Investigating fMRI and fNIRS signal with balloon model during breath hold task.

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Introduction

Multimodal investigation of blood oxygenation level-dependent (BOLD) signal, using both functional near infrared spectroscopy (fNIRS) and functional magnetic resonance imaging (fMRI), may give further insight to the underlying physiological principles and the detailed transient dynamics of the vascular response. In order to fully unveil the physiological basis of these transients of hemodynamic response, a comprehensive balloon model describing BOLD signal as a function of CBV,CBF and HbR should be utilized as a guide in these multimodal studies [1-3].

The aim of the present study is to fuse fNIRS and fMRI measurements into expanded balloon model (EBM) and interpret their transients during breath hold task (BHT). It has been shown that simple BHT offers a convenient method of assessing CO_2 reactivity without requiring CO_2 administration [4]. To include the BHT effects, we integrated partial pressure of CO_2 ($PaCO_2$) changes as a driving function to the balloon model rather than CBF.

Methods and Data Analysis

fMRI and fNIRS measurements were conducted for both subjects when they were positioned in supine position. They are asked to breath normally during rest periods. After an initial 90 seconds of rest, they were asked to exhale all the air and hold their breaths for 30 seconds. In order to obtain post-stimulus undershoot effect, a relatively longer rest block, 90s, was chosen [5].

The fNIRS data were acquired NIROXCOPE 201 which was developed at Bogazici University Biophotonics Laboratory. The probe which houses sources and detectors was positioned such that its base aligns with the eyebrows of the subject and the middle with the Fz location from 10-20 EEG electrode placement pattern. The concentration changes in HbO and HbR signals are calculated from the Beer-Lambert Law using two wavelengths (735 nm and 850 nm).

All experiments with fMRI were performed on Siemens Symphony 1.5 Tesla MR System at Department of Radiology, Istanbul Medical School. A single shot T^*_2 weighted gradient echo (GE) echo planar imaging (EPI) sequence was used for BOLD measurements. Seventeen transverse slices over a field of view of 192 x 192 mm with 128 x 128 resolution were acquired with a slice thickness 3 of mm. Other imaging parameters were TR 2000 ms, TE 60 ms and flip angle 90 degrees.

Pixels in a region of interest (ROI) in the first couple of millimeters of the frontal cortex were averaged to generate the BOLD signal. Then, within each subject resulting time courses were averaged for all 4 repetitions. The same averaging procedure was also applied for fNIRS data.

Originally it was assumed that the driving function of the system, f_{in} (identical to CBF) had a trapezoidal shape [1]. In this study, we modeled f_{in} as a function of $PaCO_2$ and utilized a sigmoidal function describing the relationship between CBF and $PaCO_2$. According to this relationship, the CBF changes with respect to PaCO2 can be modeled as follows:

$$f_{in}(t) = \frac{a}{1 + e^{-b*(p(t)-c)}} + 1 \qquad [1]$$

Where, P(t) is the $PaCO_2$ during breath hold, a is the scaling parameter for the CBF, and, b and c are the characteristic parameters of sigmoid.

Results

For each subject, EBM parameters are customized to represent the signals acquired in both modalities. Fig. 1 illustrates BOLD signals measured by fMRI (BOLD fMRI), and HbR signals measured by fNIRS (HbR fNIRS) for all subjects. Fig. 1a indicate balloon model outputs and HbR measurements of fNIRS while the graphs in Fig. 1b show the BOLD output of balloon model fitted to BOLD fMRI measurements. Acquired BOLD signal time courses are highly ($R^2 > 0.9$) correlated with simulated balloon model time courses. Furthermore, during post-stimulus response (shaded area in Fig. 1a), CBF starts to decrease at the end of the breath hold and returns to baseline, while CBV decrease is slower. This also causes an increase in HbR which produces the post-stimulus effect during breath hold.

Discussion and Conclusion

This study demonstrates an expanded application of balloon model which has been mentioned as a neglected but much needed research for combined fNIRS-fMRI experiments in a recent review article [3]. Our results suggest that post-stimulus undershoot measured by fMRI is dominated by slow return of CBV which is supported by our both fNIRS measurements and EBM simulations.

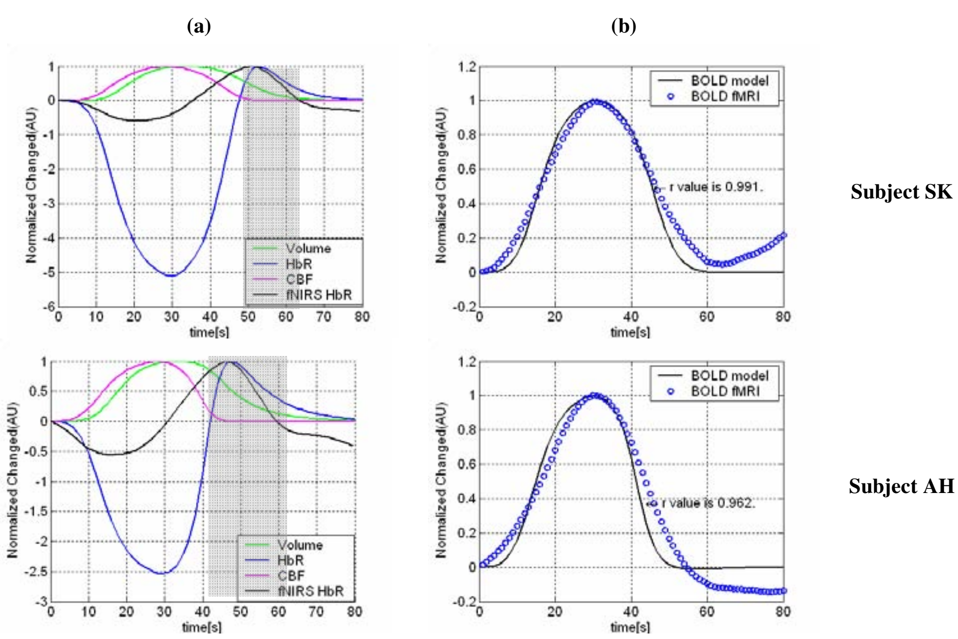

Figure 1 (a) Average time course of fNIRS derived HbR data and balloon model outputs for HbR, CBF and Balloon Volume, Shaded areas represent the post stimulus undershoot duration. (b) Average time course of BOLD signal measured from fMRI and derived balloon model BOLD signal

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