Critical Thinking Analysis Using Functional Near-Infrared Spectroscopy (fNIRS)

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Abstract. Critical thinking which is also known as creative thinking, is a fundamental skill needed to solve any problems in our life. The behaviour of critical thinking involves reviewing the results of the application of decisions made and implementing change where possible. It also happens when someone aims to achieve the best possible outcomes in any situation. It plays an important role in innovation, development, and health. Hence, knowing someone’s critical thinking behaviour is essential to improve one’s ability. However, to have good critical thinking skill is very challenging without understanding its features and biological behaviour. To understand the critical thinking behaviour based on cognitive function and neural activities, the psychological research methods and principles from neuroscience are necessary. Thus, this study aims to analyse critical thinking behaviour in the human brain by looking on the Hemodynamic Response Function (HRF). The instrument used in this study is a functional Near-Infrared Spectroscopy (fNIRS) device, called Wearable Optical Topography (WOT-100) with 16 channels where it measured the HRF of oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) concentration and Platform Optical Topographic Analysis Tools (POTATo) developed by HITACHI performed the pre-processing of raw data. Experimental results show that the mean concentration of HbO measured for High Scores (HS) group at right and left PFC were slightly different with concentration value of 17.6945mol/µm and 17.3514mol/µm while for Low Scores (LS) group shows the mean concentration of HbO at left PFC was higher than right PFC with concentration value of 25.0353mol/µm and 14.2499mol/µm respectively. Hence, these results show that the LS group tend to use their left PFC during task given due to laborious decision-making process happen influences by time duration subjects answering the tasks. Therefore, these results suggest an imperative role for individual differences in their neural activation. The outcome of this study highlights the significance of individual differences and their cognitive preference and potentials in performance of functional tasks such as attention, creativity, imagery, decision making and working memory that leads to critical thinking behaviour.

1. Introduction
Principally, the critical thinking behaviour transpires when a state of mind was continually question “Who? What? How? When? Why?” and “Where?” about something [1]. The process of think critically was happens once a person continues and actively thinking, skilfully conceptualizing, analysing, synthesizing, applying and evaluating information gathered by observation, experience, reflection, reasoning and environment [2] [3]. Critical thinking or creative thinking is essential skills needed, particularly in industrial area. Typically, the employer is tending to choose a worker that has such a proficient skill in problem solving. As concerned, this high-order thinking skills can be trained and
improve by continually doing practices. However, it is not easy to know someone’s level of critical thinking by simply referring to their exam grade or just simply conclude by their traits personality test. In some cases, the test answer cannot be proven and synchronize on how someone’s was thinking. There are several methods used to increase this kind of skills and to know their level of critical thinking skill is important to develop their cognitive function suitably. Hence, we need an instrument to explore how their cognitive function works during critical and creative thinking to get to know the suitable intervention to improve the skills in term of scientific method. Cognitive psychologists and brain science use psychological research methods and principles to better understand how the mind works. Moreover, various neuroimaging techniques have been applied to clarify neural activities in the human mind, where essentially a measurement of neural activity can be separated into three dimensions which are spatial resolution, temporal resolution and measured phenomenon. Spatial resolution is referring to what region of brain tissue are activate when neural activity being averaged, while temporal resolution is referring to how much elapsed time when neural activity is being averaged and measured phenomenon is referring to what is being measured and what kind of neural activity does it correlate with the human behavior. There were several non-invasive neuroimaging technique used in measuring neural activities. For example, some study was using Electroencephalography (EEG) because it was classically considered as having an excellent temporal resolution, however, it has a limited spatial resolution in measuring brain activities. To get high spatial resolution, the use of functional Magnetic Resonance Imaging (fMRI) is needed but it is a bit costly. As current technology has found an alternative way of detecting spatial and temporal resolution by using functional Near Infrared Spectroscopy (fNIRS) technique. This study applied an fNIRS device as a tool to get to experience and show meaningful insight on the critical thinking skill level based on their cognitive function. It is therefore hoped it can be further used to help enrich and unleash the skills.

