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Activation of the visual cortex imaged by 24-channel near-infrared spectroscopy

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Abstract. Near-infrared spectroscopy (NIRS) is a noninvasive technique for continuous monitoring of the amounts of total hemoglobin (total-Hb), oxygenated hemoglobin, (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb). The purpose of the present study was to demonstrate the utility of NIRS in functional imaging of the human visual cortex. A new NIRS imaging system enabled measurements from 24 scalp locations covering a 9 cm sq area. Topographic images were obtained from interpolations of the concentration changes between measurement points. Five healthy subjects between 25 and 49 years of age were investigated. After a resting baseline period of 50 s, the subjects were exposed to a visual stimulus for 20 s, followed by a 50 s resting period in a dimly lit, sound attenuating room. The visual stimulus was a circular, black and white, alternating checkerboard. In four of five subjects the visual cortex was the most activated area during visual stimulation. This is the first reported use of a NIRS-imaging system for assessing hemodynamic changes in the human visual cortex. The typical hemodynamic changes expected were observed; the total-Hb and oxy-Hb increased just after the start of stimulation and plateaued after 10 s of the stimulation period. [S1083-3668(00)00301-4]

Keywords: NIRS; visual cortex; functional imaging.

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1 Introduction

Near-infrared Spectroscopy (NIRS) is a noninvasive technique for continuously monitoring total hemoglobin (total-Hb), and the amounts of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb).[1] Although NIRS provides only low spatial resolution and can generate only two-dimensional surface mapping, it offers the advantages of noninvasive measurement and high temporal resolution. Further, NIRS provides relatively strong immunity to artifacts from body movements; its compact mechanism can conveniently make long continuous recordings from the bedside, and it does not prevent the simultaneous use of other measurement systems such as electroencephalograms (EEGs).

Vision is the most-studied and perhaps best understood modality in human information processing, and it is an important component in human sensation, perception, and recognition. Demonstrating the feasibility of NIRS imaging of the visual cortex is an important step for developing its clinical use. Functional imaging with NIRS could play an important role in the development of cognitive testing. The present study demonstrates that NIRS can be used to derive functional imaging of the human visual cortex.

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2 Method

The 24-channel NIRS system (developed by Central Research Laboratory, Hitachi Ltd.) used in the present study features new multiwavelength, multiposition methods.[2–4] Figure 1 shows the grid arrangement of the 16 optical fibers (closed gray circles) and 24 measuring points (numbered black squares). Optical fibers were evenly spaced at 30 mm intervals. Two wavelengths of light, 780 and 830 nm, were combined and emitted through the optical fibers every 500 ms. Light reflected from the underlying cerebral cortex was also detected by the optical fibers. The set of 16 optical fibers was fixed on the subject's head that was encased in a thermoplastic shell molded to precisely fit each subject's right or left hemioccipital area. The fiber array covered a 9 cm×9 cm area of the scalp. The changes in oxy-Hb and deoxy-Hb concentration were measured at each fiber simultaneously. The total-Hb was calculated as the sum of oxy-Hb and deoxy-Hb.

Topographic images were obtained from a third-order spline function for interpolating Hb concentration changes in 24 measurement positions. Concentration changes in Hb were calculated based on Beer–Lambert law. No pathlength correction was used. The concentration changes were localized within the cerebral cortex for brain activity. Pathlength correction is usually effective for global Hb concentration changes so there was little merit in considering pathlength correction.

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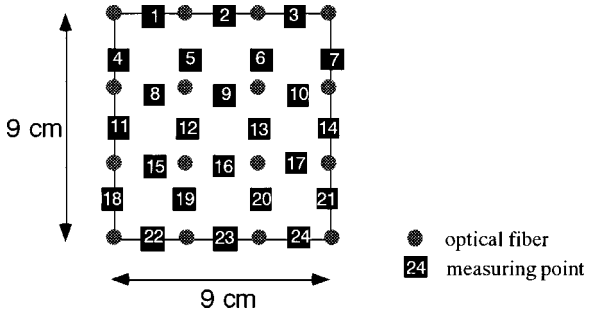

Fig. 1 Arrangement of 24-channel measuring points. Sixteen optical fibers (closed gray circles) were arranged at 30 mm intervals, enabling measurement at 24 points (numbered black squares) on the scalp. The optical fiber array covers a 9 cm×9 cm area.

