

# Changes of Evoked Cerebral Blood Oxygenation and Optical Pathlength in the Frontal Lobe During Language Tasks: A Study by Multi-Channel, Time-Resolved Near-Infrared Spectroscopy and Functional MRI

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**Abstract** To determine the alterations in optical characteristics and cerebral blood oxygenation (CBO) in the frontal lobe during language tasks, we evaluated the changes in mean optical pathlength (MOP) and CBO induced by a verbal fluency task (VFT) in the right and left frontal lobes in normal adults ( $n = 9$ , mean age =  $29.6 \pm 4.8$  years). We employed a newly developed 8-channel time-resolved near-infrared spectroscopy (TRS) instrument. The results demonstrated differences in MOP in the fronto-temporal areas with subject and wavelength; however, there was no significant difference between the right and left sides ( $p > 0.05$ ). Also, the VFT did not affect the MOP significantly as compared to that before the tasks ( $p > 0.05$ ). In all of the recording regions, the VFT caused increases in concentration of oxyhemoglobin and total hemoglobin associated with a decrease in deoxyhemoglobin concentration, indicating that these cortical areas were activated by the VFT. However, the mean concentration changes of oxyhemoglobin and total hemoglobin on the left side were larger than those on the right side. In addition, functional MRI demonstrated that the inferior frontal gyrus on the left side was activated in the subjects who exhibited increases in oxyhemoglobin concentration in these areas. These results suggest that TRS may be useful to study language function and to assess hemispheric dominance for language.

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## 1 Introduction

Near-infrared spectroscopy (NIRS) is a non-invasive method for investigation of functional activation in the human cerebral cortex [1]. BOLD-fMRI is also useful to image activated areas in brain. BOLD-fMRI does not provide precise information about evoked cerebral blood oxygenation (CBO) changes during activation.

In the present study, employing newly developed multichannel TRS, we evaluated the evoked CBO changes in the bilateral frontal-temporal area, including Broca's area, during a language task. In order to determine language dominance, we compared the evoked CBO changes in the left and right measurement sites. The results were compared with activation maps of BOLD-fMRI. In addition, we examined whether the MOP affects the determination of language dominance by measurements of evoked CBO changes.

## 2 Method

We investigated 10 normal adult subjects (9 men and 1 woman; mean age,  $28 \pm 0.05$  years [mean  $\pm$  SD]). We employed a verbal fluency task (VFT), which entails naming as many animals or fruits as possible, as the language task; the VFT is a well-established neuropsychological test of frontal lobe function [2]. An 8-channel TRS system was used [3]. Four channels on each side were mounted on a thermoplastic shell, which were placed over the inferior frontal gyrus (including Broca's area) on both sides. The location of the channels was adjusted by MRI (Fig 1a). The evoked CBO changes were compared with the results of BOLD imaging obtained by means of 1.5 T MRI (Symphony, Siemens, Germany).

## 3 Results

In all subjects, the VFT significantly altered the CBO in all measurement sites. The VFT caused increases of oxyhemoglobin ( $O_2Hb$ ) and total Hb (tHb) associated with a decrease of deoxyhemoglobin (HHb). These evoked CBO

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**Fig. 1** (continued) **(a)**: Eight channel probes were placed over the bilateral fronto-temporal area including inferior frontal gyrus based on surface anatomical imaging by MRI. The probes were named as follows; R1 (*right* side superior probe), R2 (*right* side anterior probe), R3 (*right* side inferior probe), R4 (*right* side posterior probe), L1 (*left* side superior probe), L2 (*left* side anterior probe), L3 (*left* side inferior probe), L4 (*left* side posterior probe). **(b)**: Typical example of the CBO changes in the *right* and *left* fronto-temporal areas during the course of the experiments. The ordinates indicate the concentration changes of  $O_2Hb$  (*red* lines), HHb (*blue* lines), and tHb (*green* lines) in  $\mu M$ . The thick bars below the NIRS parameter changes indicate the periods of the tasks. The VFT caused increases of  $O_2Hb$  and tHb associated with a decrease of HHb