2. Related Work

2.1 Neuroimaging Technology

Researchers apply a form of neuroimaging tools to study the creative thinking and it depends on what types of the task given and their research targets. There are several numbers of accepted imaging techniques used in the research facilities and hospitals such as functional magnetic resonance imaging (fMRI), Computed tomography (CT) scan, Positron Emission Tomography (PET), Electroencephalography (EEG), Magnetoencephalography (MEG), and Functional Near-Infrared Spectroscopy (fNIRS) [4]. All those imaging techniques have a different measured phenomenon in measuring neural activities. For example, EEG uses electrodes on the scalp to detect average electrical activity along the skull surface while MEG measures neural activity in an interior magnetic signal analysis. Besides, both fMRI and PET imaging are measuring the average activity of neuron in 3D voxels but based on oxygen consumption and glucose consumption respectively. Other than that, fMRI and fNIRS also share the similarity in measuring neural activity which is based on oxygen consumption that called hemodynamic response function (HRF). Table 1 below summarizes the type of neuroimaging technology and its measured phenomenon.

| Type of neuroimaging technique | Acronym | Type of measured phenomenon          |
|-------------------------------|---------|--------------------------------------|
| Computed tomography scan      | CT      | Glucose consumption                  |
| Positron Emission Tomography  | PET     | Glucose consumption in 3D voxel      |
| Functional Magnetic Resonance Imaging | fMRI | Oxygen consumption in 3D voxel     |
| Functional Near Infrared Spectroscopy | fNIRS | Oxygen consumption                   |
| Electroencephalography        | EEG     | Electrical activity                  |
Magneto encephalography

MEG

An interior magnetic signal analysis (electrical activity)

In addition, those non-invasive neuroimaging techniques that widely used for research purpose particularly in non-clinical cases are EEG, fMRI and fNIRS. They used non-invasive instrument as a neuroimaging technique tool to measure brain activities because it is a safer technique [4] [5]. Also, it is safe to use for all generations from infant to elderly [6] [7]. From the list of neuroimaging technique tools, the most convenience tool to use for neural activity study is fNIRS. It is because the EEG device was reported sensitive to artifacts by Myo-electricity due to body movement while the fMRI and MEG neuroimaging technique are not fit because they need to perform the measurement in a special room and it has a limitation on the task and movement [8] [9].

2.2 The Traits of Prefrontal Cortex (PFC) Study

This study has focused on the prefrontal cortex region since its play role in creative thinking, decision making and alerting. Fundamentally, human brain consists of four lobes, which are parietal lobe, occipital lobe, temporal lobe and frontal lobe and every lobe are connecting to each other during task performance. Prefrontal cortex is one of the central and the largest region in the human brain. There are numerous studies on prefrontal cortex (PFC) reported that PFC are associated with decision making, working memory and emotion [10] [11] [12]. Moreover, another study found that the prefrontal cortex (PFC) is influencing of learning style and task performance where during auditory task activation in the left prefrontal cortex are more than the right side [13]. Then, it was different from Scott Shane (2014) studies, where he claims entrepreneurs are likely using their right prefrontal cortex, which is linked with creativity, while manager tend to practice only the left prefrontal cortex were connected to logical thinking effects from their different experiences. Additionally, right prefrontal cortex also was reported related to engineering where their right prefrontal cortex is activated during the critical thinking [14]. Also, throughout paper [15], right hemisphere of the frontal region activated by alerting and orienting attention demands. Other studies of Parkinson’s patients reported that PFC plays a vital role during simple walking [16]. Hence, at that place is more or less of the PFC’s function needs to be let out and confirm.

3. Methodology

3.1 Flow of the Study

Figure 1 illustrates the research flowchart for this study. The first step consists of survey distribution and sample selection followed by experimental process, data collection, data analysis and last is result and discussion. The survey was used to select the sample subject, then classify the subject into two groups (High Scores (HS) and Low Scores (LS)). Selected subject from both groups is moving through an experimental procedure to measure their neural activity of the brain by using functional Near-Infrared Spectroscopy (fNIRS) technology. Next, the wearable optical topography software collects the data, and the pre-processing data are performed by using a plug-in based application called Platform Optical.
Topography Analysis Tools (POTATo) on MATLAB, where the undesirable data are eliminated [7] [17]. The data analysis and classification are performed by statistical analysis tools in Microsoft excel.

3.2 Sample Selection
The population of this study is engineering students from Malaysia-Japan International Institute of Technology (MJIIT). Fifty-nine undergraduate students and postgraduate students (68% female, 32% male; age range 20–26 years) respond to the survey question. In general, the results show all the respondents were answering the spatial intelligence test with duration of less than 5 minutes and others were answering with duration of 5 to 10 minutes. Therefore, the subject selection process will be selected by mean score method. All the subjects will be given the written informed consent after the procedure had been explained to them.

