Original Article

Assessment of Brain Cortical Activation in Passive Movement During Wrist Task Using Functional Near Infrared Spectroscopy (fNIRS)

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Abstract

Purpose: Nowadays, the number of people diagnosed with movement disorders is increasing. Therefore, the evaluation of brain activity during motor task performance has attracted the attention of researchers in recent years. Functional Near-Infrared Spectroscopy (fNIRS) is a useful method that measures hemodynamic changes in the brain cortex based on optical principles. The purpose of this study was to evaluate the brain's cortical activation in passive movement of the wrist.

Materials and Methods: In current study, the activation of the brain's motor cortex during passive movement of the right wrist was investigated. To perform this study, ten healthy young right-handed volunteers were chosen. The required data were collected using a commercial 48-channel continuous wave fNIRS machine, using two different wavelengths of 765 and 855 nm at 10 Hz sampling rate.

Results: Analysis of collected data showed that the brain's motor cortex during passive motion was significantly activated ($p \leq 0.05$) compared to rest. Motor cortex activation patterns depending on passive movement direction were separated. In different directions of wrist movement, the maximum activation was recorded at the primary motor cortex (M1).

Conclusion: The present study has investigated the ability of fNIRS to evaluate cortical activation during passive movement of the wrist. Analysis of recording signals showed that different directions of movement have specific activation patterns in the motor cortex.

1. Introduction

The brain is the most complex part of the human body that controls all the tasks we do. It houses billions of nerve cells [1]. Nowadays, extracting brain cortical activation patterns when performing movement is an important issue in neuroimaging [2]. Functional Magnetic Resonance Imaging (fMRI) has been mostly used in neuroimaging researches on brain cortical activation patterns during movements of various body parts [3-5]. However, fMRI has significant restriction in the execution of movements of different body parts such as the arm and leg, because it is sensitive to motion artifacts.

Functional Near Infrared Spectroscopy (fNIRS) is a good neuroimaging method for evaluating the brain's cortical activity (a measure of the hemodynamic changes in the brain cortex). It is particularly advantageous in evaluating the brain's activity during movements of extremities because it is less sensitive to motion artifacts

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[6-8]. Compared to other neuroimaging methods, fNIRS is non-invasive, cheap and portable [9, 10].

fNIRS is a powerful, indirect, neuroimaging tool that monitors the hemodynamic changes in response to brain cortical activation, on the basis that neural activity and vascular changes are firmly coupled, the so called 'neurovascular coupling' [11, 12]. Specific parameters of the hemodynamic changes evaluated with fNIRS consist of changes in oxygenated (ΔHbO2) and deoxygenated hemoglobin (ΔHHb) at a particular location in the cortical surfaces that are evoked following stimulation [13]. This tool provides a lot of information about the physiological and functional changes of the brain by measuring the changes in oxygenated and deoxygenated hemoglobin [14].

Every part of the brain is responsible for certain action control, but the function of many areas of the brain is unknown. Neurological researches have shown that the specific nerve cells in the Premotor Cortex (PMC), primary motor cortex (M1) and the cerebellum code the direction of movement of different body parts [15].

Motor tasks have been a topic of fNIRS researches because this method is suitable for evaluating the associated brain cortex, the PMC and M1[1]. Passive movement, task observation and motor imagination have been proposed to motivate motor cortex [16]. In passive movement execution, the extremities moved by the therapist could activate the brain's sensorimotor cortex [17]. Previous studies have shown that the concept of activating brain neural networks in passive movement can be used in motor rehabilitation [18-20].

Extracting brain activation maps during the execution, imagination and passive movement of motor task is a hot topic in neuroscience and neuro-rehabilitation studies [21, 22]. The aim of current study was to extract the activity changes of the brain's cerebral cortex during passive movement of the right wrist using fNIRS data. This study was done to attain activation patterns of hemodynamic changes in brain cortex using the collected data from the functional near infrared and the discernment between brain cortical activation patterns.