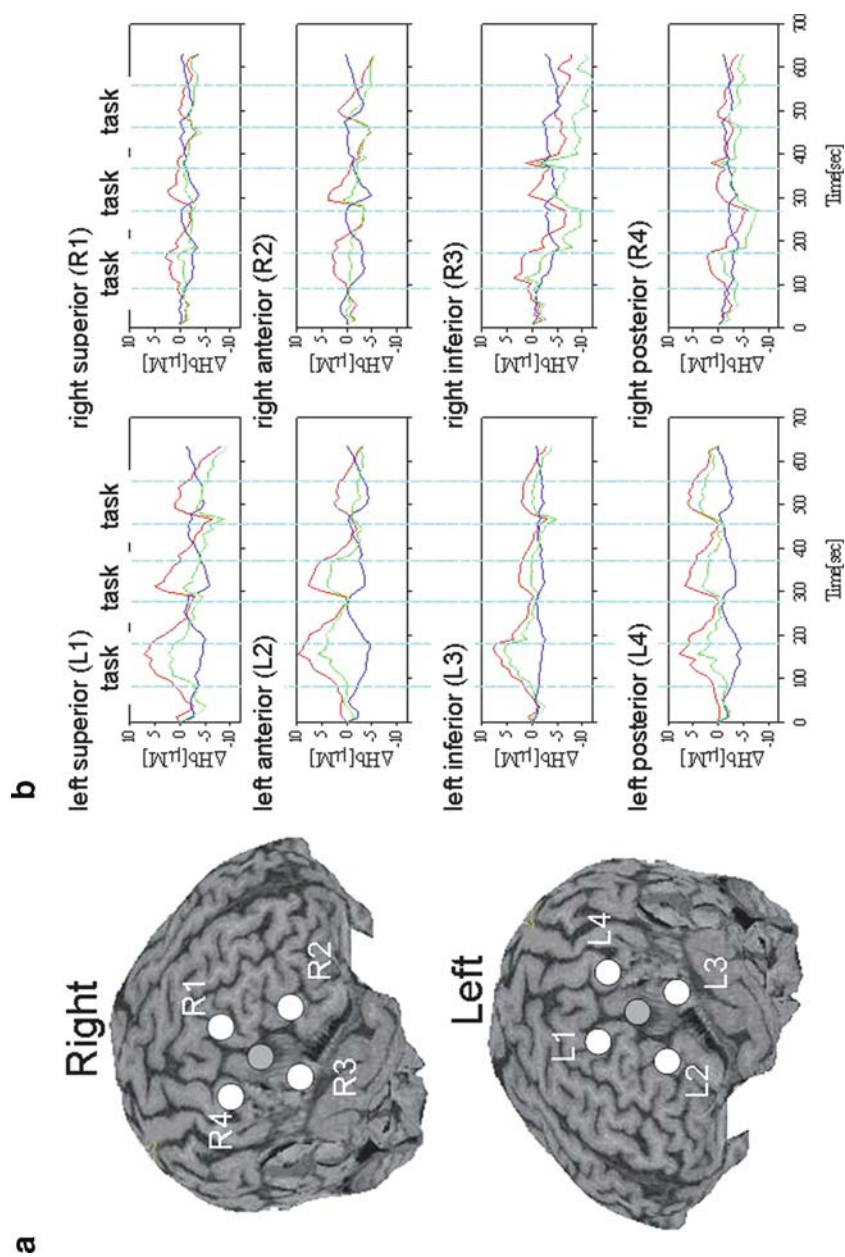


Fig. 1 (a) (continued)

changes returned to the control level during the recovery phase. Figure 1b shows a typical example of the CBO changes. The mean concentration changes of O<sub>2</sub>Hb and tHb on the left side of all measurement sites were larger than those on the right side, and the difference between the left and right sides was significant for O<sub>2</sub>Hb, though not for tHb (Fig. 2). The results demonstrated differences in MOP in the fronto-temporal areas with subject and wavelength; however, there was no significant difference between the right and left sides in each measurement site ( $p > 0.05$ ). Also, the VFT did not affect the MOP significantly as compared to that before the tasks ( $p > 0.05$ ). The BOLD-fMRI results demonstrated that the fronto-temporal area, particularly around the inferior frontal gyrus on the left side, was activated in the subjects (Fig. 3)

