Sains Malaysiana 51(3)(2022): 823-834
http://doi.org/10.17576/jsm-2022-5103-16

Simple Coordination and Cognitive Stimulation Activities for Cognitive Function Assessments using Functional Near-Infrared Spectroscopy

(Aktiviti Koordinasi Mudah dan Rangsangan Kognitif bagi Penilaian Fungsi Kognitif menggunakan Spektroskopi Inframerah Dekat Berfungsi)

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Received: 28 February 2021/Accepted: 11 August 2021

ABSTRACT

Functional near-infrared spectroscopy (fNIRS) is a non-invasive and high-density imaging device used for the evaluation of cognitive functions by measuring the oxygenated haemoglobin (HbO) and deoxygenated haemoglobin (HHb) levels in the prefrontal cortex. The present study determined the utilisation of fNIRS in detecting cerebral haemoglobin oxygenation level during coordination and simple cognitive stimulation activities in healthy young volunteers. Thirty subjects comprising equally of both genders were recruited. Subjects were tasked with coordination tests (plate tapping and block transfer tests) and cognitive stimulation activities (ruler drop test and MRAVLT) while the fNIRS system was attached to their prefrontal cortex area. The HbO and HHb levels were recorded and analysed using Repeated Measures ANOVA. The HbO levels during coordination tests differ significantly from resting state ($p<0.05$) in all but channel 2. All coordination tests elevated HbO levels compared to resting state except during block transfer test in channel 1. No significant difference was observed in HHb levels between coordination tests and resting state in all channels ($p>0.05$), except channel 3. All cognitive stimulation activities increased HbO levels compared to resting state; this change was significant in channels 3 and 4 ($p<0.05$). In contrast, HHb levels during all cognitive tests were lower compared to the resting state and was found to be significant in channels 2 and 3 ($p<0.05$). These findings suggested that coordination and cognitive stimulation activities activate prefrontal cortex in healthy young adults and could be potentially utilised as a valid screening tool for cognitive function assessments via fNIRS.

Keywords: Brain monitoring; cognitive stimulation; coordination test; fNIRS; functional near-infrared spectroscopy

ABSTRAK

Spektroskopi Inframerah Dekat Berfungsi (fNIRS) ialah peranti pengimejan berketumpatan tinggi yang tidak invasif dan mampu menilai fungsi kognitif berdasarkan tahap pengoksigenan (HbO) dan dioksigen (HHb) hemoglobin pada bahagian korteks prefrontal otak. Kajian ini menganalisis penggunaan fNIRS untuk mengesan tahap oksigenasi hemoglobin otak serebral semasa ujian koordinasi dan aktiviti stimulasi kognitif ringkas dalam kalangan sukarelawan yang muda dan sihat. 30 subjek (15 lelaki dan 15 perempuan) dipilih menyertai kajian. Subjek perlu melakukan ujian koordinasi (ujian mengetuk plat dan pemindahan blok) dan aktiviti stimulasi kognitif (ujian jatuhan pembaris dan MRAVLT) dengan sistem fNIRS terpasang pada dahi subjek. Tahap HbO dan HHb direkod dan dianalisis menggunakan ANOVA Pengukuran Berulang. Tahap HbO semasa aktiviti koordinasi berbeza secara signifikan berbanding sewaktu rehat bagi kesemua saluran ($p<0.05$) kecuali saluran 2. Semua ujian koordinasi meningkatkan tahap HbO berbanding rehat kecuali semasa ujian pemindahan blok di saluran 1. Tiada perbezaan signifikan bagi tahap HHb sewaktu aktiviti koordinasi berbanding rehat pada semua saluran ($p>0.05$) kecuali saluran 3. Semua aktiviti stimulasi kognitif meningkatkan tahap HbO berbanding rehat, dengan peningkatan signifikan diperhatikan di saluran 3 dan 4 ($p<0.05$). Manakala, tahap HHb menurun semasa aktiviti stimulasi kognitif berbanding rehat, dengan penurunan signifikan direkodkan di saluran 2 dan 3 ($p<0.05$). Hasil kajian menunjukkan bahawa aktiviti koordinasi dan stimulasi kognitif mengaktifkan bahagian korteks prefrontal dalam kalangan subjek yang sihat dan berpotensi digunakan sebagai alat penilaian fungsi kognitif melalui aplikasi fNIRS.

