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2 Two Near infra-Red Spectroscopy (NIRS) Experiments

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EXPERIMENT 1: Differential Memory Effect

Introduction

We studied the differential memory (Dm) effect by using the subsequent memory paradigm. In this paradigm, brain activation during the encoding phase is examined based on later recognition performance. If there are differences in brain activation during the encoding period between recognized and forgotten items, we may attribute recognition errors to some problems in encoding—the Dm effect. The Dm effect has been observed in experiments with fMRI, event-related brain potentials (ERPs), and skin conductance response (SCR) (see, Paller & Wagner, 2002). In the present experiment, we recorded PFC (prefrontal cortex) activation in response to emotional stimuli by NIRS and conducted a recognition test 2 weeks later. We examined whether differences exist in PFC activation during encoding between recognized and forgotten items. This experiment is the first study of the Dm effect with NIRS.

Methods

Ten right-handed undergraduates (6 females, 4 males) participated in the experiment. A 3×5 (22-channels) probe system was attached to the PFC of the participants. The center of the system corresponded to the midline and the lowest channels were placed at the level of Fpz of the International 10-20 system (Okamoto et al., 2004). Thirty negative, positive, and neutral emotional pictures each were selected from the International Affective Picture System (IAPS) based on the ratings by 60 undergraduates.

There were two phases: encoding and recognition. These phases were separated by an interval of 2 weeks. Sixty emotional pictures (20 pictures of each type) were presented randomly for 2 s with 10-s interstimulus interval in the encoding phase. Participants were requested to rate the valence of the pictures with a 5-point scale (unpleasant-neutral-pleasant). Thus, participants were not instructed to memorize the pictures (the incidental learning paradigm). Two weeks after the encoding phase, the recognition test was conducted. In this test, half of the previously used pictures from each category were replaced by 10 new pictures each. These 60 pictures were presented randomly, and participants were required to judge whether they had been presented 2 weeks before or were new.

PFC activation was measured by NIRS during the encoding and recognition phases. Changes in oxygenated hemoglobin (oxy-Hb) concentration were analyzed. Based on the recognition performance, PFC activation during the encoding phase was examined separately between hit (recognized) and missed (forgotten) items (the subsequent memory paradigm).

Results

The hit rates of neutral, unpleasant, and pleasant pictures were 62, 79, and 72%, respectively. The difference in hit rate between neutral and unpleasant pictures was statistically significant . Pleasant pictures tended to be more recognized than neutral pictures, but less recognized than unpleasant pictures. Figure 1 shows changes in oxy-Hb concentration for hit and missed items. All pictures reduced activation in the PFC for hit items. The greatest deactivation was observed for unpleasant pictures. Neutral pictures showed the least deactivation. Different oxy-Hb changes were observed for missed items. Unpleasant pictures increased PFC activation for missed items. Neutral and pleasant pictures showed greater

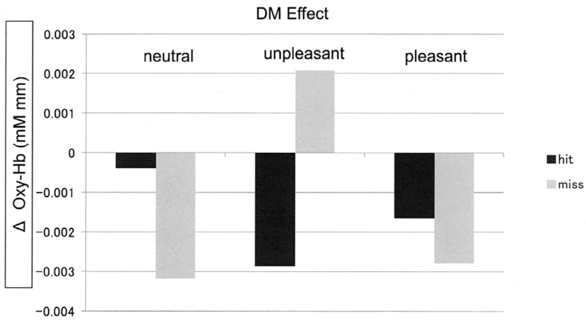

Figure 1. Differential memory (DM) effect in the emotional picture recognition experiment. Hemodynamic changes during the encoding neutral, negative and positive pictures between hit and misses items.

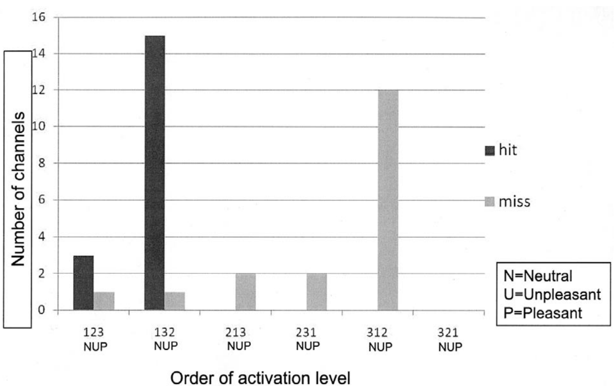

Figure 2. Number of channels for each category of hemodynamic changes (see text for details) between hit and missed items.

