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Comparison of Cortical Activation During Real Walking and Mental Imagery of Walking – The Possibility of Quickening Walking Rehabilitation by Mental Imaginary of Walking

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1. Introduction

Non-invasive brain imaging technologies have become an increasingly important part of research in neurosciences. The thirst for information about brain function is universal, and imaging of the human brain has been used by many as a medium for the discussion. So far, Functional brain imaging with positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalographic (EEG), and Magnetoencephalography (MEG) have greatly increased scientists' ability to study localized brain activity in humans and carry out studies for better understanding of the neural basis of mental states. They have been used extensively to map regional changes in brain activity, not only in neuroscience researches, as well as in social sciences to objectively and quantitatively evaluate psychological problems. PET and fMRI are based on changes in local circulation and metabolism (Raichle & Mintun, 2006). PET produces detailed three-dimensional images of certain processes in the brain by detecting gamma rays emitted indirectly by radioactive material which has been injected into the person's blood stream prior to scanning. fMRI produces high quality pictures of the brain's delicate soft tissue structures using strong magnets and pulses of radio waves to manipulate the natural magnetic properties of hydrogen, creating useful images of organs and soft tissues. MEG and EEG image electrical activity in the brain. MEG measures magnetic fields generated by small electrical currents in neurons of the brain using arrays of SQUIDs (superconducting quantum interference devices). EEG uses multiple electrodes fixed to the person's scalp to measure the dynamic pattern of electrical fields in the brain. In cognitive neuroscience, researchers use EEG technology to study event-related potentials (ERPs)—brain measurements that are associated with a response to a stimulus.

These methods provide information about changes in electrical, hemodynamic and metabolic activities. Each of these techniques has its advantages and disadvantages, but

helps to elucidate certain aspects of the capacity of neural networks to process information. MEG and EEG provide unique insights into the dynamic behaviour of the human brain as they are able to follow changes in neural activity on a millisecond time-scale. In comparison, PET and fMRI are limited in temporal resolution to time scales on the order of one second by physiological and signal-to-noise considerations. On the other hand, MEG, PET and fMRI provide high resolution brain images. The resolution of fMRI is about 2-3 mm at present, limited by the spatial spread of the hemodynamic response to neural activity. However, MEG, PET and fMRI techniques are very expensive, highly sensitive to motion artifact, confine participants to restricted positions, which severely limits their application in daily use outside hospitals and research centers. Although EEG is much cheaper, it is highly sensitive to artifacts whose amplitude can be quite large relative to the size of amplitude of the cortical signals of interest. The artifacts include both biological artifacts such as eye-induced artifacts, cardiac artifacts and muscle activation induced artifacts, and environmental artifacts such as body movement, settling of the electrodes, and electrical appliances. Therefore, EEG, MEG, PET and fMRI are difficult to measure brain activity in natural environment. A brain imaging technology, which is non-invasive, less constrictive, low-cost, with a relatively higher temporal and spatial resolution, is desirable.

Functional near-infrared spectroscopy (fNIRS) is an emerging brain imaging technology monitoring concentration changes of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) at the cortex by measuring the absorption of near infrared light between 650nm and 950nm through the intact skull (Chance et al., 1993; Villringer et al, 1993). Specifically, the transmission and absorption spectra of oxy-Hb and deoxy-Hb are distinct in this wavelength region. The fundamentals of the optical topography system utilize the phenomenon, using the better penetrating near infrared light, rather than visible light, to measure changes in blood hemoglobin concentrations in the brain. As shown in Fig.1, a laser optode is illuminated onto head from optical fibers attached to the scalp. The near infrared light passes through the skull and reaches the cerebral cortex. It is scattered by hemoglobin in the blood. The light is partially reflected back through the scalp. The reflected light back on the scalp contains the information about the cerebral cortex. When a specific area of the brain is activated, the localized blood volume in that area changes quickly. It can thus be detected, where and how active the specific regions of the brain are, by continuously monitoring the blood hemoglobin levels according to the absorption level of near infrared light, while having the examinee do some specific action or task paradigm.

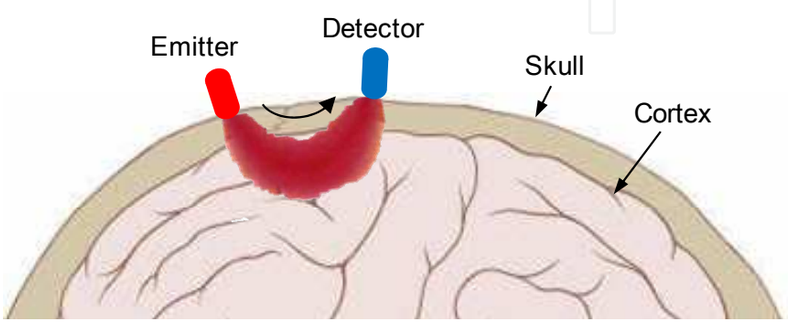


Fig. 1. Cortical activation measurement with near infrared light.

