COGNITIVE FUNCTION ASSESSMENT IN YOUNG ADULT BASED ON MENTAL ARITHMETIC, TRAIL MAKING, AND STROOP TASKS

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Specially dedicated to *Mama* and *Ayah*
all my lovely sisters and husband.

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ABSTRACT

Executive Function (EF) is an important cognitive skill which undergoes three main processes: updating, shifting and inhibition. However, many brain researchers do not look deeper in Functional Connectivity (FC) between brain regions, and connection of EF from other brain areas still remains unclear. In order to determine cortical networks, FC measurement is needed. This study determines the cortico-cortical FC between brain regions using Partial Directed Coherence (PDC) and investigates the Power Spectral Density (PSD) of brain activity while performing cognitive function assessments. 20 young Malaysian adults were asked to perform three tasks/tests: Mental Arithmetic task (updating), Trail Making Test (shifting); Trailing A and B, and Stroop task (inhibition). Electroencephalography machine was used to record brain signals, and the data were analysed using PDC and PSD. Findings showed that in updating, most of the brain area that generated information was from frontal areas: Fp_1, Fp_2 and F_7, based on correct and incorrect answers given by the subject. Results from two trailing showed that for Trailing A, the information mostly was generated from fronto-temporal areas: Fp_2, F_7 and T_3, whereas for Trailing B, the information generated was almost similar to Trailing A, but slightly different in scalp locations: F_7, T_3 and T_4. For inhibition, fronto-temporal area produced the highest number of information sources: Fp_1, Fp_2 and T_4. In receiving the information, all parts of brain region were interconnected for all three processes. For all processes, significantly increased theta band was found at frontal region with 15.32%, while significant decreased of alpha band was found at occipital (30.73%), temporal (29.83%), and parietal (34.91%) areas. Meanwhile, gamma (γ) and high-gamma (hγ) bands were significantly higher at central (γ=35.73%, hγ=70.10%), parietal (γ=52.00%, hγ=84.87%), and occipital (γ=63.74%, hγ=74.65%) areas for shifting and inhibition processes. In conclusion, all parts of brain are interconnected for generating and receiving information during EF task and it shows that EF is not dependent on frontal area only.

ABSTRAK

Fungsi Eksekutif (EF) ialah satu kemahiran kognitif penting yang menjalani tiga proses utama: pengemaskinian, peralihan dan perencatan. Walau bagaimanapun, ramai penyelidik otak tidak membuat kajian mendalam Keberkaitan Fungsi (FC) antara kawasan otak dan sambungan EF dari kawasan otak lain masih tidak begitu jelas. Dalam usaha menentukan rangkaian kortikal, pengukuran FC diperlukan. Kajian ini menentukan FC korteks-kortikal antara bahagian otak menggunakan Koheren Separa Berarah (PDC), dan mengkaji Ketumpatan Spektrum Kuasa (PSD) aktiviti otak ketika menjalankan ujian fungsi kognitif. 20 orang dewasa muda Malaysia diminta menjalani tiga tugasan/ujian: Ujian Aritmetik Mental (pengemaskinian), Ujian Membuat Jejak (peralihan); Penjejak A dan B, dan Ujian Stroop (perencatan). Mesin elektroensefalografi diguna bagi merekod isyarat otak dan data dianalisis menggunakan PDC dan PSD. Penemuan menunjukkan bahawa dalam mengemaskini, kebanyakan kawasan otak yang menjana maklumat adalah dari kawasan frontal: Fp_1, Fp_2 dan F_7, berdasarkan jawapan diberi betul ataupun tidak. Hasil daripada dua penjejak menunjukkan bahawa Penjejak A, maklumat kebanyakannya dijana dari kawasan fronto-temporal: Fp_2, F_7 dan T_3, manakala Penjejak B, maklumat dijana hampir sama seperti Penjejak A, tetapi sedikit berbeza di lokasi kulit kepala: F_7, T_3 dan T_4. Bagi perencatan, kawasan fronto-temporal menghasilkan bilangan sumber maklumat tertinggi: Fp_1, Fp_2 dan T_4. Dalam menerima maklumat, semua bahagian otak adalah saling berkaitan untuk ketiga-tiga proses. Untuk semua proses, peningkatan jalur teta didapati di kawasan frontal dengan 15.32%, manakala pengurangan jalur alfa didapati di kawasan oksipital (30.73%), temporal (29.83%), dan parietal (34.91%). Sementara itu, peningkatan jalur gama (γ) dan gama tinggi ($h\gamma$) diperolehi di kawasan sentral (γ=35.73%, $h\gamma$=70.10%), parietal (γ=52.00%, $h\gamma$=84.87%), dan oksipital (γ=63.74%, $h\gamma$=74.65%) untuk proses peralihan dan perencatan. Kesimpulannya, semua bahagian otak adalah saling berkaitan dalam menjalankan FE dan ia tidak bergantung kepada kawasan frontal sahaja.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