deactivations for missed than hit items. Similar activation patterns were obtained over the PFC channels. Figure 2 also shows the number of channels in each activation pattern. Numbers in the x-axis indicate the order of activation for neutral, unpleasant, and pleasant pictures, respectively. Therefore, the number 132, with the highest proportion of hit items, indicates that neutral pictures show the greatest activation (or the least deactivation); the lowest activation (or the highest deactivation) was observed for unpleasant pictures. The number 312, with the highest proportion of missed items, indicates that unpleasant items show the greatest activation (or the lowest deactivation); the lowest activation (or the highest deactivation) was observed for neutral pictures. There were very few overlaps in the activation pattern between hit and missed items.

Discussion

These results show that clear differences exist between hit and missed items during the encoding phase. Recognition errors may partly be attributable to problems in the encoding phase. However, there may be problems in the interpretation of the results of deactivation, although the issue of deactivation is not limited to NIRS. What does deactivation reflect in terms of neural activity? Does it indicate decrease in blood volume as a result of increment in blood in other active regions of the brain? The medial PFC is reportedly deactivated when one directs attention to the external world (Gusnard and Raichle, 2001). Negative pictures probably drew attention of the participants in the present experiment. This may led to deactivation in the frontal cortex. Activation in the encoding phase for missed items may be interpreted as the result of inattention to these items, and may be adequate for the interpretation of the results for forgotten negative pictures. However, this interpretation cannot be applied to missed pleasant and neutral items, which showed greater deactivation for missed than for hit items.

There are clear relationships between valence of pictures and PFC activation in the encoding phase and valence of pictures and recognition performance. The unpleasant pictures were difficult to forget and deactivated the PFC. The opposite pattern was observed for neutral pictures. Although it is difficult to directly compare PFC activation between the encoding and recognition phases, it is possible to speculate that reappearance of PFC activation to an item in the encoding phase may lead to recognition of the item in the recognition phase (Damasio, 1989).

EXPERIMENT 2: Personality

Introduction

We often regulate our behaviors to emotional events (Hariri et al., 2000;

Beauregard et al., 2001; Ochsner et al., 2002). Personality is closely related to individual differences in the regulation of emotional events. We examined relationships between personality traits measured by the Revised NEO Personality Inventory (NEO-PI-R) and PFC reactivity to emotional pictures measured by NIRS. It is expected that each dimension will show a unique correlation pattern (Canli et al., 2001; Canli et al., 2002; Canli, 2004).

NEO-PI-R is a personality inventory measuring 5 dimensions of personality traits: neuroticism (N), extraversion (E), openness (O), agreeableness (A), and conscientiousness (C). Each trait containes 6 subdimensions. Each subdimension consists of 8 questionnaires (a total of 240 questionnaires).

Methods

Participants were right-handed 18 graduates and undergraduates (12 females, 6 males). A 3×5 probe system (22-channels) was placed symmetrically on the left and right PFC, with the center of the system at the midline. Twelve neutral, aversive, and pleasant pictures each were selected from the IAPS based on valence ratings by 60 Japanese undergraduates. During NIRS recordings, these pictures were randomly presented for 3 s with a 9-s interstimulus interval in a passive-viewing condition (a total of 12 s).

We analyzed oxy-Hb concentration as an index of PFC reactivity to the emotional pictures. There were two phases: stimulus and control. The former started 1.5 s after a picture was presented and lasted for 7.5 s; that is, the stimulus phase ended 6 s after the picture was presented. The control phase was a total of 4.5 s. Pleasant PFC responses were defined as pleasant-neutral (i.e., reactivity to neutral pictures was subtracted from that to pleasant pictures); aversive PFC responses were defined as aversive-neutral. Differences in PFC responses between the stimulus and control phases were expressed by t-statistics. Significant correlations ($p < 0.05$) between dimensions and subdimensions of each trait in NEO-PI-R and pleasant and aversive PFC responses were examined. No channel showed statistically significant activation or deactivation between stimulus and control.

