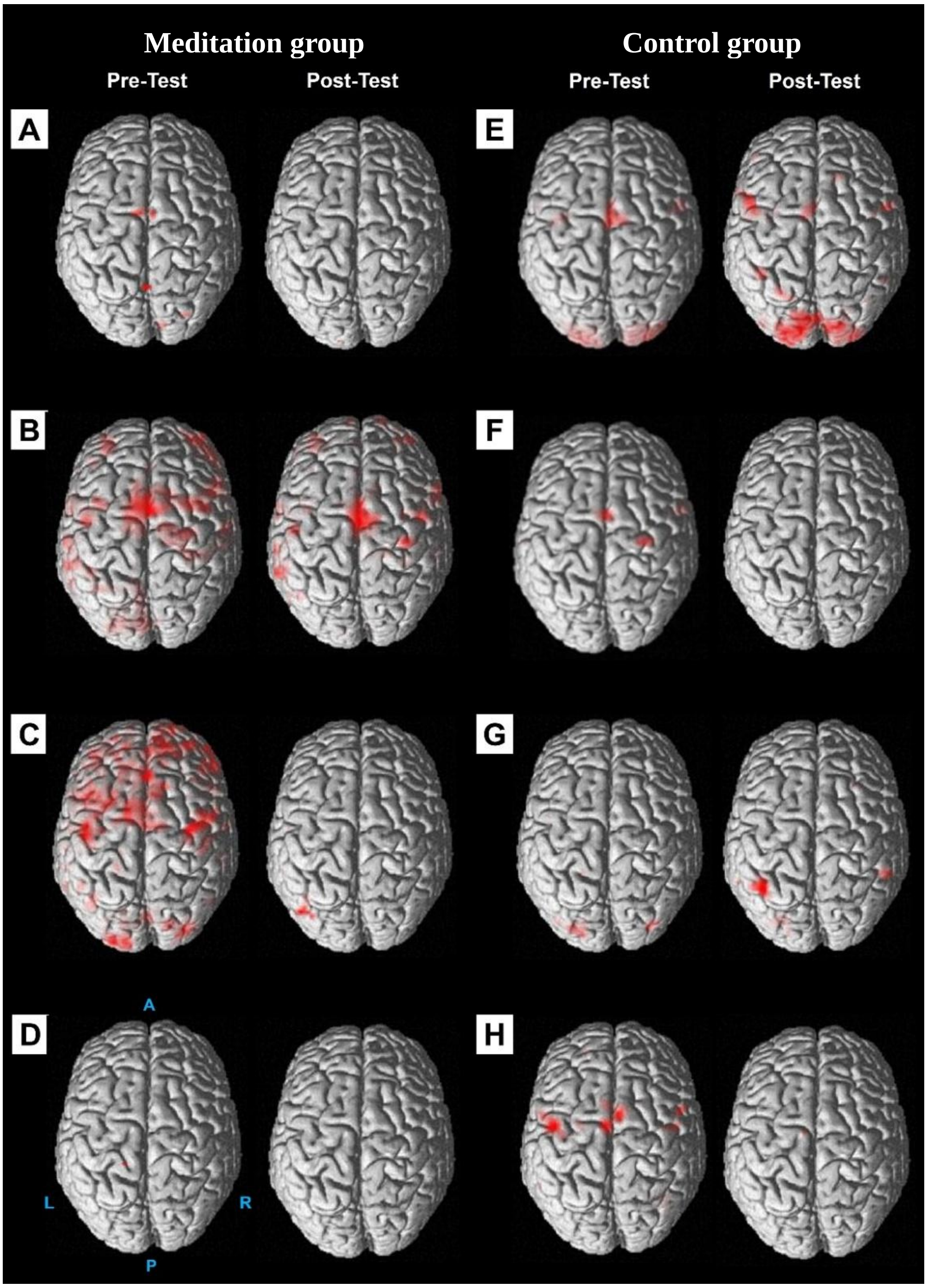
Note: A: anterior;L: left; P: posterior; R: right. All images were threshold at $p < 0.05$, FWE.