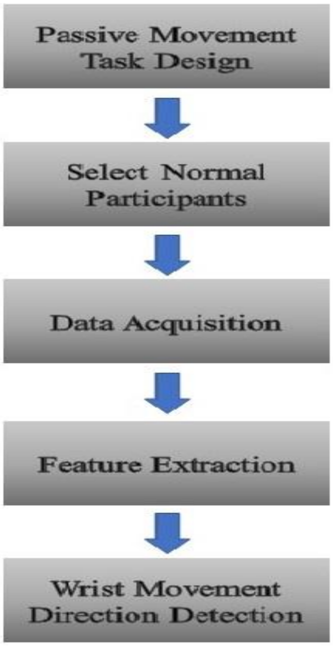

Figure 1. A schematic diagram of different stages in the process of right wrist passive movement direction detection

2. Materials and Methods

2.1.Participants

For this experiment, ten healthy right-handed young men were recruited. The age range of the participants was between 25-40 years old (29.2±3.64). Furthermore, they had no history or signs of neurological and psychosocial diseases. The protocol of this human study was approved by the local ethics committee of Tehran University of Medical Sciences (TUMS), Tehran, Iran (Approval number: IR.TUMS.MEDICINE.REC.1396.3968).

2.2.Data acquisition

For this study, the required data were collected at the National Brain Mapping Laboratory, Tehran, using a 48-channel fNIRS MR-Compatible device (OxyMon fNIRS from Artinis) with two wavelengths of 765 and 855 nm.

The hemodynamic changes in the brain cortex were used to specify the location of the activated area during passive movement of the right wrist. fNIRS systems calculate the changes in oxygenated, deoxygenated and total hemoglobin, using the Beer-Lambert law. To obtain fNIRS data, a 3-centimeter distance between optodes was used. In addition, an international system [1, 10-19] was used to determine the location of fNIRS optodes.

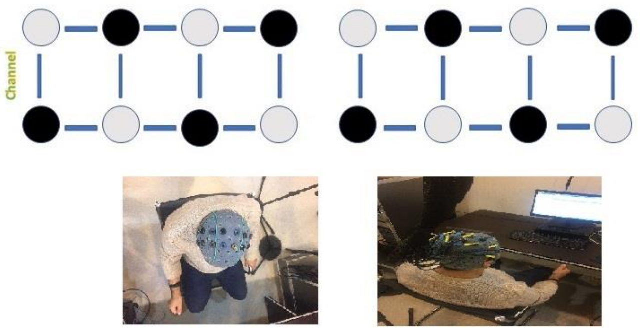

Figure 2. This figure shows how the optode (receivers and transmitters) should be placed on participants' heads (black color represents transmitter and grey color represents receiver)

2.3.Task and Data Analysis

All participants were seated on a chair and were asked not to move the trunk. During the experiment, we performed a step-tracking task for participants by moving their right wrists in four directions. In this task, we moved a right wrist in up, down, left and right directions and performed flexion, extension as well as ulnar and radial deviations. Figure 3 shows the task pattern. In each time, one of the directions was randomly activated and we moved the wrist of participants to that direction. The period of stay in each direction was 3 seconds, but the duration of time the participants held their hands at the center was between 2-4 seconds. For the whole test, each stage lasted 496 seconds. These 496 seconds was in reference to each angle 20 times.

The acquired data of current study were analyzed using NIRS-SPM software that runs in MATLAB R2016a software. The t-statistics SPM maps were measured at a significant level of 5%. For calculating the brain's cortical activation, ΔHbO2 was used because HbO is a good marker for evaluating brain cortical activation and fNIRS is very sensitive to changes in HbO concentration.

NIRS-SPM provides an option to remove the entire unknown process due to breathing, the heart and vascular motion, or other experimental errors. The Wavelet-MDL detrending algorithm effectively eliminates the overall unknown processes due to breathing, vascular motion, or other experimental errors. A Gaussian filter was used to reduce the signal noise recorded by the fNIRS device.

