Research Report

Motion illusion activates the visual motion area of the brain: A near-infrared spectroscopy (NIRS) study

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ABSTRACT

Near-infrared spectroscopy (NIRS) enables noninvasive measurement of concentration changes of oxy- and deoxy-hemoglobin. The present study investigated cerebral representations of motion illusion by NIRS and examined several experimental procedures to determine an efficient procedure that can shorten the experimental time. We compared hemodynamic responses to figures with and without motion illusion. The number of repetitions of the tasks in the experiments and other factors were also examined. Results showed significant responses around area MT/V5 to the motion illusion from the analyses of three cycles (blocks) of presentation of illusion induction stimulus. These findings indicate that motion illusion can be detected by NIRS, and we propose a concise and efficient procedure for NIRS.

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1. Introduction

Near-infrared spectroscopy (NIRS) monitors regional changes of hemoglobin concentration associated with cortical activation, utilizing the tight coupling between neural activity and regional cerebral blood flow (Villringer and Dirnagl, 1995). NIRS is a very noninvasive and highly flexible neuroimaging method (Maki et al., 1995; Okamoto et al., 2004), and numerous cognitive studies have employed NIRS in various fields such as color Stroop (Schroeter et al., 2003), phonemic processing (Minagawa-Kawai et al., 2002), verbal fluency (Herrmann et al., 2003), Go–NoGo (Herrmann et al., 2005) and working memory (Hoshi et al., 2003). Most of these studies focused on the function of the frontal or temporal lobe. Some studies explored the occipito-temporal lobe using visual stimuli (Jasdzewski et al., 2003; Meek et al., 1995; Sato et al., 2004; Schroeter et al., 2004); however, to date, no studies have examined cerebral responses to motion illusion.

Motion illusion is a visual illusion in which subjective perception of the stimulus differs from its objective nature. There are many types of motion illusion, such as motion aftereffect, induced motion, apparent motion, autokinetic motion, wheel illusion, peripheral drift illusion, etc. Motion aftereffect is a well-known phenomenon in which a stationary stimulus appears to move in the direction opposite to a previously viewed moving pattern. Neuroimaging techniques have demonstrated that area MT/V5 is activated during perception of this illusion (Hautzel et al., 2001; Taylor et al., 2000; Théoret et al., 2002). Peripheral drift illusion refers to an anomalous rotatory motion illusion that can be observed in peripheral vision (Kitaoka and Ashida, 2003). It contains no physical motion for inducing the illusion and differs from the motion aftereffect in this respect. To our knowledge, only one PET study examined the neuronal correlates of the illusion induced by static stimuli (Zeki et al., 1993), and no neuroimaging investigation of the peripheral drift illusion has been reported.

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Table 1 – Number of channels that showed a significant oxy- and deoxy-Hb changes in response to the motion illusion (direct and indirect comparisons) and the actual motion

		Direct comparison			Indirect comparison			Actual motion
		5 cycles	First 3 cycles	First cycle	5 cycles	First 3 cycles	First cycle	
Left hemisphere	Oxy-Hb	7.10.11.19	7.11.17.21	–	7.8.9.11.12.13.16.17.18.21.22	7.9.13.18	–	7.12
	Deoxy-Hb	7	7	–	3.7	–	–	7.20
Right hemisphere	Oxy-Hb	3.4.7.17	11	–	10.11.12.14.18	1.5.11.14.16	–	7.12
	Deoxy-Hb	16	7.11.15.16	16.20	16	7.11.15.16	16.20	7.11

Since NIRS is highly noninvasive and requires no rigid fixation of the head, it is one of the best systems for measuring infants' brain function. However, because infants cannot remain quiet for a long time during recording, an efficient procedure for NIRS is required. A typical procedure for using NIRS is a block design, consisting of rest and test conditions. In their study on the executive functions of the prefrontal cortex, Hoshi et al. (2003) examined hemodynamic changes in this cortical area during the n-back task. They compared oxy-Hb changes in the 2-back test (Task A) with the rest (R) condition (Task A–R) and those in the 0-back test (Task B) with the R condition (Task B–R). Subsequently, they subtracted the latter from the former (Task A–R) – (Task B–R) to show the executive functions of the prefrontal cortex. Is it possible to directly compare Task A with Task B (Task A–Task B) in order to shorten the experimental time? In this direct method, however, it is important to know when the hemodynamic changes return to a baseline level. If they persist long after the end of Task A, and therefore after the start of Task B, the direct comparison might produce artifacts and imprecisely reveal the function of the recorded area.