fNIRS has several unique advantages over current measurement methods. It is non-invasive, and can be used under a variety of conditions with minimal restriction on the examinee. Measurements can be made under more natural conditions, giving more freedom in task design. It also enables simultaneous measurements with other testing modalities such as EEG, fMRI and MEG because near infrared light is not interfered by EEG, fMRI and MEG, and does not interfere them. fNIRS facilitates longitudinal studies and monitoring over extended time periods. Therefore, fNIRS technology allows the design of portable, safe, affordable and accessible monitoring systems. These qualities pose fNIRS as an ideal candidate for monitoring cognitive activity-related hemodynamic changes not only in laboratory settings but also under natural conditions. The reliability of fNIRS signals has in most cases been proven to be sufficient at a group level for observation of brain activity (Plichta et al., 2006; Sato et al., 2005; Sato et al., 2006).

The authors and their colleagues have been developing machines for walking rehabilitation and walking support. In an aging society with a low birth rate in countries like Japan, people suffering from walking impairments due to illness or accident are increasing and the number of physical therapist cannot meet with the demand for walking rehabilitation. Therefore, rehabilitation machines, which can help with early recovery and relieve burden of physical therapists, have drawn great attentions (Okada et al., 2001; Horst, 2009). In previous studies, we have developed omnidirectional walkers for standing exercise (Tan et al., 2011) and seated exercise, shown in Fig. 2(a) and Fig. 2(b) respectively. The walker for standing exercise is designed for those able to keep standing posture by themselves, and the walker for sitting exercise is designed for the severe patients unable to stand. Omnidirectional walking exercise has been proved effective for early recovery of walking disabilities (Ishida et al., 2008).

(a) For standing exercise (b) For seated exercise

Fig. 2. Omnidirectional walkers.

The causes for walking disabilities include not only muscle weakness but also neural dysfunctions due to stroke or Alzheimer's disease. 58% of walking disabilities are caused by problems in the neural system. However, up to now, most of the developed walking rehabilitation machines aim at enhancing muscle strength, neglecting the recovery of the neural system. Thus it is necessary to consider the brain activities besides muscle strength in walking rehabilitation, in order to improve the efficiency of walking rehabilitation. Furthermore, for the severe patients who are completely bed-ridden, it is important to activating their neural system related to walking movement. A hybrid walking

rehabilitation system is proposed which includes both muscle strength enhancement by walking rehabilitation machines and neurological rehabilitation by imaginary of walking. This system has the following most prominent advantages compared with traditional rehabilitation methods considering only physical rehabilitation.

- Early rehabilitation of cognitive functions related to walking. After falling ill (stroke et al.), surgery or injure, physical rehabilitation might not be able to performed in a certain period of time according to the patient's condition. During this period, neurological rehabilitation by imaginary of walking is considered to be an effective method to keep the brain areas related to walking active and maintain the cognitive functions related to walking.
- Quickening walking rehabilitation. Walking is a complex cognitive task that is associated with higher-level cognitive function (Fukuyama, 1997; Riecker et al., 2003). Even routine walking is suggested to be considered as a relatively complex task that involves higher-level cognitive input (Hausdorff et al., 2005). In hospitals or rehabilitation facilities, physical rehabilitation time is limited due to the schedule of the physical therapist or the condition of the patients. However, there is no such limit in neurological rehabilitation. Therefore, the combination of physical rehabilitation and neurological rehabilitation may lead to earlier recovery of walking ability.

However, the neural mechanism of neurological rehabilitation is yet to be elucidated and there is no standard method to carry out neurological rehabilitation.

Recently, motor imagery, as a method of neurological rehabilitation, is drawing more and more attention.Motor imagery is widely used in sport to improve performance, which raises the possibility of applying it as a rehabilitation method. The effectiveness of motor imagery training at restoring motor function after stroke has been indicated by several studies (Sharma et al., 2006; Dickstein et al., 2004). However, the underlying mechanism of motor imagery training-induced improved performance remains unexplained. Understanding the effect of rehabilitative techniques on brain plasticity is potentially important in providing a neural substrate to underpin rehabilitation and hence in developing novel rehabilitation strategies. An fMRI study has shown that premotor cortex (PM) and supplementary motor area (SMA), as shown in Fig. 3, are involved in the observation of gait and related conditions in combination with motor imagery of gait (Iseki et al., 2008; Wagner et al., 2008). However, since the MRI environment excluded real gait movement, the comparison between brain activities involved in walking and imaginary walking was still insufficient. In this chapter, we compared the activation in motor area of the brain during real walking and imaginary walking by means of fNIRS. Two experiments were conducted.

