Studying brain function with near infrared spectroscopy concurrently with electroencephalography

Y. Tong[1], E. J. Rooney[2], P. R. Bergethon[2], J. M. Martin[1], A. Sassaroli[1], B, L. Ehrenberg[1], Vo Van Toi[1], P. Aggarwal[3], N. Ambady[4], and S. Fantini[1]

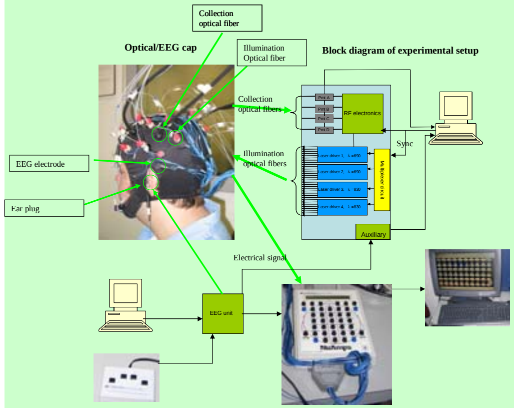
[1]Tufts University, Department of Biomedical Engineering, Medford, MA; [2]Tufts New England Medical Center, Department of Neurology, Boston, MA; [3]Boston University, Department of Psychology, Boston, MA; [4]Tufts University, Department of Psychology, Medford, MA.

Abstract:

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 topographically and temporally with near-infrared spectroscopy (NIRS). The NIRS measurements demonstrate a hemodynamic change in the fronto-temporal cortex within the first few seconds after the appearance of the electrical potential (P300).

Introduction:

Near-infrared spectroscopy (NIRS) and electroencephalography (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 approximate 5s and happened in close proximity to the areas of peak electrical activities[1], while Silvina et al detected NIRS signal and event-related potentials simultaneously during a semantic processing task[2]. These previous studies suggest that there is some kind of coupling between evoked potentials, representing electrophysiological responses, and the NIRS signals, representing hemodynamic and metabolic responses [3,4,5]. There is potential to use combined electrical and optical evoked responses to identify the neuronal activation and corresponding hemodynamic response temporally and spatially. To explore this potential, in this study we have concurrently collected evoked electrical potentials and optical responses (related to hemodynamic changes) associated with cognitive tasks (odd-ball paradigm) using a specially-designed opto-electrical helmet worn by the subject.

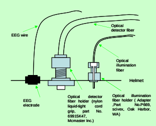


Instrumentation for concurrent electrical and optical recordings:

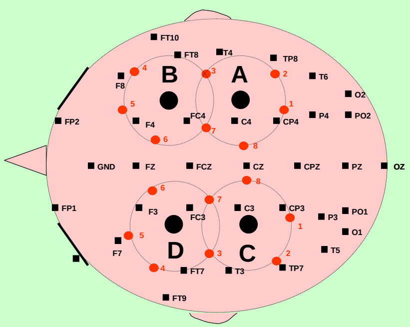
The block diagram of the experimental setup, the optical instrument, and a detail of the EEG-NIRS helmet are shown in the figure on the left. The EEG equipment for the measurement of the event related potentials (ERP) is based on a NuAmps, a 40-channel digital EEG amplifier running SCAN 4.3, a software system designed to acquire and analyze amplified EEG data. Stimulus is provided by STIM, a software environment for custom stimulus and task design as well as presentation (all from NeuroScan Inc., Abbotsford, Australia). The acquisition rate of the digital EEG was 1000 Hz with digital filtering applied in the post-analysis. Each one of the 40 electrodes was applied with an impedance below 5 kW. The evoked potentials were extracted from the continuous EEG file by averaging epochs of the EEG surrounding the stimulus locked auditory stimuli.

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 a standard 40-channel EEG cap (NeuroScan Inc., Abbotsford, Australia) to allow simultaneous recording of EEG and NIRS data.

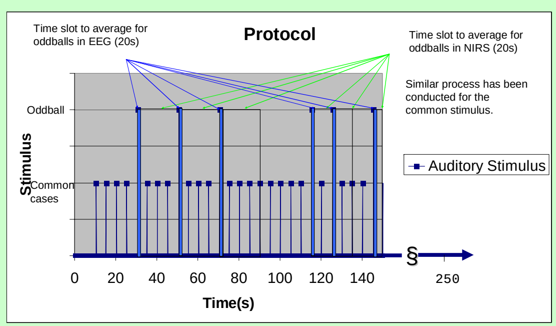
Close-up look of arrangement of optical fibers on the EEG helmet



Arrangement of electrodes and optical fibers



- ● Optical detector fiber
- ● Optical illumination fiber
- ■ EEG electrode



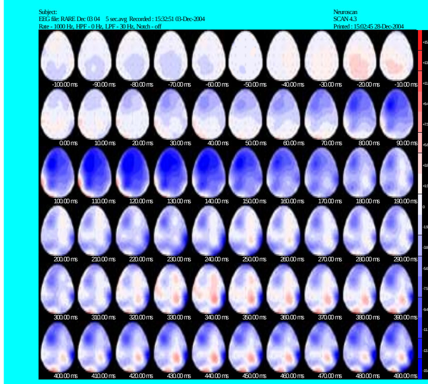
Protocol:

The subject (an adult health male 24 years of age) is asked to sit comfortably in a chair wearing bilateral ear phones. Half minute of baseline optical data is acquired, then subject hears 50 consecutive tones (20 ms in length) with 5s intervals in between them. 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) when he hears the rare cases and to otherwise be quiet and relaxed.