The event-related design is another method of shortening the experimental time. The choice between these two designs depends on the functions to be examined.

In the present study, we examined hemodynamic responses to peripheral drift illusion using three stimuli. The first of the three stimuli had colors and produced motion illusion (Stimulus [Task] A). The second stimulus also had colors but did not induce motion illusion (Stimulus [Task] B). The third stimulus was monochromatic and did not produce motion illusion (Stimulus [Task] C). In the indirect method, we compared Task A with Task C, which might produce hemodynamic responses to color and motion illusion. We also compared Task B with Task C to examine the effects of color. Subsequently, we compared (Task A–Task C) with (Task B–Task C) to reveal hemodynamic changes in response to motion illusion. In the direct method, we contrasted Task A with Task B (Task A–Task B). If the results obtained by these two procedures are similar, the direct comparison would be preferable to shorten the experiment.

In conducting these experiments, we did not use a period of rest because resting is well known to evoke unstable brain activation (Gusnard and Raichle, 2001) and also spontaneous oscillations in hemodynamic levels that result in the noise component of NIRS signals. In addition to the assessment of methodology, we also examined the effects of the number of task repetitions on hemodynamic responses. Taken together, the present study examined whether NIRS can capture the brain activations around area MT/V5 elicited by the peripheral drift illusion and explored the possibility of a simple and efficient procedure for NIRS.

2. Results

Table 1 shows channels in which statistically significant Hb changes were observed in response to motion illusion. In
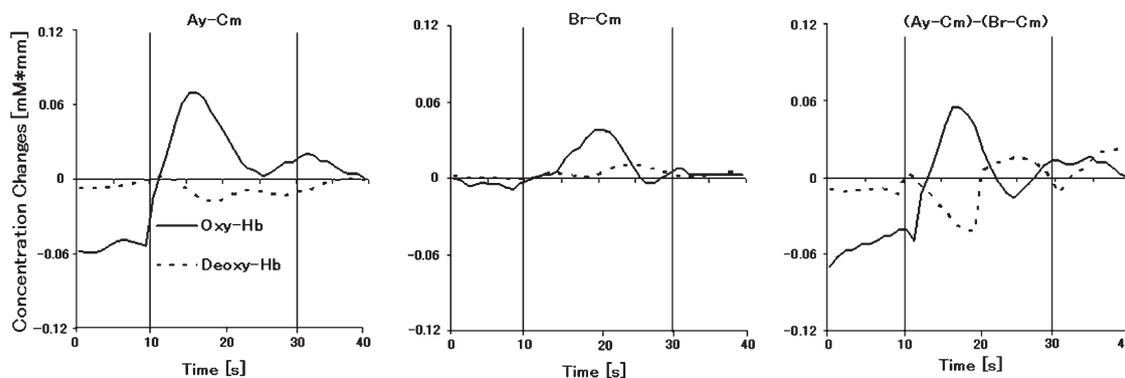