3 Subjects and Procedure

Five healthy subjects between 25 and 49 years of age were investigated after informed consent was obtained. The visual stimulus was a circular, black and white, alternating checkerboard displayed on a screen positioned 60 cm from the subject's eyes in a sound-attenuated, dimly lit room. A checkerboard reversal was parametrically manipulated at four frequencies, 1, 3.75, 7.5, and 15 Hz. After a baseline period of 50 s, the subjects were exposed to the visual stimulus for 20 s, followed by a 50 s resting period. Each experimental series consisted of 72 stimulation intervals.

After visually identifying and excluding trials contaminated by artifacts, data from all four of the checkerboard reversal frequencies mentioned above were averaged for each subject. The number of data used for calculations ranged from 59 to 68 across subjects. The average concentration change during the last 40 s in the pre-stimulation period was used as the baseline value for each trial. The average increase or decrease of oxy-Hb, deoxy-Hb, and total-Hb during each stimulation period was calculated and used to generate a contour map.

4 Results

Figure 2 topographically represents the changes in regional oxy-Hb concentration recorded by 24-channel NIRS topography of five subjects (ss-A, B, C, D, E). The values represent changes during the 20 s visual stimulation period compared to the pre-stimulation period. Each topographic view is a rear view of the head, with a vertical dotted line indicating the midline of the brain. The asterisked (*) point on each topographic view shows the measuring point that is nearest to each subject's anatomically identified visual cortex according to magnetic resonance imaging (MRI). Dark gray areas indicate increases in oxy-Hb by visual stimulation. Light gray areas indicate decreased oxy-Hb concentration. With the exception of subject ss-B, the asterisked V1 area identified from MRI in four of five subjects was mapped as the most activated area. We have presented only the map of oxy-Hb. The map of total-Hb is similar to the map of oxy-Hb, and the map of deoxy-Hb is almost a reverse pattern of the map of oxy-Hb.

Figure 3 presents the time course of the concentration changes in three hemoglobin measures as the total average from five subjects. Because there were considerably large differences among individuals in the range of values that changed, averaging raw data of individuals was not specific enough to determine a representative time course for the five subjects. To minimize interindividual variations of ranges, the individual data were *Z* transferred (a series of individual data were transferred to obtain a mean of 0 and a variance of 1) and averaged. The black line represents changes in oxy-Hb, while the dotted and gray lines show changes in deoxy-Hb and total-Hb, respectively. Data were selected from the measuring point nearest to each subject's MRI-identified visual cortex (shown by asterisks in Figure 2). The hemoglobin values at the selected measuring point were then standardized by *Z* transformation for each subject before these values were averaged for all five subjects.

An expected series of hemodynamic changes is clearly evident in Figure 3; the total-Hb and oxy-Hb increased immediately following the onset of stimulation, plateauing after 10 s for the remainder of the stimulation period. These changes then decreased to their pre-stimulation level in the 10 s following the end of stimulation. Similarly, and opposite to the change in total-Hb and oxy-Hb, deoxy-Hb decreased during the stimulation period.

5 Discussion

NIRS has previously been used to measure activation of the cerebral cortex. Obrig et al. reported motor area activation by a finger opposition task.[5] The same task has also been shown to activate the primary sensorimotor cortex.[6,7] Hock et al. showed that during the performance of a verbal fluency task,