Kata kunci: fNIRS; pemantauan otak; pengimejan neuro; stimulasi kognitif; ujian koordinasi

INTRODUCTION

Functional near-infrared spectroscopy (fNIRS) was introduced by Jobsis in 1977; however, the first functional fNIRS was utilised in 1993 by four different groups (Chance et al. 1993; Hoshi & Tamura 1993; Kato et al. 1993; Villringer et al. 1993). The device is a non-invasive instrument capable of providing cognitive function assessments by measuring the oxygenated (HbO) and deoxygenated (HHb) haemoglobin levels as biomarkers. The device comprises three parts: the headpiece that holds the fNIRS emitters and detectors, a host server, and an electronic system hosted by the data acquisition board, which controls the light source and collects the reflected light (Arenth et al. 2007; Bracken et al. 2019). The device can be safely utilised across all ages, from neonates to the elderly. In several cases of preterm birth, fNIRS was used to measure cortical activity in the developmental phase of the brain. In addition, this device was used to detect hemodynamic response to stimulus-induced cortical activation in infants (Watanabe et al. 2017). The fNIRS instrument is now more widely used in many countries because it is more portable compared to the functional magnetic resonance imaging (fMRI), which measures the blood oxygen level-dependent response. fNIRS is also preferred due to its flexibility, light weight, wearability, and mobility since it is battery-operated and has wireless operation. In comparison, fMRI is limitedly used because it is expensive, strictly restricted to motions, produces a noisy scanner and physiological noise to the surrounding (Gefen et al. 2014; Rieke et al. 2020).

In this study, we proposed the use of simple coordination and cognitive stimulation activities to measure brain oxygenation level via fNIRS, which reflects the cognitive function. This is a pilot study to establish a standard reference range data for healthy subjects using the fNIRS during simple coordination tests and cognitive stimulation activities. The use of fNIRS will address some of the drawbacks of fMRI usage and assess the feasibility of measuring HbO and HHb levels from the cortical surface of subjects without being invasive and with reduced cost (Xu et al. 2011). The standard area of placement is to achieve coverage of frontal and motor cortical areas.

MATERIALS AND METHODS

STUDY DESIGN

This quasi-experimental study to determine the cerebral haemoglobin concentration changes in young healthy adult subjects was approved by the Universiti Sains Islam Malaysia (USIM) Research Ethics Committee (USIM/JKEP/2017/27). The fNIRS was used to measure the changes in cerebral HbO and HHb concentration in subjects at resting time in comparison during coordination tests and cognitive stimulation activities for a certain period.

All subjects were informed about the nature of the experiments as well as the purpose of this study, and signed informed consent forms were obtained from those who agreed to participate in this study.

All subjects included in this study were healthy without any history of chronic non-communicable diseases, blood disorders (such as anaemia and thalassemia), mental health problems, and genetic or congenital disorders. Their health was also assessed by physical appearances and assessment of vital signs. Subjects with any visual, hearing, mild or extreme physical and psychological disabilities were excluded from this study.

Prior to performing each of the coordination or cognitive stimulation activities, the subjects were asked to sit down on a comfortable chair while the fNIRS device was attached to the subjects' prefrontal cortex area to record the cerebral HbO and HHb levels. Elastic straps were used to ensure good contact between the fNIRS probes and the subjects' heads. The fNIRS signals were acquired by a hardware system that includes the optical fibre probes, control and transmission module, photoelectric conversion module acquisition card and computer that detects brain haemoglobin concentration changes. Four fNIRS channels (2 emitters light source and 2 detectors) were positioned at the prefrontal cortex area with 3 cm gaps between each other.

Subjects were reminded to minimise body movements throughout the experiment because an alert will be triggered in response to movements. The experiment began with 5 min of resting time, during which soothing music was played to the subjects to help them relax their mind. Based on Tai and Lin (2018), music has a significant effect on brain wave and is able to relax the mind. This was followed by the first coordination test or cognitive stimulation activities. Upon completion of the activities, the subjects underwent resting state for another 5 min, followed by the second coordination or cognitive stimulation activities. Finally, the subjects underwent the final resting state for 5 min before the experiments were concluded. The study design implemented in this research is depicted in Figure 1.