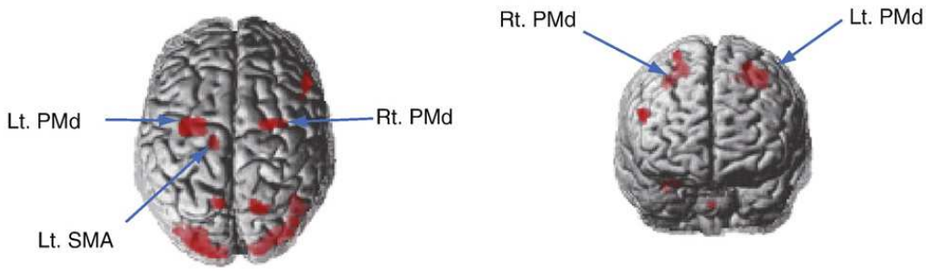


Fig. 3. Activated brain regions by mental imagery of walking (Iseki et al., 2008;).

In the first experiment, we compared the activation in motor area of the brain during real walking (RW) and walking observation (WO) (Jiang et al., 2010). Two subjects participated in the experiment. During WO, the subjects were instructed to imagine that they were walking with the same pace to a person in the video being shown to the subjects. As a result, the concentration of oxygenated hemoglobin in motor area during WO was higher than that during RW in both of the subjects. This was because that it was not necessary to pay attention to the movements of the legs and feet during normal walking on the plain road without any obstacles, while movement planning was required when the subjects imagined their walking in the same way to another person. The experiment result indicated that it is possible to quicken walking rehabilitation by mental imagery of walking.

In the second experiment, we compared the activation in motor area during RW, virtual walking (VW), and WO. Subjects stood on a treadmill throughout the experiment (Jiang et al., 2011). In the VW, subjects were shown moving scenes of a virtual visual environment in which subjects easily imagined as if they were actually walking from the first-person perspective. In the WO, subjects were instructed to imagine that they were walking with the same pace to a person in the video being shown to the subjects (third-person perspective). Four subjects participated in the experiment. As a result, the oxy-Hb in motor area during both VW and WO were higher than that during RW on the average. This was because that it was not necessary to pay attention to the movements of the legs and feet during normal walking, while movement planning was required when the subjects imagined their walking according to the videos. There was no significant difference between the oxy-Hb during VW and that during WO. The importance of stimulus diversity in mental imagery of walking was suggested.

2. fNIRS measurement

Regional hemodynamic changes in brain tissue were monitored using fNIRS system ETG-7100 (Hitachi Medical Corporation) (Fig. 4). This system uses two wavelengths of near-infrared light (695 nm and 830 nm) to separate the two types of hemoglobin concentration

Fig. 4. ETG-7100 system and its shell to hold 4×4 optodes.

changes independently. The distance between the detector optode and emitter optode was 30 mm, which enabled cerebral blood volume measurement at a 2 to 3 cm depth from the surface of cerebral cortex (Toronov et al., 2001). The midpoints of pairs of emitter-detector optodes were regarded as the points of measurement (channels). Data were measured with a sampling rate of 10 Hz. Light emitters and detectors were alternated at an equal distance of 3 cm to give one 4×4 optode probe sets (Fig. 4). All of the transmitted intensities of the two wavelengths that left the tissue were continuously recorded over 24 channels to estimate changes in the concentrations of oxy-Hb and deoxy-Hb.

Data collection by this system is comfortable for subjects, since it requires less constrictive circumstances of measurements and fewer movement restrictions, yielding more ecologically valid conditions. The whole system is fixed on a platform installed with casters so that the system can move with the subject in moving tasks. In our study, the subjects walked in the experiment. Therefore fNIRS is more suitable for this study (Suzuki et al., 2004; Miyai et al., 2001).

3. Cortical activation during real walking and mental imagery of walking

This section introduces two experiments in which we compared the cortical activation during real walking and that during mental imagery of walking.

3.1 Experiment 1

We compared the activation in the primary motor area and the primary somatosensory area of the brain during RW and WO by means of fNIRS. The possibility to quickening walking rehabilitation by mental imagery of walking is discussed based on the experiment results.

3.1.1 Subjects

Two male graduate students (SL and ZJ) of Kochi University of Technology participated in the experiment. Their ages were 27 to 28 years. All were right-handed and had no medical history of neurological or psychiatric disorders.

3.1.2 fNIRS measurement

As shown in Fig. 5, the optodes were fixed with a plastic shell and placed on the subject's left frontal areas according to the international 10-20 system, which is widely used in EEG measurement (Homan et al., 1987; Steinmetz et al., 1989; Okamoto et al., 2004). The numbers between the emitters and detectors were channel numbers. Channels were labelled from front to back as CH1-CH24. Data were measured with a sampling rate of 10 Hz. CH16 was placed on Cz · The areas measured by CH11, 12, 15, 18, 19 and CH13, 14, 17, 20, 21 covered the primary somatosensory cortex which processes the sensory information and the primary motor cortex which plans and executes movements related to walking.

