Studying brain function with near-infrared spectroscopy concurrently with electroencephalography

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ABSTRACT

Near-infrared spectroscopy (NIRS) has been used for functional brain imaging by employing properly designed source-detector matrices. We demonstrate that by embedding a NIRS source-detector matrix within an electroencephalography (EEG) standard multi-channel cap, we can perform functional brain mapping of hemodynamic response and neuronal response simultaneously. In this study, the P300 endogenous evoked response was generated in human subjects using an auditory odd-ball paradigm while concurrently monitoring the hemodynamic response both spatially and temporally with NIRS. The electrical measurements showed the localization of evoked potential P300, which appeared around 320 ms after the odd-ball stimulus. The NIRS measurements demonstrate a hemodynamic change in the fronto-temporal cortex a few seconds after the appearance of P300.

Keywords: near-infrared spectroscopy, electroencephalography, evoked potentials, brain imaging

1. INTRODUCTION

NIRS and EEG are non-invasive imaging modalities with the ability to give complementary information about the functioning of the brain. Concurrent NIRS and EEG have been used to investigate the synchronized activities of neurons and the subsequent hemodynamic response in human subjects[1-5]. In particular, Richard *et al* found that hemodynamic responses associated with the "oddball" auditory stimulus had a latency of approximately 5 s and happened in close proximity to areas of peak electrical activities[1]. Alternatively, Silvina *et al* detected NIRS signal and event-related potentials simultaneously during a semantic processing task[2]. These previous studies suggest that there is coupling between the evoked potentials, which represent electrophysiological responses, and the NIRS signals, which represent hemodynamic and metabolic responses[3-5]. Further insight into brain function can be obtained by combining electrical and optical evoked responses to identify the neuronal activation and the corresponding hemodynamic response, both temporally and spatially. In this study, we have concurrently collected evoked electrical potentials and optical responses (related to hemodynamic changes) associated with cognitive tasks (oddball paradigm) using a specially-designed opto-electrical helmet.

2. METHOD

2.1 Instrumentation for concurrent electrical and optical recordings

A detail of the EEG-NIRS helmet is shown in the Fig. 1. The EEG equipment for the measurement of the event related potentials (ERP) is based on a NuAmps, a 40-channel digital EEG amplifier running SCAN 4.3, a software system designed to acquire and analyze amplified EEG data. Stimulus is provided by STIM, a software environment for custom stimulus, task design, and presentation (all from NeuroScan Inc., El Paso, TX). The acquisition rate of the digital EEG was 1000 Hz with digital filtering applied in the post-analysis. Each of the 40 electrodes were applied with an impedance below 5 kΩ. The evoked potentials were extracted from the continuous EEG temporal trace by averaging epochs of the EEG surrounding the auditory or odd-ball stimuli of interest.

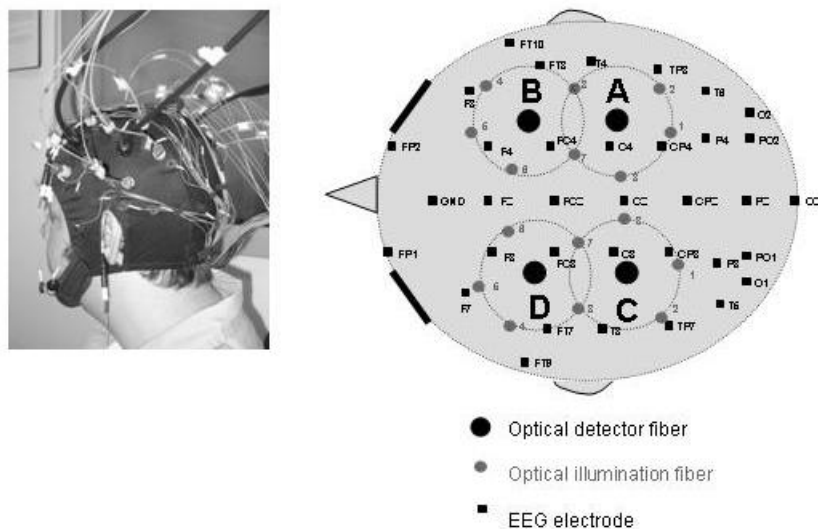*Yunjie.tong@tufts.edu; phone 1 617 627 4359

Figure 1: Photograph and top view of the helmet with optical source-detector matrix and electrodes. Positions of optical source fibers and detector fibers are shown relative to the 10-20 system locations, where electrodes are placed. Only the right side of the brain (detectors A and B) is monitored by NIRS in this study.

