Brain regions involved in verbal or non-verbal aspects of facial emotion recognition

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To depict the neural substrates for facial emotion recognition and to determine whether their activation is confounded by a verbal factor, we studied eight normal volunteers with functional magnetic resonance imaging (fMRI). Verbal and non-verbal sample stimuli were used in a facial emotion matching task and a gender matching task (control condition). Compared with the gender tasks, the emotion tasks significantly activated the right ventral prefrontal cortex, the right lingual cortex, and the left lateral fusiform cortex, irrespective of sample stimuli. The visual association cortices showed a significant interaction between the task and the material presented, as the activation for verbal materials was higher than for non-verbal materials during the emotion matching tasks. By contrast, no significant interaction was found in the right ventral prefrontal cortex. These results suggest that the verbal factor has a different effect on the neural networks for facial emotion processing. *NeuroReport* 11:2571–2576 © 2000 Lippincott Williams & Wilkins.

Key words: Affect; Emotion; Face; fMRI; Ventral prefrontal cortex; Verbal factor

INTRODUCTION

Clinical studies have repeatedly demonstrated that the right hemisphere is dominantly involved in facial emotion processing [1–3]. However, some researchers have suggested that if a verbal factor is confounded in the task, the left hemisphere, which supports verbal knowledge of emotion, may also play a crucial role in facial emotion recognition. From the clinical findings [4,5], Bowers *et al.* [6] have proposed that labeling facial expressions requires connections between the left hemisphere, which stores verbal knowledge of emotion, and the right hemisphere, which stores non-verbal knowledge of emotion. Furthermore, evidence from a patient with a split-brain procedure [7] suggested that, when facial expressions are associated with verbal labels, the left hemisphere can discriminate facial expressions without connection to the right hemisphere.

Although several neuroimaging studies on facial emotion recognition have been reported, none has focused on the verbal factor [8–10]. Thus, the aim of the present study was to elucidate the brain regions involved in facial emotion recognition and to determine whether activities of these regions are confounded by the verbal factor. We used fMRI to depict task-related changes in neural activities by the blood oxygen level-dependent (BOLD) technique [11]. The verbal factor in facial emotion tasks was explicitly modeled in the task design. We compared neural substrates activated by an emotion matching task with a gender matching task, with verbal (words) and non-verbal (faces) sample stimuli in each task. Since both emotion and gender are categorical knowledge conveyed by the face, we adopted the gender task as a control condition to subtract the cognitive components other than the processing of emotion.

MATERIALS AND METHODS

Subjects: Eight right-handed healthy volunteers (five men and three women), aged 23–29 years, with no history of neurological or psychiatric illness, participated in the study. The study was conducted at the Biomedical Imaging Research Center, Fukui Medical University, where the protocol was approved by the ethical committee. All subjects gave their written informed consent for the study. Data from one woman were excluded from the analysis owing to motion artifacts during the fMRI.

Stimuli: We used 24 facial expressions from Ekman and Friesen [12]. These faces consisted of four faces of Caucasian adults (an equal number of men and women) expressing anger, fear, happiness, surprise, sadness and disgust. A cross-cultural study [13] has shown that Japanese persons can judge the facial emotions of Caucasian persons with a high level of agreement when they select a single verbal label for each expression.

Experimental tasks: Subjects performed four different delayed matching-to-sample tasks: a verbal facial emotion matching task (VE), a non-verbal facial emotion matching task (NE), a verbal gender matching task (VG) and a non-verbal gender matching task (NG). For each task, a single sample stimulus (a word or a face; Fig. 1a) was presented for 400 ms, followed by two choice stimuli (faces) presented for 1000 ms side by side (Fig. 1b). The sample word was presented in Kanji (Japanese morphogram). Trials were presented every 3200 ms. The subject extended the thumb or the index finger of the right hand, according to whether the left or right choice stimulus matched the sample stimuli with respect to emotion (for emotion tasks), or to gender (for gender tasks), respectively. In the emotion tasks, both the sample emotion and the pairing emotion were changed randomly across trials. Similarly, the sample gender was changed randomly across trials in the gender tasks. The verbal and non-verbal tasks were identical except for the type of sample stimuli presented (Fig. 1a). Since the interstimulus interval was short, we expected the subjects to perform the NE task without converting a sample emotion into a verbal label. The faces used in the gender tasks also expressed emotions in order to control the unconscious effect of expressions between the facial affect task and the gender task. Stimuli were presented on a rear projection screen placed at the foot of the scanner bed and viewed by the subjects through a mirror.

