Multichannel Near-infrared Spectroscopy Analysis of Brain Activities During Semantic Differential Rating of Drawings

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Multichannel near-infrared spectroscopy analysis of brain activities during semantic differential rating of drawings [1,2]

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Through the use of 24-channel near-infrared spectroscopy (NIRS), we measured brain activities in the temporal, parietal and frontal regions of 8 Japanese women while they were engaged in the semantic differential task of rating drawings. Based on our previous study (Suzuki & Gyoba, 2003), we used fifteen adjective scales which could be categorized within three semantic classes (Evaluation, Activity, and Potency). While the participants were rating the drawings with adjectives which belonged to the semantic class of Activity, the relative changes in total hemoglobin concentration showed an increase around the right superior temporal gyrus and the right inferior parietal lobule. In contrast, while using adjectives which belong to the class of Potency, the total hemoglobin concentration was found to decrease, except in the left cortices around the central fissure. While using adjectives which belonged to the semantic class of Evaluation, no specific change in total hemoglobin concentration was observed. Our results suggest that the activation patterns of the temporal and parietal regions are significantly modified according to which semantic class the rating scales belong to.

Key words: near-infrared spectroscopy, hemoglobin concentration, auditory cortex, somatosensory cortex, semantic differential, drawing

Introduction

The semantic differential technique developed by Osgood (1962) has been widely used and found to be very useful for measuring the affective meanings of various stimuli. With this technique, participants rate stimuli on adjective scales, and potential factors that structure the multivariate data are extracted by factor analysis. In most cases three factors are extracted; Evaluation (representative scale: good-bad), Activity (active-passive), and Potency (strong-weak). These factors have been commonly found across different cultures and various stimulus domains (Osgood, 1962; Tanaka, Oyama & Osgood, 1963).

Recently, different brain activities have been observed when words which belong to different semantic classes, as defined by the three factors, are being processed. Previous studies have reported that the affective meanings of words can systematically alter event-related brain activities (Chapman, McCrary, Chapman, & Bragdon, 1978; Chapman, McCrary, Chapman, & Martin, 1980; Skrandies, 1998; Skrandies & Chiu, 2003). Chapman et al. (1980) compared the evoked

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potentials for the semantic rating class of word stimuli with those for the semantic class of scales and they reported that the two kinds of semantic effects in evoked potential tend to be quite independent. On the other hand, Skrandies (1998) reported that the topography, the latency, and the field length of ERPs can be modified by the semantic class of the word stimuli being used, especially in the brain activities at small latencies. These findings suggest the possibility that the cortical regions which are responsible for processing each of semantic classes are different. However, previous studies have not been able to adequately clarify which region is related to each factor, since they investigated brain activities during semantic differential tasks mainly through the use of ERP recording.

In the present study, we employed multichannel near-infrared spectroscopy (NIRS). NIRS measures spectroscopic reflection and scattering from a single region with a light source and a detector (Chance, Zhuang, Unah, Alter & Lipton, 1993; Hoshi & Tamura, 1993; Kato, Kamei, Takashima & Ozaki, 1993; Villringer, Planck, Hock, Schleinkofer & Dirnagl, 1993). Multichannel NIRS is able to record temporal changes in hemoglobin oxygenation simultaneously from multiple regions (Koizumi, Yamashita, Maki, Yamamoto, Ito, Itagaki & Kennan, 1999; Maki, Yamashita, Ito, Watanabe & Koizumi, 1995; Yamashita, Maki & Koizumi, 1996) and it can demonstrate temporal changes in the concentration of both oxy-hemoglobin (oxy-Hb) and deoxy-hemoglobin (deoxy-Hb), as well as changes in total-hemoglobin. There are several advantages with multichannel NIRS, such as flexibility, portability and low cost compared with other neuro-imaging methods. Several studies have reported that the multichannel NIRS is a useful measure of brain activities, including motor activities (Maki, Yamashita, Watanabe, & Koizumi, 1996), speech recognition (Sato, Takeuchi & Sakai, 1999), epileptic seizures (Watanabe, Maki, Kawaguchi, Yamashita, Koizumi & Mayanagi, 2000), language lateralization (Kennan, Maki , Koizumi, & Constable, 2002) and language recognition (Pena, Maki, Kovacic, Dehaene-Lambertz, Koizumi, Bouquet, & Mehler, 2003).