fNIRS ASSESSMENT DURING COORDINATION

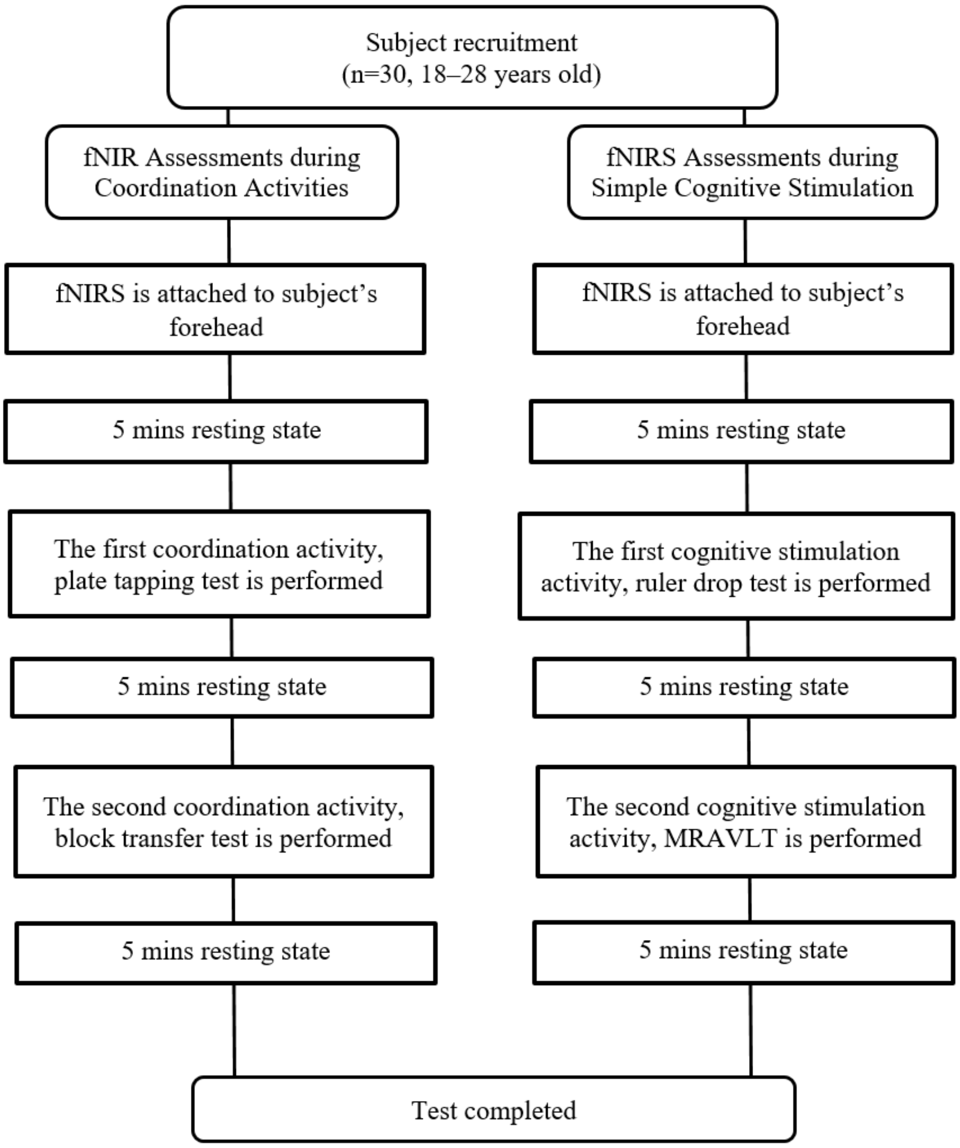

FIGURE 1. Study design utilising fNIRS to measure cerebral HbO and HHb levels during coordination tests and cognitive stimulation activities

ACTIVITIES USING PLATE TAPPING AND BLOCK TRANSFER TEST

All subjects were asked to perform two coordination tests (plate tapping and block transfer), while their HbO and HHb levels were measured by the fNIRS device. Before the plate tapping test was carried out, the height of the table was adjusted to match the height of the subjects so they can sit comfortably in front of the disks or plates. Two yellow disks, 60 cm apart, were placed on the table, where a rectangle plate was placed equidistantly between the disks. The subjects' non-dominant hand was placed on the middle rectangle, then the dominant hand of the subjects was moved back and forth between the disks over the middle hand as quickly as possible to tap each disk. The task was repeated for 25 full cycles (50 taps), and the protocol was repeated twice (Batez et al. 2021; Berisha & Cilli 2017).

Similarly, for the block transfer test, the height of the table was adjusted to match the subject's height before the task was performed. This was to ensure that subjects can sit comfortably while facing a rectangular box that was divided into two compartments with a partition in the middle. The rectangular box was oriented lengthwise and placed at the centre line of the subjects with their hand on the side of the box. The block compartment was oriented towards the dominant hand of the subjects. Subjects were instructed to move the maximum block numbers (n=150) from one compartment to another as quickly as possible within 60 seconds, using only their fingertips, with subjects' hand crossing the separator (Julien et al. 2017; Lee et al. 2018; Li et al. 2020).

fNIRS ASSESSMENT DURING COGNITIVE STIMULATION USING MALAY REY-AUDITORY VERBAL LEARNING TEST (MRAVLT)

The cognitive stimulation using Malay Rey-Auditory Verbal Learning Test (MRAVLT) allow the assessment of subjects' verbal memory, the nature and severity of memory dysfunction, and monitor changes in memory function over time. The MRAVLT protocol used in this study was adapted and modified from Jamaluddin et al. (2009). It consisted of two lists, List A and List B, which comprised 15 Malay words in each list, as shown in Table 1.