Image acquisition: A time-course series of 66 volumes was acquired with T2*-weighted, gradient echo, echo planar imaging (EPI) sequences with a 1.5 T MRI system (Signa Horizon; General Electric Medical Systems, Milwaukee, Wis., USA) equipped with a standard birdcage head coil. Each volume consisted of 24 slices with a slice thickness of 5.0 mm, with a 1.0 mm gap, to cover the entire cerebral and cerebellar cortex. The time interval between two successive acquisitions of the same image was 6000 ms, echo time was 40 ms, and flip angle was 90°. The field of view was 24 cm. The digital in-plane resolution was 64×64 pixels with a pixel dimension of 3.75×3.75 mm. Head motion was minimized by placing comfortably tight foam padding around the subject's head.

All imaging series began with a prescan period followed by a rest period and ended with a task period; total time for an imaging run was 396 s. Each of the four tasks was administered in a separate imaging series. Each activation task period contained 15 trials of matching tasks, resulting in a total of 60 trials per imaging run. During the rest periods, subjects gazed at a cross on the screen. The presentation order of the four runs was counterbalanced across subjects in pseudorandom order.

Image analysis: The image data were analyzed with statistical parametric mapping (SPM96 software from the Wellcome Department of Cognitive Neurology, London, UK) implemented in Matlab (Mathworks Inc., Sherborn, MA, USA) [14]. The first two volumes of each fMRI run (prescan period) were discarded because magnetization was unsteady, and the remaining 64 volumes were used for the statistical analysis. Images were realigned, normalized to the standard stereotaxic space [15], and smoothed with an isotropic three-dimensional Gaussian filter of