The optical instrument used in these studies is a frequency domain optical spectrometer from ISS, Inc., Champaign, IL (OxyplexTS) comprising 2 PMT-based detector channels, 16 laser diodes coupled to optical fibers (8 at a wavelength λ = 690 nm, and 8 at λ = 830 nm), and intensity modulated at 110 MHz. The acquisition rate of the optical system was set to 7.8125 Hz. Sixteen optical source fibers and two optical detectors are embedded into the right side of a standard 40-channel EEG cap (NeuroScan Inc., El Paso, TX) to allow simultaneous recording of EEG and NIRS data. The cap has the capability of having 32 optical source fibers and 4 optical detectors as shown in Fig. 1. In this study, EEG signal was obtained from both left and right side of the brain, while NIRS signal was measured only from the right side of the brain.

2.2 Protocol

The subject (an adult healthy male 24 years of age) is asked to sit comfortably in a chair wearing bilateral ear phones. After the acquisition of 30 s of baseline optical data, during which the subject is at rest, 50 consecutive tones (20 ms in length) with 5 s intervals in between them are sent to the ear phones. Among these 50 tones, 10 are high-pitch tones (2000Hz), representing the rare cases. The other 40 tones are low-pitch tones (1000Hz), representing the common cases. The high-pitch and low-pitch tones are mixed randomly. The subject was asked to press a button (with his right finger, which is ipsilateral to the motor cortex of the brain covered by the optical detectors) when he hears the rare cases and to otherwise be quiet and relaxed. The sequence of random auditory pulses is showed in Fig. 2.
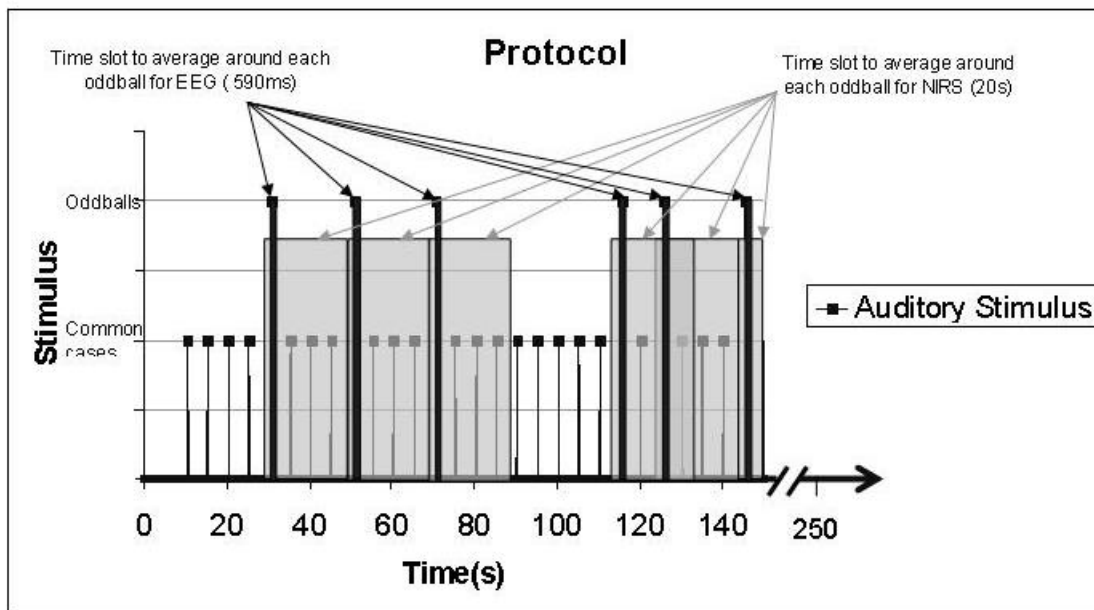
Figure 2: Protocol and data analysis of the experiment. Similar analysis is applied to the common cases too.