TABLE 1. List A and List B for MRAVLT adapted and modified from Jamaluddin et al. (2009)

		LIST A		
KAPAK	HARIMAU	SIKU	KATIL	TELINGA
KAPAL	ANJING	TUKUL	KERUSI	AYAM
MATA	KERETA	PISAU	JAM	BASIKAL
		LIST B		
MANGKUK	MONYET	KASUT	LEMBU	JARI
BAJU	SEMUT	CAWAN	TEBUAN	ITIK
TOPI	KAKI	CEREK	TIKUS	JAM

In trial 1, List A was read aloud, and the subjects were instructed to recall all the words as much as they can remember. This task using List A was repeated for another two times (trials 2 and 3). Then, List B was read aloud, and the subjects were asked to remember and subsequently recall the words. This protocol with List B was used as a disturbance to the subjects. Following that, the subjects were asked to recall any of the words they could remember from List A for trial 4.

MRAVLT is the Malay-translated version of Rey Auditory Verbal Learning Test (RAVLT), which has been accepted as the main tool utilised for cognitive stimulation (Silva & Seabra 2020). MRAVLT is a valid instrument that can be used in the Malaysian population to assess cognitive functions, especially for the early detection of Alzheimer's and dementia diseases. The test is also used to assess episodic memory by providing scores for evaluating different aspects of memory. This test is very sensitive to verbal memory deficits caused by a variety of neurological disorders such as Alzheimer's disease (Balthazar et al. 2010; Estévez-González et al. 2003; Schoenberg et al. 2006).

fNIRS ASSESSMENT DURING COGNITIVE STIMULATION USING RULER DROP (REACTION TIME) TEST

Reaction time is measured to estimate the capacity of subjects to respond quickly to a stimulus (Milic et al. 2020). The ruler drop test measures the reaction time when a ruler is dropped based on the length (cm) of the ruler that could be captured by the subjects. The dominant hand of the subjects was positioned at the end of the table, and the falling ruler was to be captured by the thumb of the subjects. Subjects were given three trials to perform the task (Ferreira et al. 2021). The ruler drop test was first described by Pieron in 1928 and termed by Woodworth and Schlosberg in 1954 as a measure of simple reaction time. It has been used largely in recreational sports testing. The test requires minimal skills on the part of both the tester and subjects to complete (Ortolano et al. 2017). The test is susceptible to practice effects; therefore, as recommended in previous literature, the subjects in this study were all given one practice session before establishing their baseline value (Del Rossi et al. 2014). Although the test requires small movement of reaction, it involves synchronise stimulation between motor and cognitive functions. When the subjects saw the ruler is being dropped, the eyes send nervous signals to the visual cortex, where the subjects perceive that the ruler has dropped or that it is dropping. The signals are then relayed to the spinal cord, which subsequently sends a message to muscles in the hands, including individual neurons that relay electrochemical signals to other neurons. This consequently result in the finger muscles running to capture the dropping ruler (Ferreira et al. 2021).

STATISTICAL ANALYSIS

Descriptive statistics such as the percentage, mean, standard deviation, and frequency distribution, as well as the data analysis using Repeated Measures ANOVA (RM ANOVA) were computed using SPSS Statistics version 24. P values of less than 0.05 ($p<0.05$) were considered as statistically significant.

RESULTS

DEMOGRAPHIC DATA

Table 2 summarises the demographic data of subjects involved in this study. A total of 30 healthy young adults consisting of 15 males and 15 females were recruited with the mean age of 22.47±1.85 years, within the range of 20 to 28 years.

TABLE 2. Demographic data of subjects (n=30)

Demographic	Characteristics	n (%)	Mean ± SD
Age (years)	20–22	19 (63.33%)	22.47 (1.852)
	23–25	10 (33.33 %)	
	26–28	1 (3.33%)	
Gender	Male	15 (50.0%)	
	Female	15 (50.0%)	
Ethnicity	Malay	30 (100.0%)	

