PREFRONTAL ACTIVATION DURING EMOTIONAL EXPERIENCE AS MEASURED BY NIRS

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Abstract

To investigate brain activation in the prefrontal cortex (PFC) during emotional experiences, we examined blood oxygenation changes of healthy female volunteers by using multi-channel Near Infrared Spectroscopy (NIRS). Results directly confirmed that the PFC was activated during emotional tasks suggesting that the levels of oxy-Hb increased significantly larger in negative periods compared with positive or neutral in the bilateral dorsolateral PFC. There is a possibility that this brain area is associated with the regulation of negative emotion. Our results suggest that it may be possible to evaluate emotional changes using NIRS sensitively.

Key words: Near-Infrared Spectroscopy (NIRS), functional neuroimaging, prefrontal cortex (PFC), emotional regulation

INTRODUCTION

Emotional responses are thought to play a vital role in an ability to adapt to the environment. Specifically, the emotional regulation has a function to defend against threats. The failure of emotional regulation may cause many psychiatric disorders (Davidson et al., 2000; Phillips et al., 2003).

Over the years, investigation of the neural basis of human emotion has received considerable attention. By means of new brain imaging technologies, such as Near - Infrared Spectroscopy (NIRS) or functional Magnetic Resonance Imaging (fMRI), it is possible to scientifically determine the mechanism of emotional brain. Recent neuroimaging studies have

investigated that certain brain regions have been identified as being involved in emotional information processing (Phan et al., 2002, 2004; Phillips et al., 2003). These areas comprise the insula, amygdala, ventral striatum, thalamus, hypothalamus and brainstem nuclei, and PFC which have been subsumed within a regulation system of emotional processing (Phillip et al., 2003). In particular, PFC has been considered as a key player in the emotional regulation (Miller & Cohen, 2001; Davidson, Putman, & Larson, 2000; Davidson, 2002; Ochsner & Gross, 2005; Davidson & Irwin, 1999). However, the neural representation in PFC involved in emotional experiences is unclear.

NIRS is a novel neuroimaging tech-

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nology. Compared with other neuroimaging methods such as fMRI and Positron Emission Tomography (PET), measurement with NIRS is quite simple, which is advantageous in a clinical setting. NIRS is non-invasive in nature, portable, has a low running cost, and is available for continuous and repetitive measurements; albeit with the limitation of low spatial resolution and the inability to examine deep brain structures. Furthermore, NIRS makes it possible to measure brain activity with body motion. From such a characteristic, NIRS would be suited as a tool for studying emotion, because negative emotion caused by measured stress can be included. This characteristic, also, will clear the problem of previous neuroimaging study. However, the characteristics of signal change in NIRS associated with emotional processing are not well understood.

The aim of this study is to examine the hemodynamic changes induced by viewing the different emotional types of pictures by NIRS and to investigate the relationship between the relative changes of oxygenized hemoglobin (oxy-Hb) in the PFC and emotional experiences. In addition, we look to confirm the utility of NIRS as an emotional index by measuring Skin Conductance Response (SCR) which has previously been established as an emotional index at the same time, because NIRS is a new technique.
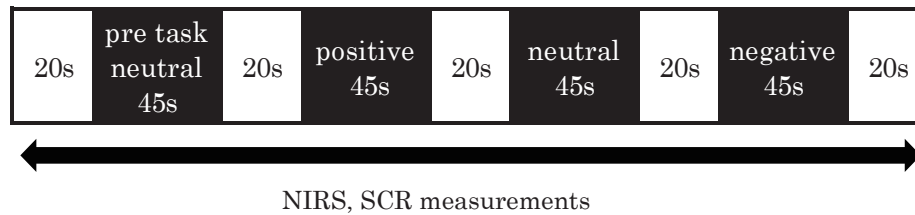
METHOD

Participants

Twenty-eight Japanese healthy female volunteers were chosen in for the study. The mean age of the participants was 21.9 years of age (Max = 27, Min = 21, SD = 1.2 years of age). Only females were studied, in line with previous neuroimaging studies on emotional regulation (Ohira et al., 2006, Ochsner et al., 2002). These previous studies showed that females responded more strongly to the emotional stimuli than males. Thus, we assumed that only females wouldyield more reliable data.

Participants were confirmed to have no history of major mental illness, neurological illness, traumatic brain injury, and individual and family history of substance abuse and addiction. All participants were right-handed based on the Edinburgh Inventory (Oldfield, 1971). Their estimated-IQ was 99.3 (SD = 8.04) which was evaluated with the Japanese version of the National Adult Reading Test (JART, Matsuoka et al., 2006). Written informed consent was obtained from each subject for participation in this investigation; which was approved by the Ethical Committee of the University of Tokushima. Each participant sat on a comfortable chair and oxy-Hb, total-Hb, and deoxy-Hb changes were measured by NIRS during an emotional activation task.