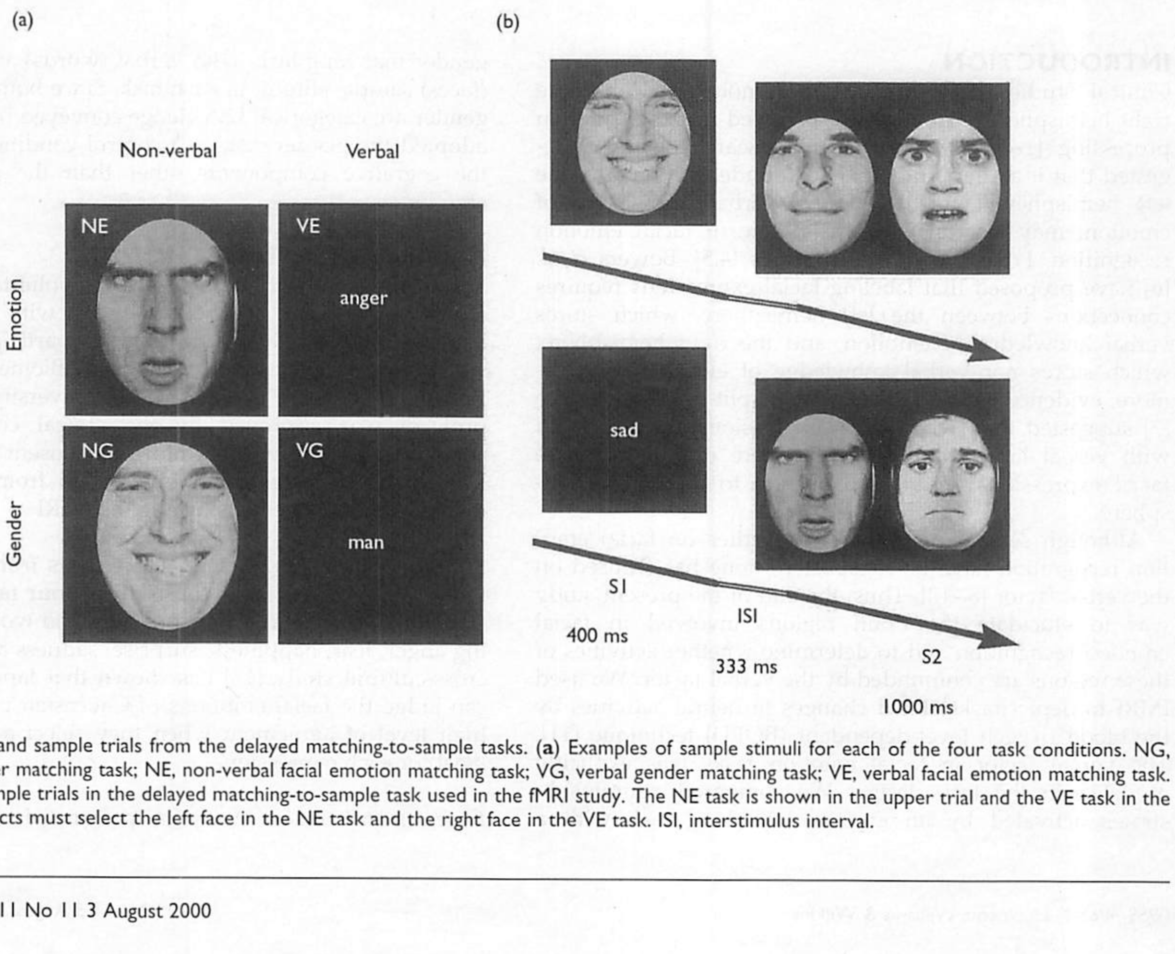

Fig. 1. Stimuli and sample trials from the delayed matching-to-sample tasks. **(a)** Examples of sample stimuli for each of the four task conditions. NG, non-verbal gender matching task; NE, non-verbal facial emotion matching task; VG, verbal gender matching task; VE, verbal facial emotion matching task. **(b)** Design of sample trials in the delayed matching-to-sample task used in the fMRI study. The NE task is shown in the upper trial and the VE task in the lower trial. Subjects must select the left face in the NE task and the right face in the VE task. ISI, interstimulus interval.

10 mm. Finally, a group analysis of all seven subjects was performed.

The statistical analysis was performed by modeling the task-related neural activity as reference waveforms (i.e., delayed box-car functions convolved with a hemodynamic response function) in the context of a general linear model. To test hypotheses about regionally specific condition effects, the estimates were compared using linear contrasts (Table 1). First, we delineated the areas activated during the emotion tasks compared with the rest condition. We also isolated the areas showing significant activation during the emotion tasks compared with the gender tasks by subtracting gender tasks from emotion tasks. This comparison was performed to depict the neural correlates of matching by emotional content, because these two tasks are identical in visual input, the motor aspect of matching, and recognizing faces as objects. The resulting set of voxel values for each contrast was a statistical parametric map of the t-statistic SPM{t}. The SPM{t} values were transformed to the unit normal distribution (SPM{Z}). Statistical significance was set at $p < 0.05$, with a correction for multiple comparisons, for the entire brain at voxel levels corresponding to $Z > 4.56$ [14]. Then, we examined the task × sample interaction within the regions defined by contrast 2 in Table 1. In this comparison, we performed a Bonferroni-type correction to keep the false-positive rate at the defined level of significance ($p < 0.05$). Finally, we performed direct comparison between emotion tasks. The statistical threshold was set at $p < 0.05$, with a correction for multiple comparisons at voxel levels.