fNIRS ANALYSIS DURING COORDINATION TESTS

Comparison of HbO levels between resting state and coordination activities showed that both hand-eye coordination activities (plate tapping and block transfer tests) performed by subjects in this study generally resulted in brain activation at the frontal areas. As shown in Table 3, the mean HbO levels during all activities were found higher in all fNIRS channels compared to resting state, except during block transfer test in channel 1. Further statistical analysis via RM ANOVA reported significant differences between the HbO levels while performing coordination tests versus resting state ($p<0.05$) for three channels, channel 1 (F(2,58)=4.373, p=0.019, $\eta_p^2=0.131$), channel 3 (F(2,58)=4.767, p=0.016, $\eta_p^2=0.141$) and channel 4 (F(2,58)=3.408, p=0.049, $\eta_p^2=0.105$), except for channel 2 (F(2,58)=0.829, p=0.438, $\eta_p^2=0.028$). In contrast, no significant changes ($p>0.05$) in HHb levels were observed when subjects were performing the coordination tests versus during resting state for three fNIRS channels: channel 1 (F(2,58)=0.189, p=0.825, ηp^2=0.006), channel 2 (F(2,58)=0.125, p=0.880, ηp^2=0.004), and channel 4 (F(2,58)=0.066, p=0.919, ηp^2=0.002), except for channel 3 (F(2,58)=4.766, p=0.014, ηp^2=0.141). The corresponding bar graphs showing the HbO and HHb levels between resting state and during coordination tests are illustrated in Figures 2 and 3, respectively.

TABLE 3. Comparison of cerebral HbO and HHb levels detected via fNIRS at resting state versus during coordination tests

HbO level (Mean±SD)					
fNIRS channel	Resting state	Plate tapping	Block transfer	F	P value (ηp^2)
Channel 1	-0.126±1.26	0.555±1.500	-0.386±1.29	4.373	0.019 (0.131)*
Channel 2	-0.114±1.418	0.343±1.621	0.234±1.223	0.068	0.917 (0.002)
Channel 3	-0.455±1.308	0.761±1.765	0.133±1.467	4.767	0.016 (0.141)*
Channel 4	-0.399±1.370	0.133±0.281	0.258±1.191	3.408	0.049 (0.105)*
HHb level (Mean±SD)					
fNIRS channel	Resting state	Plate tapping	Block transfer	F	P value (ηp^2)
Channel 1	0.162±0.795	0.165±0.892	0.053±0.643	0.189	0.825 (0.006)
Channel 2	0.138±0.585	0.174±0.512	0.222±0.639	0.125	0.880 (0.004)
Channel 3	0.045±0.627	0.001±0.529	0.403±0.503	4.766	0.014 (0.141)*
Channel 4	0.087±0.308	0.073±0.193	0.060±0.338	0.066	0.919 (0.002)

*Data were analysed using RM ANOVA where p<0.05 (*) is considered statistically significant

fNIRS ANALYSIS DURING COGNITIVE STIMULATION ACTIVITIES

Table 4 shows the comparison between HbO and HHb levels during resting state and while performing two cognitive stimulation activities, i.e., MRAVLT and ruler drop test. For HbO levels, both cognitive activities were found to activate the pre-frontal cortex as the HbO concentration were increased in all channels versus resting state; significant differences were observed in channel 3 (F(2,58)=11.402, p=0.000, $\eta_p^2=0.282$) and channel 4 (F(2,58)=6.476, p=0.010, η_p^2=0.183). In contrast, the HHb levels were recorded much lower during cognitive stimulation versus resting state in all channels, where significant differences were observed in channel 2 (F(2,58)= 39.285, p=0.000, η_p^2=0.575) and channel 3 (F(2,58)=4.706, p=0.027, η_p^2=0.140). The corresponding bar graphs demonstrating the HbO and HHb levels between resting state versus during cognitive stimulations activities are illustrated in Figures 4 and 5, respectively.

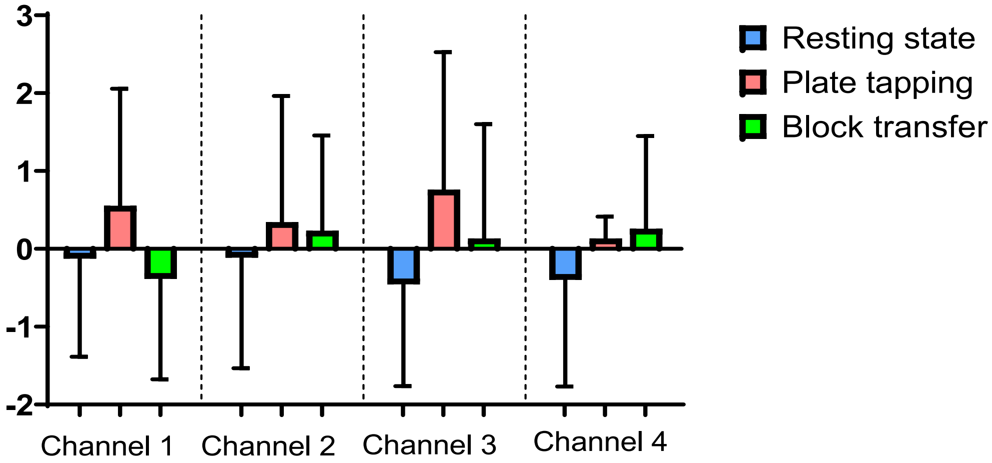

FIGURE 2. The cerebral HbO levels detected via fNIRS between resting state and during coordination tests