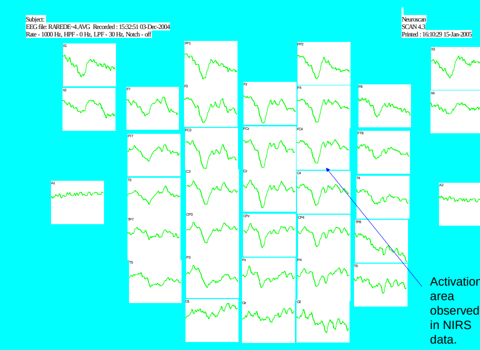
Data analysis:

EEG: Following routine artifact removal and baseline DC correction, the EEG data were averaged for rare and common cases of the tone, starting 100ms before each stimulus and ending 490ms after. The average files of the rare stimulus and the common stimulus are then used for further analysis with the waveforms presented topographically at each of the 40 electrode positions with reference to a linked ear reference. The P300 wave is seen in the "oddball" cases.

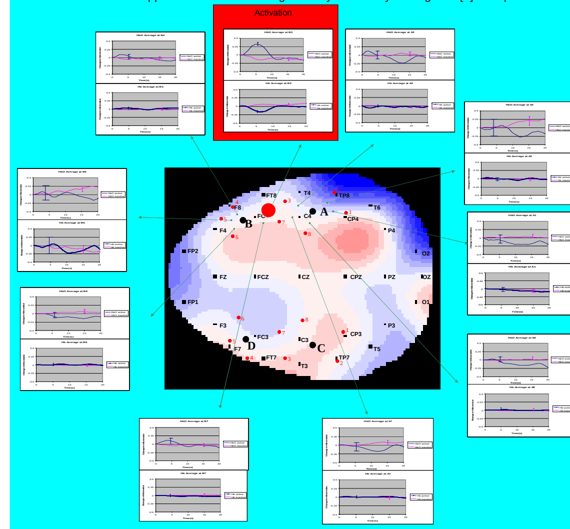
Temporal evolution of spatial maps of evoked potentials



Temporal trace of evoked potentials in "oddball" paradigm



NIRS: The optical data were filtered to cut off low frequencies (< 0.0125Hz) and high frequencies (> 0.3Hz), and then averaged over the rare case events (folding average). Considering the relatively longer time in the hemoglobin response compared to the latency of evoked potentials, 20 sec is chosen for the time interval to average, starting 3 sec before the stimuli and ending 17 sec after. This time interval is chosen also because it matches the average rare case interval time. The modified Lambert-beer law was applied to obtain the changes in oxy and deoxy hemoglobin [6]. Temporal trends and spatial mapping are obtained for both EEG and NIRS.



- ● Optical detector fiber
- ● Optical illumination fiber
- ■ EEG electrode

Result: The evoked potential of "oddball" is mapped in the graph on the left (Red pattern represents the positive potentials, blue pattern represents the negative potentials at 340ms after the stimuli). Clear hemodynamic response is observed in the area between detector B and illumination fiber 3 (in the temporal and parietal cortical regions).

Summary: 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 and a decrease in deoxy hemoglobin, representing an activation, in fronto-temporal regions. Though the actual cortical source of the P300 wave is not known, this finding is consistent with reports in the literature that the P300 wave especially to novel stimuli (as elicited by our odd-ball paradigm) originates from the frontal and fronto-temporal cortical regions. The time latency for the hemoglobin signal to reach the peak is about 5 second, considerably longer than the latency of the evoked potential. 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: This work was supported by the National Science Foundation, Award No. BES-93840, and by the National Institutes of Health, Grant No. DA14178. We thank William Lowenthal and Michael Stevenson for their help in the initial phase of this project.

REFERENCES

1) R. P. Kennan, S. G. Horovitz, A. Maki, Y. Yamashita, H. Koizumi and John C. Gore, "Simultaneous Recording of Event-Related Auditory Oddball Response Using Transcranial Near Infrared Optical Topography and Surface EEG", Neuroimage 16, 587-592 (2002)
2) S. G. Horovitz and John C. Gore, "Simultaneous Event_Related Potential and Near-infrared Spectroscopic Studies of Semantic Processing", Human Brain Mapping 22:110-115 (2004)
3) M. Moosmann, P. Ritter, I. Krastel, A. Brink, S. Thees, F. Blankenburg, B. Taskin, H. Obrig and Arno Villringer, "Correlates of alpha rhythm in functional magnetic resonance imaging and near infrared spectroscopy", Neuroimage 20 145-158 (2003)
4) H. Obrig, H. Israel, M. Kohl-Bareis, K. Uludag, R. Wenzel, B. Müller, G. Arnold and A. Villringer, "Habituation of the visually evoked potential and its vascular response: implications for neurovascular coupling in the health adult", Neuroimage 17, 1-18 (2002)
5) M. Wolf, U. Wolf, J. H. Choi, R. Gupta, L. P. Safonova, L. A. Paunescu, A. Michalos, and Enrico Gratton " Functional Frequency-Domain Near-Infrared Spectroscopy Detects Fast Neuronal Signal in the Motor Cortex", Neuroimage 17, 1868-1875 (2002)
6) Delpy D T, Cope M, van der Zee P, Arridge S, Wray S, Wyatt J," Estimation of optical path length through tissue from direct time of flight measurements" ,Phys. Med. Biol 33, 1433-1442 (1988).