In all of the previous ERP studies, only word stimuli have been used in the semantic differential task. However, the semantic differential technique has in fact been used for various stimuli, for example, drawings, colors, etc. Takahashi (1995) reported that some aspects of semantic factors are different between drawings and words. She suggested that it is quite possible that the meanings of words are connotative in nature, whereas the meanings of drawings are judged in terms of sensory-relevant concepts. Especially in the case of the Potency factor, it has been confirmed that tactile impressions, for example soft-hard, smooth-rough, and blunt-sharp are more strongly evoked by drawings than by word stimuli (Takahashi, 1995; Suzuki & Gyoba, 2001, 2003). In the case of the Activity factor, both word stimuli and drawing stimuli can be represented by scales such as active-passive, dynamic-static, and lively-unlively. In contrast, the Evaluation factor is characterized by scales such as likable-repugnant, beautiful-ugly and unpleasant-pleasant. Thus it is highly likely that Evaluation factor is associated with subjective emotional concepts, while the Potency and Activity factors are much more closely related to sensory-relevant properties. To demonstrate these differences more clearly, we used drawings in the present research.

Multichannel NIRS allows us to measure only the surface level activities of the cortices.

However we can confirm the extent of sensory-relevance for each semantic factor by the measurement of changes in hemoglobin concentration on the sensory-related association cortices. In the present study, we arranged the probes of the multichannel NIRS on the bilateral temporal parietal regions, since the previous studies (Takahashi, 1995; Suzuki & Gyoba, 2001, 2003) using multivariate analysis showed the possibility that the Activity factor is related to auditory or kinesthetic modalities while the Potency factor is related to somatosensory (especially tactile) modalities. If the activation patterns of the cortices related to such kinds of sensory processing are found to be modified depending on the factor properties, then the present study would provide clues as to which of the cortical regions are responsible for processing during semantic differential judgments.

Method

Selection of drawings

Suzuki & Gyoba (2001, 2003) and Takahashi (1995) studied the affective properties of line drawings by the semantic differential technique. From among those drawings, we selected seven drawings (Figure 1). These stimuli had high factor scores on the Evaluation, Activity, or Potency factors. They had also been confirmed as representative of abstract concepts (*depression, joy, anxiety, human energy, femininity, anger, and tranquility*) in our previous studies.

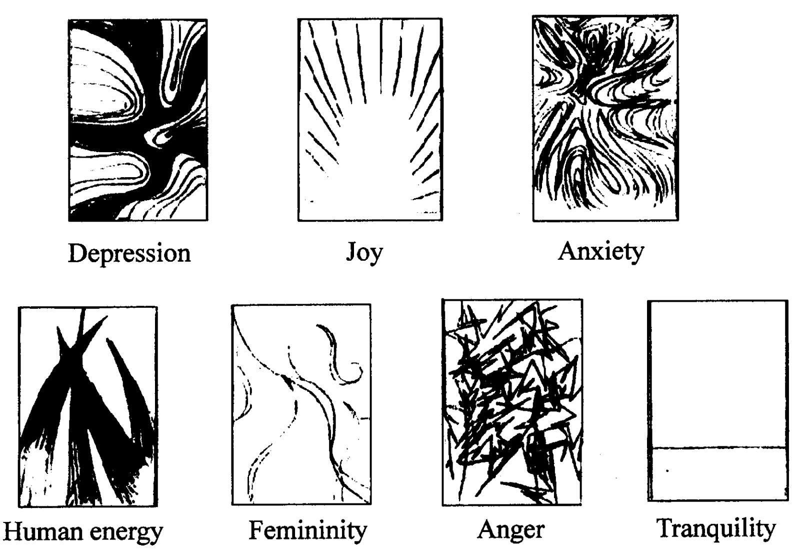

Figure 1. The eight drawings used in the present study. These stimuli were selected from those used by Takahashi (1995) and Suzuki & Gyoba (2003). Each drawing was preliminarily confirmed to represent the concept described in Japanese.

