

Concurrent near-infrared spectroscopy (NIRS) and functional magnetic resonance imaging (fMRI) of the brain

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Background

The project of combined NIRS-fMRI aims at studying the spatial and temporal correlations between the fMRI BOLD (blood oxygen level dependent) and the near-infrared spectroscopy (NIRS) signals. The BOLD signal is mainly sensitive to the deoxy-hemoglobin and to the blood flow, while the NIRS signal is sensitive to both species of hemoglobin (oxygenated and deoxygenated). The advantages of NIRS towards fMRI are: a) a higher temporal resolution (a few ms for NIRS compared to 1-2 seconds for fMRI); b) its relative insensitivity to subject's movements; c) its cost effectiveness. In particular, NIRS is one of the few techniques that afford direct *in vivo* monitoring of oxygenation and perfusion of tissues during functional activities or pathological conditions. Limitations of NIRS with respect to fMRI are the lower spatial resolution, and its lack of sensitivity to deeper brain areas (>3 cm of depth). The field of noninvasive optical imaging of the brain is rapidly advancing and is exploring applications in a number of areas from a basic understanding of brain physiology, to mapping functional activation, to developing clinical tools to aid the diagnosis

of neurological disorders [see for example the *Special Section on Optical Imaging* in *Psychophysiology*, vol. **40**, pp. 487-571 (2003)]. Some representative articles involving the concurrent application of NIRS-fMRI are [Chance et al. 1998; Hoge et al. 2005; Seyama et al. 2004; Strangman et al. 2002; Toronov et al. 2003].

Experimental methods for NIRS

Our optical approach consists of arranging a number of illumination and collection optical fibers within a helmet that is worn by the subject. This set of optical fibers cover a wide area of the head with a number of source-detector fiber pairs having a fixed inter-fiber separation. These measurements are intended to provide spatial mapping and temporal trends of the hemoglobin changes during activation tasks such as a finger tapping test. The experimental setup is shown in Fig. 1, which displays the NIRS cap and the block diagram of the NIRS instrument (Imagent, ISS, Inc., Champaign, IL) featuring thirty-two laser sources (sixteen at 690 nm, sixteen at 830 nm) and four photomultiplier tube detectors, all coupled to 10-m long optical fibers.

