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Localization of Extrastriate Body Area using Functional Near-infrared Spectroscopy and 3D Digitizer*

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Abstract— **The extrastriate body area (EBA) is a brain region that responds selectively to visual stimuli of human bodies or body parts. Previous studies using functional magnetic resonance imaging (fMRI) have shown that EBA occupies a relatively small region and varied across subjects in its anatomical location. This study investigated whether EBA activity can be detected by functional near-infrared spectroscopy (fNIRS) that imposes few physical constraints on the subjects and has higher temporal but lower spatial resolutions compared to fMRI. For this purpose the subject's brain activity in the occipitotemporal area during observation of images of body parts and objects was measured using fNIRS. The NIRS optode positions were recorded using a 3D digitizer and mapped onto a probabilistic anatomical model. We found that the activity in the occipitotemporal region during observation of body stimuli was significantly greater than that of object stimuli in 11 out of 16 subjects. The group analyses also showed that channels located near the position where the previous studies reported EBA activation were more activated during observation of the body stimuli compared to the object stimuli. The spatial variance of those channels among subjects was relatively small. These results suggest that EBA activity and its anatomical location can be sufficiently measured by using fNIRS and a 3D digitizer.**

I. Introduction

The extrastriate body area (EBA) refers to an occipitotemporal brain region that responds selectively to visual stimuli of human bodies and body parts and showed lower activity for objects, tools, animals, and human faces [1]. Since human beings are highly social species, it is critical to detect human bodies to recognize the existence of, or interpret the meaning of actions of others. Indeed, several studies have shown the differential activation of EBA for self and other's bodies [2, 3]. Furthermore, untypical activation of EBA was found in neuropsychiatric patients, such as anorexia nervosa and developmental prosopagnosia [4-6]. These studies imply that measurement of EBA activity can be informative for social communication studies as well as clinical diagnosis.

EBA occupies a relatively small portion of brain cortical region so that the most studies used functional magnetic resonance imaging (fMRI) to detect activity in EBA. However, in order to utilize EBA activity in social communication studies or simplified clinical diagnosis, it is preferable that EBA activity can be measured by low-cost and highly flexible neuroimaging methods, such as functional near-infrared spectrosocopy (fNIRS).

fNIRS is a non-invasive neuroimaging method that measures changes in the oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb), and total-hemoglobin (total-Hb) concentrations [7]. It has been applied to various cognitive studies, including sensorimotor [8], visual perception [9], and executive functions [10], developmental studies [11], and clinical studies [12]. Despite its relatively low spatial resolution and small coverage of brain areas, fNIRS is advantageous for social communication studies and clinical applications. It imposes relatively few physical constraints on the subjects, so that their body movements and social interactions are nearly natural, which is difficult to achieve in fMRI experiments. In this study we investigated whether EBA activity during observation of visual stimuli of human bodies and body parts can be measured by fNIRS. To localize the activation foci we utilized a 3D digitizer to map the fNIRS channels onto the anatomical regions using a probabilistic registration method [13]. Using these techniques, we localized EBA on a subject by subject basis as well as at the group level, in order to compare those with the previously reported anatomical positions by fMRI studies.

II. Materials and Methods

A. Subjects

Sixteen healthy adult subjects (eight females and eight males, aged 22.8 ± 1.6 years, mean ± SD) participated in the experiments. All but two subjects were right-handed. All subjects had normal or corrected-to-normal vision. Written informed consent was obtained from all subjects. The experiments were approved by the ethics committee of the School of Science and Technology, Meiji University, and conducted according to the principles and guidelines of the Declaration of Helsinki.

B. Experimental Procedure

The experiment was performed in a quiet room. The visual stimuli were displayed on a liquid-crystal color monitor (LCD-MF241XBR, I-O Data, Ishikawa, Japan). Subjects were seated comfortably on a chair in front of the monitor and instructed to watch the monitor throughout the experiment. The viewing distance was approximately 1 m.