Selection of semantic scales

The 15 adjective scales (Table 1) were selected from those used by Suzuki & Gyoba (2001, 2003). Five of them belonged to each of the semantic classes defined by the three factors (Evaluation, Activity or Potency).

Participants

Eight female native Japanese speakers (age: 19-25 years) participated in the present study. All the participants were right-handed. They were recruited on a voluntary basis after their informed consent had been obtained according to formal guidelines.

NIRS

We used 24-channel (12 on each side) near-infrared spectroscopy (Hitachi ETG-100) for this study. Laser diodes with two wavelengths (780 nm and 830 nm) were used as the light sources. The reflected lights were detected with avalanche photodiodes located 30 mm from an incident position. The detected signal was separated into two components corresponding to the two wavelengths with lock-in amplifiers. The relative changes in oxy-hemoglobin concentration and deoxy-hemoglobin concentration were calculated using the difference in the absorption indexes for the two wavelengths. Total hemoglobin concentration was defined as the sum of oxy-hemoglobin and deoxy-hemoglobin. The sampling interval was 100 ms. For further details of the experimental apparatus, see Maki et al. (1995) or Watanabe et al. (2000).

In the present study, the (6 cm × 6 cm) arrays covered a portion of the bilateral temporal, parietal and frontal regions (Figure 2). The open circles and filled circles denote light source fibers and detection fibers. The numbers signify the measurement channel corresponding to the central zone of the light path between the source and the detection fibers. A pair of head shells with probe sockets was attached, one shell either on side of the participant's head. The center column of the probe sockets was adjusted to become an extension of the ear lobe. The 3D coordinates for the location of each probe and the scalp shape of each participant were measured by a Polhemus sensor system.

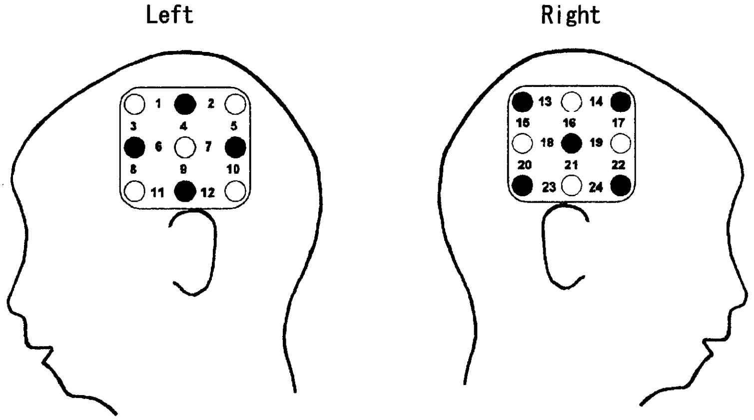

Figure 2. The position of the NIRS head shell. The open circles, filled circles and numbers signify light source fibers, detection fibers and the measurement channels, respectively.

Tasks

During the experiment, the participant sat in a darkened, soundproofed room, with a chin-rest. The time course of the drawing presentation and the semantic differential judgment within one block of NIRS measurements was as follows. (1) Resting time: A blank image was presented for 40 sec on a CRT display, including the pre-time (5 sec) for the NIRS measurement. (2) One drawing stimulus (11.51° in height and 8.02° in width) was presented at the center of the display and one of the semantic scales was simultaneously presented for 6 sec just below the drawing. The participant was asked to make a verbal report of their semantic differential judgment by calling out the numbers depicted on the scale within 6 sec. (3) The drawing stimulus remained but the semantic scale was replaced by another scale that belonged to the same semantic class. Then the participant made another verbal report. (4) After the five scales within the same semantic class had been presented for 6 sec each and the participant had responded five times, the blank image was presented again for 40 sec, including the relaxing time (10 sec) and the post-time (5 sec), together with the pre-time (5 sec) for the next block of NIRS measurements. In the next block, another drawing stimulus was presented together with the scales of a different semantic class. The presentation order of the semantic classes was changed and counterbalanced among the participants. After the measurement of seven blocks, the participant was given a five-minute break. In total, 21 blocks of NIRS measurements were conducted. This means that the participants were presented with each of the 7 drawings 3 times, that is once for each of the three semantic classes during the semantic differential rating tasks.