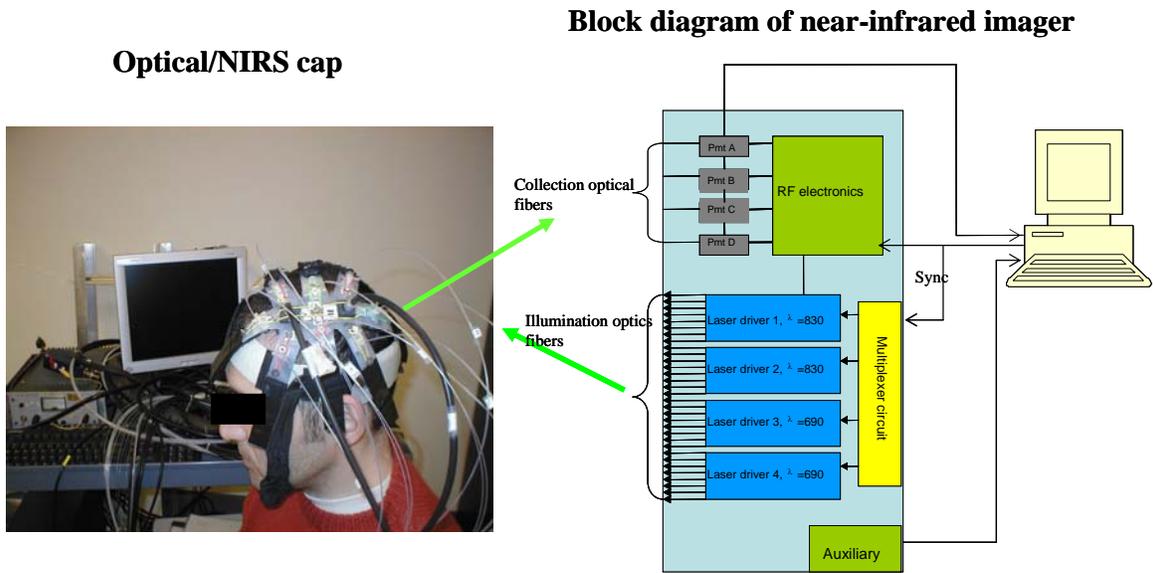


Fig. 1. NIRS helmet and block diagram of the near-infrared imager (Imagent, ISS, Inc.).

Experimental methods for fMRI

The fMRI data were collected with a 3 Tesla Siemens Trio magnetic resonance scanner and a quadrature birdcage radio-frequency coil shown in Fig. 2. For the spatial and temporal correlation of fMRI and NIRS signals it is fundamental to know the exact location of the optical

fibers on the subjects head. This was done by using the anatomical MRI scan which is sensitive to the small perturbations induced by the fibers on the scalp. Fig. 3 shows how it is possible to identify the positions of the optical fibers in this way. The update rate of fMRI data was 0.5 Hz.

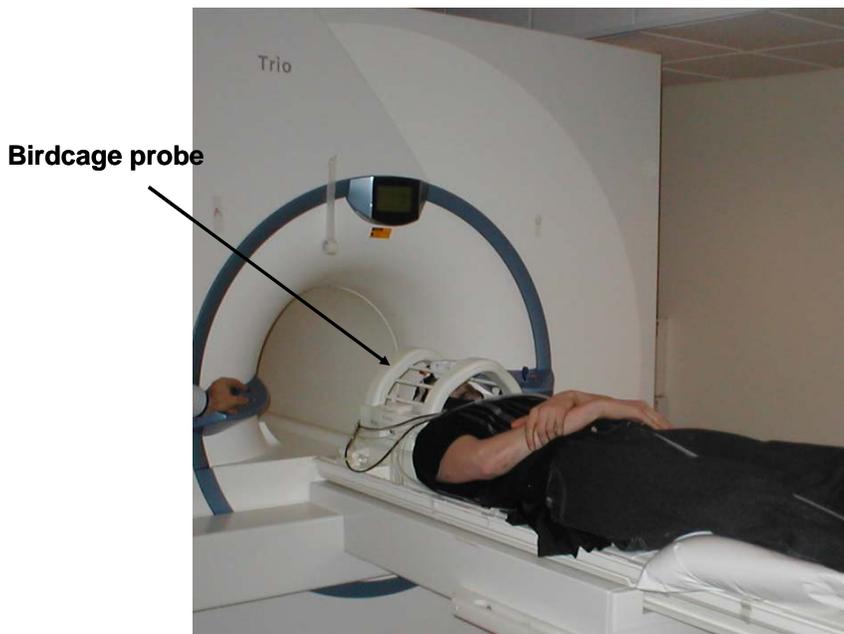
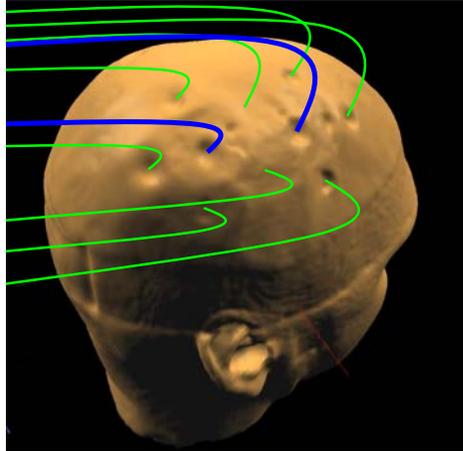


Fig. 2. MRI system (3 Tesla Siemens Trio) and birdcage radiofrequency coil for fMRI measurements.