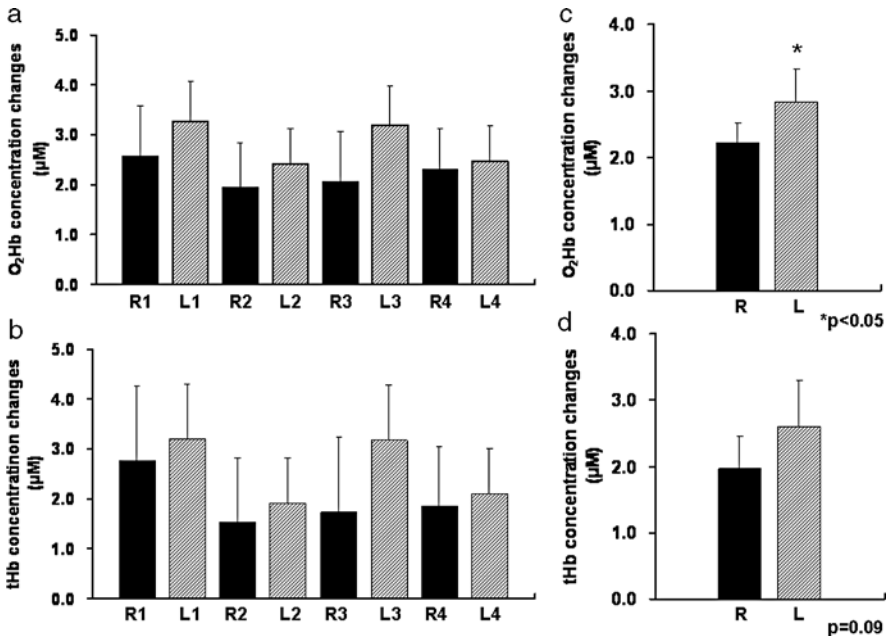


Fig. 2 Bar graphs indicate the average of O<sub>2</sub>Hb (a) and tHb (b) concentration changes during the task detected by each probe (i.e. R1-4, L1-4). Both O<sub>2</sub>Hb and tHb were significantly increased during the task. Additionally, the average of O<sub>2</sub>Hb and tHb changes on the *left* side were larger than those in the *right* side, however, the differences were not significant at each measurement site. Bar graphs (c) and (d) show comparisons between the mean O<sub>2</sub>Hb and tHb concentration changes in all measurement sites on the *left* side and those on the *right* side. O<sub>2</sub>Hb and tHb changes on the *left* side were larger than those on the *right* side. The difference between the *left* and *right* sides in O<sub>2</sub>Hb was significant ( $p < 0.05$ ), whereas that in tHb was not significant ( $p = 0.09$ )

