VENTROLATERAL PREFRONTAL CORTEX ACTIVITY DURING REWARD-PUNISHMENT GO/NOGO TASK: A NEAR-INFRARED SPECTROSCOPY STUDY

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It is unclear whether behavioral inhibition leads to heightened brain activation in response to reward or punishment incentives. In this study, we utilized near-infrared spectroscopy (NIRS) to evaluate right ventrolateral prefrontal cortex (VLPFC) activity during a reward/punishment Go/No-go task. As hypothesized, the activation of the right VLPFC was modulated according to different incentive outcomes during the Go/No-go task. Under the reward-only condition, oxyhemoglobin (oxy-Hb) concentrations in the right VLPFC significantly increased as compared with those under the punishment-only condition. In addition, the percentage of commission errors under the punishment-only condition was negatively correlated with neuroticism. These results provide new evidence that the role of the right VLPFC is modulated according to the reward/penalty outcomes, and the relation between motor inhibition and personality traits.

Key words: impulsivity; motor inhibition; reward/punishment go/No-go task; NIRS; VLPFC

The ability to inhibit planned or ongoing actions is an important control mechanism that facilitates efficient reaction in response to sudden changes in the environment (de Jong, Coles, Gratton, & Logan, 1990). A deficit in such motor-inhibition capabilities tends to increase the probability of inconvenient results. At its worst, motor disinhibition can lead to several psychopathological and neurological disorders such as attention-deficit/hyperactivity disorder (ADHD) and obsessive-compulsive disorder (OCD) (for a review, see Verbruggen & Logan, 2008).

Behavioral studies have revealed two dissociable types of impulsivity: reward-delay impulsivity and rapid-response impulsivity. Reward-delay impulsivity is defined as the inability to delay the response to a reward, which leads to an increased tendency to select immediate small rewards over the comparatively larger delayed rewards (Monterosso & Ainslie, 1999). On the other hand, rapid-response impulsivity refers to the inability to correctly evaluate and thus, respond to environmental and social contexts, thereby causing commission errors; this type of impulsivity can be clearly depicted in a test that requires...
careful examination of the stimuli, as in Go/No-go tasks. Moreover, motor-inhibition deficit is comparable to rapid-response impulsivity.

Brain neuroimaging studies have shown that motor-response inhibition is linked to the activation of the right ventrolateral prefrontal cortex (VLPFC) in healthy participants (Garavan, Ross, & Stein, 1999; Horn, Dolan, Elliott, Deakin, & Woodruff, 2003; Konishi, Nakajima, Uchida, Sekihara, & Miyashita, 1998). In addition, lesion studies have shown that patients with right frontal damage exhibit less efficient inhibition than those with left frontal damage (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron, Monsell, Sahakian, & Robbins, 2004). Moreover, findings for schizophrenic or manic patients who exhibit impulsivity as a major personality trait show decreased activation of the right VLPFC during Go/No-Go tasks (Mazzola-Pomietto, Kaladjian, Azorin, Anton, & Jeanningros, 2009; Kaladjian et al., 2007), thereby suggesting that the right VLPFC plays a key role in the processing of motor-response inhibition.

The ability to orient toward goals and to flexibly control actions according to the contingencies between one’s responses and the rewarding or punishing outcomes in the environment seems essential. However, no study that has directly addressed this issue has focused on whether behavioral inhibition also leads to heightened right VLPFC activation, in response to rewarding or punishing incentives. A study by Wrase et al. (2007) seems to offer several important suggestions regarding this issue. They investigated adaptations to a simple motor response in healthy subjects by using a reward-providing (monetary gain versus monetary loss) reaction time task and reported that the activation of the VLPFC in response to the omission of cued gain is correlated with the probability of improving performance during the next reward trial. Additionally, they reported that the anterior cingulate and orbitofrontal cortices are correlated with motor adaptation in response to punishment outcomes. These findings suggest that different—although somewhat overlapping—brain circuits mediate the same behavioral adaptation according to varied incentive outcomes.

In this study, we utilized near-infrared spectroscopy (NIRS) to evaluate the activity of VLPFC during a Go/No-go task under reward-punishment feedback conditions. NIRS is a noninvasive optical technique that can be used to measure changes in the concentrations of oxyhemoglobin (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) in cortical vessels (Jöbsis, 1977). Changes in oxy-Hb concentration during a task reflect neuronal activity, because they correlate with changes thus evoked in the regional cerebral blood flow (rCBF) (Tanida, Katsuyama, & Sakatani, 2007). On the basis of previous research (Wrase et al., 2007), we hypothesized that the concentration of oxy-Hb in the VLPFC can be modulated according to different incentive outcomes during a Go/No-go task.