Figure 4.4 Activation maps of right hand motor imagery of each participant in meditation and control group at before and after intervention.

4.4.2.2 LEFT HAND MOTOR IMAGERY

Figure 4.5 shows activation maps of left hand motor imagery of each participant in the meditation and control groups before and after intervention.

Most participants showed NR during the pre-intervention test, except participant G who showed NA. After MM training, activation was found restricted in participant C. No similar change was observed in the rest of the participants. No activation was revealed during the post-intervention test for participants A, D, F and H.



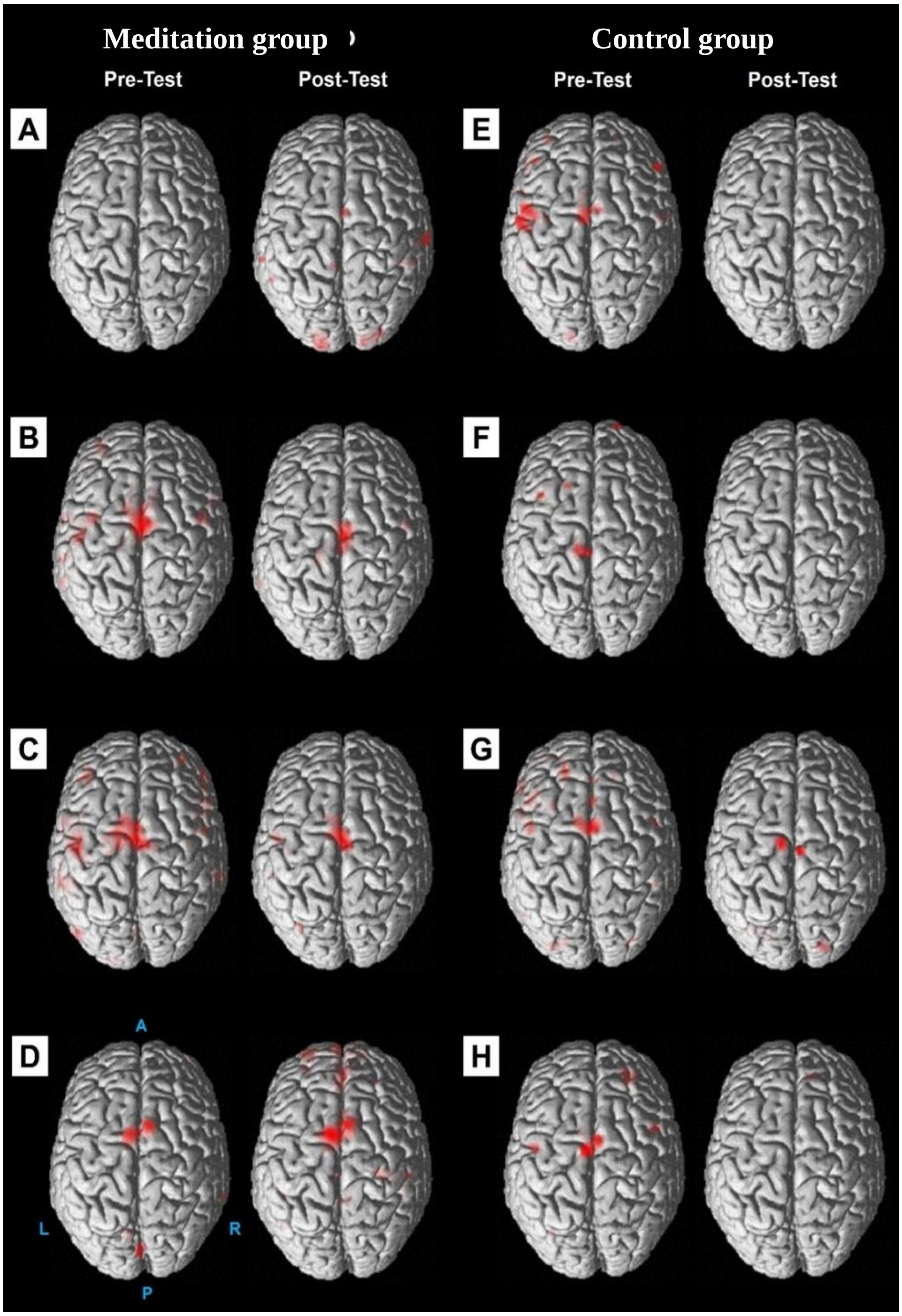
Note: A: anterior; L: left; P: posterior; R: right. All images were threshold at $p < 0.05$, FWE.

