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Title

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Permalink

<https://escholarship.org/uc/item/1kw5j5bp>

ISBN

9781557528209

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Publication Date

2000

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Peer reviewed

Detecting cerebral functional slow and fast signals by frequency-domain near-infrared spectroscopy using two different sensors

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Abstract: Using near-infrared-spectroscopy a slow signal due to hemodynamic changes following brain activity is well characterized, while a fast signal is not enough investigated. With our frequency-domain-spectrometer and two different sensors we detected both signals.

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OCIS codes: (170.5270) Photon density waves; (170.6510) Spectroscopy, tissue diagnostics

1. Introduction

Brain activity is associated with physiological changes in the optical parameters of the tissue that can be assessed by near-infrared spectroscopy (NIRS). Two major types of signals are reported in the literature. A slow signal in the range of seconds, mainly due to light absorption related in particular to changes in hemoglobin concentration. This signal has been demonstrated by many authors [1]. Only a few authors reported the evidence of a fast signal in the range of milliseconds [2]. This signal is much smaller and was suggested to be associated with changes in light scattering due to changes in the refractive index at neuronal membranes [1]. We investigated the possibility to detect this fast signal during visual stimulation with two different sensors for our frequency-domain spectrometer.

2. Material and methods

The two set-ups use a frequency-domain tissue oximeter (modified model no: 96208 Omnia ISS Champaign IL USA). The instrument uses a frequency of 110MHz to modulate the light intensity of the laser diodes. The second dynode of the photomultiplier tube is modulated with 110.005MHz.

Set-up 1

In this linear sensor the light of two laser diodes at 758nm, which were in phase and turned on at the same time to increase the emitted light intensity, were led by two glass-fibers to the sensor. They were placed as close as possible to each other in order to explore the same region of the sample. No multiplexing was used to further optimize the noise reduction.

At two different distances (2.8 and 3.3cm) from the light source two glass-fiber bundles of 3mm diameter were placed which led to two detectors. Light source and both detector-fibers were arranged in one row. The data was recorded with 96 Hz sample rate.

Set-up 2

This π sensor uses two pairs of laser diodes at 670nm and 830nm. The distance between the two pairs was 2.0cm. All laser diodes were turned on at the same time, using no multiplexing to optimize the noise reduction. At the same distance from each pair of laser diodes a liquid light-guide was placed which was connected to a photomultiplier tube as a detector, such that source-fibers and detector-fibers were arranged at the corners of a quadrangle. In front of the detector that was closer to the source-fibers emitting at 830nm a light-filter removed the light coming from the 830nm-laser diode. Thus at this position only the 670nm light was detected. Each light-filter had a blocking optical density of >6 . Analogously in front of the other detector was a filter that removed the light at 670nm. Using this arrangement the two paths of light correspond to the two diagonals of the quadrangle and the effective source-detector separation was 2.8cm. This sensor is called π sensor because when the product of the two signals at the

detector is taken, one reduces the sensitivity to fluctuations near the surface and is more sensitive to signals referring to deeper regions of tissue [3]. For this arrangement we used liquid light guides of 5mm diameter to improve the signal. The data was recorded at a sample rate of 64 Hz.

Measurement protocol

The source and detector fibers were attached to the subject's head directly above the visual cortex, i.e. center between source and detector was 1.5 cm above the inion and 1.5 cm to the right. One subject was seated, one was lying down in a dark environment in front of a checkerboard. The checkerboard was turned on for 10s, after which its pattern started reversing for 20s. During these 30s the subject focused on a red LED in the center of the checkerboard. This was followed by a 30s resting period, where the checkerboard was turned off and the subject could relax. The duration of a whole cycle was 60s. For each subject 20 cycles were carried out. At the beginning and the end of each measurement 2 minutes of baseline were recorded.

This protocol was approved by the Institutional Review Board of the University of Illinois at Urbana-Champaign.

In order to obtain control-data for each set-up measurements were performed with sources and detectors attached to a solid medium of approximately the same optical properties as the human head.