**METHOD**

**Participants**

Twenty right-handed female undergraduate students (mean age of 20.4 ± 1.2 years) with normal visual acuity—either unaided or with correction—participated in this study. All the participants provided informed consents after receiving a detailed description of the study.
Behavioral Procedures

Participants were asked to perform a reward/punishment Go/No-go task (LeMarquand et al., 1998; LeMarquand, Benkelfat, Pihl, Palmour, & Young, 1999). Through trial and error, they were required to learn how to respond to certain double figures, which corresponded to “active” stimuli (go task), and inhibit their responses to other figures, which corresponded to “passive” stimuli (no-go task). The trial was initiated by the presentation of a white fixation point in the center of the screen for 2000 ms. Immediately after the fixation cross, either the active or passive stimulus was presented for 800 ms, with equal occurrence probabilities of 0.5. The participants had to press a button as fast and as accurately as possible in response to “active” stimuli, whereas they were told to inhibit their prepared response if “passive” stimuli followed the fixation cross. After 800 ms, irrespective of whether or not there was a response, the correct responses were rewarded through visual feedback by displaying the word “CORRECT” for 1000 ms on a computer screen; accordingly, the participants gained 1 point as feedback. On the other hand, incorrect responses were punished by displaying the word “WRONG” for 1000 ms, and 1 point was deducted from their earnings. After an interstimulus interval of 2500 ms, the next trial started.

The reward/punishment Go/No-go task constituted two sessions (See details: LeMarquand et al., 1998, 1999). In the first session, ten numbers (five active and five passive) were repeated four or five times in a randomized order for forty-eight trials. In the second session, twelve numbers (six active and six passive) that were different from those of the first session were repeated five times in a randomized order for a total of sixty trials. The participants were allowed a 30 s break after every twelfth trial and a 60 s break between the first and second sessions. Four different sets of stimuli were employed per session, with one set for each condition.

Each participant carried out the task under the following four conditions, which were randomized between subjects. Under the reward-only (RR, Rew-Rew) condition, responding to active stimuli and withholding responses to passive stimuli were both rewarded. Under the punishment-only (PP, Pun-Pun) condition, withholding responses to active stimuli and responding to passive stimuli were both punished. Under the reward-punishment (RP, Rew-Pun) condition, a response to active stimuli was rewarded, while a response to passive stimuli was punished. Finally, under the punishment-reward (PR, Pun-Rew) condition, withholding responses to active stimuli was punished, while withholding responses to passive stimuli was rewarded. Participants were provided information regarding the nature of the reward/punishment Go/No-go task, which was characterized by reinforcement contingencies. Moreover, the process of learning by trial and error and receiving rewards or punishments was communicated to the participants through feedback. In addition, participants were also informed regarding the feedback under every condition and instructed that they would be rewarded depending on their total points. In fact, they received the same remuneration (which was equivalent to 100 yen), regardless of the points acquired. After the Go/No-go task, they were administered two questionnaires.

NIRS Measurement of PFC Activity

Cerebral blood oxygenation was measured in the right and left VLPFC using a NIRS monitor, which employed spatially resolved reflectance spectroscopy (NIRO-200, Hamamatsu Photonics K.K., Hamamatsu, Japan). In brief, near-infrared light from four laser diodes (775, 810, 850, and 910 nm) is directed at the head through a fiber-optic bundle, and the reflected light is transmitted to a multi-segment photodiode detector array. The NIRO-200 monitor simultaneously measures the concentrations of oxy-Hb, deoxy-Hb, and total hemoglobin (total-Hb; oxy-Hb + deoxy-Hb). The hemoglobin concentrations were expressed as changes from the baseline concentration (arbitrary units). Further, the sampling time was 1.0 s.

The distance between the emitter and detector spacing was set to 4 cm or 5 cm, depending on the specific light attenuation (Fig. 1). NIRS probes were placed symmetrically at positions F3 (left) and F4 (right) of the international electroencephalographic 10–20 system (Homan, Herman, & Purdy, 1987). These positions correspond to Brodmann’s areas 46 and 47. The emitter was located at 2 cm caudal and the detector at 2 cm cranial to the corresponding position, thus allowing a depth penetration of approximately 2 cm (Villringer & Chance, 1997). During the experiment, participants were seated in comfortable chairs in a quiet, dimmed room and were instructed to restrict movement, except when responding with the right and left ring finger of either hand.
Questionnaires

NEO Five-Factor Inventory

The NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1992) consists of sixty items that are selected from the Revised NEO Personality Inventory (NEO-PI-R). It is a five-point scale ranging from 1 (not at all true) to 5 (very true) and has five subscales: Extraversion, Neuroticism, Openness to experience, Agreeableness, and Conscientiousness. The Japanese version of the NEO-FFI was translated by Shimonaka, Nakazato, Gondo, and Takayama (1999) and has been found to demonstrate good reliability and concurrent validity.