The experiment was conducted with a blocked design. In each block, 10 different images from one category (body or object) were presented (Fig.1). The size and color of the visual stimuli were comparable between the two categories. Each image was presented for 300 ms, followed by a blank screen

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for 500 ms. Six 8-s blocks each for the two categories with inter-block interval of 16 s were conducted. The order of the categories was pseudo-randomized. Because the experimental session was less than 7 min and no subjects reported drowsiness or other complaints after the experiment, we assume that the subjects were attentive to the stimuli throughout the experiment.

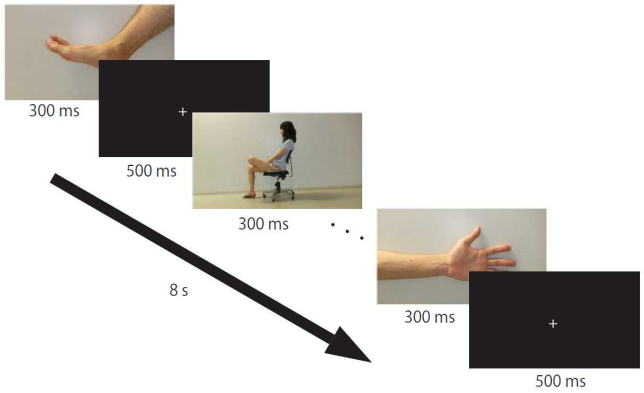

Figure 1. Schematic illustration of the experimental procedure.

C. NIRS and 3D Digitizer Measurement

NIRS measurements were performed throughout the experiment. A multi-channel NIRS unit operating at 780, 805, and 830 nm wavelengths (OMM-3000, Shimadzu, Kyoto, Japan) was used to measure temporal changes in the concentrations of oxy-hemoglobin (oxy-Hb), deoxy-hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb). Sixteen optodes constituting 24 channels were placed on the occipitotemporal area of the right hemisphere, including T6 of the international 10/20 system (9 × 9 cm square area, Fig. 2). T6 was determined for each subject by manually measuring head size. The probe holder was placed horizontally (parallel to the nasion-preauricular line), and T6 was located between channel 19 and 20.

Each channel consisted of one incident optode and one detector optode located 3 cm from the incident optode. This configuration is considered sufficient to detect hemodynamic changes in the cerebral cortex. Optical signals were emitted from the incident optode and detected by the corresponding detecting optode within 5 ms. Optical signals were exclusively and sequentially emitted from incident optodes. Thus, one cycle (24 channels) of measurement required 5 (ms) × 3 (wavelengths) × 8 (incident optodes) + 10 (ms, for data transfer) = 130 ms. As a result, the sampling rate at each channel was approximately 7 Hz. The optical data were converted to signal changes in hemodynamic responses (oxy-Hb, deoxy-Hb, and total-Hb) using the modified Beer-Lambert law. An extensive description of NIRS theory can be found elsewhere [7]. Although each NIRS parameter was measured, we focused on the results for oxy-Hb because we consider oxy-Hb to be the most sensitive parameter of hemodynamic response [14, 15].

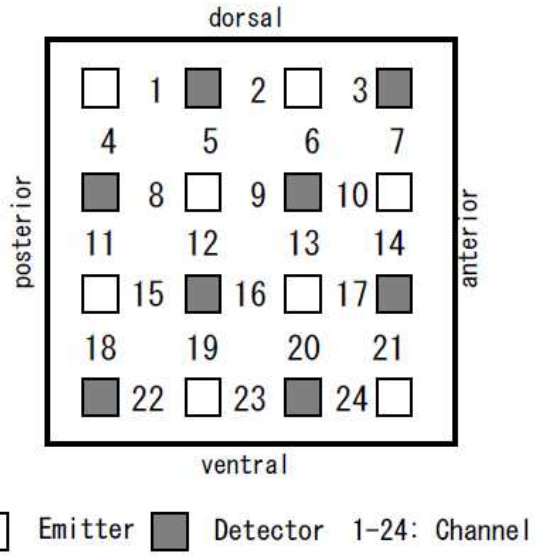

Figure 2. Location of NIRS optodes. The distance between each emitter and detector was 3cm. T6 of 10/20 system was located between channel 19 and 20.