Fig. 1 – Oxy-Hb and deoxy-Hb time courses of the representative subjects for the indirect comparison task. Left: Task Ay–Task Cm. Middle: Task Br–Task Cm. Right: (Task Ay–Task Cm)–(Task Br–Task Cm).
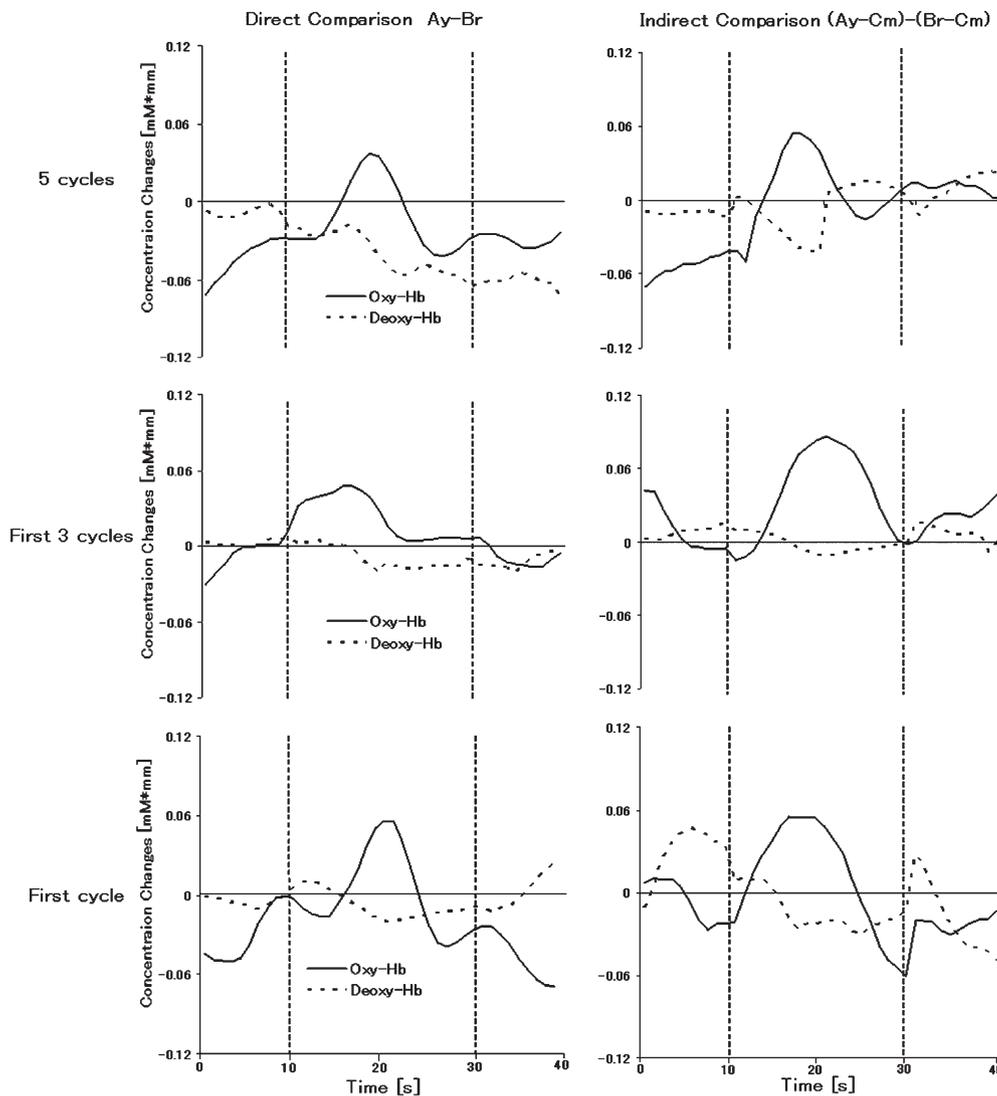
Fig. 2 – Oxy-Hb and deoxy-Hb time courses of the representative subjects for the direct and indirect comparison tasks in different analyses of repetition times. Left: direct comparison task (Task Ay–Task Br). Right: indirect comparison task ((Task Ay–Task Cm)–(Task Br–Task Cm)). Upper: data for the all 5 cycles. Middle: data for the first three cycles. Lower: data for the first cycle.

general, oxy-Hb increased and deoxy-Hb decreased during the presentation of the motion illusion in the direct and indirect conditions, i.e., (Ay–Cm) and (Ay–Cm)–(Br–Cm) comparisons.

Although deoxy-Hb decreased mainly in the target MT/V5 area, oxy-Hb increased in the target area and in the posterior temporal cortex. Channels in which changes in both oxy- and

Table 2 – Oxy-Hb and deoxy-Hb concentration changes [mM mm] averaged for all twelve subjects for each condition

		Direct comparison		Indirect comparison	
		Left MT test/control	Right MT test/control	Left MT test/control	Right MT test/control
Oxy Hb	5 cycles	0.025/0.012*	0.010/0.004*	0.017/0.005***	0.023/0.004*
	First 3 cycles	0.017/−0.011**	0.097/0.078*	0.015/−0.008*	0.027/−0.007*
	First cycle	0.010/−0.012	−0.013/−0.014	0.009/0.001	0.029/−0.012
Deoxy-Hb	5 cycles	−0.0214/−0.0148	−0.0350/−0.0161	−0.0008/0.0016	−0.0051/0.0036*
	First 3 cycles	−0.0267/−0.005*	−0.0125/−0.0008	−0.0094/−0.0022*	−0.0140/0.0042**
	First cycle	0.0019/0.0080	0.0063/0.0087	−0.0051/−0.0058	−0.0106/0.0041

The levels of significance for t test of comparison of test are indicated with *$P < 0.05$, **$P < 0.01$, ***$P < 0.005$.

deoxy-Hb were observed were located in the target MT/V5 area. Accordingly, we restrict the description of the Hb results to the target area.