Stimulus Seeking Scale

The Stimulus Seeking Scale (SSS; Kida, Tanaka, Ito, & Kawano, 1993) consists of eighteen items that measure a person’s sensation-seeking level as a personality trait. The SSS has two subscales—the outer sensation-seeking and the inner sensation-seeking personality traits. The SSS has been found to demonstrate good reliability and discriminant validity.

Data Analysis

Behavioral Data

The mean reaction times and the percentages of commission and omission errors were calculated for each stimulus condition and analyzed by a repeated-measures analysis of variance (ANOVA) with one factor, the task conditions (RR versus PP versus RP versus PR). The Greenhouse-Geisser correction was employed for the degrees of freedom for all the comparisons involving repeated measurements. Thereafter, the correlations among the behavioral data and questionnaires (NEO-FFI and SSS) were calculated by using Pearson’s product-moment correlation.

NIRS Data

NIRS data were converted into a digitized format via the multipurpose analysis program, nmult_aq1.0
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The cerebral blood oxygenation changes in the right and left VLPFC were continuously monitored by NIRS during: (1) the control phase for 10 s; (2) the Go/No-Go task for 52 s; (3) the recovery phase for 30 s. The obtained data were averaged every second for each subject over these three time segments. Values during the control phase were subtracted from the task values for each condition to describe the hemodynamic changes in the right and left VLPFC during each study period. Using repeated-measures ANOVA and Bonferroni’s post hoc comparison, the averaged oxy-Hb and deoxy-Hb concentrations in each side under the RR, PP, RP, and PR conditions were compared.

RESULTS

Behavioral and Self-Report Questionnaires

Separate one-way ANOVA of commission and omission errors revealed no significant differences in reaction or and percentage of errors, thus indicating that the feedback pattern had no effect on either type of error (Table 1).

Correlation analysis between the behavior and the self-report questionnaires revealed that the reaction times of Hit (positive response to an active stimulus) in the PP condition showed a positive correlation with Agreeableness ($r = .468$, $p < .01$). The results also showed that the percentage of commission errors in the PP condition showed a negative correlation with Neuroticism ($r = -.508$, $p < .05$). In addition, the reaction times of Hit in the PR condition showed a positive correlation with Agreeableness ($r = .444$, $p < .01$).

NIRS Results

A repeated-measures ANOVA of oxy-Hb concentration in the right and left VLPFC under each condition revealed that the right VLPFC showed a significant increase in oxy-Hb concentrations under the RR condition compared with the PP condition ($p < .01$), and demonstrated a tendency toward significant increase under the RR condition compared with the PR condition ($p < .10$). In contrast, there were no significant differences in the left VLPFC with respect to the conditions. Fig. 2 shows time series of variations in the

| Table 1. Reaction time and percentage of errors under the each condition |
|-------------------------|-----------------|-----------------|-----------------|-----------------|
|                         | RR          | PP          | RP           | PR           |
| Reaction time (ms)     | ANOVA      |              |              |              |
| Hit                    | 489.6 ± 59.0 | 521.6 ± 67.0 | 501.9 ± 130.9 | 506.4 ± 69.2 | 1.154, 0.326 |
| CER                    | 500.4 ± 52.5 | 504.9 ± 43.1 | 521.7 ± 50.1 | 509.9 ± 52.9 | 0.552, 0.577 |
| Percentage of errors (%) | ANOVA      |              |              |              |
| OER                    | 30.6 ± 12.4 | 29.4 ± 13.1 | 33.9 ± 14.2 | 33.7 ± 13.7 | 0.950, 0.408 |
| CER                    | 43.9 ± 19.5 | 38.0 ± 15.8 | 37.9 ± 22.3 | 38.3 ± 18.4 | 0.766, 0.506 |

Note. RR; reward-only condition, PP; punishment-only condition, RP; reward-punishment condition, PR; punishment-reward condition, CER; commission errors, OER; omission errors
average oxy-Hb concentrations in the VLPFC during the control phase and the task. The gray area denotes the task period. As indicated in Fig. 2, the task led to increased average oxy-Hb concentrations in both regions. A repeated-measures ANOVA of deoxy-Hb concentrations in the right and left VLPFC under each condition revealed no significant difference among the conditions on either side. Fig. 3 shows time series of the variations of the average deoxy-Hb concentrations in VLPFC during the control phase and the task. The gray area denotes the task period. As indicated in Fig. 3, the task led to decreased average deoxy-Hb concentrations in both regions.