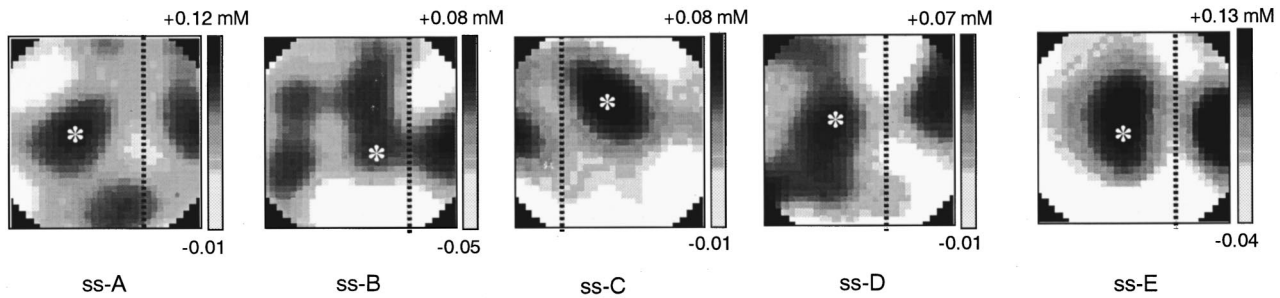

Fig. 2 NIRS 24-channel topography for five subjects. Each topographic view (subjects ss-A, -B, -C, -D, -E) is rear view of the head. The vertical dotted line indicates the midline of the brain. The points shown by asterisks (*) were anatomically identified from MRIs of each subject to be nearest the primary visual cortex. Dark gray areas indicate increases in oxy-Hb by visual stimulation. Light gray areas indicate decreases in oxy-Hb.

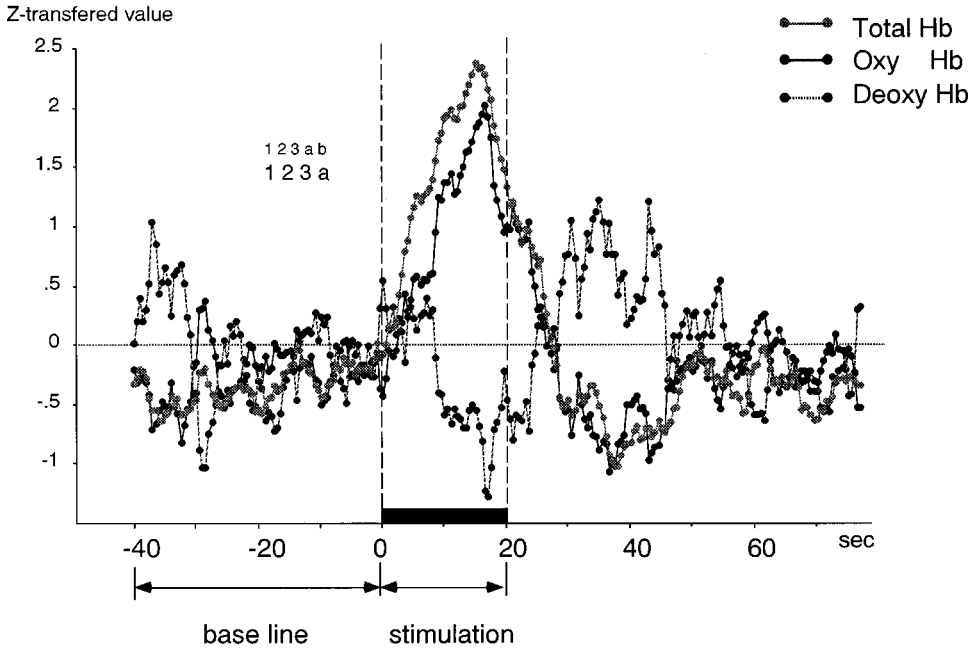

Fig. 3 Hemodynamic changes at the visual cortex. The time course of total-Hb, oxy-Hb, and deoxy-Hb changes at the visual cortex represented by *Z*-transferred values as the total average of five subjects (standardized and averaged from five subjects). The black line represents oxy-Hb; the dotted line deoxy-Hb; the gray line total-Hb. The typical hemodynamic changes expected were observed; total-Hb and oxy-Hb increased during stimulation whereas deoxy-Hb decreased.

normal subjects showed activation of the left superior parietal cortex.[8] Right frontal activation during the continuous performance test was reported by Fallgatter and Strik.[9] The time course of total-Hb, oxy-Hb, and deoxy-Hb changes in the activated cerebral cortex found in these studies is consistent with the present results, that is, during cortical activation the total-Hb and oxy-Hb increase and deoxy-Hb decreases.

A few studies have reported NIRS evidence of hemodynamic changes related to the human visual cortex.[10–12] Villringer et al.[10] reported hemodynamic changes in the visual cortex that were induced by light flashing and picture stimulation.

For the most part the NIRS studies described above used single channel systems. Few have reported multichannel analyses. Watanabe et al.[13] reported activation of the precentral gyrus during opposing finger movements that was measured using a 10-channel NIRS system. To our knowledge there has been no reported study of the visual cortex using multichannel NIRS or NIRS imaging. The present study appears to be the first to report the use of a NIRS-imaging system to assess changes in the human visual cortex. Zeki et al. reported that activation of the visual cortex could be visualized using positron emission tomography (PET)[14] and their results agree with our findings; the area nearest to the V1 cortex was activated during visual stimulation.