3.3 Functional Near-Infrared Spectroscopy (fNIRS) Device
Basically functional near-infrared spectroscopy is a non-invasive neuroimaging technology. It is widely used among researchers. This technology is used to measure neural activity in human brain in terms of the hemodynamic response function (HRF). Concentration of Oxy-hemoglobin (HbO) and Deoxy-hemoglobin (HbR) represent the activity in human brain. This experiment uses functional Near-Infrared Spectroscopy (fNIRS) as a neuroimaging technique. The fNIRS device used is the Wearable Optical Topography (WOT-100) with 16 channels manufactured by HITACHI. These 16 channels are consisting of optic sources and optic receiver. WOT-100 headset is measuring the prefrontal cortex (PFC) with a light source and built-in detector. Figure 2 shows the WOT-100 headset and the system configuration where the measurement controller was connected to the portable control box and headset via two-way communication of wireless LAN. All of the detection points are on the forehead, and so there is no disturbance or miss-setting due to the hair. The near-infrared light detecting probes arrayed on the upper part and lower part were set around the F7-Fpz-F8 line of the international 10-20 system [8].

![Figure 2. WOT-100 headset and the system configuration](image)

3.4 Survey Question, Experimental Stimulus and Paradigm Design
This study makes use of the survey questions, which is distributed to engineering students at MJIIT to discover the ability of the subject to understand and solve complicated spatial problems among objects or space. It consist of five different pattern of questions for Spatial Intelligence test. All five questions are consists of different type of problem such as rotating shapes and objects, constructing 2D pattern into 3D shapes, and organizing shapes. The idea of this section originates from [14] study.

Basically, our brain is active even without external stimuli [18]. Therefore the selection process of stimulus is important because the brain activation depends on the type of stimulus. To select the best image and give an encouragement to the subject, characteristics of the images were chosen based on
current technology and situation. In this circumstance, the experimental stimulus was choose one of the problem from survey question, which is constructing 2D pattern into 3D shapes. These problem was chosen because it was covered all the characters needed for this study. Subject were able to focus (alert), imagine and at the same time make a decision during task. Thus, these reason can achieve the objective of this study. **Figure 3** shows the paradigm design and arrangement of the stimulus used in this experiment.

| SPATIAL INTELLIGENCE (SI) TEST |
|---------------------------------|
| Fixation | Instruction | Stimulus (3 pieces of images) | Fixation |
| “+”      |             |                               | “+”      |
| 5s        | 4s          | 30s                           | 5s        |

**Figure 3.** Paradigm Design

This experiment consists of three parts, which are fixation, instruction and stimulus. The fixation block function as indication to draw the attention from the subject and it gives the subject’s neural activity less active and relax. The instruction block was used to instruct the subject what they need to get along to the next task, in a simple word to get them ready before the task. The three pieces of spatial intelligence test images were used to trigger and encourage subject’s right prefrontal cortex for critical thinking. The images of spatial intelligence test were used to measure the ability to understand and solve complicated spatial problems among objects or space. Besides, the spatial visualization ability allows the subject to visualize three-dimensional images in their mind and to mentally manipulate these images and twist and turn them into the shape they want. Thus, this block paradigm takes 30s duration for stimulus and it consist of three tasks (10s per test). Basically, this block design is modified and referring from [14] paper. The total length of one paradigm was 44s. Therefore, this experiment may take 5 to 10 minutes for one experiment, including the preparation of the subject.

### 3.5 Data Collection and Analysis

The fNIRS technique measures cerebral hemoglobin concentration changes caused by neural activities. The subject’s hemodynamic response will be measured by using WOT-100 and the dataset will be presented and transfer into excel and the concentration of HbO and HbR measured by WOT-100 software were analyzed by using Platform Optical Topography Analysis Tool (POTATo) software [17]. POTATo is a platform developed for analysis of Optical Topography by central laboratory of Hitachi, Ltd. A raw dataset from device WOT-100 can be analyzed and go through pre-processing by using POTATo where all the artifact will be removed from the raw data. Moreover, it is equipped with functions such as band-pass filtering, moving average, addition average, and baseline revision necessary for pre-processing analysis. In addition, to perform the data analysis MATLAB of Mathworks, Inc. is necessary separately. In this study, pre-processing applied are motion check, a band-pass filter and moving average. The value of band pass filter applied is with a range of 0.01Hz to 0.8Hz cut off frequencies and the moving average used in this study is 5s time. This method commonly used with time series data to smooth out short-term fluctuations and highlight longer-term trends or cycles. Then, the extracted data were saved into XLS file before average and observe to classification process.