**DISCUSSION**

By using NIRS, we provide evidence that variations in reward/punishment feedback effectively modulate right VLPFC activation within the neural network that is engaged by the Go/No-Go response-inhibition task. The results of the present study are consistent with the theoretical role of right VLPFC in response to inhibitory functions, as proposed by previous fMRI studies on healthy subjects subjected to a Go/No-Go task (Garavan et al., 1999; Horn et al., 2003; Konishi et al., 1998). Notably, although the RR condition resulted in significant increase in right VLPFC activity as compared to the PP and PR conditions, the results of the behavioral data showed that the reward/punishment feedback did not affect reaction time and the percentage of errors. This result suggests that the
behavioral performances accomplished by different neural processing are similar according to the rewarding or punishing outcomes.

Generally, punishment or negative feedback given as a result of the responses easily inhibit motor responses (Rabbitt, 1966; Nichols & Newman, 1986; Patterson, Kosson, & Newman, 1987). Li, Huang, Constable, and Sinha (2006) mentioned that males exhibit impulsive personality traits more than females and found that males need more neural resources to inhibit their pre-potent motor response, even though their behavioral performance showed no difference from females. Combined with this result, one possible explanation for our finding could be that the probability of reward outcome as a result of correct responses strongly recruited the activation in the right VLPFC which is the central region of motor inhibition to effectively control impulsivity.

Interestingly, the correlation analysis revealed that the commission error rate, a behavioral measure of impulsivity, under the PP condition is negatively correlated with the score on Neuroticism. This result suggests that the participants who obtained a high score on Neuroticism were more inhibited in their response when it entailed the probability of receiving punishment. As Rodríguez-Fornells, Lorenzo-Seva, and Andrés-Pueyo (2002) mentioned that such cautious participants who show low willingness to take risks increased their caution after lack of inhibition was punished, reflected in the latency of the consequent RT trials in the stop-signal task, these changes in the adoption strategy of motor inhibition can be evoked by various factors such as personality and biological traits.
For instance, it has been suggested that a dysfunction in serotonin (5-HT) neurotransmission in the central nervous system causes impulsive behavior (Meltzer, 1990). Previous studies have revealed that dysfunction in the VLPFC, which causes impulsive behavior, results in brain functions being modulated by serotonin (Leyton et al., 2001). Using positron emission tomography (PET) employing $^{[18F]}$altanserin to demonstrate 5-HT$_{2A}$ receptor binding, Kaye et al. (2001) revealed a reduction in VLPFC 5-HT$_{2A}$ binding in a female who had recovered from bulimia nervosa, which is characterized by impulsive behavior. Nomura et al. (2006) discovered a gene polymorphism in the 5-HT$_{2A}$ receptor (A-1438G) that modulates rapid-response impulsivity in a reward/punishment Go/No-go task and indicated that such incentive feedback in the results of the participants’ responses signifies individual differences (Nomura & Nomura, 2006). Because our findings as well as these observations indicate a possible involvement of serotonin in the VLPFC, which is modulated by reward and punishment information, further investigation in healthy participants is needed to clarify the effect of these neurotransmitters in the future.

The limitation of the present study is that only female participants were recruited. Li et al. (2006) found that males required more neural resources than females to inhibit a motor response in a wide array of cortical and subcortical areas, including the globus pallidus and motor thalamus, which might be associated with the often reported observation that males have more behavioral impulsivity than females. On the basis of this finding, it can be said that the present study clarified that the neural activation of females, even if they show lower neural responses than males, is also modulated by reward/penalty information as a result of their responses.

In summary, on the basis of NIRS findings the present study provides new evidence that the activation of the right VLPFC is modulated by reward incentives accompanied by behavioral inhibition during Go/No-Go tasks. In addition, we found that the percentage of commission errors under the punishment-only condition were negatively correlated with neuroticism. Further behavioral studies with concurrent measurements of brain functions are necessitated to clarify the complex relationships between personality traits and vulnerability to impulsive behaviors.

REFERENCES


(Manuscript received December 31, 2008; Revision accepted May 12, 2009)