δ	-	Delta band
θ	-	Theta band
α	-	Alpha band
β	-	Beta band
γ	-	Gamma band
hγ	-	High-gamma band

LIST OF ABBREVIATIONS

PDC	-	Partial Directed Coherence
EEG	-	Electroencephalography
EF	-	Executive Function
MA	-	Mental Arithmetic
MA07	-	Mental Arithmetic – subtract number 7
MA13	-	Mental Arithmetic – subtract number 13
TMT	-	Trail Making Test
TMTA-al	-	Trail Making Test A – Alphabet
TMTA-num	-	Trail Making Test A – Number
TMTB-num&al	-	Trail Making Test B – Number & Alphabet
ST	-	Stroop Task
MVAR	-	Multivariate Autoregressive Model
FFT	-	Fast Fourier Transform
ECoG	-	Electrocorticographic

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

In recent research, brain is one of the most prominent studies which have opened the eyes of the researchers especially in the areas of psychology, neuropsychology, rehabilitation, neuroscience, and biomedical engineering. It connects to our nervous system as it controls our body organs and behaviour.

Figure1.1 shows four important lobes in our brain area; frontal (F), parietal (P), temporal (T), and occipital (O) lobe. Table 1.1 explains the function and activity of each brain areas.

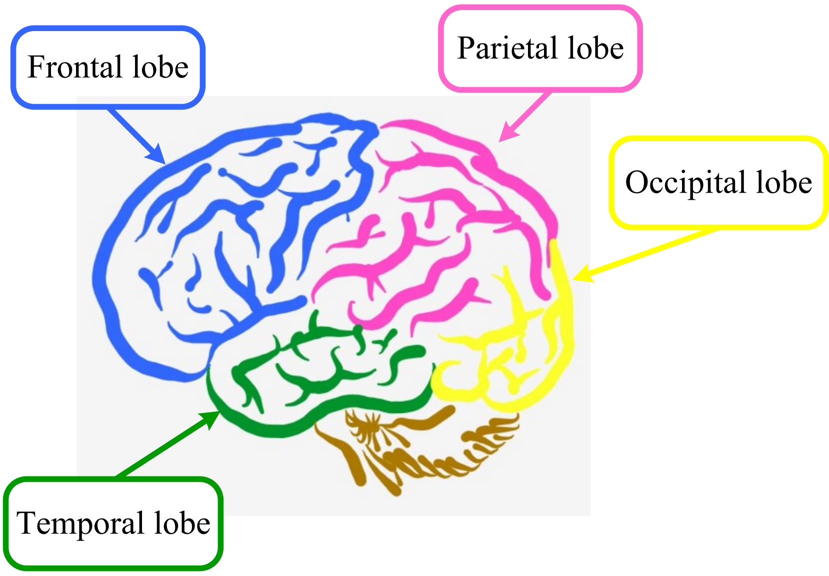

Figure 1.1 Four important brain areas

Table 1.1 Brain regions and its function

Brain region	**Function**
Frontal lobe	• Trigger voluntary action; blink eyes (Daly *et al.,* 2013). • Controlling learned motor skills and complex processes (Jaušovec and Jaušovec, 2012; Kleibeuker *et al.,* 2013). • Showing expressions and gestures by mood and feelings (Marci *et al.,* 2007).
Parietal lobe	• Interpret sensory information from the whole body (Ioannides *et al.,* 2013). • Integrate information (Yu *et al.,* 2013). • Comprehend mathematic skills and language (Libertus *et al.,* 2009). • Storing spatial memories; orient people in space and maintain a sense of direction (Prado and Weissman, 2011).
Temporal lobe	• Essential to auditory perception and language (Sun *et al.,* 2009). • Produce memory and emotions (Sidhu *et al.,* 2015). • Storing and retrieving long-term memories (Van Geldorp *et al.,* 2014).
Occipital lobe	• Process and interpret vision (Sun *et al.,* 2009). • Form visual memories (Vansteensel *et al.,* 2014).

Brain is an organ which it has the ability to keep and retain countless information that we collect everyday either in short-term or long-term memory. It also can conduct our daily routine from simplest to most complex task, based on our mental processes that involves perception, attention, memory, motor skill, language skill, visual and spatial processing. This process is called as executive function (EF) (Diamond, 2013; Han *et al.,* 2013).