Green lines: Illumination optical fibers
Blue lines: Collection optical fibers

Fig. 3. Determination of the location of the illumination and collection optical fibers on the scalp by using MRI data, which shows the indentation in the scalp surface caused by the optical fibers (one can also see the effect of the elastic head band around the subject's head).

Spatial and temporal correlation between NIRS and fMRI data

Our initial measurements show strong spatial and temporal correlations between both species of hemoglobin and the BOLD signal during the finger tapping test. The spatial correlation between the fMRI BOLD map and the NIRS deoxy-hemoglobin map is illustrated in Fig. 4.

Figure 5 compares the temporal traces of NIRS data (namely the changes in oxy-hemoglobin and deoxy-hemoglobin concentration at locations C-11 and C-15, as defined in Fig. 4) and fMRI BOLD data averaged over the activation area. After introducing normalization factors (the normalization factor for deoxy-hemoglobin is negative), the NIRS and BOLD data show highly correlated temporal features.

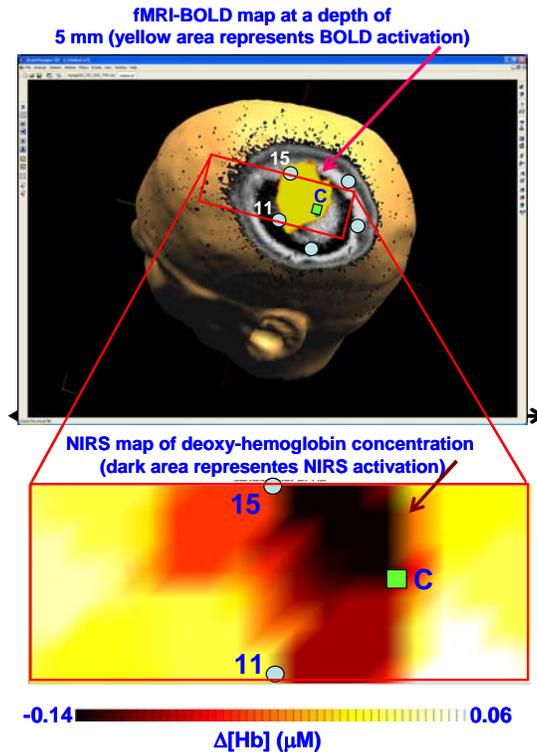


Fig. 4. Spatial maps of the BOLD signal (top) and the NIRS-measured change in deoxy-hemoglobin concentration (bottom).

Temporal correlation among NIRS $\Delta[\text{HbO}]$, $\Delta[\text{Hb}]$ and fMRI BOLD signal

