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Effect of Electrical Stimulus Intensity to Hemodynamic Responses of Somatosensory cortex

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***Abstract*— To investigate the relationships between neuronal activity and hemodynamics, regional changes of hemoglobin concentration associated with cortical activation in the primary somatosensory cortex (SI) to the electrical stimulation were investigated by near-infrared spectroscopy (NIRS). We measured the hemodynamic evoked responses to the electrical stimuli of some intensities applied on the right thumb. NIRS measurements were performed on 3 healthy right-handed volunteers and we investigated the spatial and temporal features and the magnitude of the optical signal induced by cerebral activation. In this study, we consistently found that an increase in the cerebral concentration of oxygenated hemoglobin [oxy-Hb], and that a decrease in the cerebral concentration of deoxygenated hemoglobin [deoxy-Hb] at somatosensory area. Moreover, as the intensity of electrical stimuli changes stronger from 3 times to 6 times intensity of the sensory threshold of thumb, the increment of [oxy-Hb] and [total-Hb] are augmented.**

***Key words*—Near-infrared spectroscopy (NIRS), hemodynamic responses, somatosensory cortex, electrical stimuli**

I. Introduction

NIRS, a recently developed promising optical instrument, basing on the intrinsic optical absorption of blood, enables noninvasive measurement of regional relative hemodynamic evoked responses associated with cortical activation [1][2]. The electrical nerve stimuli are widely used to stimulate peripheral parts of the human body, and corresponding somatosensory evoked potentials have been extensively studied in both clinical practice and experimental research. These investigations depicted the changes occurring within the central nervous system and cortex in humans in response to an external stimulus. Modern advances of neuroimaging techniques, such as PET and fMRI, have enabled researchers to assess cerebral hemodynamic changes following electric nerve stimulation [3]. Since stimulus related hemodynamic activation is dynamic rather than static, it is important to evaluate the temporal patterns of evoked hemodynamic responses. In this respect, unlike PET and fMRI, by which it is difficult to directly measure ongoing hemodynamics, NIRS allows us to monitor real-time hemodynamic easily. There are several studies related to somatosensory response by NIRS [4][5].

In this study, we performed an experiment to investigate what the blood flow in SI changes when the intensity of electrical stimulus changes. We applied multi channel NIRS to observe hemodynamic evoked responses temporary in the somatosensory area.

II. Materials and Methods

A. Subjects

Three healthy volunteers aged 21-43 years, men participated in this study. All subjects reported they were right-handed. All the subjects reported no physical, pain or any other neurological problems, which might limit their ability to participate in the present experiments. The subjects have the privilege to stop the experiment at any time when they feel uncomfortable.

B. Electrical stimuli

Electrical stimuli were delivered with a pair of electrodes applied to the subject's right thumb. Square-wave pulses, 5Hz in frequency, 0.2ms in duration, were delivered by a constant current electrical stimulator connected via a trigger cable to the NIRS device. The electrical stimuli induced a clear pricking sensation at the fingers.

C. NIRS measurements

We used ETG-4000 (Hitachi Medical Corporation). We installed these 16 optical fibers over the subject's left scalp. We placed the center of the pad 30 mm lateral to the C3 to cover primary sensorimotor hand area (Fig.1). The [oxy-Hb] and [deoxy-Hb] concentration changes in 24 channels were recorded with a sampling rate of 10 Hz.

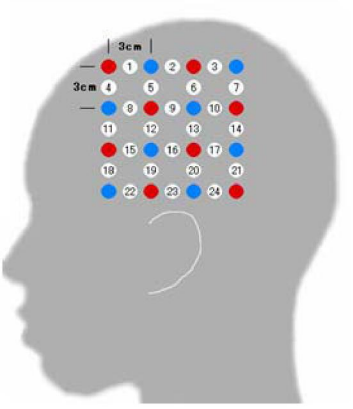


Fig.1 Probe set on head, the red circles represent the laser diodes (light transmitter), the blue circles represent the photodiode (light detector), and the white circles written with number from 1 to 24 represent the 24 channels (measurement point), respectively.

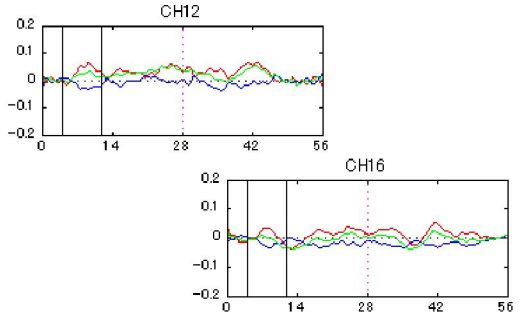
D. Procedure

Subjects sat comfortably in an armchair, with their hands supinated and were instructed to stay awake.

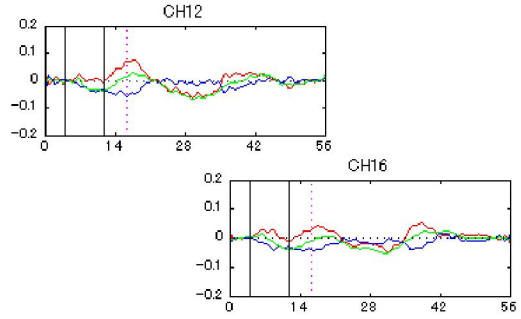
In this experiment, the stimuli were delivered in trains of 8s at a frequency of 5 Hz followed by 52s of rest to thumb. For each participant, we changed the current intensity to 3 times, 4 times and 6 times of the level of sensory threshold of thumb. The whole experiment paradigm consisted of an initial baseline of 30s for the subject to calm down in order to raise steady response, following by 20 alternating trains of stimulation (8s) and rest (52s). Therefore, te complete session consisted of an initial reference rest period of 30s followed by a blocked design of 20 task/rest sequences without any interruption.