EF often associated with the behaviour of shifting attention from one task to another, updating information from earlier information until recent, and inhibition of response from environment (Kirk *et al.,* 2015; Roelofs *et al.,* 2013). EF majorly performs at frontal lobe, which occurs at prefrontal cortex. Figure 1.2 shows the example of executive skills that execute at the frontal lobe, together with the example of other brain's functions.

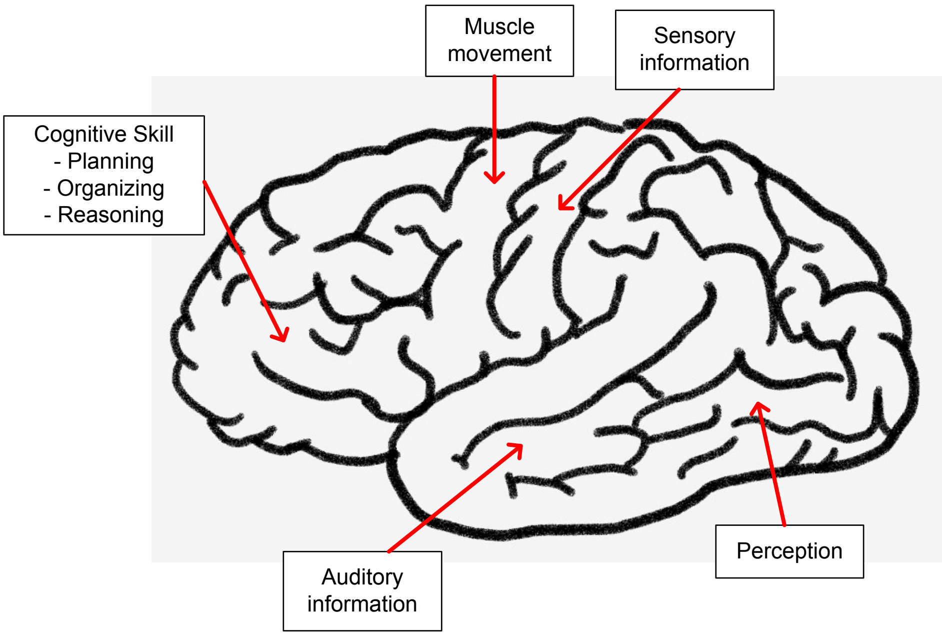

Figure 1.2 Example of executive skills with other functions of the brain

Recently, EF is growing some interest especially in psychology, neuropsychology, cognitive science, and biomedical field, in order to study the brain's development (Salminen *et al.*, 2012), mental health (Shimada *et al.,* 2014), and brain impairment (Rai *et al.,* 2015) that related to cognitive processes. There are several assessments that can be conduct depends on the research objective, such as mental task, trail making test, Stroop task, letter-memory task, sorting task, and other cognitive ability task.

A young adult which is between 18 to 30 years are the range of age where cognitive function develops (Veroude *et al.,* 2013). In a process of maturation, the skills that we develop everyday make our working memory and attention becomes better (Jolles *et al.,* 2012). In addition, through working memory training from the age of young adult will improve and maintain our cognitive function as we grow older (Heinzel *et al.,* 2014).

As there are many region and subcortical in the brain, the interrelated between them may varies when someone is thinking or solving problems (Lee *et al.*, 2014; Wang *et al*, 2005). The cortical activity can be observed when doing EF skills by applying functional connectivity. Functional connectivity is defined as temporal interaction (correlation) between different neural of brain region (Sakkalis, 2011), and it is the most capable way to investigate the brain networks (Santarnecchi *et al.,* 2014). Electroencephalography (EEG) signal is the most frequent recorded network that used in brain mapping research, which represent the functional connectivity (Joudaki *et al.,* 2012; Langeslag *et al.,* 2013).

In order to record and capture the brain signal, functional imaging has been used in order to make better understanding of brain. There are several functional imaging that are portable and non-invasive techniques, such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), functional near-infrared spectroscopy (fNIRS), and transcranial magnetic stimulation (TMS).

There are some methods of connectivity measures can be applied in order to discover the pattern of the functional connectivity; i.e. transfer entropy (TE), phase slope index (PSI), Granger causality (GC), directed transfer function (DTF), and partial directed coherence (PDC). Figure 1.3 shows an example of simulation of functional connectivity pattern. The source of the information is mark in grey colour. The arrow represents the direction of the information, while the nodes are the one that receive the information (the sink).