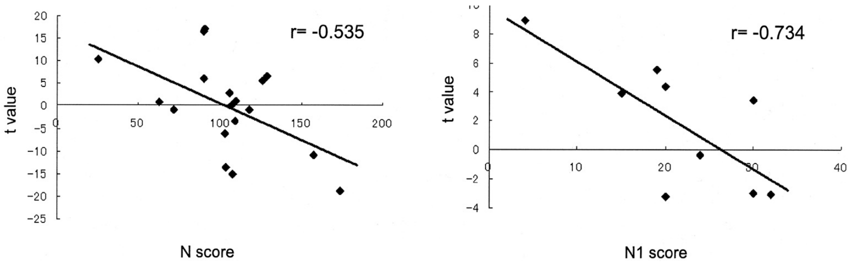

Figure 3. Correlation between N scores and positive PFC responses (left). Correlation between N1 (anxiety) scores and positive PFC responses (right).

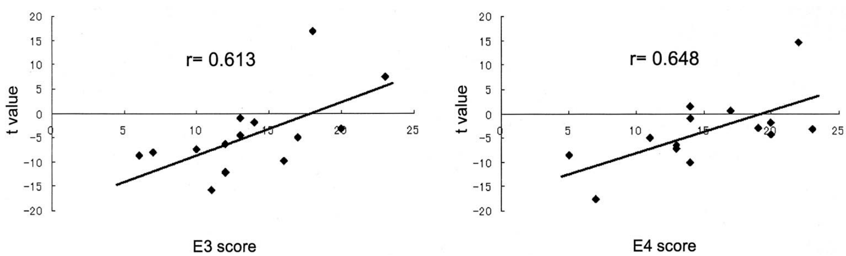

Figure 4. Correlation between E3 (assertiveness) scores and negative PFC responses (left). Correlations between E4 (activity) scores and negative PFC responses (right).

Results

Because of the limited spatial resolution of NIRS, we focused on correlations that were stable among subdimensions and/or were anatomically distinct. We divided the PFC into 4 parts (or 5 parts, if necessary): left, right, ventral, dorsal (and medial) parts. Correlations between NEO-PI-R scores and NIRS activities in these 4 parts were described. Twelve of the 13 subdimensions of N were negatively correlated with pleasant (a total of 9 subdimensions) and aversive (3 subdimensions) PFC responses (see Figure 3). Nine of these correlations were observed in the ventral part of the right hemisphere. Six of the 7 subdimensions of E positively correlated with aversive PFC responses; five of the 6 correlations were observed in the dorsal parts of the PFC (see Figure 4). Of these, 4 were located in the left hemisphere. Although there were a total of 9 correlations between PFC responses to emotional stimuli and

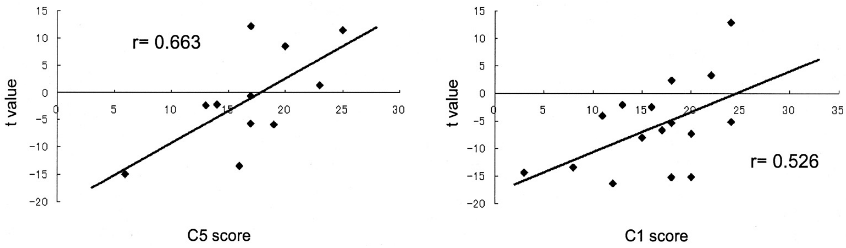

Figure 5. Correlation between C5 (self-discipline) scores and negative PFC responses (left). Correlations between C1(competent) scores and negative PFC responses (right).

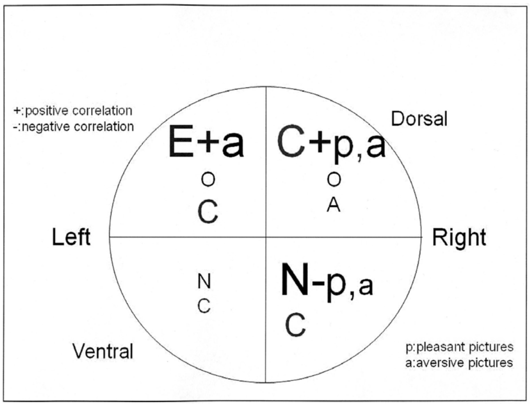

Figure 6. Summary of the results. The prefrontal cortex is divided into four parts. The size of letters indicates the strength of correlations.

subdimensions of O, no distinct tendency was observed. There was no correlation in the ventral parts of the right hemisphere, and when positive correlations to aversive stimuli were observed, they were located in the medial part. The smallest number (a total of 4) and unclear correlations were observed between PFC responses to emotional stimuli and subdimensions of A. These correlations were observed in the dorsal part of the right hemisphere. The largest number of correlations (a total of 21) was observed between PFC responses to emotional stimuli and subdimensions of C. Twenty of the 21 subdimensions of C were positively correlated with both pleasant (a total of 11) and aversive (a total of 9) pictures (see Figure 5). These correlations were observed widely in the PFC, but 10 correlations were in the dorsal parts of the right hemisphere. Figure 6 shows correlations of the scores of the subdimensions of N, E, O, A, and C with *t*-statistics, summarizing the results of the correlations between personality traits and PFC responses to emotional pictures.

