COMBINE NIRS AND FMRI TO INVESTIGATE HEMODYNAMIC RESPONSE TO TRANSIENT ACTIVATION AND DEACTIVATION

L. Tang[1], M. J. Avison[1], and J. C. Gore[1]
[1]Vanderbilt University Institute of Imaging Science, Nashville, TN, United States

Introduction:

We used transcranial near-infrared spectroscopy (NIRS) and fMRI at 3T to investigate both positive and negative BOLD effects in human brain activation. Using NIRS we recorded concentration changes in both oxy- and deoxy- as well as total hemoglobin levels by measuring changes of absorption at two different wavelengths in brain in response to both transient activations and deactivations. Similar experiments were also performed using fMRI. In addition to different nonlinear BOLD responses to activation and deactivation, we also investigated the relationship between NIRS and fMRI data.

Method:

An 8Hz large-field contrast-reversing checkerboard pattern at 100% contrast served as a visual stimulus (denoted as condition "ON"). In our baseline condition subjects viewed a spatially homogeneous black screen (denoted as condition "OFF"). Two event-related paradigms generated by E-prime (Psychology Software Tools, Inc) were presented to healthy subjects: I. Brief stimulus-ON (2sec or 4sec) during otherwise continuous stimulus-OFF; II. Brief stimulus-OFF (2sec or 4sec) interspersed during otherwise continuous visual stimulation-ON. In total 80 trials were presented in 4runs, and each condition (ON-2/4sec and OFF-2/4sec) was presented 20times with a 20sec target to target interval.

MR images were acquired on a 3T Philips Achieva scanner. Ten T1-weighted anatomic images were collected parallel to AC-PC line with 5mm slice thickness and 1mm gap and positioned to cover the visual areas. Then functional images were collected in the same planes, using a gradient echo EPI sequence (TR/TE=1s/35ms, flip angle=70^o, FOV=22x22cm^2 and acquisition matrix size=80x80 reconstructed to 128x128), then analyzed using BrainVoyager and custom analysis software running under MATLAB.

NIR data were collected using a 15-channel (matrix 3x5) NIR optical topography system (Hitachi topoETG4000) with optodes positioned on the surface of the skull to be able to sample signals from a central posterior region corresponding to primary visual cortex. NIR data were down sampled from 10Hz to 1Hz, temporally filtered to avoid drift, and analyzed assuming a General Linear Model to obtain measurements of the event-related optical signals representing changes in both oxy- and deoxy- as well as total hemoglobin ([Hb], [HbO_2] and [HbT]) for both ON and OFF stimuli.

Results:

NIR studies found, as expected, that brief (4sec) activation increased oxy- (HbO_2) and total-hemoglobin (HbT) and decreased deoxyHb (Hb) (Fig1a), while transient deactivation decreased HbT and HbO_2, and increased Hb in V1 (Fig1b). The decrease in [HbO_2] is faster than the increase in [Hb] in response to transient deactivation. Also, the pre-undershoot/overshoot and post-undershoot/overshoot are more pronounced for NIR data in response to brief activation as compared to the response to brief deactivation. These observations were qualitatively and quantitatively consistent with the observed fMRI time courses for a 4sec activation/deactivation. [HbO_2] and [HbT] in particular showed similar relative magnitude and temporal properties for activation and deactivation with the corresponding BOLD signals, verifying that NIRS can be used as an alternative method for measuring HRF in event related studies of activation.

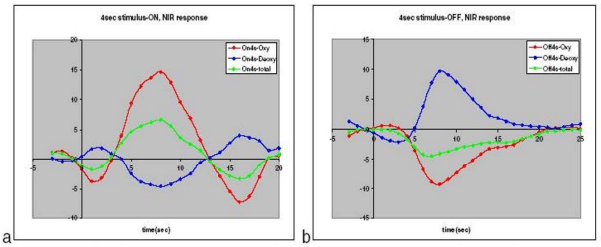

Figure 1. Transient changes in both oxy-hemoglobin and deoxy-hemoglobin in V1.
a. NIR data in response to 4sec stimulus-ON.
b. NIR data in response to 4sec stimulus-OFF.