Figure 4.5 Activation maps of left hand motor imagery of each participant in meditation and control group at pre- and post-intervention test.

4.4.2.3 BOTH FEET MOTOR IMAGERY

Figure 4.6 shows activation maps of both feet motor imagery of each participant in the meditation and control groups.

All participants showed NR at the pre-intervention test. RA was found in participant B and C at post-intervention test. Participant E and F showed NA during the post-intervention test. The activation pattern of other participants remained unchanged.



Note: A: anterior; L: left; P: posterior; R: right. All images were threshold at $p < 0.05$, FWE.

Figure 4.6 Activation maps of both feet motor imagery of each participant in meditation and control group at pre- and post-intervention test.

4.4.2.4 ASSOCIATION OF FMRI ACTIVATION AND BCI PERFORMANCE

Changes in the activation pattern of the fronto-parietal network during MI and their correlation with individual BCI performance are summarized in Table 4.2.

Table 4.2 Changes in activation of fronto-parietal network during motor imagery of each participant and correlation with individual BCI performance.

Participant	Motor cortex activation on fMRI						Changes in BCI accuracy, % (Post – Pre)
	Right hand MI		Left hand MI		Both feet MI		
	Pre	Post	Pre	Post	Pre	Post	
Meditation Group							
A	NR	RA	NR	NA	NR	NR	+14.76
B	NR	RA	NR	NR	NR	RA	+11.39
C	NR	RA	NR	RA	NR	RA	+25.81
D	NR	NR	NR	NA	NR	NR	+4.44
Control Group							
E	NR	NR	NR	NR	NR	NA	-15.28
F	NR	RA	NR	NA	NR	NA	+25.77
G	NR	NA	NA	NR	NR	NR	+3.96
H	NR	NA	NR	NA	NR	NR	+4.72

Note: MI: motor imagery, RA: restricted activation, NR: non-restricted activation, NA: no activation

Overall, NR was shown in most MI tasks at pre-intervention test for participants from both the meditation and control groups. After MM training, participants from the meditation group revealed more RA in different MI tasks, as compared to participants from the control group.

The activation region during right hand MI of 3 participants (A, B, and C) in meditation group had changed from NR to RA. No similar change was found in participant D. Meanwhile, 3 participants A, B and C showed more than 10% for the changes in the BCI performance while participant D only showed less than 5% of changes.

Only one participant from the control group showed changes from NR to RA during right hand MI task. Interestingly, this participant also demonstrated better improvement in BCI performance compared to other participants from the control group.

The association trend of restricted activation during right hand MI and improvement of BCI performance was observed here.

CHAPTER 5

DISCUSSION

An earlier study (Tan et al., 2014a) showed that participants who underwent a 12-week mindfulness meditation training demonstrated significant improvement in BCI performance compared to participants who received music training and those from the no-treatment control group. The current study is an extension of the earlier study, with the aim to determine the effect of a shorter 4-week meditation training programme on BCI performance.

The ANCOVA test revealed that MM group demonstrated significantly improved BCI performance compared to the no-treatment control group after the 4-week MM training programme. Further statistical analysis using Bayes factor (*B*) calculation also provided strong evidence to support the experimental hypothesis over the null hypothesis. This again confirms the effect of MM training over the control on the BCI performance.

Previous studies showed that short-term meditation training can improve cognitive abilities, such as sustained attention (Tang et al., 2007; Zeidan et al., 2010b), enhanced creativity performance (Ding et al., 2014), improved mood and self-regulation (Tang et al., 2007; Zeidan et al., 2010c; Tan et al., 2014b) -- the similar benefits that have been previously reported with long-term meditation practice (Tang et al., 2007; Zeidan et al., 2010b; Zeidan et al., 2010c).

