Simultaneous Measurement System of Hemodynamic Responses using Functional MRI and Near-Infrared Spectroscopy

K. Kashikura[1], H. Toyoda[2], T. Sato[2], Y. Yonekura[2]

[1]Department of Radiological Technology, Gunma Prefectural College of Health Sciences, Maebashi-shi, Gunma-ken, Japan, [2]Biomedical Imaging Research Center, University of Fukui, Yoshida, Fukui, Japan

Introduction: Functional magnetic resonance imaging (fMRI) using blood oxygenation level-dependent (BOLD) contrast is based on the coupling between neuronal activity and deoxy-Hb concentration changes. However, the BOLD contrast changes depend on the complex interaction between cerebral blood flow (CBF), cerebral blood volume (CBV), and cerebral metabolic rate for oxygen (CMRO2). Near-infrared spectroscopy (NIRS) allows a noninvasive measurement of changes in the oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) concentration, the sum of those signals provides the changes in total hemoglobin (total-Hb) concentration that may reflect CBV changes [1]. Simultaneous acquisition of fMRI and NIRS responses gives the information of oxy-Hb and total-Hb, as well as deoxy-Hb concentration changes with high spatial and temporal resolutions [2]. In this study, we set up the simultaneous measurement system for fMRI and NIRS, and investigated the spatial and temporal relationship in human using retinotopical technique and various durations of photic stimuli.

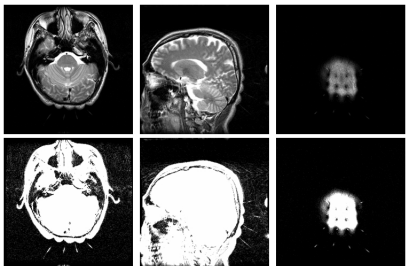

Figure 1 : Representative anatomical T2-weighted images showing the markers attached on the probes (bottom).

Materials and Methods: Eleven healthy volunteers, aged 21-43, were studied using a 3T MRI scanner (GE Signa Horizon LX) and an optical topography system (Hitachi ETG-100). All subjects gave their informed consent according to the ethics committee of University of Fukui. Subjects put the thermoplastic resin with sixteen probes (eight for NIR light illumination and eight for detecting reflected light) placed in a 4 x 4 array covering the primary and associated visual cortices. The probe position was determined by a marker with a tube of 1 mm diameter including water (Figure 1 and 2). Dual wavelength light (780 and 830 nm) was used to monitor oxy- and deoxy-Hb concentration changes at a sampling rate of 10 Hz. The optical fiber bundle with the length of 10 m was used. A waveform corresponding to the primary visual cortex was selected according to the topographic images. Each integral curve was calculated by adopting a linear curve fitting and temporal smoothing technique. The integral curves for each stimulus frequency were then averaged across all subjects. For the fMRI studies, a T2*-weighted single-shot gradient-echo EPI sequence was applied with the following parameters: TR = 2 sec, TE = 30 msec, Flip Angle = 70°, Matrix size = 64 × 64, and FOV = 240 mm × 240 mm. Twenty-three axial slices covering the whole brain were acquired with a slice thickness of 5 mm and a slice gap of 1 mm. Data were analyzed with the Statistical Parametric Mapping software package (SPM99). Pixels having t-values of significance less than 0.05 were considered active. A region of interest (ROI) was created for each run by choosing the pixel showing the highest t-value in the V1 area. The BOLD response curve was first generated as a time-locked average of the signal intensity for each subject, and these were then averaged across subjects. In the first study, subjects were given retinotopical visual stimulation using fullscreen, left-side, and right-side rectangular checkerboard, and a small circle checkerboard reversing at frequencies of 8 Hz (Figure 3). A series of “on” and “off” epochs was repeated four times, with each epoch 20 seconds long. In the second study, various durations (2, 4, 6, 8, 10 sec) of circle checkerboard stimulation were used. This was followed by 30 seconds of rest. Photic stimuli were projected onto a translucent screen located at the foot of the scanner bed with a LCD projector. The order of the trials was randomized. The visual presentation, triggered with both MRI and NIRS acquisition, was created by a PC computer using Presentation software package (Neurobehavioral Systems).