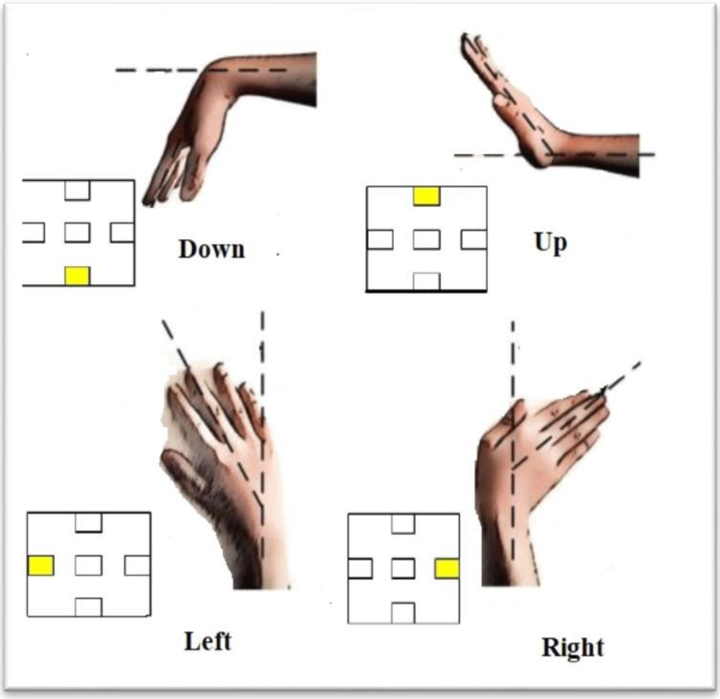

Figure 3. A schematic diagram showing the right wrist passive movement tasks. Researchers executed this test for participants and they moved their right wrists up, down, left and right directions

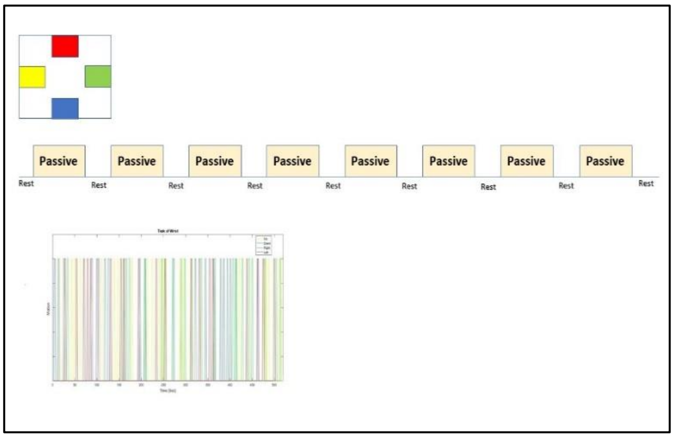

Figure 4. fNIRS task block design of current study. The step-tracking task contains 8-block test, each block included ten moves to random directions (up, down, left and right) and during the task each person randomly pointed 20 times to each direction

Table 1. MNI coordinates of fNIRS Channel

Channel Number	MNI Position			Brodmann Area	ROI
	X	Y	Z		
1	-68	-17	11	22	Superior Temporal Gyrus
2	-56	-12	53	4	Primary Motor Cortex
3	-68	-28	35	2	Primary Somatosensory Cortex
4	-71	-26	-8	21	Middle Temporal gyrus
5	-70	-39	10	22	Superior Temporal Gyrus
6	-28	-44	74	1	Primary Somatosensory Cortex
7	-43	-27	68	4	Primary Motor Cortex
8	-60	-45	51	40	Supramarginal gyrus part of Wernicke's area
9	-28	-10	73	6	Pre-Motor and Supplementary Motor Cortex
10	-13	-25	79	4	Primary Motor Cortex
11	-26	3	72	6	Pre-Motor and Supplementary Motor Cortex
12	57	-4	52	6	Pre-Motor and Supplementary Motor Cortex
13	46	-18	66	4	Primary Motor Cortex
14	17	-27	79	4	Primary Motor Cortex
15	35	-39	72	3	Primary Somatosensory Cortex
16	72	-34	14	22	Superior Temporal Gyrus
17	69	-22	36	2	Primary Somatosensory Cortex
18	63	-36	52	40	Supramarginal gyrus part of Wernicke's area
19	70	-11	16	22	Superior Temporal Gyrus
20	73	-26	-6	21	Middle Temporal gyrus