RESULTS

Task performance: Accuracy in each condition was as follows: NG, 88.3 ± 10.0%; VG, 93.6 ± 6.8%; NE, 80.5 ± 10.0%; VE, 83.3 ± 7.5% (mean ± s.d.). A two-way analysis of variance (ANOVA) showed a significant main effect of task ($F(1,24) = 7.6$; $p < 0.05$), as the accuracies for the gender conditions were higher than for the facial emotion conditions. There was no significant effect of materials, and no significant interaction.

Areas of significant activation: Compared with the rest condition, the emotion tasks significantly activated the left primary sensorimotor cortex (Brodmann area, BA, 4), the supplementary motor area (BA 6), the cerebellum bilaterally, the bilateral dorsolateral prefrontal cortex (BA 46), the right inferior prefrontal cortex (BA 47), and the ventral visual pathway, including the lingual gyrus and the fusiform gyrus (Fig. 2, Table 2). Compared with the gender tasks, the emotion tasks significantly activated the right inferior frontal cortex (BA 47), the left lateral fusiform gyrus (BA 19/37), and the right lingual gyrus (BA 18; Fig. 3, Table 2). The gender tasks, compared with the rest condition, significantly activated the right lingual gyrus and the left lateral fusiform gyrus ($p < 0.05$, corrected) but not the right inferior frontal gyrus ($p > 0.5$). Among these brain regions, the left lateral fusiform cortex and the right lingual cortex showed a significant interaction ($p = 0.024$ and $p = 0.027$, both corrected, respectively,) between the task and the material presented, as the activation for verbal materials was higher than for non-verbal materials during the emotion matching tasks. By contrast, the right inferior frontal cortex showed no significant interaction between task and material presented. There was no region where the activity for non-verbal materials was higher than for verbal materials during emotion matching tasks.

Finally, the direct comparisons of NE *vs* VE and VE *vs* NE revealed that the bilateral prefrontal cortices (BA 10/46) and the right cerebellum were activated in NE and the bilateral visual association cortices (BA 18/19) were activated in VE (Fig. 4, Table 2). In these comparisons, the perceptual aspect of materials was not controlled. Then, the distinct activation may reflect the difference of the neural system for processing verbal and non-verbal materials.

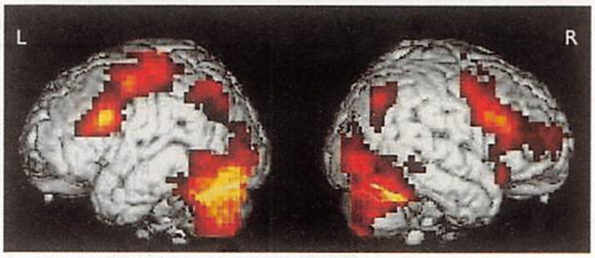

Fig. 2. Regions of significant activation for emotion tasks compared with rest condition. Activations are superimposed on a 3-D reconstruction.

DISCUSSION

The large activation caused by the facial emotion tasks, compared with the rest condition, may reflect not only emotion processing but also several other cognitive processes such as visual information processing for recognizing faces as objects, and working memory and motor response. The effect of these common cognitive processes

Table 1. Linear contrasts for comparisons.

Contrast	VE	Rve	VG	Rvg	NE	Rne	NG	Rng
1 (VE+NE)−(Rve+Rne)	1	−1	0	0	1	−1	0	0
2 (VE+NE)−(VG+NG)	1	−1	−1	1	1	−1	−1	1
3 (VE−VG)−(NE−NG)	1	−1	−1	1	−1	1	1	−1
4 (NE−NG)−(VE−VG)	−1	1	1	−1	1	−1	−1	1
5 NE−VE	−1	1	0	0	1	−1	0	0
6 VE−NE	1	−1	0	0	−1	1	0	0

Abbreviations: R, rest condition; VE, verbal emotion task; VG, verbal gender task; NE, non-verbal emotion task; NG, non-verbal gender task; Rve, rest condition paired with verbal emotion task; Rvg, rest condition paired with verbal gender task; Rne, rest condition paired with non-verbal emotion task; Rng, rest condition paired with non-verbal gender task.