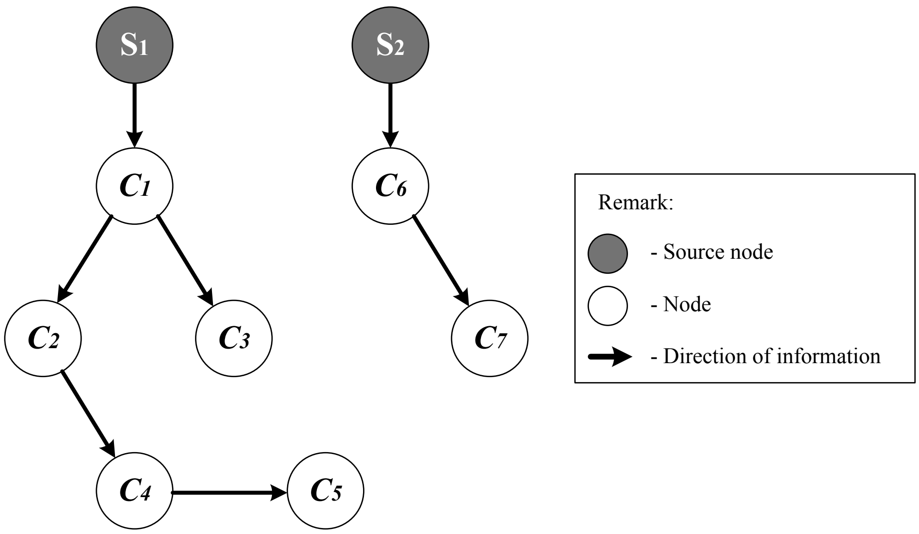

Figure 1.3 Simulation of functional connectivity pattern where source node is sending information to nodes

Partial directed coherence (PDC) is a multivariate autoregressive (MVAR) modelling that provides causality direction of information between two signals or more, which measures in frequency domain from time domain. Silfverhuth *et al.,* 2012, had made comparison among connectivity measures and declared that PDC is fast to compute, has a small signal-to-noise ratio, have less non-causal connectivity, and most sensitive to connection in simulation.

1.2 Problem Statement

In latest psychological and neuropsychological field, scientists have studied about the brain activity in each part of the area. EF is one of the favoured research areas as it has the largest function in brain system. Many studied were done with different kind of ages; children, adulthood, and older adult, and the participants were normal people and people who had mental disabilities. The results also were discovered with using different kinds of methods. A method that have always been used was statistical analysis (Holmén *et al.*, 2012; Houston *et al.*, 2014; Salminen *et al.*, 2012); which was to examine the relationship between gender, ages, function disabilities, and some other connection with the EF task given. Another method was power spectral density (PSD) to describe the brain waves of several regions (Barwick *et al.*, 2012). However, these methods did not include brain region interconnection when doing the EF assessment. To measure brain region interconnectivity, several functional connectivity measurement described aforementioned, such as PDC is used to identify the brain network and the usage is suitable for electroencephalography (Sun *et al.*, 2014; Varotto *et al.*, 2014). In addition, since many studies described that a lot of brain signal activated at the frontal region using PSD while doing the EF, there is less research about other brain region which may be contributed in processing the EF.

Executive functional connectivity is actively being investigated in foreign country for brain development (Roelofs *et al.*, 2013; Salminen *et al.*, 2012; Vink *et al.*, 2014). As compared to Malaysia, it is rarely studied in brain development, especially in information pathway between cortical networks. Most studies did not look at functional connectivity between brain regions, especially for local people in Malaysia. This research is the first attempt to discover about the functional connection during executive function assessment for Malaysian people. Furthermore, it is a known fact that EF was widely used in the frontal area but the connection from the other brain area is remaining unclear. Besides, with the advancement of mathematical computing, PDC method can be used as a measurement for direction of information flow between brain regions.

In executive function, there are various assessments that can be conducted in order to identify the cognitive processes; which include updating (Mental Arithmetic Task, MA), shifting (Trail Making Test, TMT), and inhibition (Stroop Task, ST). For Mental Arithmetic Task, many papers had studied about the brain mapping while doing the task using statistical analysis (Rinne and Mazzocco, 2014; Wang *et al.*, 2010). However, it is difficult to find a research that studied the mental task when people had given correct and incorrect answer. There was a study that focused on mental arithmetic task while giving the correct and incorrect answer (Rinne and Mazzocco, 2014; Vansteensel *et al.*, 2014), but it is lacking of proof to identify the functional connectivity of cortical networks. It is an advantage to study and clarify about the functional connectivity of brain regions for people when they give right and wrong answer in mental task. Its benefit includes improving training for brain development in children and young adults for Malaysian society. Meanwhile, MA task, TMT and ST, were usually conducted for psychology purpose but rarely did in identifying cortical networks or power spectrum of brain waves. Thus, these assessments are suitable in order to have variation in analyses methods and have participants among young adult in Malaysia.