Fig. 1 shows an example of oxy-Hb and deoxy-Hb changes in the indirect comparison task for a representative subject. As shown in the figure, in comparison with the control condition, a greater increase in oxy-Hb was observed in the motion illusion test condition (Ay–Cm) than in the color test condition (Br–Cm). On the other hand, a greater decrease in deoxy-Hb was shown in the motion illusion condition than in the color test condition.

Fig. 2 shows the time course of oxy- and deoxy-Hb changes for a representative subject for the direct (left panels) and indirect comparison (right panels). The three types of data analysis, i.e., five cycles, first three cycles and first cycle analyses for each comparison, are presented in the upper, middle and lower panels, respectively, for a representative subject. The level of oxy-Hb changes decreased slightly during the first 5 s of the test condition then rose sharply for approximately 5 s and declined to the pre-test level in many cases. Table 2 shows the oxy-Hb and deoxy-Hb changes averaged for all 12 subjects and statistical significance of each condition. Statistically significant oxy-Hb increases were revealed in the analysis of the first three and five cycles in both direct and indirect comparison tasks. Statistically significant deoxy-Hb decreases were found mainly in the analysis of the first three cycles. In contrast, the first cycle did not show significant oxy- and deoxy-Hb changes in both tasks. The greatest statistically significant oxy-Hb change was observed during the analysis of five cycles in the indirect comparison task, while that in the direct comparison was from the analysis of the first three cycles. In the direct comparison, a statistically significant deoxy-Hb change was observed in the analysis of the first three cycles showing a similar tendency to that in the indirect comparison.

The experiment using actual motion revealed that an identical target area (MT/V5) was also activated by the actual motion stimulus. The time courses of oxy- and deoxy-Hb changes in an actual motion experiment for a representative subject are shown in Fig. 3. The activation pattern including time course and amplitude was similar to that observed in the motion illusion experiments.
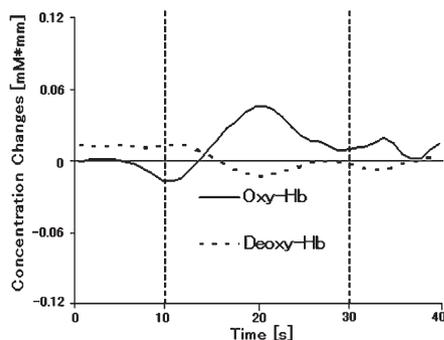

Fig. 3 – Oxy-Hb and deoxy-Hb time courses of the representative subject for the real movement experiment.

3. Discussion

Hemodynamic responses to peripheral drift illusion were observed in channels that cover the anterior occipital and posterior temporal cortices. Oxy-Hb changes were observed in the MT/V5 area and the posterior temporal cortex, whereas deoxy-Hb changes were seen around the MT/V5 area only. Thus, only the MT/V5 area showed both oxy- and deoxy-Hb changes. Peripheral drift illusion activated area MT/V5, as was reported in other motion illusion studies that employed fMRI, PET or TMS (Hautzel et al., 2001; Taylor et al., 2000; Théoret et al., 2002). The PET study by Zeki et al. (1993) reported the activation of area MT/V5 by the same type of illusion but has no actual motion. The present study replicated their results with NIRS and showed the usefulness of NIRS as a new noninvasive functional brain imaging technique. A recent NIRS study observed cerebral activation in response to actual moving colored stimuli (Schroeter et al., 2004) in the same occipito-temporal brain region as observed in our study.