Table 2. Brain regions significantly activated by the emotion task.

Region	Talairach coodinates			Z score
	X	Y	Z	
Emotion task vs rest condition				
L Middle frontal gyrus (9)	−48	12	28	8.63
R Middle frontal gyrus (9)	48	20	28	8.45
R Inferior frontal gyrus (47)	48	24	−12	6.86
SEF (8)	0	16	48	8.13
SMA (6)	4	−4	68	7.57
L PMC (6)	−40	−4	56	8.29
L SMC (4)	−28	−20	68	8.11
Thalamus	0	−20	4	6.25
Midbrain	0	−32	−8	7.04
L Superior parietal lobe (7)	−32	−64	48	6.96
R Superior parietal lobe (7)	40	−64	40	7.52
R Inferior parietal lobe (39)	36	−64	24	6.90
L Precuneus (7)	−4	−52	64	4.56
R Inferior temporal gyrus (37)	56	−60	−4	6.36
L Fusiform gyrus (19)	−56	−64	−4	8.22
R Lingual gyrus (18)	12	−80	−16	9.31
L Cuneus (19)	−8	−80	36	7.75
R Cuneus (19)	8	−76	40	7.79
L Cerebellum	−44	−64	−28	9.19
R Cerebellum	40	−60	−36	8.91
Emotion task vs gender task				
R Inferior frontal gyrus (47)	48	24	−16	5.76
L Fusiform gyrus (19/37)	−48	−68	−16	5.91
R Lingual gyrus (18)	20	−84	−16	4.68
NE vs VE				
L inferior frontal gyrus (10)	−48	48	0	6.36
R middle frontal gyrus (46)	48	40	16	5.43
R cerebellum	44	−60	−28	6.19
VE vs NE				
R lingual gyrus (18)	16	−84	−4	5.09
L fusiform gyrus (19)	−40	−76	−16	4.61

Number in parenthesis refers to Brodmann area. Abbreviations: L, left; PMC, premotor cortex; R, right; SEF, supplementary eye field; SMA, supplementary motor area; SMC, sensorimotor cortex; NE, non−verbal emotion task; VE, verbal emotion task.

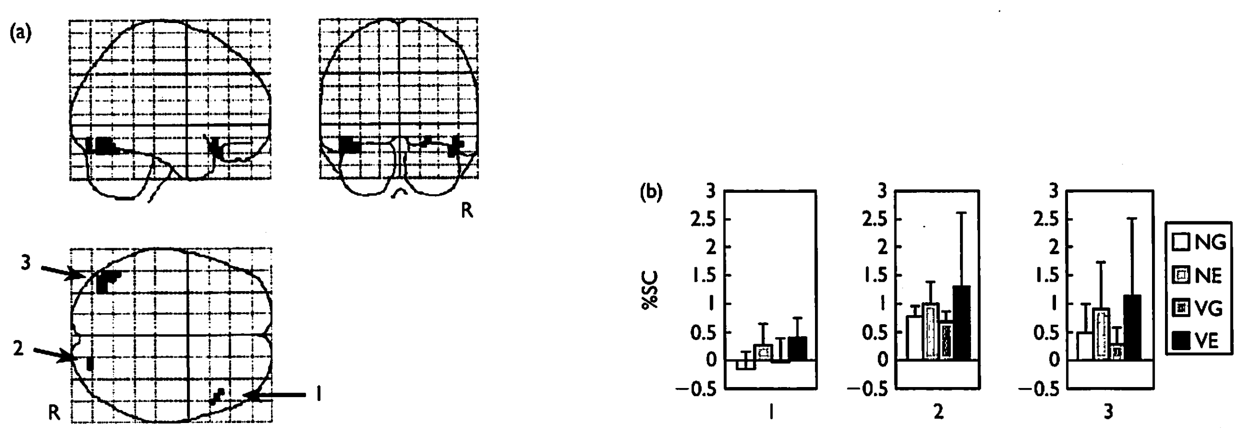

Fig. 3. (a) Regions of significant activation for emotion task compared with gender task. (b) Mean (± s.d.) percentage signal change in (1) the right inferior frontal gyrus (BA 47; X = 48, Y = 24, Z = −16), (2) the right lingual gyrus (BA 18; X = 20, Y = 84, Z = −16), and (3) the left fusiform gyrus (BA 19; X = −48, Y = −68, Z = −16).