After the 21 blocks, three-dimensional coordinates of the probe locations and the scalp shape were taken for each participant in order to reconstruct a cortical surface image by the Polhemus sensor system.

Results

Table 1 shows the mean rating scores of the semantic differential task. From the data, it can be seen that each of the drawing stimuli was rated very consistently within each semantic class. All of the standard deviations (SDs) of each drawing among the scales of the same semantic class are small, while their means differ widely. In contrast, the mean rating scores for the seven drawings on each semantic scale center around 4.0 (the midpoint of the rating) in all of the three semantic classes, while their SDs are relatively large and almost homogenous within the semantic classes. This means that the drawing stimuli used in the present study had almost the same magnitude of variations without having any biased properties for the three semantic classes. Therefore, those stimuli allow us to make an appropriate comparison of brain activities while the participants were engaged in the rating task based on the scales of each semantic class.

Table 1. Mean rating score for each of the drawings on the 7point semantic scale

Semantic Class	Semantic scale	Depression	Joy	Anxiety	Human energy	Femininity	Anger	Tranquility	Mean	SD
		Drawings								
Evaluation	beautiful-ugly	3.00	4.63	2.75	4.00	5.75	2.75	4.63	3.93	1.15
	pleasant-unpleasant	2.38	5.25	2.63	4.00	5.75	2.86	5.13	4.00	1.40
	likable-repuguant	3.00	4.50	2.88	3.88	5.50	3.25	4.38	3.91	0.95
	clear-cloudy	2.13	5.75	1.88	4.75	5.88	2.63	5.63	4.09	1.81
	light-heavy	2.13	5.50	2.38	3.88	6.38	2.88	6.00	4.16	1.79
	Mean	2.53	5.13	2.50	4.10	5.85	2.87	5.15		
	SD	0.45	0.54	0.40	0.37	0.32	0.23	0.68		
Activity	lively-unlively	4.13	5.00	5.88	2.75	2.63	6.00	2.00	4.05	1.63
	dynamic-static	5.38	5.29	6.14	4.13	3.50	6.13	2.63	4.74	1.35
	gay-sober	4.13	5.25	5.63	4.13	3.00	5.88	2.38	4.34	1.33
	powerful-feeble	4.88	3.75	5.63	4.75	2.75	5.13	2.38	4.18	1.24
	excited-calm	3.75	4.88	6.38	4.13	1.75	6.38	2.00	4.18	1.87
	Mean	4.45	4.83	5.93	3.98	2.73	5.90	2.28		
	SD	0.66	0.63	0.33	0.74	0.64	0.47	0.27		
Potency	soft-hard	3.13	4.75	3.63	4.50	2.25	6.00	4.13	4.05	1.21
	smooth-rough	2.63	4.63	3.13	5.63	2.13	6.50	3.13	3.96	1.64
	blunt-sharp	2.38	4.88	2.88	5.25	3.63	6.00	3.38	4.05	1.34
	relaxed-tense	2.75	4.25	3.75	4.75	2.75	5.50	3.38	3.88	1.03
	rugged-delicate	4.88	3.88	5.38	5.13	2.50	5.50	3.88	4.45	1.08
	Mean	3.15	4.48	3.75	5.05	2.65	5.90	3.58		
	SD	1.00	0.41	0.98	0.44	0.60	0.42	0.41		

The average SD (individual difference) of the rating scores of each stimulus on each scale are around 1.14.