We know that BOLD signal changes upon simulation are a function of the change in R_2* [1], i.e. $\Delta S/S=exp(-TE\ \Delta R_2^*)-1\approx -TE\ \Delta R_2^*$. We assume that the gradient echo transverse relaxation rate due to magnetic susceptibility differences can be expressed in terms of the blood volume (V_{bl}) and the susceptibility (χ_{bl}) difference between the blood and surrounding tissue as [2]: $R_2^* = \kappa V_{bl}\chi_{bl}$. We further assume that to 1st order, the changes in tissue relaxation rate due to activation (ΔR_2^{*act}) are separable in terms of blood volume changes (ΔV_{bl}) and blood oxygenation dependent susceptibility changes in hemoglobin ($\Delta\chi_{bl}$): $\Delta R_2^{act} = \kappa[\Delta V_{bl}\bar{\chi}_{bl} + V_{bl}\Delta\chi_{bl}]$. The magnetic susceptibility of blood depends on the blood oxygen saturation (Y) [3,4]: $\chi_{bl}=\chi_{oxy}+(1-Y)\delta\chi$. The fractional concentration of deoxyhemoglobin (1-Y) can be detected by NIRS in terms of [Hb]. Also [HbT] changes detected by NIRS reflect percent volume changes, that is to say, $\Delta V_{bl}\approx V_{bl}\Delta$[HbT] and $\Delta(1-Y)\approx\Delta$[Hb]. Therefore we obtain

%BOLD $\propto$ (Δ[HbT]-*wΔ[Hb])**

where the weight constant $w=-\delta\chi/\bar{\chi}_{bl}$. We are thus able to relate our NIR data with the measured BOLD signal (Fig2).

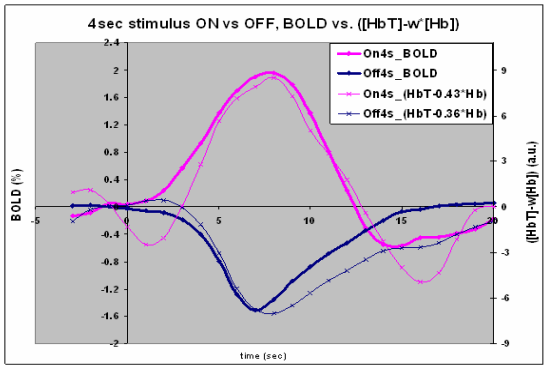

Figure 2. Compare BOLD responses with estimation from NIRS data to 4sec stimulus-ON/OFF in V1. They showed similar relative magnitude and temporal properties for activation and deactivation.

Discussion:

Both the fMRI and NIRS data demonstrate the HRF to deactivation is smaller and has a different time course to the HRF for transient activation. NIRS data are consistent with the fMRI data. A strong correlation between them is suggested from considering the physiological basis of BOLD signal changes and the contributions of blood volume and magnetic susceptibility. Our ability to detect short (<2sec) deactivations is less than our ability to detect corresponding activations. During a steady state excitation equilibrium is achieved between blood flow, volume and oxygenation. When this is interrupted the sequence of physiological changes is different from those involved in the vasodilation that occurs in response to transient excitations, and the HRF presumably reflects those differences. NIR measurements have the potential to provide additional constrain on our interpretation of the BOLD effect.

Reference:

1. Zhong, J., Kennan, R.P., Fulbright, R.K. and Gore, J.C. Magnetic Resonance in Medicine. 1998; 40: 526-536.
2. Kennan, R.P., Scanley, B.E., Innis, R.B. and Gore, J.C. Magnetic Resonance in Medicine. 1998; 40: 840-846.
3. Haacke,E.M., et al. Human Brain Mapping. 1997; 5:341–346.
4. Weisskoff, R.M. and Kiihne, S. Magnetic Resonance in Medicine. 1992; 24: 375-383.