3.1.3 Stimuli

The experiment scene is shown in Fig. 6. During the RW task, the subjects walked along a straight line at 0.3 m/s. The ETG-7100 system was pushed to follow the subject

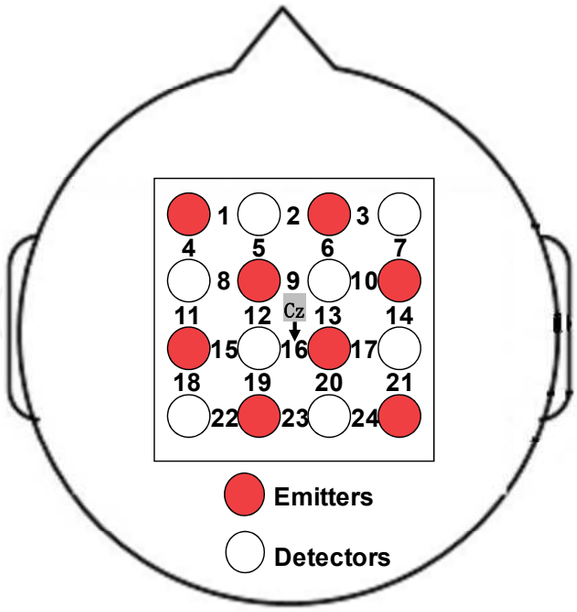


Fig. 5. Schematic placement of the emitter and detector optodes on the subject's head

(a) Real walking (b) Walking observation

Fig. 6. Experiment scene

in the task. During the WO task, the subjects were shown a video (Fig. 7) in which a person walks along a line at the same speed (0.3 m/s). The subjects were instructed to imagine that they were walking the same as the person in the video, especially to match their gaits to the video, while keep standing on the ground. The video was shot in a corridor against the wall.

3.1.4 Task paradigm

The experiment procedure is shown in Fig. 8. During the experiment, a 20 s real walking task and a 20 s imaginary walking task were performed, with a 60 s rest period before and after each task. In order to avoid the influence by the order of the tasks, two procedures were conducted. In procedure 1, the real walking task was before the imaginary walking task while in procedure 2 the order was reversed.

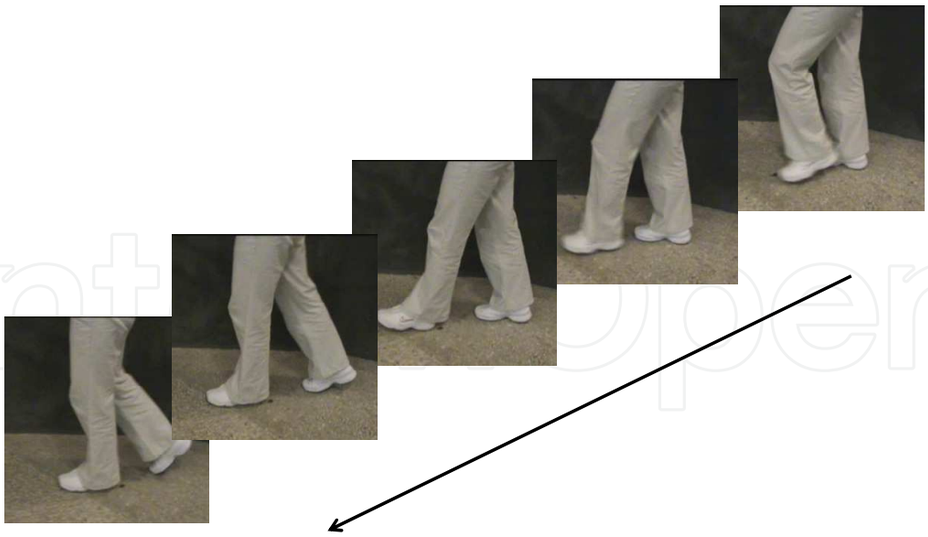


Fig. 7. Walking video shown to the subjects during WO task

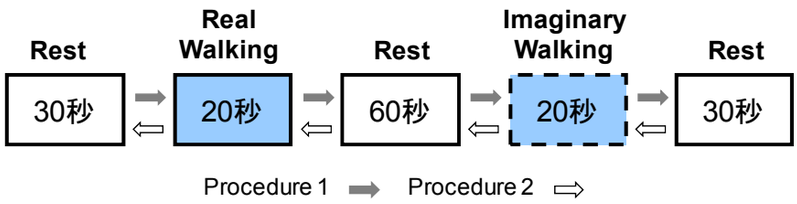


Fig. 8. Walking video shown to the subjects during WO task

3.1.5 Data analysis

According to previous studies, oxy-Hb is more useful for analysis of cortical activation than deoxy-Hb because of its higher reproducibility (Plichta 2006; Sato 2005), lower inter-subject variability (Sato 2006), and higher correlation with fMRI signals. Therefore, in the present study, oxy-Hb was measured as an indicator of changes in blood volume. The measurements of the subjects were checked visually for artifacts due to body movements. Obtained data were analyzed using the "integral mode" in the ETG-7100 software. We defined a 48 s measurement block made up of a 9 s pretask baseline period before task period (20 s), a 12s recovery period and a 7 s posttask baseline period (Fig. 9). Linear fitting