Emotional activation task

The task consisted of a pre-task period and three emotional task periods (Fig.1). Each emotional task period was 45 seconds, in which 10 emotional pictures were presented. Emotional pictures were selected from the International Affective Picture System (IAPS: Lang et al., 1999). We used 10 positive, 10 neutral, and 10 negative color pictures as the emotional tasks. For the pre-task periods, 10 neutral pictures were presented.
Each emotional picture was presented (0.5 s) combined with the warning stimulus (geometrical pattern) (2 s). Two seconds later, emotional pictures were presented. The geometrical pattern and the emotional category of picture were fixed (a circle as positive; a triangle as neutral; a cross as negative). During the rest period (20 s), the participants were required to watch a white screen.

20s	pre task neutral 45s	20s	positive 45s	20s	neutral 45s	20s	negative 45s	20s

NIRS, SCR measurements

Fig.1 Emotional activation task

An emotional task that combined the warning stimulus (geometrical pattern) and emotional picture was presented. The warning stimulus was presented (2 s), and pre-sented two seconds later, an emotional picture which taken from IAPS (0.5 s) was pre-sented. In each block 10 pictures were presented for forty-five seconds at twenty - se-conds intervals. During picture presentation, NIRS and SCR were measured.

NIRS measurement

Measurements were performed with a 24-channel NIRS system, ETG-4000 (Hitachi Medical Corporation, Tokyo, Japan). This method exploits the property of near-infrared light penetrating into tissues where it is absorbed by hemoglobin depending on the oxygenation state of the hemoglobin (Jobsis, 1977). Using different infrared wavelengths (695 nm, 830 nm), it is thus possible to measure related changes in oxy-Hb and deoxygenated hemoglobin (deoxy-Hb). It is well established that oxygen consumption, regional cerebral blood response (rCBR), and oxygenated hemoglobin supply are increased in highly activated neural regions (Hoshi et al., 2001). The distance between pairs of emissions and detectors was set at 3.0 cm. The probes of the NIRS machine were placed on the participant's frontal region. The lowest probes were positioned along the Fp1–Fp2 line according to the international 10/20 system. Twelve channels were assigned for the measurement of the right temporal cortex and 12 channels for the left (Fig. 2). The rate of data sampling was 0.1 seconds. Data were obtained and analyzed using the *Integral mode*. The pre-task baseline was determined as the mean across Ten-seconds just prior to the task period, and the post-task baseline was determined as the mean across five-15 seconds after the task period. We measured the hemodynamic changes in the left and right prefrontal cortex during emotional task.

Skin conductance response; SCR

SCR data were recorded using an MP-100 psychophysiological monitoring system (Bio Pac Systems, Santa Barbara, CA). Skin conductance was recorded using electrodes attached on the left palm, the left elbow and the middle of the left forearm with electrode paste. It was measured continuously throughout the experimental session, and data were analyzed offline using the Acknowledge software (Bio Pac Systems, Santa Barbara, CA). The integration constant of amplitude was calculated, and mean scores of SCRs during each block were analyzed statistically.

Data Analysis and Statistics

The changes of oxy-Hb, deoxy-Hb, and total-Hb concentrations time-locked to the task were obtained. In order to increase signal-to-noise ratio, data of 24 channels were filtered with digital band pass set from 0.0005 to 0.02 Hz. Our analysis focused on the oxy-Hb changes,

because recent articles have shown that oxy-Hb estimates the activation of the brain's most sensitive scale. Oxy-Hb data were averaged across three emotional types (positive, neutral, negative).

To avoid any Type I errors, data of 24 channels during each task condition was divided into four areas (Area 1 with channels 1, 2, 3, 4, 6, and 8; Area 2 with channels 5, 7, 9, 10, 11 and 12; Area 3 with channels 13, 14, 16, 17, 19 and 22; Area 4 with channels 15, 18, 20, 21, 23 and 24) (Fig.2), before it was analyzed. For statistical, a three by four (emotional type × area) two-way repeated measures analysis of ANOVA was applied to oxy-Hb as a dependent variable. When necessary, Greenhouse - Geisser correction was applied to the degrees of freedom. In this analysis, the levels were set at 0.05, and SPSS.
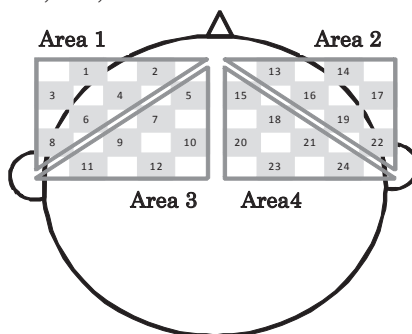
Fig.2 NIRS probe
24 channels were distributed between four domains. Probes were divided into PFC regions. Each area represents a channel; left dorsolateral PFC in Area1, left interior PFC in Area2, right dorsolateral PFC in Area3, right inferior PFC in Area4. Area 1 with channels 1, 2, 3, 4, 6, and 8; Area 2 with channels 5, 7, 9, 10, 11 and 12; Area 3 with channels 13, 14, 16, 17, 19 and 22; Area 4 with channels 15, 18, 20, 21, 23 and 24