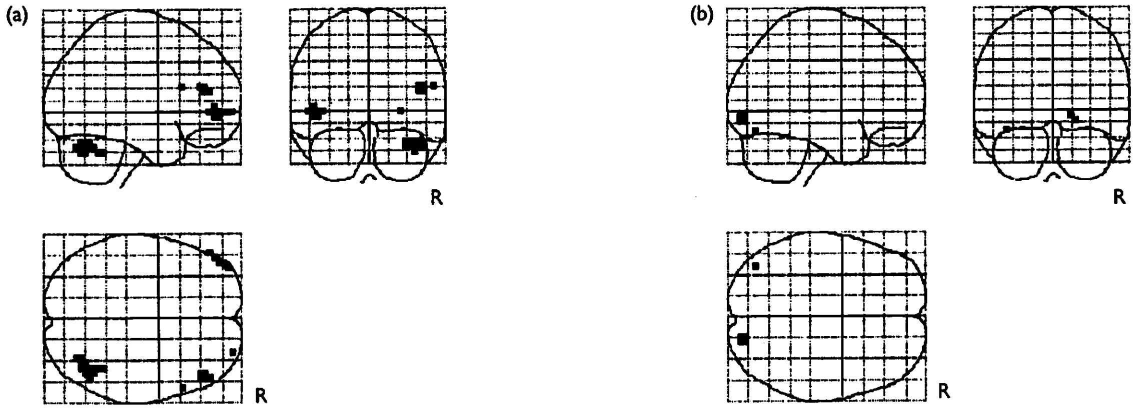

Fig. 4. Regions of significant activation for direct comparison of **(a)** NE *vs* VE and **(b)** VE *vs* NE.

was controlled by comparing the facial emotion tasks with the gender tasks. This comparison showed that the neural substrates for facial emotion processing were limited to the right ventral prefrontal cortex, the left lateral fusiform cortex, and the right lingual cortex.

Right ventral prefrontal cortex: The right ventral prefrontal cortex was activated by the facial emotion tasks, but not the gender tasks. Further, there was neither a facilitative nor an inhibitory effect of the verbal factor in the right ventral prefrontal cortex. These findings are concordant with previous studies suggesting that the right ventral prefrontal cortex is engaged in non-verbal emotional processing [8,9,16,17]. In a neuroimaging study, Nakamura *et al.* [9] found that the region was significantly activated during the assessment of facial emotion compared with that of facial attractiveness, but the comparison with the rest condition was not performed. The present study showed that the right ventral prefrontal cortex was significantly activated during the facial emotion tasks compared with the rest condition, as well as with the gender tasks. Thus, the activation of the region is not an artifact caused by deactivation during the gender tasks. There is significant but small difference in performance of ~10% (gender tasks; 91.0%, emotion tasks; 81.9%). This could be a confounding factor to depict the emotion specific areas. If the activation in the right ventral prefrontal cortex is related to the task difficulty, the activation pattern in each condition should be similar. Actually, there was no significant activation during the gender tasks compared with the rest condition even when a lenient threshold ($p = 0.5$) was used. Hence activation in this region cannot be attributed to the difference of the task difficulties, but to emotion recognition.

Our results, taken together with the results of the previous study [9], confirm the special role of the right ventral prefrontal cortex in processing of facial emotions. In addition, the activity of the region was not confounded by the verbal factor. This is compatible with the idea of Bowers *et al.* [6] that verbal labeling of facial expressions requires connections between both hemispheres. Although Stone *et al.* [7], in a split-brain study, showed that the left hemisphere could perform facial emotion tasks without connection to the right hemisphere, our result suggests that in the normal brain the right ventral prefrontal cortex is still engaged in recognizing facial emotion even though the verbal factor is confounded in the tasks.