E. Data analysis

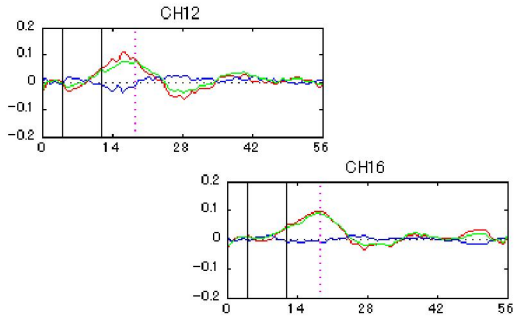
The concentration changes of [oxy-Hb], [deoxy-Hb] and [total-Hb] were calculated over the experiment sessions. In order to eliminate the artifacts like undesirable noise, missing or bad signal, the obtained raw data were firstly low-pass filtered with a 0.5Hz band pass frequency. Thereafter, we checked closely the continuous waveforms of each experiment visually to leave out the data with low signal-to-noise ratio and the motion artifacts. We set the parameters as pre time of 4s, relax time of 44s and post time of 4s. As a result, including the 8s of stimulation period, a totally 60s of hemodynamic evoked responses can be showed in a integral waveforms graph. In this graph, we can gain 24 pixels that contained the waveforms which reflected the hemodynamic responses in the 24channels separately that gained from the subject's left hemisphere. Since in optical measurement, [oxy-Hb] was reported to be the most responsive parameter of activity dependent changes in rCBV [6], our analysis mainly focused on the [oxy-Hb] changes. According to the representative hemodynamic time-course model that reported in former study [7], we considered an image pixel as activated if the [oxy-Hb] concentration change showed a steady rise after the onset of the stimuli, lasting a plateau period for a while and then dropped gradually until to the initial line. We selected the channels that almost fit the above-mentioned pattern and in which the hemoglobin concentration change was most prominent to further analyze. On the data from these channels with maximal activation we performed individual-subject analysis for a comparison of the amplitudes of the hemodynamic response across various electrical stimuli.



a)3times of the threshold



b)4times of the threshold



c)6times of the threshold

Fig.2 Waveforms of hemoglobin concentration changes in the somatosensory areas that control the thumb in a control subject. The horizontal axis in each pixel express the latency (s) and the vertical axis express the hemoglobin concentration change (mM mm). The time of the stimulation period was defined as from 4s to 12s in the time course. The red line represents the averaged [Oxy-Hb], the blue line represents the averaged [deoxy-Hb], the green line represents the averaged [total-Hb], respectively.

III. Results And Discussion

We analyzed the spatial/temporal features and the amplitude of the optical signal induced by cerebral activation during the experiment paradigms. At the case of 3times intensity of the sensory threshold (Fig.2 a), we consistently found that the cerebral concentration of [oxy-Hb] at the activated cortical region started to increase and that the cerebral concentration of [deoxy-Hb] at the activated cortical region started to decrease at about 5sec, that is to say, the time the stimulation period started, and their amplitude became the largest at about 10sec. At 15sec they become normal. Other two experiments also have similar graphs despite small difference of time courses (Fig.2 b, c). In this experiment, from the waveforms of

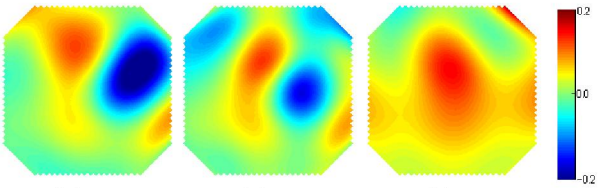


Fig.3 The topographical images of [oxy-Hb] of the intensity. Each map was calculated at the time when the most prominent [oxy-Hb] change was seen in the SI response. The red, green and blue areas in the topography indicate increase no change and decrease in [oxy-Hb], respectively.

hemoglobin concentration change, as the intensity of electrical stimuli changes stronger from 3 times to 6 times, the increment of [oxy-Hb] and [total-Hb] are augmented in CH12 and CH16 (Fig.2). There are the topographical images of [oxy-Hb] of the intensity (Fig.3). Each map was calculated at the time when the most prominent [oxy-Hb] change was seen in the SI response. The red, green and blue areas in the topography indicate increase no change and decrease in [oxy-Hb], respectively. From these topographies, the activity area was expanded from topography. Stimulus related hemodynamic activations is dynamic rather static, so it is important to evaluate the temporal patterns of evoked hemodynamics responses. In this respect, unlike PET and fMRI, by which it is difficult to directly measure ongoing hemodynamics, NIRS allows us to monitor real-time hemodynamic easily. In the present study, we employed a multi-channel NIRS system to clarify the effect of stimuli intensity on the evoked hemodynamic responses in human SI by examining the waveform amplitudes and temporal activation patterns. We have found obvious increment in hemoglobin concentration at stronger stimuli intensity of 6 times of the sense threshold than at stimuli intensity of 3 times of the sensory threshold.

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