RESULTS

The bilateral oxy-Hb was increased immediately after starting the emotional tasks and rapidly returned to the baseline after task completion. Increases in oxy-Hb predominantly observed in the frontal channels.
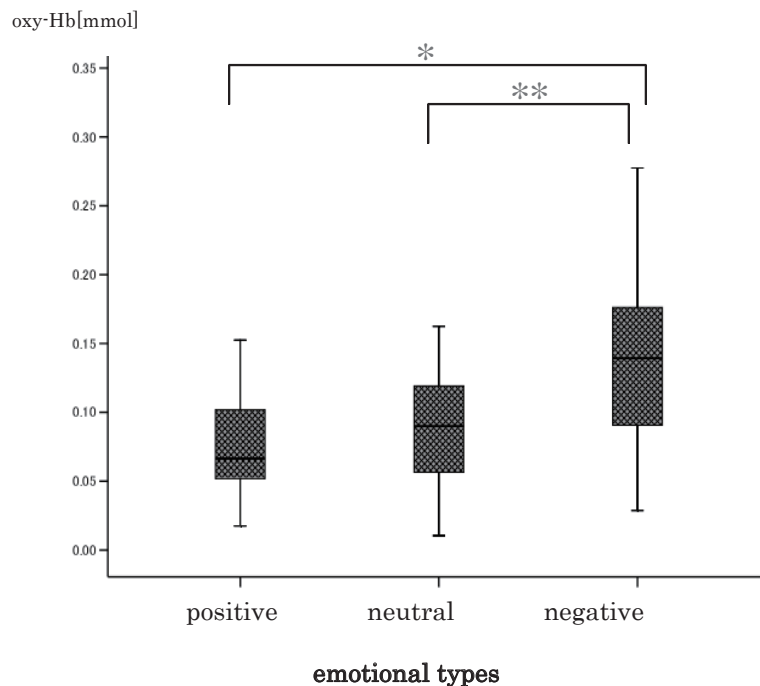
As for oxy-Hb, ANOVA revealed a significant main effect of emotional types ($F[2, 54] = 9.032$, $p < .01$) and brain area ($F[3, 81] = 20.268$, $p < .0001$), but showed no significant interaction ($F[6, 162] = 1.542$, n.s.) (Table.1). Further analyses using Bonferroni's tests showed that the levels of oxy-Hb increased significantly larger in negative pictures compared to positive or neutral pictures (Fig. 3). Area 1 is significantly large in comparison with Area 2 and 4, and Area 3 is also larger than Area 2 and 4 (Fig. 4).

Moreover, we examined which region activates in each of the emotional types, using one-way ANOVA (each emotional type × area). During the positive period, results were not statistically significant (Fig. 5). During the neutral period, Area 1 showed a significant activating compared with Area 4 ($F[3,116] = 3.899$, $p < .05$) (Fig. 6). During the negative period, the main effect was significant ($F[3, 116] = 5.760$, $p < .01$), in Area 1 and Area 3 are significantly larger than Area 4 (Fig. 7). SCR is also larger in the negative period compared to the positive or neutral periods, but it was not statistically significant.

Table.1 Mean and standard deviation of oxy-Hb concentration for the emotional stimuli

[̄oxyHb] (mmol:N=28)

Type	Area				3×4ANOVA		
					T	A	T×A
	Area1	Area2	Area3	Area4	9.032**	20.268***	1.542
positive	0.100(0.05)	0.076(0.04)	0.093(0.10)	0.069(0.06)			
neutral	0.112(0.07)	0.079(0.04)	0.094(0.06)	0.068(0.02)			
negative	0.178(0.12)	0.119(0.05)	0.160(0.08)	0.097(0.05)			