Although we showed the special involvement of the right ventral prefrontal cortex in the processing of facial emotion, studies of patients with brain lesions have emphasized involvement of the right temporoparietal region but not the prefrontal region. Bowers *et al.* [6] located the non-verbal emotion lexicon in the right temporoparietal region. Adolphs *et al.* [18] also showed the importance of the region by examining 37 brain-damaged patients. The discrepancy may be partly explained by the methodological limitation of the studies in patients with brain damage. Such studies have difficulty in detecting prefrontal involvement in the processing of facial emotion, because a lesion of the prefrontal cortex impairs general cognitive function, as well as processing of facial emotion. In fact, the study of Adolphs *et al.* [18] excluded patients with prefrontal damage for this reason.

Recently, Hariri *et al.* [19] reported the right prefrontal activation in labeling task using angry and fearful faces but not in matching task. The neural activities in the right prefrontal cortex was negatively correlated with those in the amygdalae. Based on these findings, they concluded that the right prefrontal cortex is related to conscious evaluation of emotion, suppressing emotional responses represented by amygdalar activities. By contrast, in the present study, both labeling (verbal emotion task) and matching (non-verbal emotion task) activated the right prefrontal cortex to the same degree. This may be attributed to the difference of the number of emotion types presented. Since we presented six types of emotion (anger, fear, happiness, surprise, sadness, and disgust) to subjects, they needed to interpret the displayed emotions based on categorical knowledge about specific emotions even in matching task. Thus, the present results, taken together with those of Hariri *et al.* [19], suggest that the right prefrontal cortex is involved in conscious aspect of emotion recognition.

Visual association cortices: Activation of the right lingual cortex and the left fusiform cortex was significantly greater during the emotion tasks than during the gender tasks. These regions were also activated during the gender task compared with the rest condition. Furthermore, activation of these visual association cortices was facilitated by the verbal factor. We interpret this to mean that these visual association cortices are involved in processing of the face but are not specific for the processing of emotion *per se*. In line with this interpretation, neuroimaging studies [20,21] and brain damage studies [22] have revealed that these visual association cortices are engaged in facial recognition. It is unclear which of the cognitive factors may contribute to the difference in regional activation between the emotion tasks and the gender tasks. However, one possibility would be that an attentional demand for facial processing is greater in emotion recognition than in gender recognition. Since the face expresses six emotions, retrieving categorical knowledge of emotion from the face may require more perceptual clues than retrieving categorical knowledge of gender. The facilitative effect of the verbal factor in these regions also can be explained. Matching the facial expressions with verbal labels may require more perceptual information than matching the facial expressions with each other, without the intermediation of verbal labels.

Lack of amygdalar activation: Although several neuroimaging studies [23–27] have been reported the amygdalar activation during unconscious facial emotion processing, we did not observe it. This may be attributed to the difference in the tasks. Morris *et al.* [25] and Whalen *et al.* [27] reported that positive and negative faces modulated amygdalar activity oppositely. Other studies reported amygdalar activation by using negative emotional faces as stimuli [23,24,26]. Hence difference in valence may affect the activation of the amygdala. In the present study, we showed both positive and negative faces almost equally in a condition, hence counterbalancing the valence in each condition. Thus the unconscious effect of facial emotion on the amygdala might be attenuated.

CONCLUSION

In the present study, we identified three brain regions as neural substrates for facial emotion processing, namely, the right ventral prefrontal cortex, the right lingual cortex, and the left lateral fusiform cortex. Our results suggest that the right ventral prefrontal cortex may play a special role in processing facial emotion regardless of the verbal factor confounded in the task. In contrast, the visual association cortices may be involved in processing of facial recognition. Moreover, their activation was facilitated by the verbal factor. We interpret this phenomenon in light of the attentional demand for facial processing. The verbal factor has a different effect on activation of the brain regions responsible for facial emotion recognition.

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