In this study, we analyzed the relative changes in total hemoglobin concentration ($C_{totalHb}$) during the semantic judgment compared to the concentration noted during the resting time. The changes in $C_{totalHb}$ for the seven blocks in which the participants rated the stimuli based on scales within the same semantic class were integrated. The averaged change in $C_{totalHb}$ in each channel was obtained for 16 measurement periods. These periods consisted of pre-time (5 sec), task-time (partitioned into ten periods; 10×3 sec $= 30$ sec), and post-time including the relax-time (divided into 5 periods; 5×3 sec $= 15$ sec). In order to calculate the changes in $C_{totalHb}$, the hemoglobin concentration levels of the pre-time and the post-time were adjusted to around zero in the NIRS measurement. The data of five channels (2, 4, 5, 6, and 13) were excluded because the measurements were too noisy due to problems with the probe settings.

In order to compare the brain activities corresponding to the semantic classes defined by the three factors (Evaluation, Activity, and Potency), we conducted a three-way repeated-measures ANOVA (semantic class $\times$ channel $\times$ period) on the data. As a result, the main effects of the channel ($F_{18,126} = 3.65$, $p < 0.001$) and the period ($F_{15,105} = 3.15$, $p < 0.001$) were found to be significant. The main effect of the semantic class, however, was not significant. Nevertheless, the interaction between the semantic class and the period was significant ($F_{30,210} = 2.18$, $p < 0.001$). A multiple comparison test with nominal significant levels (Ryan's test) revealed that the $C_{totalHb}$ changes for Potency were lower than those for Activity and Evaluation from 7 sec to 9 sec after the presentation of drawing stimuli (period 4), and lower than those of Activity from 10 sec to 15 sec (period 5 and 6). The $C_{totalHb}$ changes for Activity were significant higher than those for Evaluation and Potency during 22-24 sec (period 9), and those for Evaluation during 25-27 sec (period 10). These results suggest that during judgments based on the semantic scales related to Potency, the $C_{totalHb}$ changes tended to decrease in comparison with those for the other semantic classes. In contrast, the changes in $C_{totalHb}$ during Activity judgments increased until the later periods of the task-time. For Evaluation, there was no specific tendency, although the pattern of $C_{totalHb}$ changes was similar to that for Activity.

Furthermore, there was a significant three-way interaction between the semantic class, the channel, and the period ($F_{540, 3780} = 1.15$, $p < 0.05$). In Channels 3, 8, 11, 19, 22 and 24, the simple interaction effect between the semantic class and the channel was significant ($F_{30, 3990} = 2.042$, $p < 0.001$; $F_{30, 3990} = 5.111$, $p < 0.001$; $F_{30, 3990} = 1.692$, $p < 0.05$; $F_{30, 3990} = 1.641$, $p < 0.05$; $F_{30, 3990} = 3.542$, $p < 0.001$; $F_{30, 3990} = 3.004$, $p < 0.001$, respectively). In Channels 9, 20, 21 and 23, the simple simple main effects of the semantic class were significant, with which probability levels of less than 0.05.

Figure 3 and Figure 4 show the $C_{totalHb}$ changes of those channels which showed significant differences among the semantic classes. Channels 3, 8, 9 and 11 are in the left hemisphere, while Channels 19, 20, 21, 22, 23 and 24 are in the right hemisphere. In Channel 3, the changes in $C_{totalHb}$ for Activity and Evaluation are almost constant, while those for Potency decrease. In Channels 8 and 11, the changes in $C_{totalHb}$ for Evaluation and Activity increase during the task-time, in comparison with those for Potency. In Channel 9, the changes in $C_{totalHb}$ for Potency are higher than those for the other semantic classes. Among the channels that showed significant differences for the semantic class, only Channel 9 reveals an increase in the changes in $C_{totalHb}$ for Potency. In Channel 19, the $C_{totalHb}$ changes for all semantic scales decrease, with this tendency being particularly salient for Evaluation. Channels 20, 21, 22 and 23 indicate increased $C_{totalHb}$ changes for Activity, while Channel 24 shows an increase for both Activity and Evaluation.