Although the spatial resolution of the NIRS topography is poor at about 25 mm,[2,3] the topography obtained in the present study indicates the usefulness of multichannel NIRS for studying brain function, especially in situations where portability and noninvasive continuous monitoring are necessary. For example, hemodynamic monitoring during cognitive testing examinations may be one very fruitful application of NIRS imaging. Similarly, pairing of NIRS rCBV monitoring with EEG or other conventional methods could provide new opportunities to precisely measure brain functions.

References

1. F. Jobsis, ''Noninvasive infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters,'' *Science* **198**, 1264–1267 (1977).
2. Y. Yamashita, A. Maki, and H. Koizumi, ''A noninvasive optical topography measurement system,'' *OSA TOPS on Adv. Opt. Imaging Photon Migration* **2**, 344–347 (1996).
3. Y. Yamashita, A. Maki, and H. Koizumi, ''Near-infrared topographic measurement system: Imaging of absorbers localized in a scattering medium,'' *Rev. Sci. Instrum.* **67**(3), 730–732 (1996).
4. A. Maki, Y. Yamashita, Y. Ito, E. Watanabe, Y. Mayanagi, and H. Koizumi, ''Spatial and temporal analysis of human motor activation using non-invasive NIR topography,'' *Med. Phys.* **22**, 1997–2005 (1995).
5. H. Obrig, C. Hellmuth, C. Hirth, J. G. Junge-Hulsing, C. Doge, T. Wolf, U. Dirnagl, and A. Villringer, ''Cerebral oxygenation changes in response to motor stimulation,'' *J. Appl. Physiol.* **81**(3), 1174–1183 (1996).
6. A. Kleinschmidt, H. Obrig, M. Requardt, K. Merboldt, U. Dirnagl, A. Villringer, and J. Frahm, ''Simultaneous recording of cerebral blood oxygenation changes during human brain activation by magnetic resonance imaging and near-infrared spectroscopy,'' *J. Cereb. Blood Flow Metab.* **16**, 817–826 (1996).
7. C. Hirsh, H. Obrig, K. Villringer, A. Thiel, J. Bernarding, W. Muhlnickel, H. Flor, U. Dirnagl, and A. Villringer, ''Non-invasive functional mapping of the human motor cortex using near-infrared spectroscopy,'' *NeuroReport* **7**, 1977–1981 (1996).
8. C. Hock et al., ''Decrease in parietal cerebral hemoglobin oxygenation during performance of a verbal fluency task in patients with Alzheimer's disease monitored by NIRS—Simultaneous rCBV-PET measurements,'' *Brain Res.* **755**, 293–303 (1997).
9. A. Fallgatter and W. Strik, ''Right frontal activation during the continuous performance test assessed with near-infrared spectroscopy in healthy subjects,'' *Neurosci. Lett.* **223**, 89–92 (1997).

10. A. Villringer, J. Planck, C. Hock, L. Schleinkofer, and U. Dirnagl, ''Near infrared spectroscopy (NIRS): A new tool to study hemodynamic changes during activation of brain function in human adults,'' *Neurosci. Lett.* **154**, 101–104 (1993).
11. J. H. Meek, M. Fairbank, C. E. Elwell, J. Atkinson, O. Braddick, and J. S. Wyatt, ''Regional hemodynamic responses to visual stimulation in awake infants,'' *Pediatr. Res.* **43**(6), 840–843 (1998).
12. R. Wenzel, R. Obrig, J. Ruben, K. Villringer, A. Thiel, J. Bernardig, and U. Dirnagl, and A. Villringer, ''Cerebral blood oxygenation changes induced by visual stimulation in humans,'' *J. Biomed. Opt.* **1**, 399–404 (1996).
13. E. Watanabe, Y. Yamashita, A. Maki, Y. Ito, and H. Koizumi, ''Non-invasive functional mapping with multi-channel near infra-red spectroscopic topography in humans,'' *Neurosci. Lett.* **205**, 41–44 (1996).
14. S. Zeki, J. D. G. Watson, C. J. Lueck, K. J. Friston, C. Kennard, and R. S. J. Frackowiak, ''A direct demonstration of functional specialization in human visual cortex,'' *J. Neurosci.* **11**, 641–649 (1991).