F values of ANOVAs with T; main effect of emotional type, A; main effect of area, and T×A; interaction effect of type × area. *** p < .001, * p < .01 N; number of participants
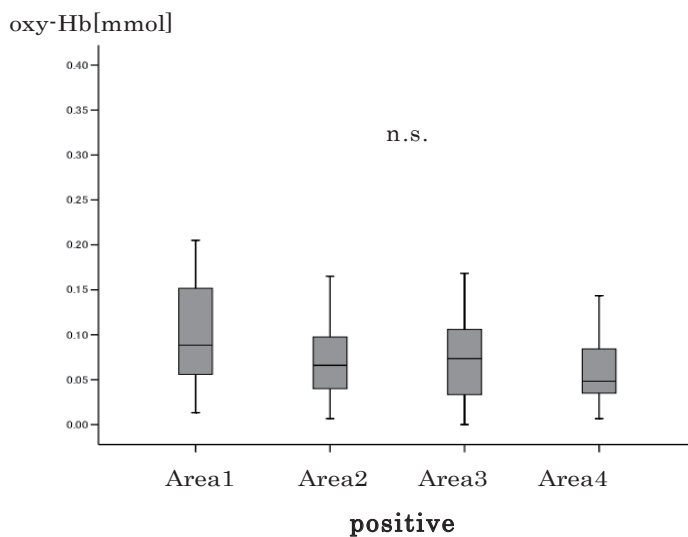

Fig.3 Changes of the oxy-Hb concentration in emotional types
   ANOVA revealed a significant main effect of emotional types (F [2, 54] = 9.032, p < .01). Further analyses showed that the levels of oxy-Hb increased significantly in negative stimuli compared with in positive (p < .05) or neutral (p < .01). ** p < .01   *p < .05
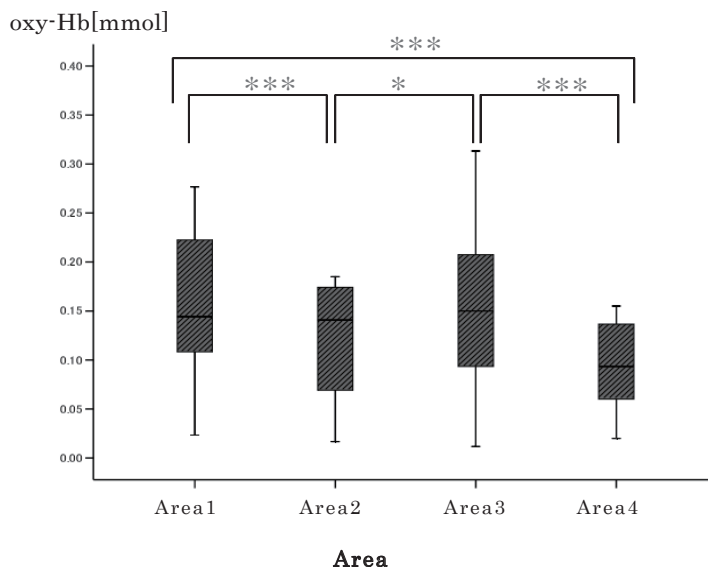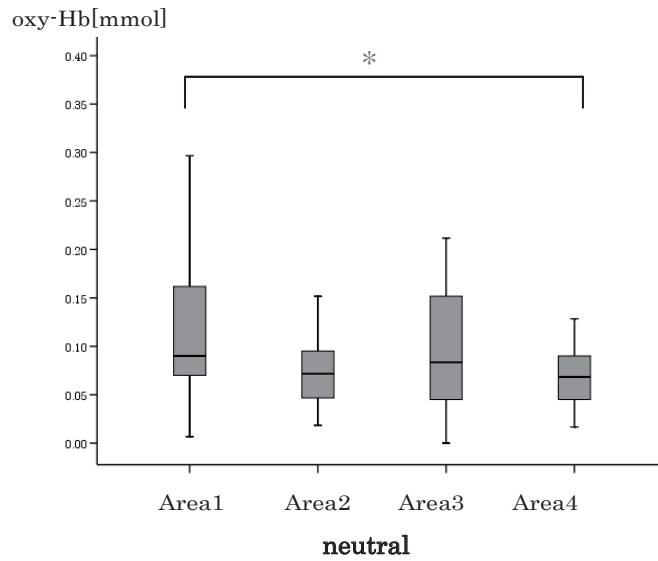
Fig.4 Changes of the oxy-Hb concentration in area
  *ANOVA revealed a significant main effect of area (F [3, 81] = 20.268, p < .0001). Further analyses showed which kind of emotional type was presented; a relative increase of oxy-Hb in bilateral dorsolateral PFC (Area1, Area3).   *** p < .001 ** p < .01 * p < .05*
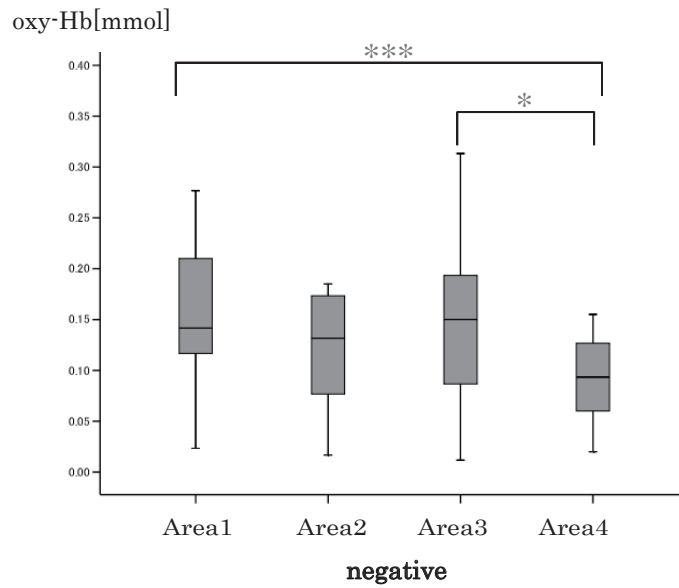