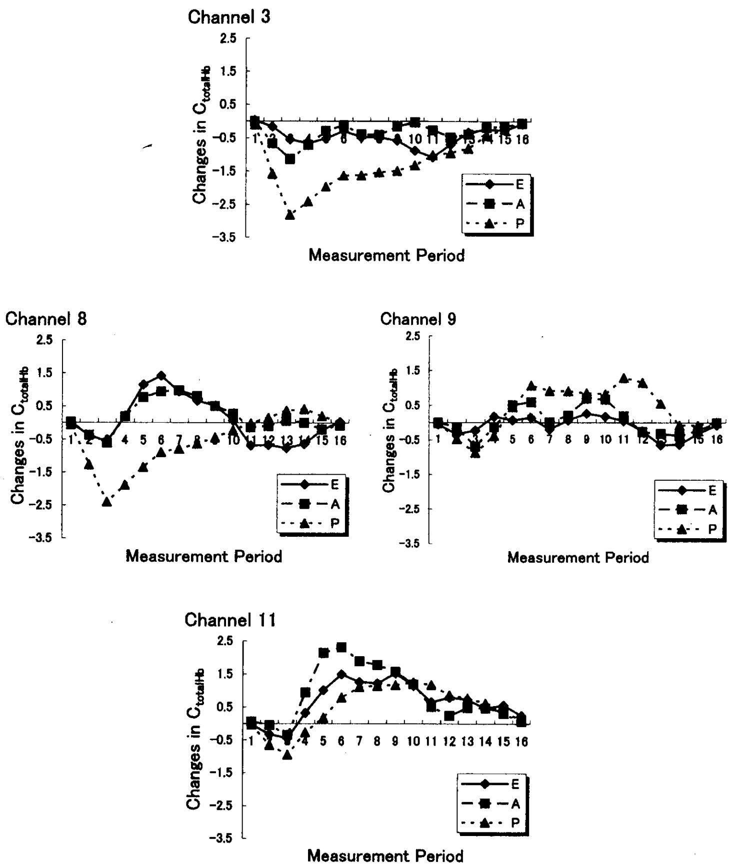

Figure 3. Left hemisphere channels where the changes in $C_{totalHb}$ showed significant differences among the semantic classes. The measurement periods 1, 2-11, and 12-16 signify pre-time (5 sec), event time (10 × 3 sec = 30 sec), and post-time (5 × 3 = 15 sec), respectively.

Based on the 3D coordinate data of the probes and the scalp shape of each participant, we estimated the Talairach coordinates (Talairach & Tournoux, 1988) of the channels that are assumed to be located in the middle of the probes between the light source and the detection fibers, as indicated in Table 2. We excluded Channels 3 and 19 since these channels did not show any salient increases in hemoglobin for all semantic classes. We found that Channels 11 and 24 are located on the superior temporal cortex, especially around the superior temporal gyrus in both hemispheres. Channel 8 is on the inferior frontal cortex, especially around the inferior frontal gyrus in the left hemisphere. These three channels (8, 11 and 24) showed increased changes in $C_{totalHb}$ for both Activity and Evaluation. Channel 9 which showed specific increases in the changes of $C_{totalHb}$ for Potency is located on the pre- or postcentral gyrus of the parietal cortex in