3. Results

In this research, there was an activation which obtained passive movement of the right wrist in a specific location of the brain cortex. The activation group analysis of the right wrist passive movement showed that the activation (increase of oxygenated hemoglobin) was contralaterally extended in the primary motor cortex, pre-motor and supplementary motor cortex as well as primary somatosensory cortex areas. Data group analysis showed that the maximum activation was observed in the primary motor cortex M1 (Brodmann area 4).

The group analysis of acquired data in the passive movement of the right wrist to the left direction showed that the focal concentration of HbO was divergent in the primary motor cortex and primary somatosensory cortex regions. The analysis of data on passive downward movement of the right wrist indicated that the activation (a significant increase in HbO) was divergent in the primary motor cortex area. The results of passive movement of the right wrist to the left direction, showed that the activation maps of the brain cortex were higher than other directions. The activation associated with the motion in the up direction was higher at the middle of the brain motor cortex.

Table 2. Responses of the brain motor cortex during passive movement of the right wrist

Wrist Movement Direction	Brain Region	Brodmann Area	MNI Position			Channel Number	T-Value
			z	y	x		
Up	Primary Motor Cortex	4	79	-27	17	14	2.79
	Primary Motor Cortex	4	79	-25	-13	10	
	Primary Motor Cortex	4	68	-27	-43	7	
down	Primary Motor Cortex	4	79	-25	-13	10	2.96
	Primary Motor Cortex	4	68	-27	-43	7	
Right	Primary Motor Cortex	4	79	-25	-13	10	2.57
	Pre-Motor and Supplementary Motor Cortex	6	73	-10	-28	9	
	Primary Somatosensory Cortex	2	51	-45	-60	8	
	Primary Motor Cortex	4	68	-27	-43	7	
	Primary Somatosensory Cortex	1	74	-44	-28	6	
	Primary Motor Cortex	4	68	-27	-43	2	
Left	Primary Motor Cortex	4	79	-25	-13	10	2.65
	Pre-Motor and Supplementary Motor Cortex	6	73	-10	-28	9	
	Primary Somatosensory Cortex	2	51	-45	-60	8	
	Primary Motor Cortex	4	68	-27	-43	7	
	Primary Somatosensory Cortex	1	74	-44	-28	6	
	Primary Somatosensory Cortex	2	35	-28	-68	3	
	Primary Motor Cortex	4	68	-27	-43	2	

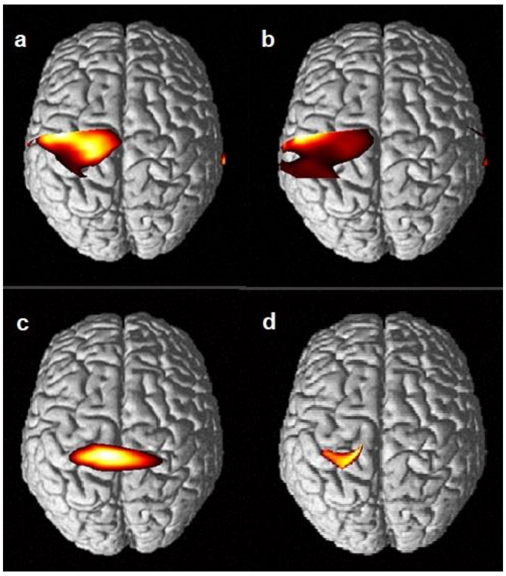

Figure 5. The results of group analysis from NIRS_SPM. Activation maps acquired from passive movement of right wrist in brain motor cortex. a) Activation map obtained from passive movement of right wrist to right, b) left, c) up, and d) down

Group analysis of the fNIRS data demonstrated that directional activities are spatially different during passive movements of the right wrist (Table 2). It is feasible to make separation between the different directions of the hand's passive movements.