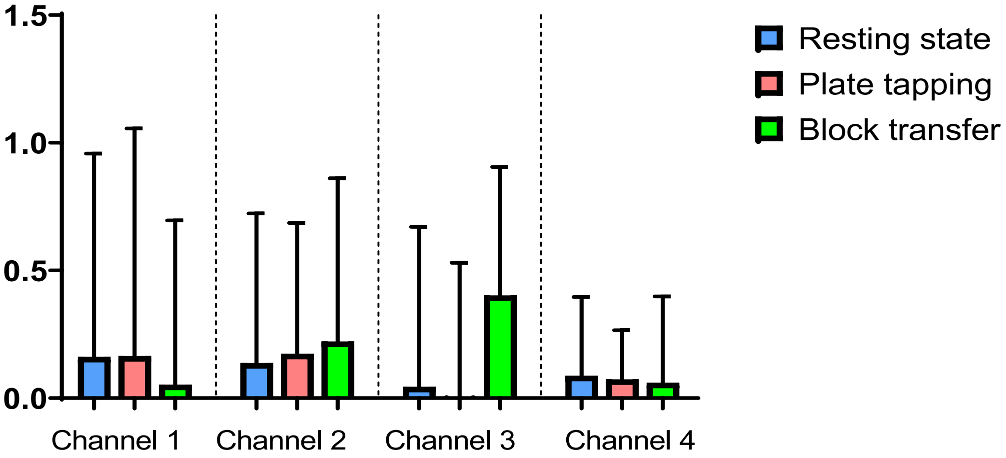

FIGURE 3. The cerebral HHb levels detected via fNIRS between resting state and during coordination tests

TABLE 4. Comparison of HbO and HHb levels detected via fNIRS at rest versus during cognitive stimulation activities

HbO level (Mean±SD)					
fNIRS channel	Resting state	MRAVLT	Ruler drop	F	P-value (ηp^2)
Channel 1	-0.126±1.260	0.961±1.795	0.809±2.453	2.828	0.094 (0.089)
Channel 2	-0.114±1.418	0.827±1.891	1.094±2.926	3.434	0.062 (0.106)
Channel 3	-0.455±1.307	1.350±1.630	1.032±1.647	11.402	0.000 (0.282)*
Channel 4	-0.399±1.370	0.646±1.303	0.755±1.587	6.476	0.010 (0.183)*
HHb level (Mean±SD)					
fNIRS channel	Resting state	MRAVLT	Ruler drop	F	P-value (ηp^2)
Channel 1	0.162±0.785	-0.568±1.011	-0.282±2.170	1.759	0.181 (0.057)
Channel 2	0.138±0.585	-0.614±0.706	-0.208±0.214	39.285	0.000 (0.575)*
Channel 3	0.445±0.627	-0.647±0.960	-0.064±1.168	4.706	0.027 (0.140)*
Channel 4	0.087±0.308	-0.151±0.693	-0.081±0.637	1.527	0.229 (0.050)

*Data were analysed using RM ANOVA where $p<0.05$ (*) is considered statistically significant

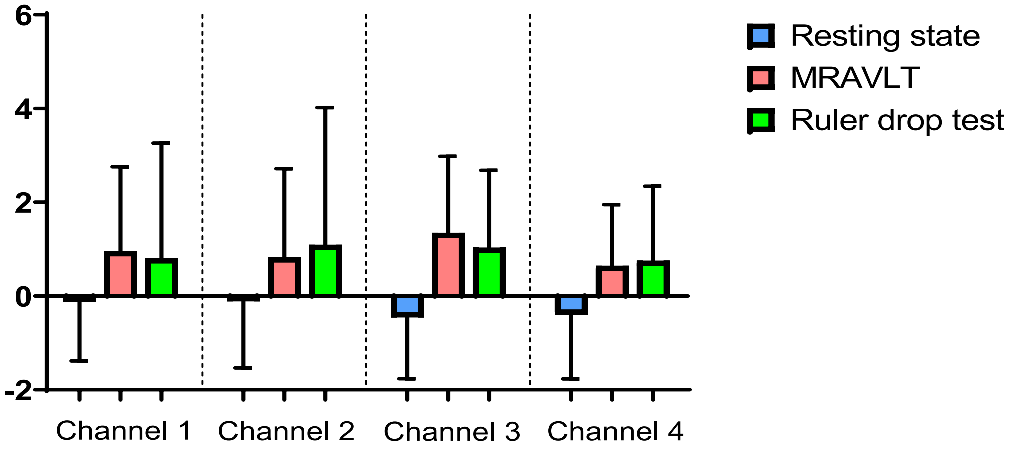

FIGURE 4. The cerebral HbO levels detected via fNIRS between resting state and during cognitive stimulation activities