Data analysis

For both set-ups the raw modulation amplitude (AC) and phase values of the frequency domain instrument were analyzed. First the time traces were inspected for artifacts. For the first set-up then the 20 periods of 60s duration were folded in order to get the average signal, which showed the slow functional reaction (slow signal) of the blood circulation to the stimulus. Furthermore all the reversing periods were folded as well, to see whether a fast reaction (fast signal) of optical properties of the brain to the stimulus could be detected. The same folding was done for the periods without stimulation as a control.

For the second set-up the normalized product of the two channels was taken and then analyzed exactly as for the first set-up. The measurements on the solid medium were evaluated in exactly the same way as the in vivo measurements.

To calculate the statistical significance of the changes in the fast signal a paired t-test was applied.

3. Subjects

Two healthy adult volunteers were included in this study. One was a female of the age of 35 years, the other was a male of 34 years. Written informed consent was obtained from all subjects.

4. Results

Set-up 1: A distinct slow signal was detected in the AC but not in the phase. The light intensity at both detectors decreased during the stimulation, which can be interpreted as an increase in blood volume.

Furthermore a significant ($p < 0.0026$) change in the phase was observed in the analysis of the fast signal at the detector at 3.3cm distance. The maximum phase change (\pm SEM) was $0.034^\circ \pm 0.0079$ at 92ms after the onset of the stimulation. No significant fast signal was found in the AC for both source-detector distances and in the phase of the detector at 2.8cm. When the same analysis was carried out on periods without stimulation, no significant changes were observed.

While performing measurements on the solid medium instead on the subject neither a slow nor a fast signal was observed.

Set-up 2: A distinct slow signal was observed in the AC and phase. The quality of the slow signal was improved using the product of the signals from the two detectors.

For the cross-correlated fast signal significant changes were detected both for the AC (-0.000105 ± 0.000026 counts², $p = 0.0031$) after 156ms and the phase ($0.014 \pm 0.035^\circ$, $p = 0.0039$) after 141ms. When the periods without a

stimulation were analyzed a significant but smaller change was found in the AC (-0.000056 ± 0.000018 counts², $p=0.015$), while no significant change was observed in the phase (0.019 ± 0.024 , $p=0.29$)

Again no changes were observed during the measurements on the solid medium.

5. Discussion

The slow signal has often been demonstrated in previous studies and we were able to detect it in this study as well. Our main focus was the fast signal.

Set-up 1: We performed two tests to make sure, that we detected the fast signal in set-up 1. The measurement on the solid medium showed that the signal is not due to the instrumental noise or interference. Furthermore the signal was only visible during stimulation. Thus we are quite confident, that the phase change we have detected is due to the stimulation. The signal was not detectable in the detector at the closer distance, probably because the penetration depth was smaller. It is quite clear, that the fast signal is at the limit of detection.

Set-up 2: The π detector was constructed to increase the signal to noise ratio in order to be able to detect the fast signal with more accuracy. According to our result it seems that the π detector is more sensitive to the fast signal than the linear sensor, especially for the phase. A significant signal was found in the AC even during the periods without stimulation. Looking at a fast Fourier analysis of the data, we think that the most likely cause for this signal is, that the visual stimulation frequency was close to the one harmonics of the heart rate of this subject. This issue certainly needs further investigation. Nevertheless the change in the AC was bigger and more significant during stimulation than without and in the phase the change was only significant during stimulation. Thus we think that a major part of our signal is due to a fast signal referring to neuronal response as previously proposed [2].

6. References

1. A. Villringer, B. Chance, "Non-invasive optical spectroscopy and imaging of human brain function", *Trends Neurosci.* **20**, 435-42 (1997).
2. G. Gratton, P. M. Corballis, E. Cho, M. Fabiani, D. C. Hood, "Shades of gray matter: noninvasive optical images of human brain responses during visual stimulation.", *Psychophysiology* **32**, 505-9 (1995).
3. M. Filiaci, V. Toronov, S. Fantini, E. Gratton, "Optical probe and frequency domain instrumentation to study spatial and temporal correlations and fluctuations in tissues" *OSA TOPS* **22**, 183-7 (1998).