2.3 Data analysis

EEG: Following routine artifact removal and baseline DC correction, the EEG data were averaged for rare and common cases, starting 100 ms before each stimulus and ending 490 ms after. The average data of the rare stimulus and the common stimulus are then calculated respectively, based upon the waveforms presented topographically at each of the 40 electrode positions with reference to a linked ear reference. Fig. 3 represents the temporal evolution of the spatial EEG mapping from the rare stimulus (oddballs). The P300 wave is clearly seen in this case.

NIRS: The optical data was filtered to cut off low frequencies (< 0.0125 Hz) and higher frequencies (> 0.3 Hz, corresponding to the fluctuation due to heart beat and respiration), and then averaged (folding average) over the rare case events and common case events respectively. Considering the relatively longer time of the hemoglobin response to the stimuli, compared to the latency of evoked potentials, intervals of 20 s are chosen for the procedure of folding average. Each time interval includes an oddball case and it started 2 s before the stimuli and ending 18 s after. This time interval is chosen also because it matches the average rare case interval time (Fig. 2.). The modified Lambert-beer law was applied to obtain the changes in oxy- and deoxy-hemoglobin[6]. Temporal trends of NIRS from two positions are shown in Fig. 4.

Subject:
EEG file: RARE Dec 03 04   5 sec.avg Recorded : 15:32:51 03-Dec-2004
Rate - 1000 Hz, HPF - 0 Hz, LPF - 30 Hz, Notch - off

Neuroscan
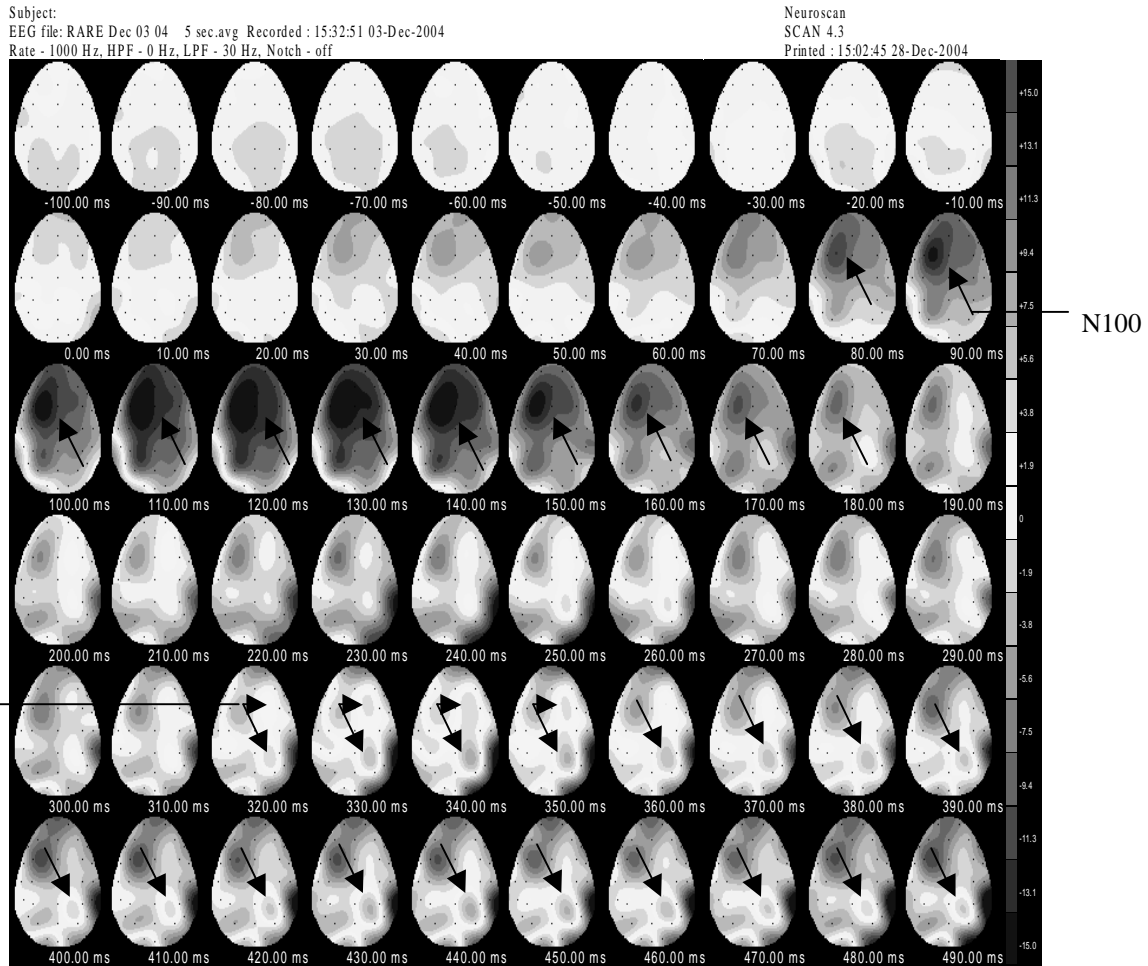SCAN 4.3
Printed : 15:02:45 28-Dec-2004