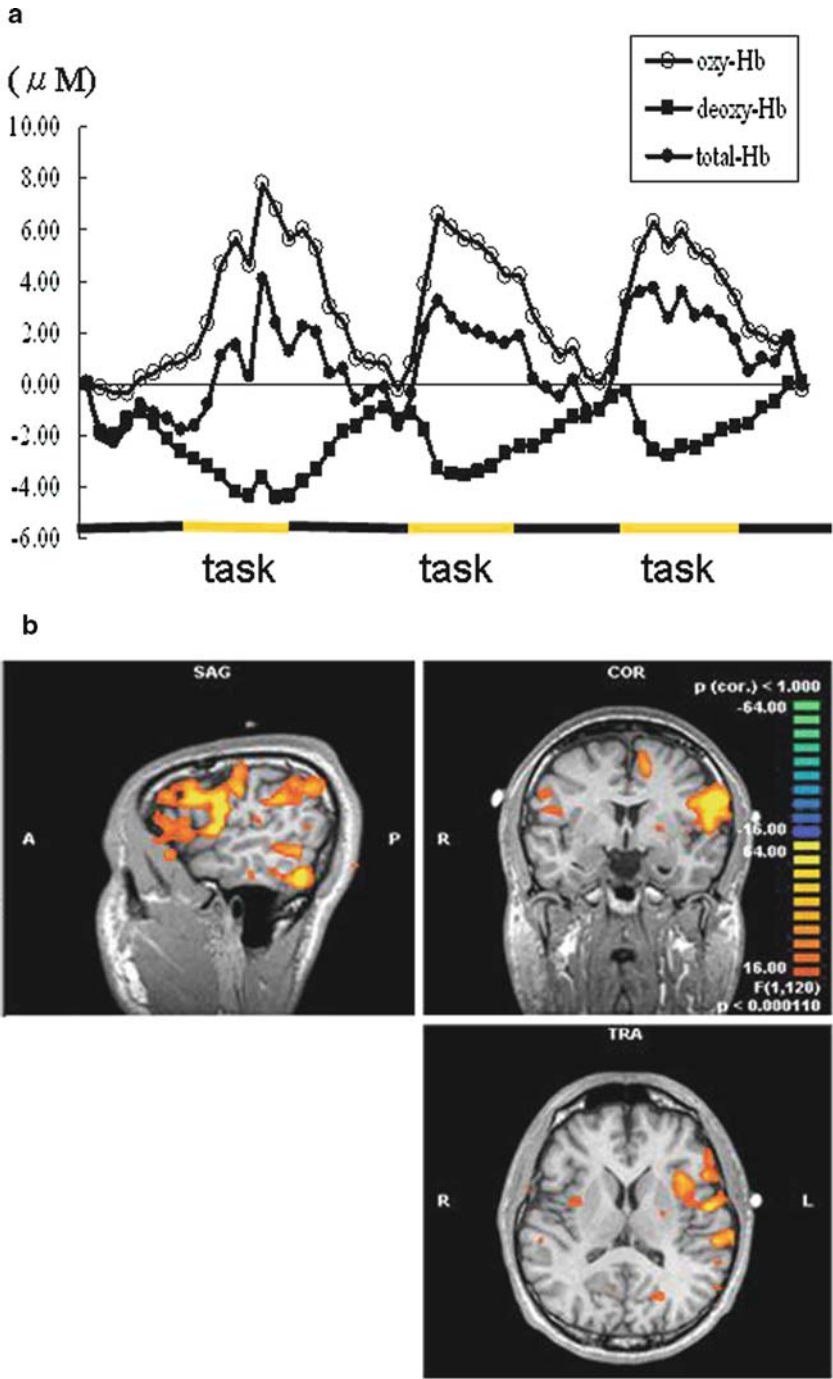


Fig. 3 (continued)

## 4 Discussion

The present time-resolved NIRS allowed measurements of the MOP changes during tasks with a sampling time of 1 s. We observed no significant difference in MOP at each wavelength during the tasks, although there were small fluctuations of the MOP ( $SD < 0.2$  cm). This implies that the task-induced hemodynamic changes in the fronto-temporal area did not significantly affect the light scattering in the brain tissue, although the absorption was affected by the Hb concentration changes. The increase in  $O_2Hb$  indicates that rCBF rises in the activated area, while the decrease in HHb is caused by a large increase of rCBF, which exceeds the increase in oxygen consumption during activation [4]. BOLD-fMRI revealed activation in the left inferior temporal gyrus during the language task in this study. Additionally, the mean concentrations of  $O_2Hb$  and tHb on the left side were larger than those on the right side in TRS measurement. It was considered that the CBO change evaluated by TRS measurement is compatible with the result of BOLD-fMRI. However, there is a possibility that systemic changes (such as blood pressure and so on) may influence the difference between left and right in NIRS measurement [5]. The findings in this study suggest that TRS may be useful to study language function and to assess hemispheric dominance for language.

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**Fig. 3** (continued) (a): CBO changes during the task detected by the L2 (*left side anterior*) probe of TRS is shown. Increases of  $O_2Hb$  and tHb associated with a decrease of HHb were observed. *Yellow* and *black* bars indicate task and rest, respectively. (b): BOLD-fMRI revealed robust activation in the fronto-temporal language area