Since the same procedures and measures were repeated in the post-intervention test, it may induce repetition and expectation effects. The study by Tan et al. (2014a) had eliminated the expectancy effect of MM as an explanation of improvement in BCI performance and suggested that MM may really help in BCI control through enhancing the emotion regulation (Tan et al., 2014a). In regard to repetition, it might give a positive effect due to more practice (Johnstone et al., 2002), or a negative effect due to adaptation(Larsson and Smith, 2012). The results of the current study may suggest that MM training helps in promoting positive repetition effect, as MM training cultivate better mental controllability.

An interesting incidental observation was made during the study. Each experiment lasted 1-2 hours and participants were required to sit still in an arm-chair. Based on oral feedback at the end of the tests, some participants from the control group commented that the tests were boring and tiring but no one from the MM group gave a similar comment. The same observation was also revealed by another research group who suggested that the meditators who had learned about the mindfulness, acknowledged anything that happened at the present moment, accepted it but not reacting to it. (Valentine and Sweet, 1999).

Previous studies had showed that the practice of meditation induced short-term state effects and these effects were more pronounced with long-term practice of meditation which may produce changes in traits. Generally, state effects refer to the immediate changes during or after a meditation practice, such as altered sensory, cognitive and self-referential awareness while trait effects refer to more lasting changes in these dimensions that persist in the practitioners (Cahn & Polich, 2006). A study by Chan and Woollacott (2007) suggested that the level of meditation experience affected the trait effect in attentional focus. A recent study also showed that participants who had better improvement of state effects after repeated meditation sessions had better changes in trait effects (Kiken et al., 2015). Benefits of meditation in various mental, cognitive, and psychological aspects had been proven on practitioners who had years of experiences (Cahn & Polich, 2006, Braboszcz et al., 2010) as well as those engaged in training programmes lasting months or weeks (Jain et al., 2007, Lutz et al., 2009, Singh et al., 2012). However, some recent studies showed that 1-5 days of short-term meditation training were also able to sustained attention (Tang et al., 2007; Zeidan et al., 2010b), improved creativity performance (Ding et al., 2014), reduced pain sensitivity (Zeidan et al., 2010a), reduce psychological stress response (Mohan et al., 2011) as well as enhanced mood and self-regulation (Tang et al., 2007; Zeidan et al., 2010c; 2010b).

The current study employed a similar methodology as the earlier study (Tan et al., 2014a), except that the same 12 hour MM programme was carried out in 4 weeks instead of 12 weeks. The results of the current study showed the MM group improved their BCI accuracy significantly as compared to a non-intervention control group. However, it is not possible to conclude that the effects of the 4-week mindfulness meditation training are similar or better or worse than those of the 12-week intervention study, because the two studies were not conducted concurrently.

In the fMRI study, more participants in the MM group showed restricted activation in their fronto-parietal cortex than participants in the control group at the post-intervention test. Fronto-parietal cortex plays an important role in cognitive tasks such as the MI tasks required in the BCI test. Changes to restricted activation from non-restricted activation indicated that the participants were able to perform the MI task with less effort. In support of this, some fMRI studies also found that meditation reduced cortical activities and task effort, suggesting that with meditation, the regulative attention skills are invoked less and less frequently, thus reducing the task effort (Brefczynski-Lewis et al., 2007; Chan and Woollacott, 2007; Lutz et al., 2008; Kozasa et al., 2012). In line with these findings, Kozasa et al. also reported that regular meditators were found to activate fewer brain regions than non-meditators for achieving the same performance during attentional tasks (Kozasa et al., 2012).

The participants of the current study were all undergraduates from Chinese racial background, with age ranging from 19-21 years old. This may limit the results of the findings to be applied to other level of society and population. However, recruiting subjects from one single population would reduce the variance caused by cultural effect.

This is not a blind design experiment, as all participants were aware of their group allocations based on the assignments given. The experimenter was aware of the grouping and the intervention status of each participant as well. To minimize the possible bias effect, a standard protocol and procedure was prepared before the assessment. The experimenter applied the same protocol and instructions to each participant for all assessments.