The present study examined cortical activation associated with peripheral drift illusion in the occipito-temporal cortex using multichannel NIRS. We adopted the international 10–20 system to place NIRS probes by defining area MT/V5 as the area around T5/T6, based on the study by Okamoto et al. (2004). We defined a relatively broad area of MT/V5 in order to consider the individual variation of the brain region. Consequently, there is the possibility of including other regions near area MT/V5; however, some of these channels should include area MT/V5 in every subject. Both actual motion and motion illusion activated the same brain area around T5/T6 of the international 10–20 system that corresponded to area MT/V5. These results suggest the usefulness of adopting the international 10–20 system for studies using NIRS.

In many cases, the experimental designs of studies employing NIRS are block designs consisting of resting, test, and post-test resting periods. It is well known that resting somehow evokes brain activation and is supposed to be unstable (Gusnard and Raichle, 2001). Therefore, it would be inappropriate to use a resting control condition in some cases. In the present study, we did not employ a resting control condition but rather imposed the same task on the subjects in both the control and test conditions. Such a comparison of two conditions would extract the genuine neural correlates of the perceptual motion illusion, probably at the rather higher level.

We compared the two tasks (direct and indirect comparison tasks) to explore the possibility of shortening the duration of experiment. As a result, the direct comparison task showed activation similar to that of the indirect comparison task, indicating the effectiveness of indirect comparison that has a shorter experimental duration. As previously mentioned, shortening the duration of the experiment is important, especially when using NIRS, which is very useful for infant studies, and these findings may help to investigate infants effectively. However, before beginning the experiment, it is necessary to determine whether the changes in the oxy-Hb and deoxy-Hb return to the pre-test level during the test phase of 20 s.
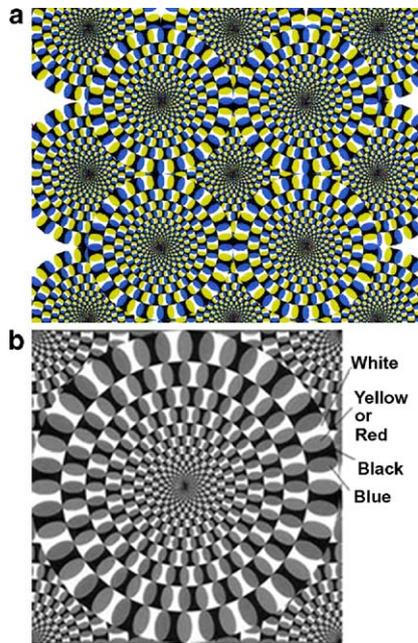
Fig. 4 – (a) The test stimulus that elicits peripheral drift illusion (Stimuli Ay and Br). (b) The control stimulus that elicits no perception of rotatory motion (Stimulus Cm).

or superior in the deoxy-Hb results to those of all five cycles. These results suggest that three repetitions are sufficient to measure the brain activation in response to the motion illusion stimulus. This also contributes to further shortening the experimental duration. Only 140 s was required to measure hemodynamic changes from a subject in the three-cycle condition in the direct task.

In summary, the region that we defined as area MT/V5 was clearly activated by motion illusion, and we developed a concise procedure for use in NIRS experiments, that is, without the resting control, two paradigms can be compared directly using only three repetitions.

4.   Experimental procedures

4.1.   Subjects

Twelve healthy right-handed volunteers (5 males, 7 females; age, 20–60 years) participated in the motion illusion experiment. In an additional actual motion experiment, 12 healthy right-handed volunteers (6 males, 6 females; age 20–60 years) served as subjects. Half of these subjects participated in the prior motion illusion experiment. They did not have any neurological and optical abnormalities. Informed consent was obtained before the experiment.

4.2.   Materials

The test stimulus was a peripheral drift illusion figure that was originally designed by Kitaoka and Ashida (2003) (http://www.ritsumei.ac.jp/~akitaoka/index-e.html). It consisted of white, yellow, black and blue circles (Stimulus Ay), and all the subjects that were present reported an obvious drift illusion in response to this stimulus (Fig. 4). The same pictures with different colors were