In order to localize the activation foci on an anatomical brain region and to compare with the brain coordinates where previous studies reported as EBA, we measured relative locations of 10-20 standard positions (Fz, Cz, C3, C4, Pz, and reference points) and NIRS optode positions by using a 3D magnetic space digitizer (FASTRAK, Polhemus, VT, USA). The measured position data were submitted to a probabilistic spatial registration method [13], which is available at their website (http://www.jichi.ac.jp/brainlab/tools.html). This method generates probabilistic mapping between a NIRS channel and its corresponding anatomical brain region, which can be used for interpretation of fNIRS activation data.

D. Data Analyses

Statistical analyses of the fNIRS data were performed with effect size analyses [16]. The effect size was calculated as follows: the mean difference in fNIRS parameters (oxy-Hb) between control and task periods was divided by the standard deviation of the data in the control period to normalize the fNIRS data. This normalization enabled the comparison of fNIRS data among subjects. Time windows for the control and task periods were defined as 3 s just before the task onset and 4-12 s after the task onset, respectively. These time windows were decided by examining the data to reflect the maximum response of fNIRS parameters. The experimental condition (task) period was contrasted with the control (rest) period. A subject-level (random-effect) analysis was performed for each experimental condition with a one-tailed t-test using effect sizes of all trials (distinct from zero). The contrast between the body and object conditions was also calculated using a one-tailed t-test, to localize EBA for each subject. The threshold level was set at $p < 0.05$.

III. Results

The fNIRS result showed significant activations during observation of body stimuli. The main activation foci were

located in the temporal region near T6, although there were also activations in the dorsal and ventral premotor areas in several subjects. These activations were significantly greater than those of object stimuli in 11 out of 16 subjects ($P<0.05$). The anatomical position (MNI coordinates) of the channel that showed the maximum t-value was assessed with the 3D digitizer data and the probabilistic registration method [13] (Table 1; Fig.3). The averaged position across the 11 subjects was (50±16, -75±19, 6±17) (mean±SD), which was very close to the EBA position previously reported [1].

TABLE I. THE MOST ACTIVATED CHANNELS FOR EACH SUBJECT

Subj. ID	Ch	MNI coordinate			BA	Anatomical Location
		X	Y	Z		
A	24	54	-75	-10	19	V3
B	19	26	-98	-17	18	V2
C	21	65	-58	14	22	Superior Temporal Gyrus
D	17	43	-90	11	19	V3
E	17	45	-90	14	19	V3
F	19	21	-96	-20	18	V2
G	21	72	-37	14	22	Superior Temporal Gyrus
H	21	65	-59	-6	37	Fusiform Gyrus
I	16	42	-82	37	19	V3
J	20	55	-75	13	19	V3
K	17	62	-63	20	39	Angular Gyrus

BA: Broadman's area

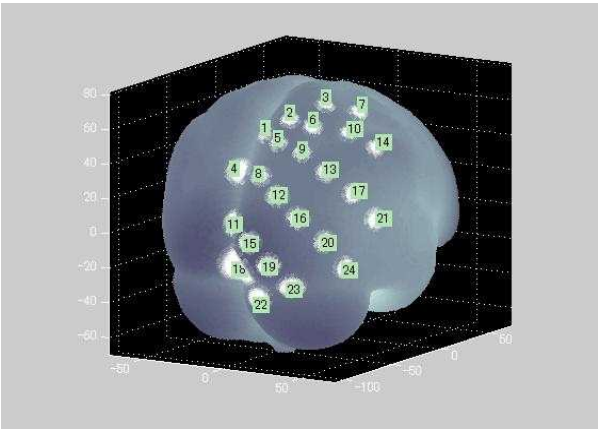

Figure 3. An example of probabilistic registration of fNIRS channels mapped onto the standard brain. The number indicates the channel ID.