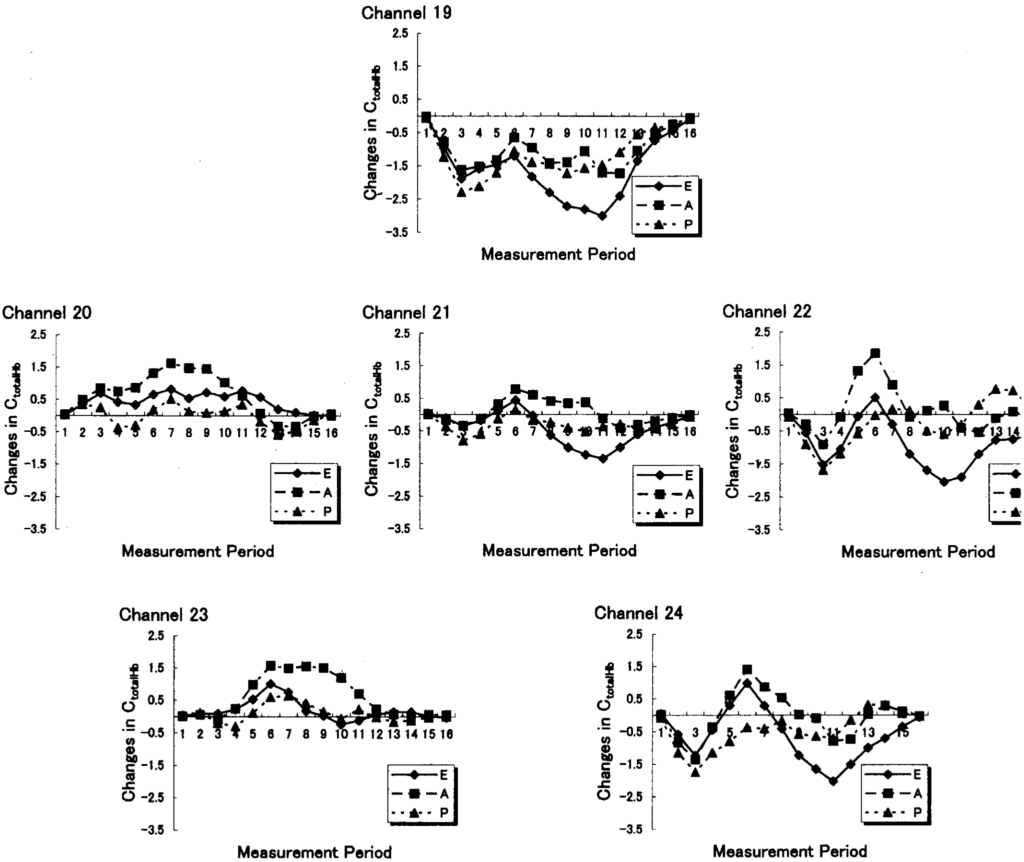

Figure 4. Right hemisphere channels where the changes in $C_{totalHb}$ showed significant differences among the semantic classes.

the left hemisphere (around Broadmann area 43). Channel 20, 21, 22 and 23 are located around the inferior parietal lobule (Broadmann area 40), the postcentral gyrus, the inferior frontal gyrus (Broadmann area 44), and the superior temporal gyrus (Broadmann area 42), respectively. In these four channels, we found that the changes in $C_{totalHb}$ for Activity were significantly higher than those for the other semantic classes.

Table 2. Estimated Talairach coodinates of the channels where the semantic classes produced significant differences in changes in $C_{totalHb}$

	Talairach coordinates		
Left hemisphere	X	Y	Z
Channel 8	-68 (4.0)	19 (9.1)	18 (10.3)
Channel 9	-69 (3.1)	-8 (9.4)	24 (10.1)
Channel 11	-70 (3.0)	2 (9.1)	10 (10.7)
Right hemisphere			
Channel 20	69 (6.3)	-35 (12.9)	26 (6.0)
Channel 21	70 (5.1)	-9 (12.8)	23 (6.5)
Channel 22	64 (4.6)	15 (11.5)	15 (6.6)
Channel 23	73 (5.7)	-24 (12.5)	13 (6.1)
Channel 24	71 (4.7)	0 (11.8)	8 (6.3)

Figures in parentheses indicate SDs for each coordinate among the estimated channel locations for the eight participants.

Discussion

In the present study, we investigated brain activities during the semantic differential task of rating line drawings by multichannel NIRS measurements. Consequently, we found significant differences in $C_{totalHb}$ changes which corresponded to the semantic classes as defined by the three factors (Activity, Evaluation, and Potency), especially around the temporal and the parietal regions. These results suggest the possibility that there exist specific activations related to the factors that represent the semantic differential judgments, as discussed below.