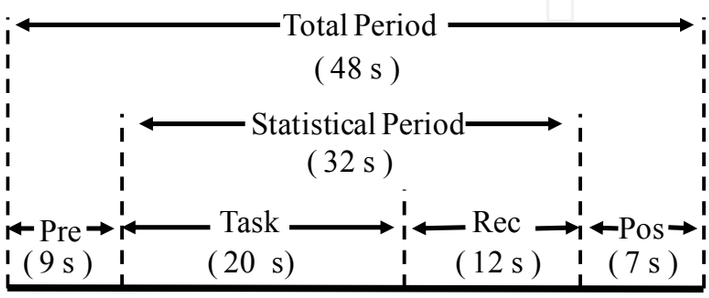
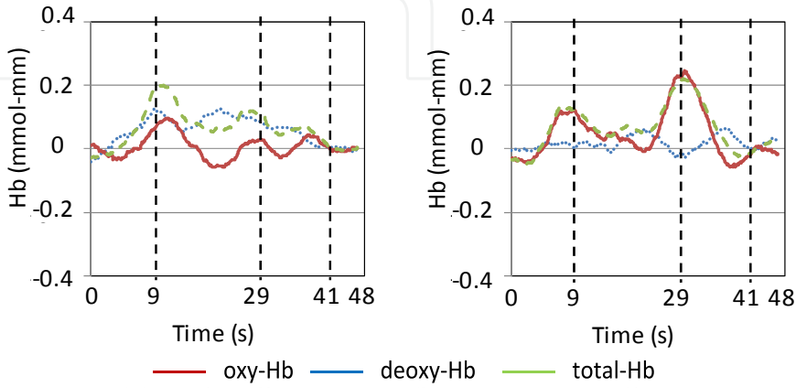


Fig. 9. Parameters of the integral mode in the ETG-7100 analysis software

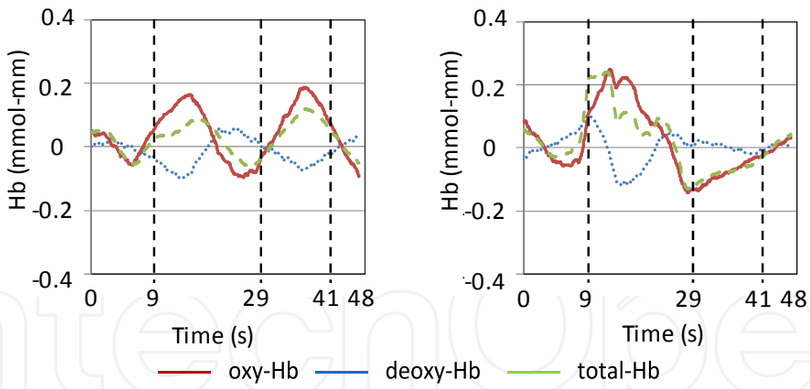
was applied to the data between these two baselines. The data in the statistical period, which was made up of task and recovery periods, were considered as the activation signals which were used to analyze the cerebral blood volume difference between real walking and imaginary walking. In the analysis we compared the average oxy-Hb of CH11, 12, 15, 18, 19 and CH13, 14, 17, 20, 21 between the RW task and the WO task.

3.1.6 Results and discussions



(a) Real walking (b) Imaginary walking

Fig. 10. Results of procedure 1



(a) Imaginary walking (b) Real walking

Fig. 11. Results of procedure 2

The average oxy-Hb of subject SL and ZJ during the statistical period of procedure 1 and 2 are shown in Fig. 10 and Fig. 11, respectively. In Fig. 10 and Fig. 11, the horizontal axis is the time shown in Fig. 9. Both oxy-Hb and deoxy-Hb, and their sum total-Hb are shown. It can be seen from the experiment results that both in procedure 1 and procedure 2, oxy-Hb increased significantly no matter the subject really walked or just imagined walking. The experiment results suggest that the cortical areas related to walking is activated by both RW and WO. The possibility of brain exercise for walking rehabilitation by mental imagery of walking was implied.

The average oxy-Hb of subject SL and ZJ during the statistical period are listed in Table 1 · We can conclude from Table 1 that although individual difference was significant, the oxy-Hb during the imaginary walking task was higher than that during the real walking task, regardless of the order of the tasks.

	Procedure 1		Procedure 2	
	RW	WO	RW	WO
Subject SL	0.027	0.147	0.056	0.114
Subject ZJ	0.043	0.135	-0.087	-0.062

**oxy-Hbs are given in mM·mm

Table 1. Average oxy-Hb during RW and WO tasks

fNIRS measures cerebral blood volume. When we walk along a straight line on a level road without any obstacles, the primary somatosensory cortex and the primary motor cortex do not involve much, with the cerebellum controlling the movement of the legs. On the other hand, during the imaginary walking task of the experiment, the subjects have to conceive their movement to match their gaits with those in the video. Although the subjects did not move, they have to plan their walking in their brain. This might be the reason why the oxy-Hb during the WO task was higher than that during the RW task. However, at present since fNIRS can only measure cerebral blood flow in cortex, not in deeper structures, how the other neural systems, such as cerebellum, the spinal cord and the peripheral nervous system, involve in mental imagery of walking is still not clear.