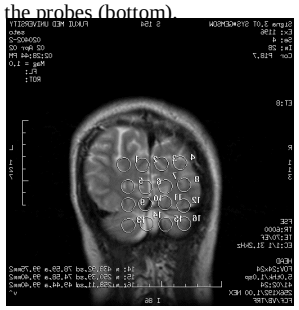

Figure 2 : Probe location mapped on the T2-weigted image.

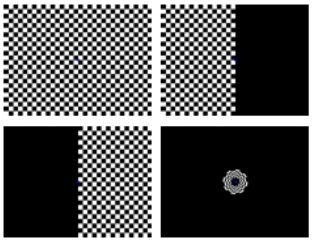

Figure 3 : Visual stimulus patterns for the retinotopical studies.

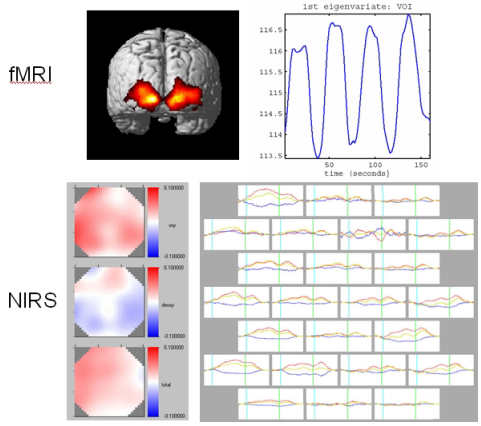

Figure 4 : Representative functional maps showing the activations and the corresponding time-courses for fMRI and NIRS.

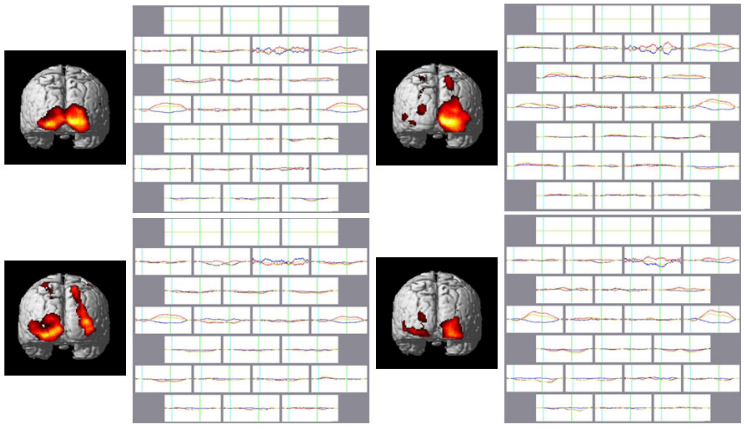

Figure 5 : Retinotopical brain activations (fMRI) and the corresponding hemoglobin dynamics (NIRS).

Results: Figure 4 represents the activation maps and the time-courses of V1 for fMRI and NIRS. Figure 5 shows retinotopical activation maps showing the BOLD responses and the corresponding hemoglobin dynamics for NIRS. Color shows the location of activations induced by full screen (left, top), left-side (right, top), right-side (left, bottom), and small circle (right, bottom) checkerboard.

Discussion: Our results showed that: 1) the localization of BOLD contrast and hemoglobin concentration changes was nearly identical, and 2) the temporal responses between BOLD contrast and hemoglobin concentrations induced by various short-time photic stimuli revealed a linear relationship (not shown). These results suggested that the signal characteristics of BOLD and NIRS may be approximately equivalent. Simultaneous measurement system provides the several physiological parameters (e.g., CBV, CMRO2, and CBF) with high spatial and temporal resolutions. This may further support the studies investigating the brain hemodynamic and metabolic functions.

References:

[1] Jones et al. (2002) NeuroImage 15: 474–487.
[2] M-Schipper et al. (2002) HBM 16: 140-23.