Discussion

Relationships between personality traits measured by NEO-PI-R and brain responses to emotional events were measured using fMRI by Canli et al. (2001, 2002, 2004). Canli et al. (2001) reported that N negatively correlated with brain responses to aversive stimuli, as observed in the present study. However, the main results of the present study were that N negatively correlated with pleasant stimuli. Individuals with high N may tend to avoid excitement, because it irritates them. This may be a basis for their high vulnerability and may be expressed by negative correlations with aversive pictures. Another possibility is that they are insensitive to pleasant, rewarding experiences, which may be a basis for their depressive tendency and may be expressed by negative correlations with pleasant pictures. These correlations were observed in the ventral part of the right PFC, suggesting that the N trait is emotional in nature. Individuals with high N score have difficulties in regulating or managing emotional experiences.

Canli et al. (2001) reported that E positively correlates with brain responses to pleasant, rewarding stimuli. They attended to warmth (E1) and positive emotion (E6) subdimensions, and are aspects of the E trait. The present study, however, showed that E positively correlated with aversive stimuli. Individuals with high E need uplifting and pursue excitement regardless of its valence value, another aspect of the E trait. Thus, it is not unnatural that E positively correlates with brain responses to aversive pictures. In addition, ratings by 60 undergraduates showed that aversive stimuli used in the present study evoked stronger arousal than pleasant pictures. These correlations were observed mainly in the dorsal part of the left hemisphere. In contrast to N, individuals with high E do not care or worry about emotional problems. The E trait may be cognitive in nature. Because the results of E were very different from those of Canli et al. (2001), we considered it is necessary to examine the reliability of the results. Therefore, the Revised Life Orientation Test (LOT-R) was

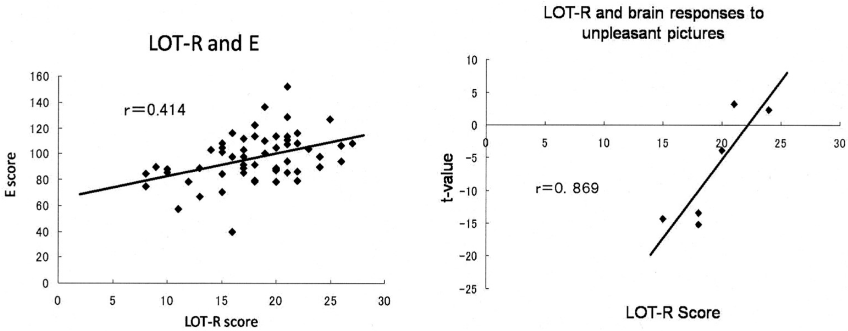

Figure 7. Correlations between LOT-R scores and E scores (left). Correlations between LOT-R scores and negative PFC responses (right).

additionally performed. LOT-R scores positively correlated with E and its subdimensions. Based on the NEO-PI-R results, positive correlations between LOT-R scores and PFC responses to aversive pictures were expected. Five of 6 such correlations observed were positive. Thus, the results are reliable. Figure 7 shows the correlation between E scores and LOT-R scores and the correlations between LOT-R scores and t-statistics.

The largest number of correlation was observed between C and PFC responses to emotional stimuli. C positively correlates with both pleasant and unpleasant pictures. These correlation patterns are different from those of N and E. Correlations were observed in wide areas of both hemispheres. This is also different from that of E and N. These results suggest that, unlike E, individuals with high C are sensitive to emotional events, but they can easily regulate emotional disturbance. Thus, the C trait may be both cognitive and emotional in nature.

Correlations of O and A with PFC responses to emotional pictures were not distinct or obvious. However, correlations were observed mainly in the dorsal parts of the bilateral PFC, suggesting that these traits may be cognitive and not simply emotional in nature.

We analyzed individual differences in PFC reactivity to emotional pictures. Interestingly, no channel showed statistically significant activation or deactivation, which might be negative data in conventional analyses. However, when we consider individual differences, we obtain meaningful data. There may be many experimental variables showing individual differences. While manipulating these variables, we must adopt analyses other than conventional methods, which is not a problem limited to NIRS (Canli, 2004).

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