3.2 Experiment 2

In the second experiment, we compared the activation in the primary motor area and the primary somatosensory area of the brain during RW, VW and WO by means of fNIRS, in order to find an effective way to activate the motor area in mental imagery. The difference between VW and WO is that VW is first-person perspective, imaging oneself is walking following the visual scene in the video, while WO is third-person perspective, imaging oneself is following the gait of the person in the video. We quantitatively compared their brain activation effect based on the experiment results.

3.2.1 Subjects

Four students (YJ, RL, QQ and LS) of Kochi University of Technology participated in the experiment. Their ages were 28 to 31 years. All were right-handed and had no medical history of neurological or psychiatric disorders.

3.2.2 fNIRS measurement

As shown in Fig. 12, the concentrations of oxy-Hb and deoxy-Hb were measured by ETG-7100 system. The subject stood on a treadmill throughout the experiment. Data were measured with a sampling rate of 10 Hz.

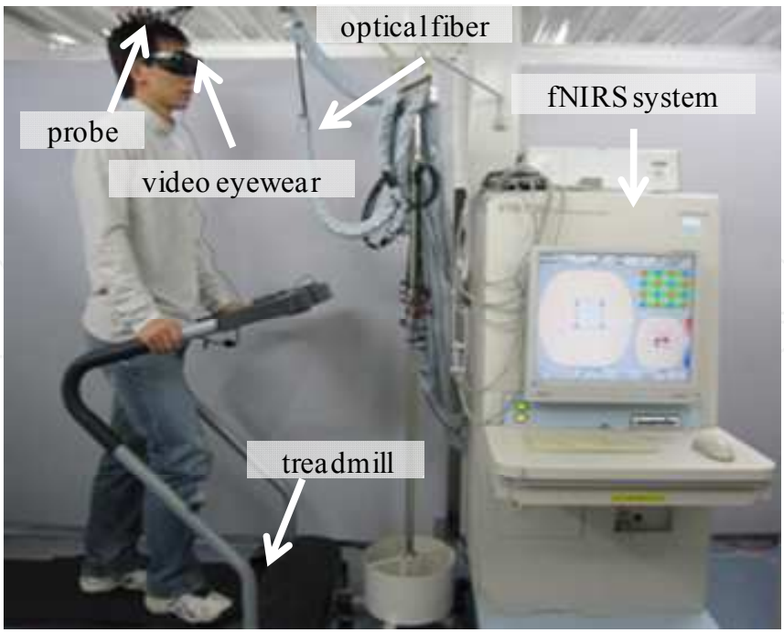


Fig. 12. Experiment scene

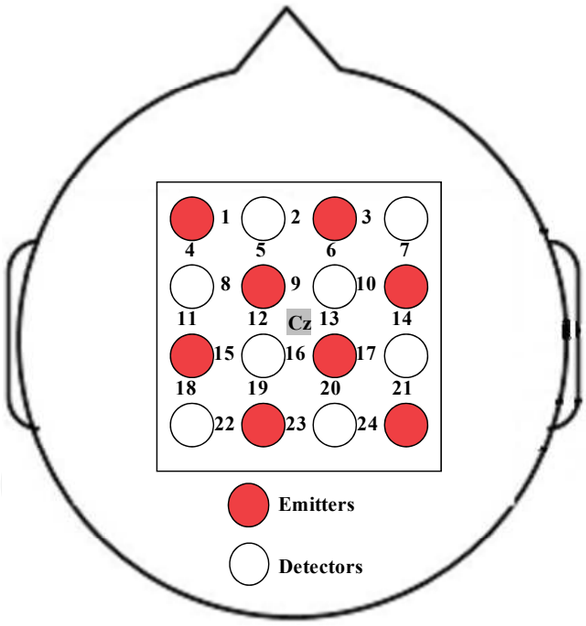


Fig. 13. Schematic placement of the emitter and detector optodes on the subject's head

Fig. 13 shows the positions of optodes on the head of the subjects. The optodes were fixed with a plastic shell and placed on the subject's head according to the international 10-20 system. The numbers between the emitters and detectors were channel numbers. Channels were labelled from front to back as CH1-CH24. The midpoint between CH12 and CH13 was placed on Cz of the International 10-20 system. According to the correlation between the international 10–20 system and cortical region, the areas measured by CH4, 5, 8, 11, 12 and

CH6, 7, 10, 13, 14 covered PM, SMA and the primary motor cortex (M1) which plans and executes movements related to walking.

