A Temporal Comparison of BOLD, ASL, and NIRS hemodynamic responses to motor stimuli in adult humans

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In this study, we have preformed simultaneous near-infrared spectroscopy (NIRS) along with BOLD (blood-oxygen level dependant) and ASL (arterial spin labeling)-based fMRI during an event-related motor activity in human subjects in order to compare the temporal dynamics of the hemodynamic responses recorded in each method. These measurements have allowed us to examine the validity of the biophysical models underlying each modality and, as a result, gain greater insight into the hemodynamic responses to neuronal activation.

During data acquisition, subjects were instructed with a visual cue to sequentially tap their thumb and fingers on their dominant hand at a self-paced rate (approximately 2-3Hz) for duration of 2 seconds. NIRS optical measurements were made using the CW4 system (prototype MGH/Techen Inc.) as previously described [1]. In these experiments, a hexagonal geometry probe consisting of 8 detector and 4 source positions was used. Laser wavelengths were chosen to minimize cross-talk between the two hemoglobin species (690nm; 830nm). Source-detector separation distance was 2.9cm. BOLD fMRI measurements were taken using a Siemens Allegra MR scanner (3T). Data was taken with a gradient echo EPI sequence [TR=500ms; TE=30ms; $\theta=90^o$]. ASL-fMRI was preformed using PICORE labeling geometry [2] with Q2TIPS saturation [3] to impose a controlled label duration. A post-label delay of 1400ms and label duration of 700ms were used and data was aquired with a gradient echo EPI sequence [TR=2s; TE=20ms; $\theta=90^o$]. The timing for the motor task was jittered on a 500ms time-step to allow deconvolution of the ASL signal at 2Hz.

As shown in figure 1, we are able to report that the fMRI measured BOLD response is more correlated with the NIRS measure of deoxy-hemoglobin ($R=0.98$; $p<10^{\wedge-20}$) than with oxy-hemoglobin ($R=0.71$; $p=6x10^{-02}$) or total hemoglobin ($R=0.53$; $p=1x10^{-01}$) as is predicted from the theoretical grounds of the BOLD response.

In addition, we found high correlation between the NIRS measured total hemoglobin and ASL measured flow ($R=0.91$; $p<10^{\wedge-10}$) and oxy-hemoglobin with flow ($R=0.83$; $p<10^{\wedge-05}$) as predicted by the biophysical models (figure 2). This correlation was stronger then ASL to the HbR signal ($R=0.13$ $p=0.5$), which was again temporally shifted approximately 2 seconds later and closely matched by the BOLD signal.

We also noted a significant amount of cross-modality, correlated, inter-subject variability in amplitude change and time-to-peak of the hemodynamic response. The observed co-variance in these parameters between subjects is in agreement with hemodynamic models and provides support that fMRI and NIRS have similar vascular sensitivity.

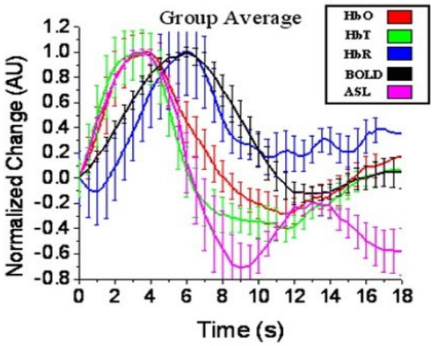

Figure 2: Simultaneous ASL and NIRS recordings showed strong temporal correlation between the ASL, HbO, and HbT signals. Here we present the group average of all five subjects. Again, all traces have been normalized to unity and the HbR trace has been inverted for this comparison

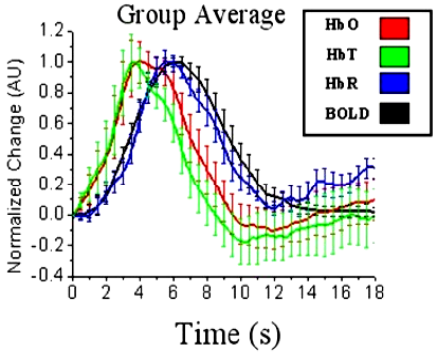

Figure 1: Here we show the temporal comparison of BOLD signal to NIRS recordings of oxy, deoxy, and total hemoglobin for the group average of all five subjects. All traces have been normalized to unity and the HbR trace has been inverted for this comparison

[1] Franceschini, M., Fantini, S, Thompson, JH, Culver, JP, and Boas, DA (2003). "Hemodynamic evoked response of the sensorimotor cortex measured non-invasively with near-infrared optical imaging." Psychophysiology **42**(16): 3063-3072.

[2] Wong, E., Buxton, R., and Frank, L. (1997). "Implementation of quantitative perfusion imaging techniques for functional brain mapping using pulsed arterial spin labeling." *NMR Biomed* **4-5**(10): 237-249.

[3] Luh, W., Wong, E., Bandettini, P., and Hyde, J. (1999). "QUIPSS II with thin-slice ti1 periodic saturation: a method for improving accuracy of quantitative perfusion imaging using pulsed arterial spin labeling." Magn. Reson. Med. **6**(41): 1246-1254.