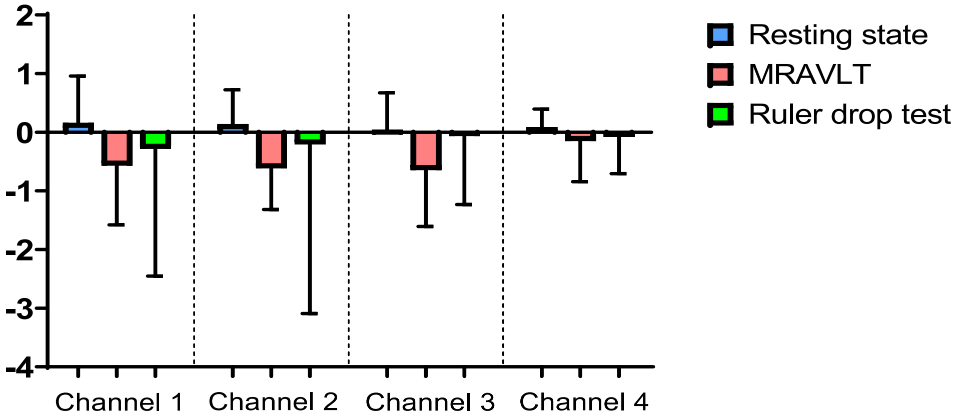

FIGURE 5. The cerebral HHb levels detected via fNIRS between resting state and during cognitive stimulation activities

DISCUSSION

This study demonstrated that the hand-eye coordination tasks increased brain activation in the prefrontal cortex as reflected by the increased HbO levels as those activities stimulates cognitive and motor functions. The rise in cerebral HbO levels during coordination activities indicates that the prefrontal lobe function plays a crucial role in completing tasks that involve 'attention to action' (Rowe et al. 2002). Decades of research in both humans and animals have emphasised the central role of the brain's frontal regions in cognition. Activities that involve attention, working memory, and decision-making such as the coordination tests performed in this study require large stimulation of this particular region of the brain (Carlén 2017). However, the prefrontal lobe may also be affected by motor movement at higher intensity and longer duration. Previous study has proven that certain types of supramaximal exercise increase brain oxygenation in relation to cognitive workload (Bediz et al. 2016).

During the coordination tests and cognitive stimulation activities, significant changes were observed in fNIRS channel 3 for both HbO and HHb levels. The significant increase in HbO level indicated an increase in oxygen supply to that particular area to execute the particular coordination tests and stimulation activities. For HHb level, the significant change indicated that the blood circulation is increased to that particular area while performing the activities. During the coordination tests, the HbO levels for fNIRS channels 1, 3 and 4 were significantly changed, while for cognitive stimulation activities, the HbO levels were significantly changed only for channels 3 and 4, and not channel 1. This is because channel 1 was positioned nearer to the areas of blood supply of the motor cortex, thus, indicating higher oxygenation levels during the execution of motor activities and functions. fNIRS channels 1 and 2 were positioned at the prefrontal cortex area but nearer to the midline section of the forehead, whereas channels 3 and 4 were positioned nearer to the ears' area. It is difficult to obtain significant changes for channel 1 due to its position in the midline of the forehead, where the area is constantly in supply of blood flow. Any significant changes during coordination tests or cognitive stimulation activities at channels 2, 3 and 4 indicated that there is an activation and stimulation in those particular areas during those activities. The significant changes in any fNIRS channels for HbO and HHb levels indicated that the coordination tests and cognitive stimulation activities require a certain amount of oxygenation and circulation of blood supply to those particular areas during its activation.