Functional neuroimaging such as fMRI and MEG were preferred to be used when it comes to diagnose mental disabilities or in detecting brain problems (Tracy *et al.*, 2014; Zheng *et al.*, 2014). Although it gives an accurate measurement in examining human brain activity, the machine is huge and it takes time to learn and handle the equipment. Furthermore, the analysis was determined using regions of interest (ROI) (Tracy *et al.*, 2014). It is preferable to use portable EEG machine in order to examine brain development and functional connectivity (Swingler *et al.*, 2011).

Therefore, studying EF processes by using MA task, TMT, and ST can identify the brain development of the development of Malaysian young adult by using the method of PDC. In addition, EF also can be observed through power spectrum of the brain by using PSD. PDC is one of the methods in observing the interconnection between brain regions. Hence, in future, this study can be develop in order to diagnose the early stage of brain impairment and can make the EF task as a cognitive training for Malaysian people.

1.3 Objectives

Two objectives have been proposed in this research based on the problem statement:

i. To investigate functional connection during executive function task using partial directed coherence (PDC) among young Malaysian people.

ii. To analyze the power spectral density of brain region during executive function processes to determine the frequency band that relates to EF.

1.4 Scope of the Study

The scopes of the study were based from the objectives that have to be achieved. Details of each scope are explained as follows:

i. Executive function task is used to investigate the connection between cortical networks. The EF assessments that are used in the study were Mental Arithmetic (MA) task, Trail Making Test (TMT), and Stroop task (ST).

Regardless of genders, participants were from young adult; aged between 20 to 30 years old and of Malaysian citizen.

ii. Electroencephalograph (EEG) machine (Neurofax μ, EEG-9100 J/K 9100n Nihon Kohden) is used to record the brain signal. After getting the RAW data, partial directed coherence (PDC) is applied in order to analyze the functional connectivity of young adult brain. In addition, power spectral density is implemented in order to observe from the perspective of brain's frequency.

1.5 Significant of Study

This study focused on the interconnection of every brain region while doing the updating, shifting, and inhibition processes. Researchers may recognize that executive function performs at the frontal region; however other brain regions such as occipital, temporal and parietal may have connections in running the task. The updating process was conducted using mental arithmetic task, shifting process was underwent through Trail Making Test, while Stroop Task was performed for inhibition process.

Another significant of this study is to compare the brain development among Malaysian people. In psychological and neuropsychological field, most studies were done using statistical method in order to determine the active brain regions while doing cognitive function task. In recent years, researches for functional connection between brain regions were actively conducted in cognitive studies. As for researchers in Malaysia, they did some studies for brain activation using statistical analysis but at the moment, it is scarcely to notice the study about functional connectivity of the brain for Malaysian citizen. Most research elaborated about the active region of the brain but their findings did not include interconnection between brain regions. This study had gone through an investigation for functional connectivity in Malaysian young adult. The findings may be used to further investigate the brain development for children and young adults, especially for Malaysian people.

1.6 Thesis Outline

Thesis outline is briefly described in order to get clear explanation about the target of the research and keep track within the scope of the study. This study can be summarised by dividing into four phases; (i) Literature review, (ii) Methodology, (iii) Results & Discussions, and (iv) Conclusion.

In the first phase, it is about a Literature Review for Chapter 2. In this chapter, it reviews based on the background of the study that is previously describe in Chapter 1. The second phase of this project is Methodology, where it is in Chapter 3. The chapter clarifies the progress of the whole study from data collection, data measurement until data analysis.

Phase three, which is Chapter 4, it is about the Result and Discussions. This is the most important part as it would explain all the findings that had been discovered for this project. Furthermore, it would indicate whether the objectives are achieved or vice versa. Last but not least, phase four for this study is Conclusion, which is in Chapter 5. It would summarize the whole project and some recommendations are being stated to make improvement for future research. Table 1.2 interprets the details for each phase.

Table 1.2 Research framework

Phases	Description
Phase 1: Literature review	Reviews: • EF assessments that have been used. • Method that has been implemented in order to identify functional connection. • The frequency band during brain activity.
Phase 2: Methodology	Implement: • EF assessments • Partial directed coherence • Power spectral density
Phase 3: Results & Discussions	Findings: • Functional connectivity using PDC. • Frequency bands of the brain using PSD.
Phase 4: Conclusion	Future project development

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