

Scalp signal subtraction improves the signal-to-noise of NIRS activations

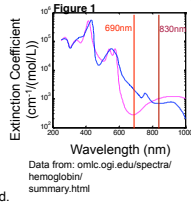
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Abstract

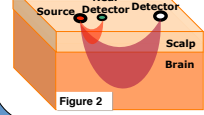
Our lab has developed a method for improving the cerebral hemodynamic signal from near infrared spectroscopy by subtracting the signal of the top scalp layer from the overall signal to isolate the signal from the brain. Only channels that showed activation as determined by a t-test and signal-to-noise (SNR) threshold were considered in the analysis. 73% of the channels that showed activation showed SNR improvement with corrected NIRS and the mean overall improvement was 35%.

Introduction

Near infrared spectroscopy (NIRS) is a noninvasive method used for monitoring brain activity. It is smaller and less expensive than other devices for measuring functional brain activity, including fMRI and PET. NIRS works by measuring absorption by oxy- and deoxy-hemoglobin (HbO₂ and Hb respectively) at wavelengths within the optical window for tissue (Figure 1). By measuring absorption of light at both 690nm and 830nm, the unknown concentration of HbO₂ and Hb can be calculated.



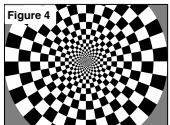
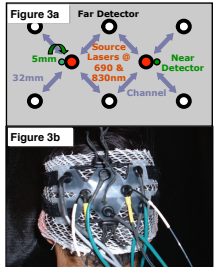
The challenge with NIRS is obtaining a clear signal representing the brain activity. To reach the hemodynamic activity in the brain, the light must pass through the scalp layer which also contains HbO₂ and Hb. To remove the top layer interference, our group developed a method to place a detector close enough to the source that it only captures the absorption within the scalp, which then can be scaled and subtracted from a far source detector, resulting in a corrected NIRS, or CNIRS (Figure 2).



Another consideration with NIRS is that not every subject shows an activation, or response peak, when stimulated. There is only value in using CNIRS when an activation is present and our group developed a method for determining if a channel meets the activation criteria or not.

Materials and data collection

The NIRS device is made up of six far detector fiber bundles, two near detector fiber bundles, and two source locations, each with a 690nm and an 830nm laser diode. The detector fibers continue to 8 avalanche photodiode modules. This source and detector orientation, as shown in Figure 3a, creates 8 channels. The device is strapped with Velcro strips to the subject's head (Figure 3b), covering the primary visual cortex within the occipital lobe, located in the posterior portion of the brain. The straps are adjusted for maximum contact with the scalp without interference of hair.



The subject sits approximately three feet from a 15" laptop. The radial checkerboard pattern in Figure 4 inverts at 10Hz for 10s, followed by a rest period of 10-35s with a blank grey screen. The stimulus is displayed 6 times in a trial.

Data filtering and activation identification

1. Bandpass filter

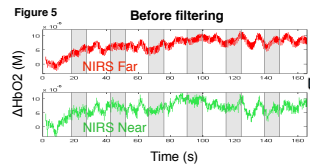
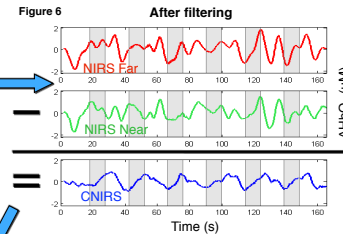


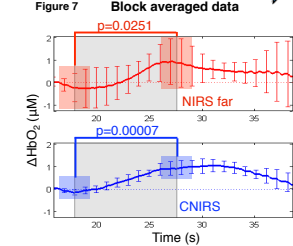
Figure 5 shows the raw data before it is passed through a bandpass filter. The high frequency fluctuation is the subject's pulse. The low frequency drift is due to natural fluctuation in hemoglobin. The grey shaded region of the plot indicates the six 10s periods during which the stimulus was on.