CHAPTER 6

CONCLUSION

6.1 CONCLUSION

Thirty eight undergraduate students completed a 4-week randomized controlled trial study consisting of an MM group and a no-treatment control group. Participants of the MM programme showed a significant improvement in BCI performance compared to the non-intervention control group. A parallel fMRI study on 8 participants of the main group showed evidence of more focus activation during motor imagery in the fronto-parietal areas of the brain of the MM participants compared with the control group and this was also associated with improved BCI performance.

6.2 FUTURE WORK

Future research should be expanded to a larger group of people from different social levels and populations to increase the accuracy and reliability of the results.

Since the BCI research aims at helping patients with severe neuromuscular disorders (NMD) such as ALS patients, future studies should be extended to actual patients. The onset and progression of the disease needs to be taken into account when deciding the duration of MM training.

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APPENDIX A

PARTICIPANTS QUESTIONNAIRE

Participation Form
University Tunku Abdul Rahman
Faculty of Engineering and Science
Brain Science Research Group
Project: Effect of Mental Training on BCI Performance: A fMRI Study

Ref No:

Name: ____
Gender: _________ Ethnic: __________ Religion: ________
Age: _______ D.O.B.: _______DD______MM______YY
Student ID: _____________ Course: __________(Y____S____)
Contact No: ________________________
Current Address: ___________________________________
____
Permanent Address: _________________________________
____

Please answer the following questions:

1. What is your native language? ___________________
2. List the language(s) you use in your daily life
   ____
3. What is your dominant hand? **(Left / Right / Ambidextrous)**
4. Do you wear glasses/lenses during reading? **(Yes – Glasses/Lenses / No)**
5. Do you have any history of colour blindness? **(Yes / No)**
6. Have you ever had a head injury with the loss of consciousness? **(Yes / No)**
7. Have you ever been diagnosed with a psychological or mental disorder? **(Yes / No)**
8. Have you ever been diagnosed with a neurological deficit? **(Yes / No)**
9. Have you ever been diagnosed with an attention deficit? **(Yes / No)**
10. Have you ever been treated for or thought you might need treatment for an alcohol or drug addiction? **(Yes / No)**
11. Have you ever had a serious illness, an accident or an operation? **(Yes / No)**
12. Do you have any history of claustrophobia? **(Yes / No)**
13. Do you have any history of heart diseases? **(Yes / No)**
14. Have you ever had formal or informal meditation practice or mental training? E.g. meditation class, yoga, self-help tapes or books.... **(Yes / No)**
    If yes, please describer the activity, the amount of time you spent for this activity (hour per day or per week) in past or current, as well as the length of the activity (e.g. "I practice breathing exercises once a week for 2 hours since January 2010).
    ____
    ____
    ____
    ____
    ____

Please submit the completed form to
Ms Tan Yin Qing
012-6631064
tanyq@utar.edu.my
Room SA129, Level 1, SA Block, FES

*only qualified participants will be selected.

APPENDIX B

INFORMED CONSENT FORM

Informed Consent for BCI Performance Test

Universiti Tunku Abdul Rahman
Brain Science Research Group

Participant Name: ____________________ **I/C No.:** ____________________

Contact No.: ____________________ **Researcher Name:** ____________________

You are invited to participate in the following study. Your participation into this study is entirely voluntary. Your participation may not benefit you directly but it will help us in improving the designs and operations of BCI system.

Title of Study: A study of Brain-Computer Interface (BCI) Performance

Purpose of Study: To quantify the functional changes in brain activity on the performance of BCI users before and after meditation using EEG that are correlated with actual performance.

Procedures:

A. Pre-test
   1. Subject will start with an EEG recording to locate the electrode location and fix the motor imagery task.
   2. A motor imagery-based BCI system will be used to classify the changes of the sensorimotor rhythms when a subject is performing a motor imagery to control the device.

B. Intervention
   1. Subjects are randomly assigned to a treatment group (attend meditation class for 12 hours) or a no-treatment control group.

C. Post-test
   1. Subjects repeat the same 2 tests carried out during the pre-test to compare the performance before and after the intervention.