Figure 3: Average temporal evolution of spatial maps of evoked potentials for the oddballs. Arrows in the second and third rows are pointing to the locations of N100, arrows in the fifth and sixth rows are pointing to the locations of P300.

3. RESULT

The evoked potential of "oddball" is mapped in Fig. 3. Predominant negative potentials appear around 100 ms, well-known to neurologists as N100, which correspond to the auditory stimulus. We observed the same negative potentials (N100) after the common auditory stimulus. Around 300 ms, positive evoked potentials, known as P300, started to appear and expand (mainly from frontal to parietal lobe). It peaked at 340 ms and continued till 500-600 ms after the stimulus. P300 is the evoked potential corresponding to the novel stimulus[7,8]. It is only observed after the oddball stimulus. Hemodynamic responses at two positions are shown in Fig. 4. A clear hemodynamic response is only observed in the area between detector B and illumination fiber 3 (B3) in the oddballs (in the fronto-temporal regions). This hemodynamic response characterized by a decrease in the deoxy-hemoglobin concentration ([Hb]) and by a concurrent increase in the oxy-hemoglobin concentration ($[HbO_2]$), is consistent with a focal increase in cerebral blood flow. No responses are observed when the procedure of folding average is applied to the common cases. For comparison, the hemodynamic response in the position between detector A and source 7 (A7) is shown to the right, no clear responses are observed in A7 in either oddball or common cases. The rest of source-detector pairs gave similar results as A7.
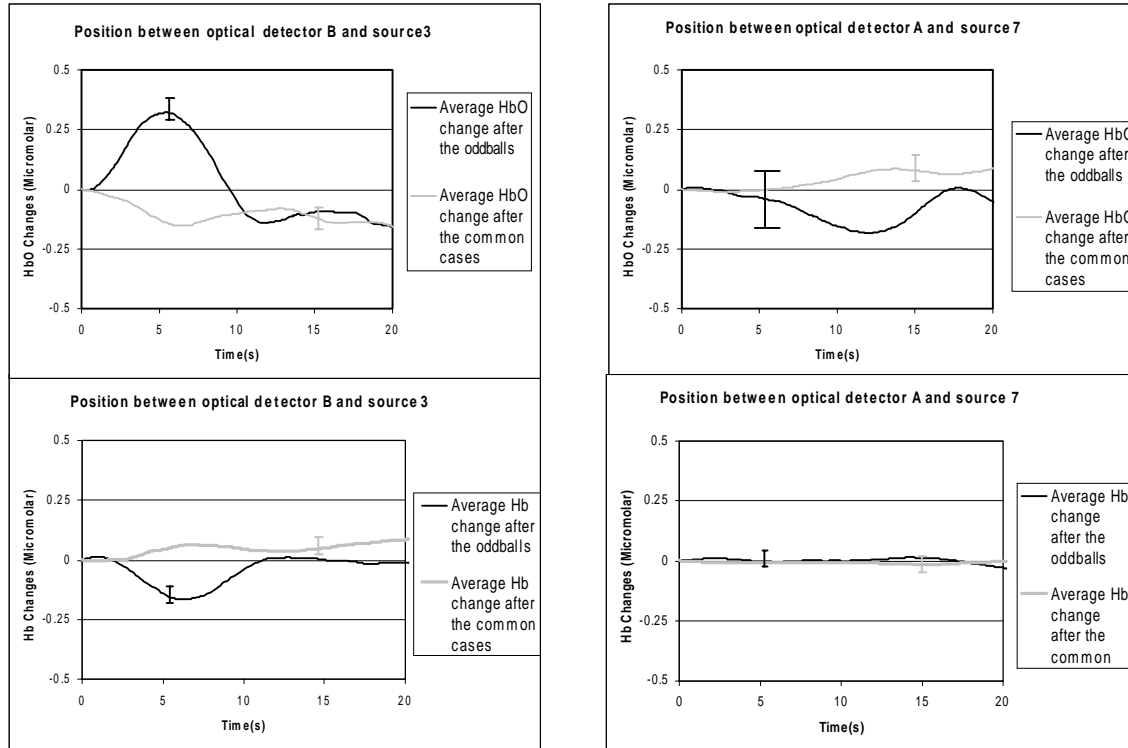
Figure 4: Hemodynamic responses after oddball stimulus and common stimulus at two positions