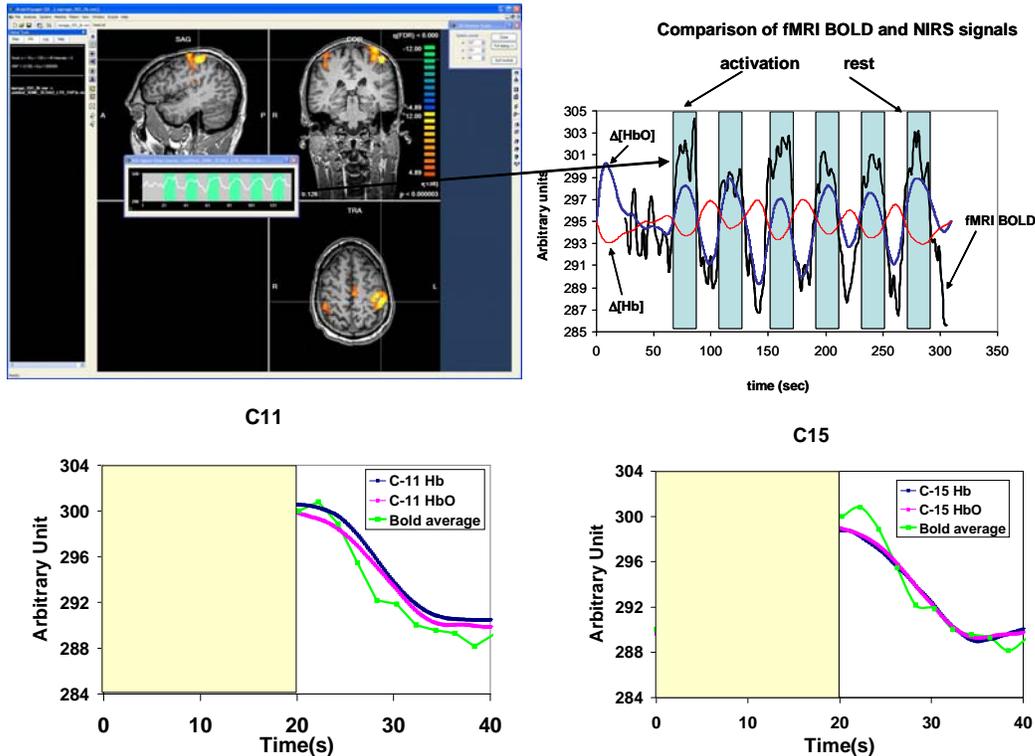


Fig. 5. Comparison of the spatial and temporal features of the fMRI BOLD signal and the NIRS-measured changes in oxy- and deoxy-hemoglobin concentrations.

References

- Chance B., Anday E., Nioka S., Zhou S., Hong L., Worden K., Li C., Murray T., Ovetsky Y., Pidikiti D., Thomas R., 1998. A novel method for fast imaging of brain function, non-invasively, with light. *Optics Express* **2**, 411-423.
- Chen Y., Tailor D R, Intes X., Chance B., 2003. Correlation between near-infrared spectroscopy and magnetic resonance imaging of rat brain oxygenation modulation. *Physics in Medicine and Biology* **48**, 417-427.
- Hoge R. D., Franceschini M. A., Covolan R. J. M., Huppert T., Mandeville J. B., Boas D. A. 2005. Simultaneous recording of task-induced changes in blood oxygenation, volume, and flow using diffuse optical imaging and arterial spin labeling MRI. *Neuroimage* **25**, 701-707.
- Seiyama A., Seki J., Tanabe H.C., Sase I., Takatsuki A., Miyauchi S., Eda H., Hayashi S., Imaruoka T., Iwakura T., Yanagida T., 2004. Circulatory basis of fMRI signals: relationship between changes in the hemodynamic parameters and BOLD signal intensity. *Neuroimage* **21**, 1204-1214.
- Siegel A. M., Culver J. P., Mandeville J. B., Boas A. D., 2003. Temporal comparison of functional brain imaging with diffuse optical tomography and fMRI during rat forepaw stimulation. *Physics in Medicine and Biology* **48**, 1391-1403.
- Strangman G., Culver J.P., Thompson J.H., Boas D.A., 2002. A quantitative comparison of simultaneous BOLD fMRI and NIRS recordings during functional brain activation. *Neuroimage* **17**, 719-731.
- Toronov V., Webb A., Choi J. H., Wolf M., Michalos A., Gratton E., Hueber D., 2001. Investigation of human brain hemodynamics by simultaneous near-infrared spectroscopy and functional magnetic resonance imaging. *Medical Physics* **28**, 521-527.
- Toronov V., Webb A., Choi J. H., Wolf M., Safonova L., Wolf U., Gratton E., 2001. Study of local cerebral hemodynamics by frequency-domain near-infrared spectroscopy and correlation with simultaneous acquired functional magnetic resonance imaging. *Optics Express* **9**, 417-427.

- Toronov V., Walker S., Gupta R., Choi J.H., Gratton E., Hueber D., Webb A., 2003. The roles of changes in deoxyhemoglobin concentration and regional cerebral blood volume in the fMRI BOLD signal. *Neuroimage* 19, 1521-1531.
- Yamamoto T., Kato T., 2002. Paradoxical correlation between signal in functional magnetic resonance imaging and deoxygenated hemoglobin content in capillaries: a new theoretical explanation.