Potential Risks:
There may be some discomfort experienced by attaching the electrodes on the scalp and skin with electro-gel and secured with stickers. Under rare circumstances, people with very sensitive skin may have some minor irritation or redness on the skin in reaction to the application of electro-gel.
Additionally, because of the length of the test and the fact that you are asked to remain as still as possible, some people find the experiment to be uncomfortable and unpleasant. The investigator will check with you to determine if you are having any such negative sensations.

Confidentiality:
Information gathered from the study may be published or presented in public forums. However your name and other identifying information will not be used or revealed.

I have fully explained to the participant the purpose and procedures of the study described above. I feel the participant has been adequately informed and has consented.

Researcher Signature: ____________________ Date: ____________________

I have been fully informed and understood the above information. I have had the opportunity to discuss with the researcher and I have had my questions answered by him/her in a language that I understand. In signing this consent form, I agree to follow the procedures of the study, and I understand that my participation is voluntary, and I am free to withdraw my consent and discontinue my participation in this study at any time without any penalty.
I agree to take part in this study.

Participant Signature: ____________________ Date: ____________________

APPENDIX C

THE EEG BIPOLAR CHANNELS USED FOR STUDY

Table C. 1 The conventions of the names of the derived EEG bipolar channels usedin BCI study.

Brain region	Name of EEG channel	Electrode position
C3	ac_C3	aC3, C3
	ap_C3	aC3, pC3
	pc_C3	C3, pC3
Cz	ac_Cz	aCz, Cz
	ap_Cz	aCz, pCz
	pc_Cz	Cz, pCz
C4	ac_C4	aC4, C4
	ap_C4	aC4, pC4
	pc_C4	C4, pC4

Table C. 2 Combination of EEG bipolar channels

No.	Combination	No.	Combination	No.	Combination
1	ac_C3	13	ap_C3, ap_Cz	25	ac_C4, pc_Cz
2	ac_C3, ac_C4	14	ap_C3, pc_Cz	26	ap_C4
3	ac_C3, ap_C4	15	pc_C3	27	ap_C4, ac_cz
4	ac_C3, pc_C4	16	pc_C3, ac_C4	28	ap_C4, ap_Cz
5	ac_C3, ac_Cz	17	pc_C3, ap_C4	29	ap_C4, pc_Cz
6	ac_C3, ap_Cz	18	pc_C3, pc_C4	30	pc_C4
7	ac_C3, pc_Cz	19	pc_C3, ac_Cz	31	pc_C4, ac_Cz
8	ap_C3	20	pc_C3, ap_Cz	32	pc_C4, ap_Cz
9	ap_C3, ac_C4	21	pc_C3, pc_Cz	33	pc_C4, pc_Cz
10	ap_C3, ap_C4	22	ac_C4	34	ac_Cz
11	ap_C3, pc_C4	23	ac_C4, ac_Cz	35	ap_Cz
12	ap_C3, ac_Cz	24	ac_C4, ap_Cz	36	pc_Cz

APPENDIX D

PATIENT INFORMATION SHEET

PATIENT INFORMATION SHEET

**Please read the following information carefully, do not hesitate to discuss any questions
you may have with your experimenter.**

Study Title

Effect of mindfulness meditation on brain-computer interface performance: A fMRI study

Introduction

A brain–computer interface (BCI) can activate electronic or mechanical devices with brain activity alone. BCI able to translate human intentions into control signals to establish a direct communication channel between the human brain and output devices. As a communication and control system, a BCI establishes a real-time interaction between the user and the outside world. BCI research is advancing very rapidly and mostly aims at helping people with severe neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), stroke, or spinal cord injury to regain control over their environment and to communicate with their social environment.

Recent study indicated that mental training programs such as mindfulness meditation show promising potential in terms of improving BCI performance, potentially through mechanisms such as improved the stabilities of mental states and produced more consistent EEG patterns. Mindfulness meditation is a mental practice based on focusing on the sensations of the breath/body while maintaining a relaxed state of mind.