4. Discussion

The purpose of current study was to investigate the efficacy of fNIRS as a tool for evaluating brain cortical activation during passive movement of the right wrist. fNIRS as a functional neuro imaging method enables detection of hemodynamic changes in the cerebral motor cortex (a parameter for evaluating brain activity). The present fNIRS research shows that activations related to passive movement in particular directions are spatially different within the right wrist representation in brain motor cortex. Oxygenated hemoglobin is a good marker widely used in fNIRS researches. With this marker, we can indirectly measure the brain's cortical activation [23, 24].

GLM analysis of acquired data showed that the highest activation was recorded in the primary motor cortex. In moving towards up and down directions, the primary motor cortex was activated (Table 1). For movements to the left direction, in addition to primary motor cortex, the pre-motor, supplementary motor and primary somatosensory cortex were activated. These results show that different and separate neural cells were activated and the activation maps were focused on the cerebral motor cortex to control passive movement of the wrist. Our results indicated that differentiation between the various directions of wrist passive movement is feasible using fNIRS.

A study by Jinung *et al.* [25] for evaluating cortical activation pattern during passive movement of grasping showed that the primary somatosensory-motor cortex (SM1), premotor cortex (PMC), and primary motor cortex (M1) were activated, which is in agreement with our results. From our research, we were able to assess changes in the brain's cortical activity during passive movement of the right wrist in different directions.

Group analysis showed that the activation pattern of the left direction is very similar to that of the right direction. A wide activation map in the passive movement of the wrist to the left was recorded compared to other directions (Figure. 3). Data analysis revealed a significant relationship between passive motor task execution and activity changes in the brain's motor cortex (Figure. 3). In this study, we were able to examine and differentiate between patterns of brain's cortical activation maps in the motion of the wrist. In addition, the results showed that fNIRS is a suitable neuroimaging method for research on hemodynamic changes in the brain cortex following the activation of neuronal cells as a result of executing wrist motion tasks. Signal pattern extraction from the acquired data in this study can be used in future for controlling neuro rehabilitation devices to help people with motion disorders.

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References

1- M. Abtahi, A. Amiri, D. Byrd, and K. Mankodiya, "Hand Motion Detection in fNIRS Neuroimaging Data," in

Healthcare, 2017, vol. 5, no. 2, p. 20: Multidisciplinary Digital Publishing Institute.

2- S. S. Yeo, P.-H. Chang, and S. H. Jang, "The cortical activation differences between proximal and distal joint movements of the upper extremities: a functional NIRS study," *NeuroRehabilitation,* vol. 32, no. 4, pp. 861-866, 2013.

3- M. J. Kim and J. H. Hong, "The cortical effect of clapping in the human brain: a functional MRI study," *NeuroRehabilitation,* vol. 28, no. 2, pp. 75-79, 2011.

4- E. Kapreli *et al.*, "Lower limb sensorimotor network: issues of somatotopy and overlap," *Cortex,* vol. 43, no. 2, pp. 219-232, 2007.

5- E. Kapreli *et al.*, "Lateralization of brain activity during lower limb joints movement. An fMRI study," *Neuroimage,* vol. 32, no. 4, pp. 1709-1721, 2006.

6- L. Gagnon *et al.*, "Quantification of the cortical contribution to the NIRS signal over the motor cortex using concurrent NIRS-fMRI measurements," *Neuroimage,* vol. 59, no. 4, pp. 3933-3940, 2012.

7- P. M. Arenth, J. H. Ricker, and M. T. Schultheis, "Applications of functional near-infrared spectroscopy (fNIRS) to neurorehabilitation of cognitive disabilities," *The Clinical Neuropsychologist,* vol. 21, no. 1, pp. 38-57, 2007.

