BOLD Physiological Noise Reduction using Spatio-Spectral-Temporal Correlations with NIRS

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Introduction: Near Infrared Spectroscopy (NIRS) and BOLD fMRI measure complementary quantities relating to changes in the concentration of oxy- and deoxy-hemoglobin (HbO and HbR respectively) [1]. NIRS offers superior temporal resolution (40ms versus 2000ms), whereas BOLD offers superior spatial resolution and whole brain coverage. We are exploring the NIRS and BOLD relationship through simultaneous acquisition on human subjects in a resting-state scan along with measures of systemic physiology (respiration and cardiac). We have found that the NIRS time courses can account for approximately 25% of the resting-state BOLD fluctuations in cortex beyond that accounted for by the physiological measures alone. The spatial pattern of the NIRS-BOLD correlation was highly dependent on frequency band, and in surprising ways differed between HbO and HbR.

Method and Results: Subjects underwent 3 resting-state fMRI scans while two-wavelength (690 and 830nm) NIRS, respiration, and cardiac data were simultaneously acquired. A bilateral NIRS probe with 8 sources and 16 detectors [2] was placed on the head, centered over the central sulcus. The NIRS waveforms were converted to HbO and HbR concentrations and filtered into three bands at 0.1Hz (Mayer wave [3]), 0.3Hz (respiration), and 1Hz (cardiac) which were then used as regressors in a general linear model (GLM) analysis of the BOLD fMRI signal. Regressors for the cardiac and respiration were created with RETROICOR [4]. Temporal drift in the fMRI was modeled as a 2nd order polynomial.

In one analysis, the HbO and HbR concentrations were analyzed separately, and the significance of the correlation of each frequency band was tested. The results in one axial slice are shown in Figure 1. There is a considerable difference between the frequency bands, with the 0.1 Hz band being dominant and affecting almost exclusively gray matter. The HbO correlation is expected to the extent that changes in HbO correlate with changes in HbR, as would happen by changes in blood volume without changes in oxygen saturation. As is apparent in Figure 1, however, some BOLD voxels correlate more strongly with HbO than HbR. This requires further investigation, but may arise from the blood volume dependence of the BOLD signal [5]. One important observation is that there were very strong correlations in areas far removed from the NIRS probes – in other words, the presence of long range spatial coherence of the physiological fluctuations at these frequency bands allows for local (NIRS) measures to inform the global cortical (fMRI) picture.

In a second analysis, we tested a series of 5 models by successively adding regressors: (1) temporal trend only (T-Only), (2) cardiac RETROICOR (T+P), (3) respiration RETROICOR (T+P+R), (4) HbR 0.1Hz (T+P+R+D), (5) HbO 0.1Hz (T+P+R+D+O). The amount of noise variance reduction was quantified relative to T-Only. This ratio was then averaged over various brain structures. The results (Figure 2) show that NIRS almost always improves noise reduction over cardiac and respiration RETROICOR alone. In cortex, the noise was reduced by an additional 25%. Even in deep structures (the hippocampus and amygdala), noise was reduced by an additional 12%.Consistent with the first analysis, HbO provided additional noise reduction above that provided by HbR alone.

Conclusions: NIRS and BOLD are related in a complicated manner that depends on frequency band and brain area, and NIRS and BOLD may be correlated in areas far away from the NIRS detectors. The correlations were the strongest in the Mayer frequency band (0.1Hz), and HbO correlated with BOLD more than HbR. NIRS reduced fMRI noise significantly more than using cardiac or respiration RETROICOR alone. These results suggest that a simple NIRS probe could be used to routinely reduce BOLD variance and potential increase power in the estimation of evoked BOLD responses.

Figure 1

Figure 2
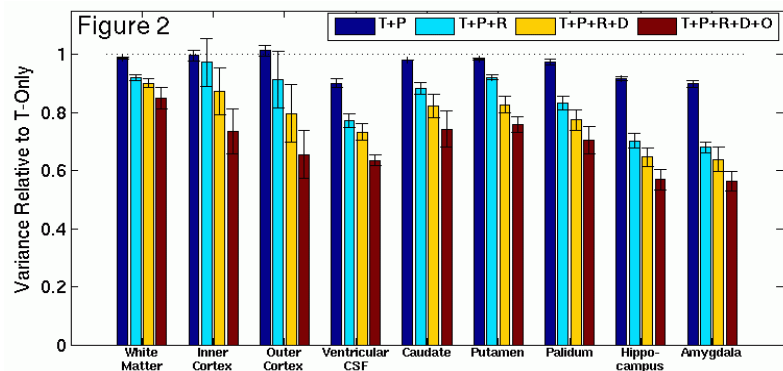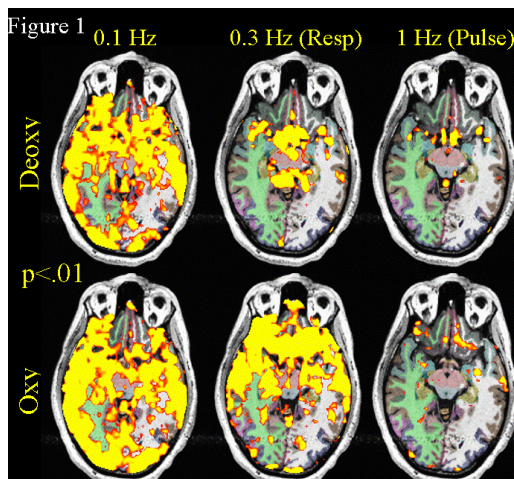
References: [1] Huppert, et al, Neuroimage, 2006, p368. [2] Franceschini, et al, Psychophysiology, 2003, p548. [3] Julien, Cardiovascular Research, 2006, p12. [4] Glover, et al, MRM, 2000, p162. [5] Obata, Neuroimage 21:144 (2004).