Many channels showed increased changes in $C_{totalHb}$ during the judgment of Activity scales. Some of them (Channels 11, 23 and 24) were located around the superior temporal gyrus in both hemispheres. The superior temporal gyrus, especially around Broadmann areas 41 and 42, has been reported as being an auditory association area where ascending auditory information converges. As described in the Introdution, Suzuki and Gyoba (2001, 2003) pointed out that the scales within the semantic class of Activity are strongly related to auditory modalities. The present findings are in accordance with their report. Moreover, it can be seen that the activation of auditory-related areas are more dominant in the right hemisphere. Moreover, Channel 20 indicates increased activity of the inferior parietal lobule (approximately corresponding to Broadmann area 40) in the right hemisphere during Activity judgments. This area has been considered to be an association area for integrating or analyzing information from various sensory modalities, especially visual and tactile modalities (Kawashima, Watanabe, Kato, Nakamura, Hatano, Schormann, Sato, Fukuda, Ito, & Zilles, 2002).

For judgments based on scales related to Potency, the changes in $C_{totalHb}$ decreased in most channels, with only Channel 9 showing increased $C_{totalHb}$ changes. The estimated location of Channel 9 is around the pre- or the postcentral gyrus in the left hemisphere. We can not make a precise decision as to which of the gyri really corresponds to Channel 9 due to the relatively low spatial resolution of the NIRS measurement. However, if it is in fact the postcentral gyrus, then we can assume that Potency judgments are related to somatosensory processing. This view is also supported by the results of previous research (Takahashi, 1995; Suzuki & Gyoba, 2001, 2003) which indicated that the scales which represent the Potency factor contain many tactile words, for example, soft-hard, smooth-rough, and blunt-sharp. Suzuki and Gyoba (2001, 2003) further confirmed that tactile images can be evoked by picture stimuli. The present findings are in line with their reports. There is a possibility that the activity of the somatosensory cortex becomes higher during Potency judgments, due to the tactile images that pictorial stimuli have the potential to bring to mind. However, it should be noted that Channel 21, which corresponds to Channel 9 in the right hemisphere, did not show any specific activity for Potency. Channel 21 was primarily activated during Activity judgments.

We did not find any characteristic results for the rating task on Evaluation scales. Channels 8, 11, and 24 showed increased $C_{totalHb}$ changes for Evaluation, but those channels also indicated increased $C_{totalHb}$ changes for Activity. It is highly likely that the judgments on Evaluation scales (e.g., likable-repugnant, beautiful-ugly, and pleasant-unpleasant) may be related to subjective emotional responses. Several brain researchers (Murphy et al., 2003; Phan et al., 2002) have reported that the medial prefrontal cortex and some deeper brain regions (e.g. the amygdala, the insula, the orbitofrontal cortex, or the anterior cingulate cortex) are correlated with evaluative processing of emotion. However, in the present study, we could not investigate the activity of these regions, simply because hemoglobin concentration changes within the deeper parts of the brain can not be measured by NIRS. Thus, there is a possibility that the activation pattern specific to Evaluation judgments can scarcely be observed on only the surface levels of the cortices as was investigated in the present study.

Furthermore, previous research has reported the possibility that the neural activities are different between the polarities of semantic scales (Chapman et al. 1978, 1980; Skrandies, 1998; Skrandies & Chiu, 2003). In the present study, we did not analyze the results for each semantic polarity. There is a possibility that different patterns of hemoglobin change are found depending on the polarities of scales, even if the scales belong within the same semantic class. The effects of polarity may also differ between semantic classes.

It is also true that in order to confirm specific brain activities related to the factors that represent the semantic differential judgments, it is necessary to increase the number of NIRS channels and to measure simultaneously the hemoglobin concentration in wider regions, especially regions including the occipital and the frontal cortex. As for investigating the activities of deeper regions of the brain, PET or fMRI would be useful, especially for activities related to the Evaluation factor.

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