8- B. Seraglia, L. Gamberini, K. Priftis, P. Scatturin, M. Martinelli, and S. Cutini, "An exploratory fNIRS study with immersive virtual reality: a new method for technical implementation," *Frontiers in human neuroscience,* vol. 5, p. 176, 2011.

9- X. Cui, S. Bray, D. M. Bryant, G. H. Glover, and A. L. Reiss, "A quantitative comparison of NIRS and fMRI across multiple cognitive tasks," *Neuroimage,* vol. 54, no. 4, pp. 2808-2821, 2011.

10- H. Shibasaki, "Human brain mapping: hemodynamic response and electrophysiology," *Clinical Neurophysiology,* vol. 119, no. 4, pp. 731-743, 2008.

11- S. Lloyd-Fox, A. Blasi, and C. Elwell, "Illuminating the developing brain: the past, present and future of functional near infrared spectroscopy," *Neuroscience & Biobehavioral Reviews,* vol. 34, no. 3, pp. 269-284, 2010.

12- Y. Hoshi, "Functional near-infrared spectroscopy: current status and future prospects," *Journal of biomedical optics,* vol. 12, no. 6, p. 062106, 2007.

13- A. Gibson, J. Hebden, and S. R. Arridge, "Recent advances in diffuse optical imaging," *Physics in Medicine & Biology,* vol. 50, no. 4, p. R1, 2005.

14- L. Couch, M. Roskosky, B. A. Freedman, and M. S. Shuler, "Effect of skin pigmentation on near infrared spectroscopy," *American Journal of Analytical Chemistry,* vol. 6, no. 12, p. 911, 2015.

15- S. Kakei, D. S. Hoffman, and P. L. Strick, "Direction of action is represented in the ventral premotor cortex," *Nature neuroscience,* vol. 4, no. 10, p. 1020, 2001.

16- A. Guzzetta *et al.*, "Brain representation of active and passive hand movements in children," *Pediatric research,* vol. 61, no. 4, p. 485, 2007.

17- X. Hu *et al.*, "Effectiveness of functional electrical stimulation (FES)-robot assisted wrist training on persons after stroke," in *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology,* 2010, pp. 5819-5822: IEEE.

18- J. W. Krakauer, "Motor learning: its relevance to stroke recovery and neurorehabilitation," *Current opinion in neurology,* vol. 19, no. 1, pp. 84-90, 2006.

19- R. A. Schmidt, T. D. Lee, C. Winstein, G. Wulf, and H. N. Zelaznik, *Motor control and learning: A behavioral emphasis*. Human kinetics, 2018.

20- M. E. Stoykov, D. M. Corcos, and S. Madhavan, "Movement-based priming: clinical applications and neural mechanisms," *Journal of motor behavior,* vol. 49, no. 1, pp. 88-97, 2017.

21- M. Kaplan, "Plasticity after brain lesions: contemporary concepts," *Archives of physical medicine and rehabilitation,* vol. 69, no. 11, pp. 984-991, 1988.

22- D. York, "Review of descending motor pathways involved with transcranial stimulation," *Neurosurgery,* vol. 20, no. 1, pp. 70-73, 1987.

23- J. Steinbrink, A. Villringer, F. Kempf, D. Haux, S. Boden, and H. Obrig, "Illuminating the BOLD signal: combined fMRI–fNIRS studies," *Magnetic resonance imaging,* vol. 24, no. 4, pp. 495-505, 2006.

24- T. J. Huppert, S. G. Diamond, M. A. Franceschini, and D. A. Boas, "HomER: a review of time-series analysis methods for near-infrared spectroscopy of the brain," *Applied optics,* vol. 48, no. 10, pp. D280-D298, 2009.

25- J. An *et al.*, "Cortical activation pattern for grasping during observation, imagery, execution, FES, and observation-FES integrated BCI: An fNIRS pilot study," in *2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC),* 2013, pp. 6345-6348: IEEE.