4. DISCUSSION

Figs. 3 and 4 show the temporal evolutions of EEG maps and NIRS signal. An evoked potential starting around 300 ms is observed in only oddball cases but not in common cases (not shown here), while another well-known evoked potential N100 (corresponding to auditory stimulus) is observed in both cases. In Fig. 4, we observed a clear increase in oxy-hemoglobin and a decrease in deoxy-hemoglobin in oddball cases at position B3, which are broadly accepted as the trademark of cortical activation. The peak latency is about 5 s, which is consistent with previous studies[1,11]. The fact that no such activation was found in the common cases at the same position B3 shows that the activation is in response to P300, not to N100 (i.e. response to novel stimulus, not to the auditory stimulus). Since the subject was asked to press a button whenever he heard an oddball, it might be possible that the activation we observed was actually from finger movement. However, as we noticed before, since the subject used his right finger, the right (ipsilateral) side of the motor cortex should be less activated than the left (contralateral) side. Moreover, one would expect changes in [HbO₂] and [Hb] induced by motor activation to be less localized and visible also at position A7 (as we observed in finger tapping task protocols). In Fig. 4, no activation is observed at position A7. However, to rule out this possibility completely, a different protocol will be applied in future studies. Even though the hemodynamic activation site that we observed is consistent with previous studies[1,9,10], the areas of electrical and NIRS activation are at different locations. To address the reliability, reproducibility, and origin of this difference, more experiments and more subjects are needed.

5. CONCLUSION

We have presented preliminary results on simultaneous NIRS-EEG data acquisition for the study of functional imaging of the brain during a cognitive task. We observed an increase in oxy-hemoglobin concentration and a decrease in deoxy-hemoglobin concentration in fronto-temporal regions. Though the actual cortical source of the P300 wave is not known, this finding is consistent with previous studies that reported that the P300 wave (especially for novel stimuli elicited by oddball paradigms) originates from the frontal and fronto-temporal cortical regions. The time latency for the hemoglobin signal to reach its peak is about 5 s, considerably longer than the latency of evoked potentials. Future experiments will

be conducted with more refined and spatially extended mapping capabilities and with attention to both the dipole source mapping of the P300 and a further analysis of frequency-domain coherence between related cortical regions. Many more trials will be included to achieve statistically significant results.

ACKNOWLEDGEMENTS

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