Discrimination of Finger Area of Somatosensory Cortex by NIRS

Mingdi Xu* Non-member
Takehito Hayami** Member
Keiji Iramina*** Member

We carried out a near-infrared spectroscopy (NIRS) study to observe the hemodynamic responses associated with cortical activation in the primary somatosensory cortex (SI) by finger electrical stimulation. We examined whether NIRS can assist in investigating the somatotopic arrangement of fingers on the SI hand area. We found that although relatively low in spatial resolution, NIRS can to some extent help to discriminate the representations of thumb and ring finger on the SI hand area.

Keywords: near-infrared spectroscopy (NIRS), hemodynamic responses, primary somatosensory cortex (SI)

1. Introduction

NIRS, a new emerging distinguished optical instrument, basing on the intrinsic optical absorption of blood, enables noninvasive measurement of regional relative hemodynamic evoked responses associated with cortical activation. In a former fMRI study[1], representations of thumb and little finger were reported to be 17mm apart and consistently showed a somatotopic arrangement with the thumb representation inferior, lateral, and anterior to the representation of the little finger. In this study, with NIRS, comparatively limited in spatial resolution but superior in temporal resolution, we tested whether it can to some extent help to spatially discriminate the somatotopic arrangement of thumb and ring finger on the hand area of the SI.

2. Materials and Data Analysis

Measurements were performed with multi-channel ETG4000 (Hitachi Med.Co). At two wavelengths, relative concentration changes of oxy-Hb/deoxy-Hb/total-Hb were calculated according to the modified Beer-Lambert law. The probe was centered at C3 of the international 10-20 system to cover the SI hand area. The distance between source and detector fibers was 30mm, forming a zone of the international 10-20 system to cover the SI hand area. The probe was centered at C3 to the modified Beer-Lambert law. The probe was centered at C3 of the international 10-20 system to cover the SI hand area. The distance between source and detector fibers was 30mm, forming a measurement area of 90°(Fig.1(a)). The 0.2ms-in-length monophase square-wave pulses were delivered at frequency of 5Hz by a constant current stimulator with a pair of electrodes applied to the subject’s right thumb and ring finger, separately.

All the experiments were conducted in a lighted room. Subjects (2 males and 2 female, aged 22-25 years) sat comfortably in an armchair, with hands supinated and stayed awake. For each participant, we adjusted the current intensity to 3 times of the sensory threshold (3ST) of each finger (ring finger:4.2±0.6mA; thumb:3.6±0.3mA). The block-designed task consisted of 30s reference period, followed by 10 alternating trains of stimulation (8s) and rest (52s).

Since commercial NIRS instrument can only measure the relative concentration change of Hb species, we corrected the baselines using a linear fitting method, which was performed by connecting the pre-task baseline to the post-task baseline. The pre-task baseline was determined as the mean value of the pre-task period (5s) immediately preceding the electrical stimulation period (8s), and the post-task baseline was determined as the mean value of the post-task period (5s) just after the recovery period (15s) (immediately following stimulation period), as shown in Fig.1(c).

3. Results

It is reported that measurement positions with high probabilities of activation in the SI were around the center of the measurement area[3]. Therefore, we focused on the hemodynamic responses in CH5,6,8,9,10,12,13,15,16,17,19,20. We regarded a channel as activated if the responses of oxy-Hb during the stimulation period were different from during pre-task period. Because of NIRS’s relatively low spatial resolution, we averaged the waveforms of the adjacent channels with most robust responses and took them as the activated “hot spot”. From the grand averaged waveforms of the four subject (Fig.1(c)), we found that when the electrical stimulation was applied to the ring finger, the activation hot spot lay in the upper part of the probe among CH5,6,8,9,12,13, while when applied to the thumb, the activation hot spot lay in the lower part of the probe among CH12,13,15,16,19,20. Topography images of oxy-Hb showed that the representation of the ring finger is located superior comparing to the thumb representation. The average distance between the activation hot spots of thumb and ring finger stimulation was approximately 30mm. (Fig.1(b))

4. Discussion

Cortical activation patterns in human somatosensory cortex are widely known to be dependent on various parameters of the experimental setup. Therefore, we set the experiment conditions according to some former fMRI and NIRS studies[3-5] on hemodynamic responses to electrical stimulation. All of these studies applied square-wave pulses with duration of 0.2ms. Regarding the current intensity, motor threshold (MT) or 90% MT or combination of MT and ST (sensory threshold), were applied, ranging from 3.2mA to 10mA. The current intensity we used here was also within this range. With respect to stimulus frequency, A.Ferretti et al.[3] reported most obvious responses of contralateral SI at frequency of 4Hz. M.A. Franceschini et al.[5] stimulated the median nerve at frequency of 4-5Hz. M.Tanasaki et al.[5] employed frequency of 2,5,10 and 20Hz and observed most active responses in both SI and SII (secondary somatosensory cortex) area at 20Hz but responses only in SI at 2Hz. We also tried...
frequency at 10 and 20Hz, however, all of the subjects complained of pain. In order to avoid a possible confounding effect of painful sensations on Hb signals, we set the frequency at 5 Hz. When it comes to the task time-course, these studies used block paradigm of alternating stimulation/rest at (36s,36s); (28s,28s) and (10s,18s), respectively. Because of the specific temporal analysis method of NIRS as described above, we suspected that with rest period of 20~30s, the Hb species probably could not return to the baseline when the next task period started. Therefore, we attempted shorter stimulation period (8s) and longer rest period (52s) in this study.

Furthermore, from the results we obtained, we hypothesized that with NIRS, although relatively poor in spatial resolution, the cortical representation of the thumb and ring finger can be discriminated to some extent. As repeatedly demonstrated in more or less detail, by means of different method, such as MEG, PET and fMRI, representation of the little finger is located medial, posterior and dorsal comparing with the thumb representation. In this study, even though not that fine-grained, we still observed that ring finger was located superiorly to thumb on the hand region of SI. We estimated the distance as about 30mm, different from the result (17mm) obtained in fMRI study. We owed this discrepancy to the spatial resolution of the present NIRS instrument, since the nearest distance between source and detector fibers was 30mm. In individual subjects, distinct activation foci within the SI due to stimulation of the fingers were seen, presumably reflecting the activation of different subdivisions of SI as reported in the fMRI study. Other possible reasons for this interpersonal difference may also include the anatomical characteristics and the experiment methodological problem, e.g., the possible inaccurate placement of the measurement probe, since we placed it by hand though we did determine it according to the international 10-20 system.

To generalize our results, we need to increase the number of subjects and to develop a better method for accurate positioning, if possible, also to design a new type probe to improve the spatial resolution of the present NIRS instruments. Our findings, however, confirm the potential of NIRS to become a valuable technology for noninvasive functional imaging of the brain.

(Manuscript received Oct. 25, 2007, revised Feb. 29, 2008)

References