The findings of this study are also in accordance with previous literature that highlight the capabilities of fNIRS in showing fluctuations of brain oxygenation during simple coordination (Joshi et al. 2018; Xu et al. 2020) and cognitive tasks (Lamb et al. 2019). Our current results in coordination tests concurred with the findings of Joshi et al. (2018) and Xu et al. (2020) where the current study highlighted the activation parts of the prefrontal cortex areas via fNIRS channels detection. Significant changes were described for fNIRS channels 1, 3, and 4 (HbO levels) and fNIRS channels 2 and 3 (HHb levels). The significant changes in those channels were due to the demand and increased activity levels that were conducted during plate tapping test and block transfer test. The yielded significant results also suggested that higher brain activation in prefrontal cortex areas were required to execute and perform motor functions. In addition, our study also corroborated Lamb et al. (2019) on the complex responses in the prefrontal cortex areas of the brain during cognitive stimulation activities. As described earlier, our study on cognitive stimulation activities yielded significant results on fNIRS channels 3 and 4 (HbO levels) and fNIRS channels 2 and 3 (HHb levels). The increased HbO levels served as an indicator of the elevation of oxygenated blood supply to the brain areas for it to be activated and function properly during the required activities. The increased HHb levels indicated that there is an increase in blood supply circulation for that part of the brain during the conducted activities. These results are in parallel with the findings of Lamb et al. (2019), where they stated that greater numbers of brain areas were activated via Optodes detection. The results of the current study and that by Lamb et al. (2019) are in line in emphasizing the value of neuroscience in bridging the understanding of the cognitive functions of the brain.

Importantly, fNIRS is a unique non-invasive neuroimaging and brain monitoring tool that can also be utilised to explore pathways for functional rehabilitation following brain injury (Chincarini et al. 2020; Mihara & Miyai 2016). With the increased interest in brain-computer interface (BCI) technology, fNIRS can be introduced as a therapeutic and neurofeedback tool to help assess the capacity and quality of life of patients with motor impairment syndrome and severe neurological disorders, such as cerebral palsy and amyotrophic lateral sclerosis (Chaudhary et al. 2014; Chincarini et al. 2020; Daly & Wolpaw 2008; Dobkin 2007).

Over the last three decades, non-invasive neuroimaging approaches, especially fNIRS and fMRI, have become powerful instruments in cognitive process research and analysis. Both fMRI and fNIRS hold common advantages of having more comprehensive and wider brain area coverage, broader brain field of view, non-ionising radiation or non-radioactive elements. Both devices depend on haemodynamic and metabolic changes in neuronal blood flow to active brain areas and using oxygen intake as an indirect measure for brain functional mapping (Buxton et al. 2004; Huang et al. 2019; Yücel et al. 2017).

Despite the common benefits, fMRI still maintains its dominance when it comes to spatial resolution and penetrating capacity where it can be used as a neuroimaging for whole brain activation signal detection (Power et al. 2017). However, the operation of fMRI requires a fixed and restricted setting with sensitivity to the participant's motion and noisy scanner which makes the general practice much more stringent and constrained (Chincarini et al. 2020; Gefen et al. 2014).

The rapid development and use of fNIRS is attributable to the continuous improvement of fNIRS application and advancement due its portability, ease of administration and cost-effectiveness, especially when compared to fMRI. These focal advantages make it suitable while providing versatility in adult and infant research as compared to other neuroimaging approaches such as fMRI, electroencephalography, magnetoelectroencephalography, and positron emission tomography (de Klerk et al. 2018; Lloyd-Fox et al. 2010; Urakawa et al. 2015).

That being said, fNIRS has reported several drawbacks that typically include poor reproducibility, lack of depth sensitivity to examine neural activity deeper than 1 cm below the brain's surface, and lower spatial resolution as opposed to fMRI, making it difficult to discern responses yielded from discrete cortical regions or adjacent cortical regions (Lange & Tachtsidis 2019; Wilcox & Biondi 2015). Other fNIRS constraints include its complicated device configuration that requires the detector probe to be mounted at a fixed distance between 2 cm and 5 cm on the scalp, and also undefined variation of absolute concentration's due to the unknown length of light that travels through the tissues which require additional mathematical solution with MRI's jointly anatomical images (Ferrari & Quaresima 2012; Scarapicchia et al. 2017). These issues can be resolved by implementing different near-infrared spectroscopy (NIRS) such as time domain NIRS, continuous wave NIRS or frequency domain NIRS, although not all of these NIRS forms are readily available (Lange & Tachtsidis 2019; Wilcox & Biondi 2015).

Conclusion

Our findings indicated that the simple coordination tests and cognitive stimulation activities performed in this study were associated with prefrontal activation in healthy young adults and can be detected by fNIRS. The general increase in HbO levels compared to resting state during all activities suggest that our protocols could be proposed as a valid screening tool to assess cognitive function.

ACKNOWLEDGEMENTS

The authors acknowledged the technical assistance provided by MIMOS Berhad in the operation of fNIRS and the Universiti Kuala Lumpur Short Term Research Grant (str18048) for funding this study.

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