2. Subtract scaled near channel



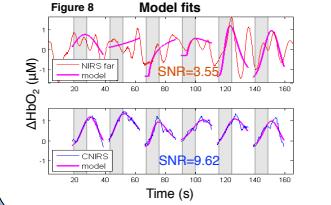
Next the scalp signal subtraction is applied to separate the top layer hemodynamic activity from the cerebral signal. Because the near detector is located only 5mm from the source, it is almost entirely measuring the oxy- and deoxy-hemoglobin in only the scalp. Using least squares fitting, the near signal is scaled relative to the far signal, which captures both scalp and brain hemoglobin volume. The scaled near signal is then subtracted from the far signal to obtain the CNIRS signal, as shown in Figure 6.

3. Perform a t-test

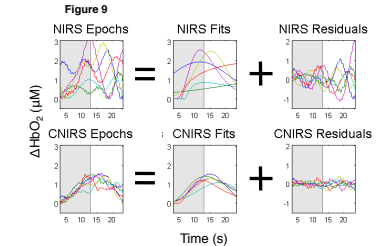


A left tailed t-test is done on the data to assess the confidence that the volume of HbO₂ is greater at end of the stimulation period than at the initiation of it, indicating that an activation may have taken place. The mean of the data from ±2s at the start of the stimulus and end of the stimulus were taken for each of the 6 epochs to be used in the t-test. Figure 7 shows the data block averaged for the 6 epochs. The shaded regions were used in the t-test calculations. Since this CNIRS plot shows a much smaller p-value than the NIRS plot, there is much greater confidence in CNIRS that the stimulus, not random fluctuation, initiated the change in HbO₂ volume.

4. Fit data to calculate SNR



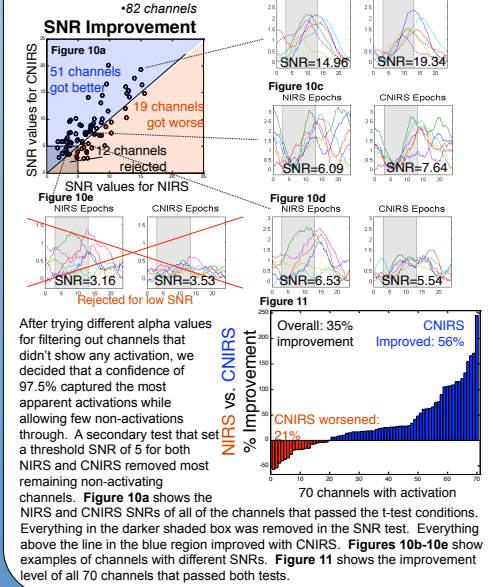
Finally, the 6 epochs are fit to a mathematical model of the hemodynamic stimulus response (Figure 8). The amplitude of the signal is compared to RMS residuals to obtain the signal to noise ratio (Figure 9). The fits clearly track the epochs much better in the CNIRS plot than the NIRS plot, leaving visibly smaller residuals and a much better SNR. Even if the channel had an acceptable p-value, only channels with a good SNR take the form of an activation.



$$\frac{\text{Amplitude of Fit}}{\text{RMS of Residuals}} = \text{SNR}$$

$$\frac{\text{CNIRS SNR} - \text{NIRS SNR}}{\text{NIRS SNR}} = \text{Improvement}$$

Results



Summary and future work

- The corrected NIRS system developed by our lab for top layer subtraction improves the signal-to-noise ratio for over 70% of channels that show activation.
- The overall mean improvement using CNIRS is 35%. When there is any improvement with CNIRS, the mean improvement is 56%, yet when the CNIRS SNR is worse, it is only 21% worse.
- An effective way of separating out only the channels that show activation is to use both a t-test at 97.5% confidence and a SNR cutoff eliminating all channels in which neither NIRS nor CNIRS has an SNR over 5.
- Further work should be done to explore what determines if a person will be a good activator and to try the system with other stimuli and placement.

Literature cited

"Measurement of layer-like hemodynamic trends in scalp and cortex: implications for physiological baseline suppression in functional near-infrared spectroscopy," R Saager, A Berger, Journal of Biomedical Optics, 2008
 "Direct characterization and removal of interfering absorption trends in two-layer turbid media," R Saager, A Berger, JOSAA, 22(9), Sept 2005