Neuroimaging studies have begun to explore the neural mechanisms underlying mindfulness meditation practice with functional magnetic resonance imaging (fMRI). fMRI demonstrates that mindfulness meditation induction activates neural structures involved in attention and control of the autonomic nervous system. A growing body of literature has demonstrated that neural systems are modifiable networks and changes in the neural structure can occur in adults as a result of training.

What is the purpose of this study?

This study aims to observe the brain activity of motor imagery used to operate BCI before and after mindfulness meditation training using fMRI and correlate the changes with BCI performance.

What are the procedures to be followed?

1. The study will start with a pre-test, followed by an intervention, and finally a post-test. The pre-test is embodied of EEG brain mapping, BCI performance test and first fMRI session. Then, the participants will be randomly assigned into control and intervention groups. The intervention group will receive mindfulness meditation training. The post-test will be completed with EEG brain mapping, BCI performance test and second fMRI session.
2. EEG experiment will be conducted in order to identify the optimum locations of the EEH electrodes and the best combination of the motor imagery tasks used to operate BCI.

3. A non-invasive EEG-based BCI will be used. A graphical user interface(GUI) is displayed to participants for selection of 4 options – "A", "B", "C" and "D". Participants can make a binary selection on each option by using two motor imagery tasks (e.g. right hand movement and both feet movement). In the BCI performance test, participants are requested to complete 12 selections in 30min by control the computer cursor (to the right or left) to choose alphabets.

4. fMRI- scanning a GE 3Tesla system will be used. The estimated scanning duration is about 30 minutes. While lying in the fMRI scanner, you need to view a projection screen via a mirror. Instruction will be given to do a series of plan activities in motor imaginary movements (alternating with rest).

5. Intervention group will attend a mindfulness meditation lesion of three-hour duration under the instruction of a professional meditation teacher once a week for 4 weeks.

Who should not enter the study?

1. History of neurological disease.

2. Participants who do not pass magnetic resonance scanning safety eligibility screen, which includes those with cardiac pacemakers or any metallic implants such as cochlear implants (ear metallic implants), intra-ocular metallic implant (eye implants), heart valve replacement and nerve stimulator.

What will be benefits of the study:

(a) to you as the subject?
No charges will be made. Your contribution will help us to obtained useful information for this study.

(b) to the investigator?
The information obtained via functional MRI will be used to study the effect of mental training on BCI users' performance. In hope eventually to apply on patient with severe neuromuscular disorders such as ALS and stroke to regain control over their environment and to communicate with their social environment via BCIs.

What are the possible drawbacks?

No added risk.

Can I refuse to take part in the study?

Yes.

APPENDIX E

CONSENT FORM FOR FMRI SCAN

CONSENT BY PATIENT FOR CLINICAL RESEARCH

I, ..., Identity Card No..

(Name of Patient)

of ....

(Address)

hereby agree to take part in the clinical research (clinical study/questionnaire study/drug trial) specified below:

<u>**Effect of mindfulness meditation on brain-computer interface performance : A fMRI study**</u>

the nature and purpose of which has been explained to me by
<u>**Dr. Kuok Su Sim (Medical Officer, Department of Biomedical Imaging)**</u>

(Name & Designation of Doctor)

and interpreted by ....

(Name & Designation of Interpreter)

to the best of his/her ability in .... language/dialect.

I have been told about the nature of the clinical research in terms of methodology, possible adverse effects and complications (as per patient information sheet). After knowing and understanding all the possible advantages and disadvantages of this clinical research, I voluntarily consent of my own free will to participate in the clinical research specified above.

I understand that I can withdraw from this clinical research at any time without assigning any reason whatsoever and in such a situation shall not be denied the benefits of usual treatment by the attending doctors.

Date: .... Signature or Thumbprint ....

(Patient)

IN THE PRESENCE OF

Name ....)

Identity Card No. ....) Signature ....

(Witness for Signature of Patient)

Designation ....)

I confirm that I have explained to the patient the nature and purpose of the above-mentioned clinical research.

Date .... Signature ....

(Attending Doctor)

CONSENT BY PATIENT
FOR
CLINICAL RESEARCH

R.N.
Name
Sex
Age
Unit