3.2.3 Stimuli

There were three tasks, real walking (RW), virtual walking (VW), and walking observation (WO) in the experiment. During the RW task, the subjects walked on a treadmill at 1.0 km/h. For the VW task, a video clip was taken by a cameraman who was naturally walking down a corridor at 1.0km/h (Fig.14). Subjects were instructed to imagine as if they were actually walking from the first-person perspective. For the WO task, a video clip in which a person walks down the same corridor at 1.0 km/h was taken (Fig.14). Subjects were instructed to imagine that they were walking the same as the person in the video, especially to match their gaits to the video.

(a) Shooting location of the video

(b) Scene for walking observation. (c) Scene for virtual walking.

Fig. 14. Walking videos shown to the subjects during imaginary walking

The subjects wore a video eyewear (Wrap920, Vuzix Corporation, NY, USA) with lightshield to block distracting outside light (Fig. 12), to display the video stimuli. This eyewear displays the video on a virtual 67-inch screen as seen from 10 feet. During the rest period between the tasks, a video clip in which there is a cross mark on a white board was displayed.

3.2.4 Task paradigm

RW, VW and WO tasks were performed 40 s every time, with a 30 s of rest before and after each task. In order to avoid the influence by the order of the tasks, two procedures were carried. Procedure 1 was performed in the following order.

Rest (30s) →VW (40s) →Rest (30s) →RW (40s) → Rest (30s) →WO (40s) →Rest (30s) →RW (40s) →Rest (30s)

Procedure 2 was performed in the following order.

Rest (30s) →RW (40s) →Rest (30s) →VW (40s)→ Rest (30s) →RW (40s)→Rest (30s) →WO (40s) →Rest (30s)

3.2.5 Data analysis

Oxy-Hb was considered as an indicator of changes in blood volume. The measurements of the subjects were checked visually for artifacts due to body movements. Obtained data were analyzed by calculating the average oxy-Hb level during RW, VW and WO. In the analysis we compared the average oxy-Hb of CH4, 5, 6, 7, 8, 10, 11, 12, 13, 14 which covered PM, SMA and M1 involved in planning and execution of movements related to walking.

3.2.6 Results and discussions

In Fig.15 and Fig.16, the color maps of typical activation pattern of oxy-Hb were extracted. These maps were created by interpolation to the measurement data of 24 measure points. It

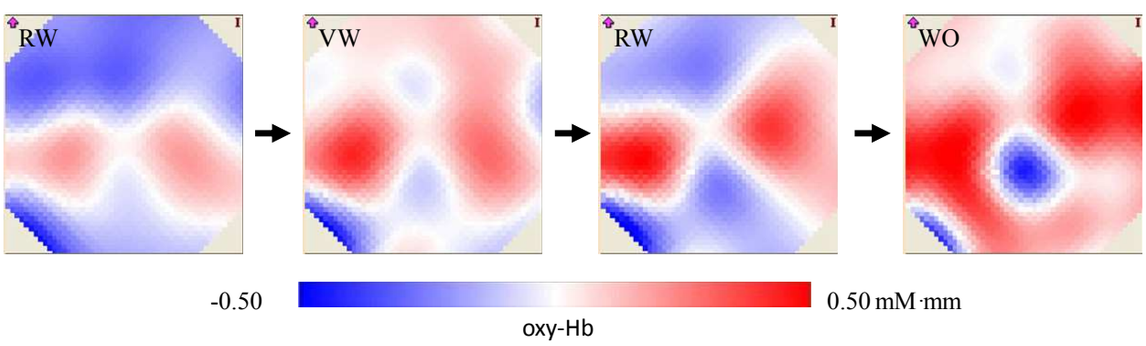


Fig. 15. Color maps of typical activation pattern in procedure 1

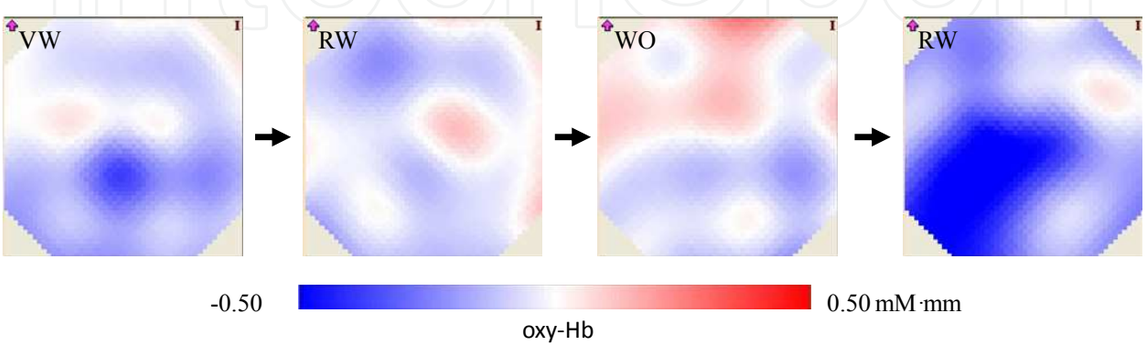


Fig. 16. Color maps of typical activation pattern in procedure 2

can be observed from the experiment results that both in procedure 1 and procedure 2, oxy-Hb increased significantly no matter the subject really walked or just imagined walking in first-person perspective and third-person perspective. The experiment results suggest that the cortical areas related to walking was activated by both real walking and imaginary walking. The oxy-Hb in procedure 2 was generally lower that in procedure 1. The same video clips were used in procedures 1 and 2. The adaptation of the subject to the tasks might be the reason for the decrease in oxy-Hb.