We further conducted a group-level analysis. For this we selected the channel that was most close to the previously reported EBA position for each subject. The averaged position of these channels was (56±8, -72±12, 3±10). The effect sizes of these channels were submitted to one-tailed t-test. The result showed that the area under these channels was significantly activated during observation of the body stimuli ($t(15)=4.53$, $P<0.05$), but not of the object stimuli ($t(15)=-0.83$, $P>0.1$) (Fig.4). There was a significant difference between body and object conditions ($t(15)=1.76$, $P<0.05$).

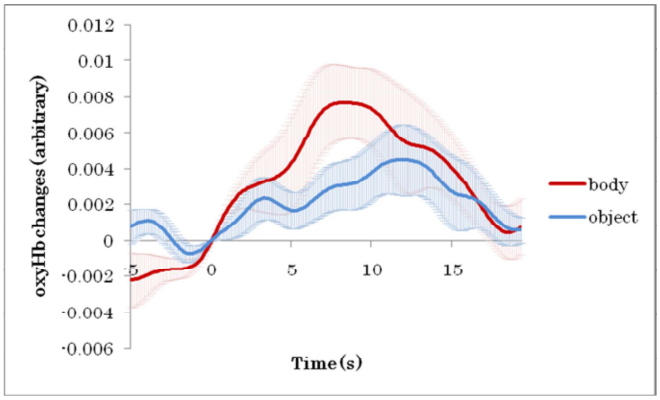

Figure 4. Time series of oxyHb changes for each condition at the channel located near previously reported EBA positions, averaged across subjects. Error bars represent the standard error of the mean.

IV. DISCUSSION

Our results showed that EBA can be localized with fNIRS in 11 out of 16 subjects at the channel near the position that was reported as EBA in several previous studies. Further, by setting the region of interest (ROI) as the position near previously reported EBA, we confirmed the differential activation between the body and object visual stimuli at the group-level analysis (Fig.4). These results indicate that EBA can be successfully measured by using fNIRS and a 3D digitizer.

The averaged MNI coordinates for EBA of the 11 subjects in our experiment was (50, -75, 6) with standard deviations of 16-19 mm. The position was very close to the previous studies with fMRI: for example, (51, -71, 1) [1], (54, -67, 8) [17], and (42, -65, 7) [18]. EBA was localized in V3 or V2 in most subjects and in temporal or temporoparietal area in a few subjects. The standard deviation of the EBA position in our experiment seems relatively large (16-19 mm), although it might be because of low spatial resolution of fNIRS channels, which was set at 30 mm in the current experimental setting. The reason why we could not detect EBA in the remaining 5 subjects may also lie on the limitation of the spatial resolution. However, this can be overcome by a dense arrangement of fNIRS probes [19]. An alternative way of analyzing data is to select channels that located near the previously reported EBA position. Our result showed that this works well at the group-level analyses with much less variance in the anatomical position (8-12 mm), demonstrating greater activation for the body stimuli compared to the object stimuli.

The volume and functionality of EBA could be attenuated by neuropsychological disorders [4-6]. Suchan et al. [4, 5] reported that the volume of the gray matter in EBA was decreased in patients with anorexia nervosa (AN), which is one of the most common eating disorders. They showed a negative correlation between the gray matter density in the EBA and the body size misjudgement rate in AN patients.

Furthermore, functional connectivity between EBA and other body processing areas were reduced in AN patients. These results indicate that the measurement of EBA activity or gray matter volume can be utilized for diagnosis and treatment of AN. It may be possible to utilize fNIRS to diagnose neuropsychiatric disorders, such as AN, by measuring EBA activity during observing body stimuli.

V. Conclusion

This study investigated whether fNIRS can measure EBA activity during observation of visual human body stimuli. The results showed that EBA could be localized at almost the same position as previous fMRI studies. This finding expands the fNIRS applicability to real-world situations and problems, including social communication and clinical diagnosis.

Acknowledgment

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