Furthermore, the number of repetitions required is of great interest. Only the one-cycle measurement is vulnerable to many factors, and almost no activation was observed during the first cycle in the present study. The results of the first three cycles were approximately equal in the oxy-Hb results
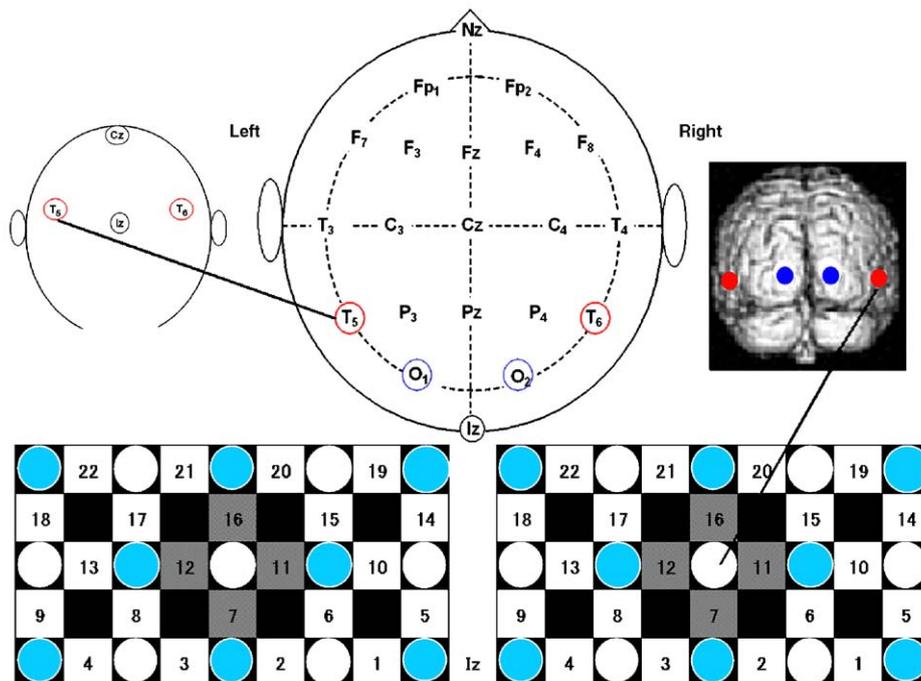

Fig. 5 – Positions of the NIRS channels. The channels were located over the occipito-temporal region (6 × 12 cm² area centered on T5/T6). The distance between the consecutive optodes was set at 3 cm.

used as control stimuli; they were the monochromatic stimulus (Stimulus Cm) and red–blue figure stimulus (Stimulus Br), in which the red color replaced the yellow color in the Stimulus Ay. The subjects reported little drift illusion in response to Stimuli Br and Cm. Each figure was 12.5 cm × 19.5 cm in size and was presented on a 17-in. monitor to the subjects at a distance of approximately 57 cm from the display.

4.3. Experimental design and procedure

Two measurement paradigms, direct and indirect comparison tasks, were given using a block design paradigm. The present study did not employ event-related design for it takes time to evoke motion illusion. In the direct comparison task, Stimulus Ay and Stimulus Br were used as stimuli in the test condition and control condition, respectively. Stimulus Ay task (Ay task, test condition) and Stimulus Br task (Br task, control condition), each of which lasted for a period of 20 s, were repeated for five cycles that began with an additional Br task (Br, Ay–Br, Ay–Br, …Ay–Br). In the indirect comparison task, Stimuli Ay and Br were used as a stimulus in the test condition, whereas Stimulus Cm was used as a stimulus in the control condition. The Br–Cm task and Ay–Cm task, each of which have a 20 s test condition period and 20 s control condition period (Cm-task), were repeated for five cycles in a random order with an additional Cm task at the beginning (Cm, Br–Cm, Ay–Cm, …Br–Cm).

In both tasks, the subjects were instructed not to gaze at a single point in the figures but to view the entire figure so as to find motion illusion in the figure. Prior to NIRS measurement, the stimulus figures were shown to all subjects to confirm that Stimulus Ay evoked strong drift illusion; in contrast, Stimuli Br and Cm did not.

All of the subjects participated in the actual motion experiment, in which a circle (4.3 cm in diameter) reported a perception of circular movement (12 cm in diameter, five cycles/20 s) in the test condition, in contrast to the stationary circle at the center of the monitor in the control condition. Both conditions lasted for a period of 20 s and were repeated for five cycles with an additional control condition at the beginning.