The average oxy-Hb of the 4 subjects during the tasks in procedures 1 and 2 are listed in Table 2. In procedure 1, for all the subjects, oxy-Hb during VW and RW were higher that that during the RW before them. In procedure 2, although the oxy-Hb was generally lower than procedure 1, the same pattern (oxy-Hb were higher during VW and RW than the RW after them.) was observed except one subject QQ with oxy-Hb during WO of -0.054 and oxy-Hb during RW of -0.031. We can conclude from Table 2 that although individual difference was significant, on the average, the oxy-Hb levels during VW and WO were higher than the RW, regardless of the order of the tasks. There was no significant difference observed in the oxy-Hb during VW and WO. Whether the subjects imagined from first-person perspective or from third-person perspective did not lead to significant difference in cortical activation of the brain regions we measured.

	Procedure 1				Procedure 2			
	RW	VW	RW	WO	VW	RW	WO	RW
YJ	-0.062	0.124	0.109	0.310	-0.050	-0.130	0.015	-0.038
RL	0.043	0.179	0.101	0.105	0.030	-0.092	-0.005	-0.090
QQ	0.182	0.286	0.387	0.443	-0.047	-0.090	-0.054	-0.031
LS	-0.047	0.002	0.002	0.056	-0.180	-0.300	-0.284	-0.311
Avg	0.029	0.148	0.150	0.228	-0.062	-0.153	-0.082	-0.117

**oxy-Hbs are given in mM·mm

Table 2. Average oxy-Hb during RW, VW and WO tasks

4. Conclusion

In our study, in order to verify the possibility of conducting neurological rehabilitation by mental imagery of walking and to find an effective way to activate the motor area in mental imagery, we compared the activation in motor areas during RW, VW, and WO, making use of the advantages of fNIRS. fNIRS measures cerebral hemodynamics non-invasively by monitoring the attenuation of near infrared light passing through tissue.

fNIRS measurement is comfortable for subjects, since it requires less constrictive circumstances of measurements and fewer movement restrictions. These advantages allow us to measure the cortical activation during real walking. The experiment results showed that the oxy-Hb during the mental imagery of walking task (VW and WO) was higher than that during the RW task. No significant difference was observed in the oxy-Hb during VW and WO, showing that they have the similar effect on the brain regions we measured. The importance of stimulus diversity was suggested in continuous stimulation of mental imagery of walking because the oxy-Hb level decreased with the adaptation of the brain to the stimuli.

On the other hand, the disadvantage of fNIRS is that it can only monitor limited brain areas and the spatial resolution is relatively low. fNIRS can only measure cerebral blood flow in the cortices, not in deeper structures. We need another method to find out how the other neural systems, such as cerebellum, the spinal cord and the peripheral nervous system, involve in mental imaginary of walking. Recently, a lot of studies which combined fNIRS with EEG (Wallois et al., 2011; Fazli et al., 2011) or fMRI with EEG (Horovitz et al, 2008; Mantini et al., 2010) have been reported. These combinations enable to make the best use of the advantages of each technology. The advantage of simultaneous EEG-fNIRS measurement is to provide a better temporal resolution and quantitative information about oxy-Hb and deoxy-Hb. The combination of EEG and fMRI is to make use of the high temporal resolution of EEG and the high spatial resolution of fMRI. A multimodal approach is necessary for better understanding the similarity and difference between RW, VW and WO.

5. Acknowledgment

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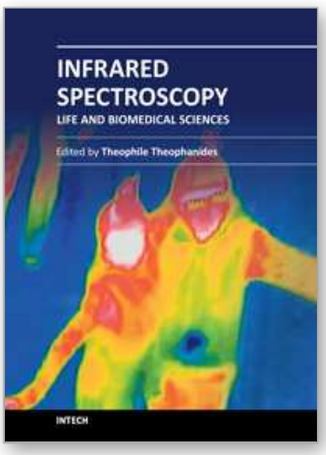

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This informative and state-of-the art book on Infrared Spectroscopy in Life sciences designed for researchers, academics as well as for those working in industry, agriculture and in pharmaceutical companies features 20 chapters of applications of MIRS and NIRS in brain activity and clinical research. It shows excellent FT-IR spectra of breast tissues, atheromatic plaques, human bones and projects assessment of haemodynamic activation in the cerebral cortex, brain oxygenation studies and many interesting insights from a medical perspective.

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