Fig.5 Changes of the oxy-Hb concentration in positive picture
  During the positive period, oxy-Hb changes were not statistically significant. n.s.; no significant

oxy-Hb[mmol]

neutral

Fig.6 Changes of the oxy-Hb concentration in neutral picture

*During the neutral period, Area 1 showed significant activation compared to Area 4 (F [3,116] = 3.899, p < .05). * p < .05*

oxy-Hb[mmol]

negative

Fig.7 Changes of the oxy-Hb concentration in negative emotion

*During the negative period, oxy-Hb changes were as the main effect (F [3, 116] = 5.760, p < .01). Area 1 and Area 3 are significantly larger than Area 4 (Fig. 7). *** p < .001 * p < .05*

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DISCUSSION

We examined the hemodynamic changes in the PFC of healthy females during emotional experience. We observed the brain activities in the PFC during viewing emotional experiences. The main effects of the factors of 'emotional types' influenced frontal blood oxygenation. In the negative condition, oxy-Hb levels in the PFC were increased larger than in the positive or neutral condition. This strong activation may be revoked from the emotional reactions that were negative. This finding is consistent with previous neuroimaging studies (Ohira et al., 2006; Ueda et al., 2003; Herrmann et al., 2003). Previous studies showed that emotional processes related with the limbic region, such as the amygdale and insula (Davidson & Irwin 1999), have found activations in the prefrontal cortical areas, and reductions of amygdala activity during emotional experiences. Thus, our results could indicate that PFC is associated with the regulation of the negative emotion arousal caused by limbic region.

According to our NIRS data for the factors 'area', oxy-Hb was increased in Area 1 and Area 3 which covers dorsolateral PFC (DLPFC). In addition, this tendency was recognized most frequently in the negative period. This result is consistent with previous researches (Beauregard et al., 2001; Levesque et al., 2003). DLPFC may be specifically related to the regulation of negative emotion.

The amplitudes of SCRs were larger in negative stimuli compared with positive or neutral stimuli. However, it was not statistically significant among emotional types. It is possible that the NIRS is more effective towards response than SCR. This effectiveness suggests that NIRS is useful as an emotion evaluation index. However, Cuthbert et al., (2000) reported that SCR has a better response to arousal of emotion than valence. In this study, the arousal rating of emo-

tional pictures was clearly unified among the emotional types to detect the emotional response from only valence. Therefore, it might be difficult for SCR to detect the differences of emotional activity. Arousal of emotions is also an important dimension related to neural activity, so further experimentation is necessary.

When interpreting the present results, we must consider the following limitation. First of all, the experimental paradigm must be considered. In this study, the influence of other acknowledgment activities was removed in doing a simple task. However, emotion is complex and subject to subjective evaluation, so interpreting the pattern of the observed brain activity. Secondly, NIRS has a poorer spatial resolution and does not achieve the accuracy of fMRI measurements, thus we must take caution when discuss the spatial interpretation.

In summary, we examined the emotional response in PFC using the NIRS. Our data showed a strong activation during negative experiences that was recognized in the DLPFC. These results indicate the possibility that the DLPFC was concerned with emotional regulation. NIRS is a new reliable optical instrument able to examine the hemodynamic changes of cerebral cortices and may be used to measure PFC activation during emotional experiences. This method may be useful to detect the emotional changes. This study provides insight into research concerning emotional processes and the neural basis of emotion.

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