### 4. Finding and Discussion

#### 4.1 Theoretical Outcome from Survey Question

The survey was conducted to select the sample subject and classified into two groups (HS group and LS group). The results obtained from the survey question are shown in Table 2.
### Table 1. Summary outcome from Survey Question

| Group (Subject) | SI Test | Duration (minute) |
|-----------------|---------|-------------------|
| HS (15)         | ↑ (Higher than mean score) | Less than 5 minutes < 5 to 10 minutes |
| LS (15)         | ↓ (Lower than mean score)  | Less than 5 minutes > 5 to 10 minutes |

As can be seen, the HS group consist of 15 students that have resulted in SI test higher than the mean score while LS group consists of 15 students have resulted in SI test lower than mean score. Besides, most of the subjects in HS group answer the test with duration 5 to 10 minutes and some of them were has ability to think quickly to get the right answer. While in LS group, the subject that answer the test with duration less than 5 minutes is more than subject answered the test with duration 5 to 10 minutes. From these results, we can see that subjects in the HS group were carefully and more conscious during answering the test. However, most subjects in the LS group were answering the test confidently with duration less than 5 minutes.

### 4.2 Experimental Outcome

This study is more focusing on HbO changes than HbR because HbO was reported more sensitive to neural activities [19]. The critical thinking behavior was observed by the mean concentration of HbO in PFC for the spatial Intelligence block. The positive changes indicate increases in the activity of HbO while negative changes indicate decreases in the activity of HbO[4].

![SPATIAL INTELLIGENCE](image.png)

**Figure 4.** Mean concentration of HbO between HS group and LS group during task

Figure 4 above shows the mean concentration of HbO between HS group and LS group in the spatial intelligence block. It is apparent from the bar chart, the positive changes of mean concentration of HbO is happening at all parts of the PFC for both groups except for middle PFC in HS group. As can be seen in HS group, the mean concentration of HbO at right and left PFC are almost similar with value of 17.6945 (mol/µm) and 17.3514 (mol/µm) respectively. While in LS group, the mean concentration of HbO at right PFC is less than the mean concentration of HbO at left PFC with value of 14.2499 (mol/µm) and 25.0353 (mol/µm) respectively.

### 4.3 Discussion

It is apparent from the survey results, subject in HS group was rather to take some time to answer the task to get the correct answer. While LS group were answering the task with less time of period, but they get less correct answer. This is happening whether they are answering with full attention or they just guest and answer the task without hesitation. When looking at the experimental result, the difference
in concentration of HbO between the two groups was observed. When comparing between HS group and LS group at right PFC, the mean concentration of HbO in HS group is higher than LS group. Whereas at left PFC, the mean concentration of HbO in LS group is higher than HS group. Hence, these results show the LS group tend to use their left PFC during task given due to laborious decision making process happen. It seems possible that the higher concentration of HbO at left PFC perhaps due to influence by the duration of the subject during performing the task.

5. Conclusion

As the conclusion, the increases in blood flow were represented the way of the brain ensure the active neurons when it gets enough blood, oxygen and nutrients it carries to gather the information. Hence, this study aims to analyse critical thinking behaviour in the human brain by looking on the Hemodynamic Response Function (HRF). To understand critical thinking features and biological behaviour in the human brain, we were looking on HRF of the increasing in concentration of HbO. The result indicates that HS group has a slightly difference in mean concentrations of HbO in right and left PFC while the LS group shows the higher mean concentration of HbO at left PFC than right PFC. Therefore, the concentration of HbO, perhaps effects of how long the subject spent the time to complete the task. The outcome of this study highlights the importance of individual differences and their cognitive abilities and preference in the performance of functional tasks such as attention, creativity, and decision-making scientifically. This high-order thinking skills were crucial in our career and daily life. Thus, these findings can support for further observation on critical thinking in the human brain, and this fact also indicates that the blood flow can reasonably represent the brain activity during think critically.

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