4.4. NIRS measurement system

We used a multichannel NIRS system (ETG-7000, Hitachi Medical Corporation). Near-infrared light with wavelengths of 780 nm and 830 nm was guided by optical-fiber bundles (2 mm in diameter) and transmitted into the cranium. The reflection of the infrared light was sampled by receiving probes placed on the scalp, 3.0 cm away from the emitting probes, and it was detected every 1 s by silicon photodiodes. The detected signal was separated into two components that corresponded to the two wavelengths of 780 nm and 830 nm with lock-in amplifiers (Maki et al., 1995). The changes in both oxy-hemoglobin (oxy-Hb) and deoxy-hemoglobin (deoxy-Hb) were calculated using the difference in the absorption indexes for the two wavelengths. No filter was used, and the moving average with a smoothing factor of 5 was applied to reduce noise. There has been controversy concerning the choice between oxy- and deoxy-Hb as an adequate index of the hemodynamic response to cognitive processes (Hoshi et al., 2001; Obrig et al., 2000). In the present study, we adopted concentration changes in both oxy- and deoxy-Hb as indicators of changes in regional cerebral blood volume (rCBV).

4.5. Placement of NIRS channels

We used a pair of probe holders on the occipital lobe of both hemispheres, each embedded with three emitting and receiving probes, resulting in 22 channels for each holder (44 in total). Since the locations in the international 10–20 system have an appropriate relationship with cortical anatomy (Okamoto et al., 2004), we
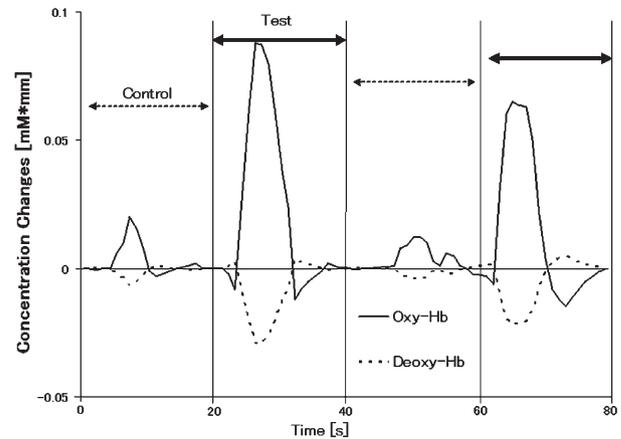

Fig. 6 – Time chart of the control and test periods.

placed the channels by referring to the system. Specifically, the channels in the left hemisphere were placed so that the central four channels (channels 7, 11, 12 and 16) fitted around the T5 of the international 10–20 system (Fig. 5). Channels in the right hemisphere were also set symmetrically. Brain activation in the occipito-temporal cortex, which includes area MT/V5 that is engaged in processing moving stimuli, can be measured by this placement.

Each channel was separated by 3 cm, and the region measured was 3 cm in diameter around T5/T6. In individual subjects, the position of area MT/V5 in both hemispheres varied by a maximum of 27 mm on the left and 18 mm on the right, after stereotaxic normalization. The methodological details of stereotaxic normalization have been reported by Friston et al. (1990). Even after averaging across groups of six subjects, the variation in location could still be as large as 13 mm (Meek et al., 1995). Thus, the regions measured by each of the four channels are considered to include area MT/V5 in all subjects.

4.6. Analysis of NIRS data

Concentration changes in oxy-Hb and deoxy-Hb were analyzed. We calculated the average concentration change of oxy-Hb and deoxy-Hb in the test and the control conditions (see Fig. 6) for each subject. Data obtained during the initial 5 s in both conditions were excluded from analysis to avoid transition period effects. For the direct comparison, the averaged Hb responses across subjects to Stimulus Ay and Stimulus Br were compared using paired t test (Ay–Br). For the indirect comparison, the responses to Stimulus Ay and Stimulus Br were subtracted from those to Stimulus Cm and then statistically compared using paired t test (Ay–Cm)–(Br–Cm). Three types of data analysis were performed: the first cycle, the average of the first three cycles and all five cycles. Oxy-Hb and deoxy-Hb changes for the actual motion were also calculated. The concentration changes of all four channels around T5/T6 were averaged. Since the region of the brain differed in individuals, we defined the averaged Hb concentration changes of four channels as the activation of T5/T6 in every subject.

Acknowledgments

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