Neuroscience Research 103 (2016) 27–33

Contents lists available at ScienceDirect

Neuroscience Research

journal homepage: www.elsevier.com/locate/neures

Differential activation of the ventromedial prefrontal cortex between male and female givers of social reputation

Iori Kawasaki[a], Ayahito Ito[a,b,*], Toshikatsu Fujii[a,c], Aya Ueno[b,d], Kazuki Yoshida[e], Shinya Sakai[f], Shunji Mugikura[g], Shoki Takahashi[g], Etsuro Mori[a]

[a] Department of Behavioral Neurology and Cognitive Neuroscience, Tohoku University Graduate School of Medicine, 2-1 Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan
[b] The Japan Society for the Promotion of Science (JSPS), Kojimachi Business Center Building, 5-3-1 Kojimachi, Chiyoda-ku, Tokyo 102-0083, Japan
[c] Kansei Fukushi Research Institute, Tohoku Fukushi University, 6-149-1 Kunimigaoka, Aoba-ku, Sendai 989-3201, Japan
[d] Division of Systems Neuroscience, Tohoku University Graduate School of Life Sciences, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
[e] Division of Health Sciences, Graduate School of Health Sciences, Hokkaido University, N12-W5, Kita-ku, Sapporo 060-0812, Japan
[f] Department of Functioning and Disability, Faculty of Health Science, Hokkaido University, N12-W5, Kita-ku, Sapporo 060-0812, Japan
[g] Department of Diagnostic Radiology, Tohoku University Graduate School of Medicine, 1-1 Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form 20 July 2015
Accepted 24 July 2015
Available online 31 July 2015

Keywords:
Social reputation
Pleasantness
Ventromedial prefrontal cortex
Gender differences
fMRI

ABSTRACT

Accumulating evidence has shown the profound influence of social reputation on human behavior and has implicated the ventromedial prefrontal cortex (vmPFC) in representing subjective values induced by social interaction. However, little is known regarding how the vmPFC encodes subjective pleasantness induced by social reputation received from others. We used functional magnetic resonance imaging (fMRI) to investigate how the vmPFC in males and females encodes the subjective pleasantness of social reputation received from the same gender and from the opposite gender. Behavioral data showed that positive reputation was perceived to be more pleasant than negative reputation. Intriguingly, both male and female subjects showed greater differences in the pleasantness scores between the positive reputation condition and the negative reputation condition from females than between positive and negative reputations from males. Imaging data revealed that the left vmPFC specifically contributed to the processing of positive reputation. The activity patterns of the vmPFC corresponded to the gender differences in behavior during the processing of social reputation. These results indicate that the vmPFC plays a role in representing the subjective value of positive social reputation and that this region might be a final computational site in a stream of value-based decision-making processes.

1. Introduction

Social interaction, ubiquitous in contemporary human societies, has supported our species' success in cross-species competition. A growing body of research has accumulated abundant evidence of how social information from other individuals modulates brain activity and affects human behavior (Edelson et al., 2011; Eisenberger et al., 2011; Garbarini et al., 2014; Ito et al., 2011; Izuma, 2012; Izuma and Adolphs, 2013; Izuma et al., 2008, 2010a; King-Casas et al., 2005; Meshi et al., 2013; Zaki et al., 2011). For example, we are strongly influenced by the presence of others (Izuma et al., 2010a,b) and show a strong tendency to conform to others' opinions, even when those opinions are erroneous (Edelson et al., 2011). These studies suggest that the presence and the opinions of others profoundly influence human decision-making in everyday life.

Among attitudes of and opinions from others, social reputation (mainly expressed by verbal appraisal) received from others has been investigated in several neuroimaging studies (Eisenberger et al., 2011; Garbarini et al., 2014; Ito et al., 2011; Izuma et al., 2008; Kawamichi et al., 2013; Kim et al., 2008; Meshi et al., 2013). Regarding the neural correlates of the processing of positive reputation, Izuma et al. (2008) reported that positive social reputation, as well as monetary reward, has positive reward value and activates reward-related regions, including the ventral striatum. Meshi et al. (2013) also showed that the ventral striatum is involved in the processing of self-related positive reputation. Regarding the neural correlates of the processing of negative reputation, Kim et al.

* Corresponding author at: Kansei Fukushi Research Institute, Tohoku Fukushi University, 1-149-6 Kunimigaoka, Aoba-ku, Sendai 989-3201, Japan. Tel.: +81 22 728 6048; fax: +81 22 728 6048.
E-mail address: ayahito.ito@gmail.com (A. Ito).

http://dx.doi.org/10.1016/j.neures.2015.07.010

(2008) found that the amygdala is associated with the processing of negative reputation relative to neutral comments.

By combining facial images of other individuals with sentences including a positive or negative adjective, some studies have directly compared brain activity when individuals received positive vs. negative reputations, and vice versa (Garbarini et al., 2014; Ito et al., 2011). Ito et al. (2011) demonstrated that the vmPFC is associated with positive reputation processing and the amygdala with negative reputation processing. Garbarini et al. (2014) found that relative to no reputation, both positive and negative reputations activate the dmPFC, although they did not find specific involvement of any regions in the processing of positive or negative reputation.

The above-mentioned studies suggest that positive social reputation activates reward-related regions, including the vmPFC, and that negative social reputation activates the amygdala. However, the neural substrates specifically involved in the processing of positive and negative reputations remain elusive because activity derived from comparing the processing of positive reputation with that of negative reputation may be elicited by decreased activity in the processing of negative reputation, and vice versa. To identify regions specifically involved in representing subjective feelings induced by positive or negative reputation, brain activity when individuals receive positive or negative reputation must be compared with brain activity when they receive neutral comments. Regions specifically associated with positive reputation should be identified by contrasting positive vs. neutral conditions with negative vs. neutral conditions, and regions specifically associated with negative reputation should be identified by contrasting negative vs. neutral conditions with positive vs. neutral conditions.

The main purpose of the present study was to identify regions that are specifically associated with the processing of positive and negative reputations. On the basis of the previous findings, we predicted that the vmPFC would be associated with positive reputation and the amygdala with negative reputation.

Recent neuroimaging studies have highlighted gender differences in the vmPFC in the processing of social stimuli, including faces. For example, O'Doherty et al. (2003) reported greater vmPFC activity in response to attractive faces of the opposite gender in male subjects than in female subjects. Similarly, Cloutier et al. (2008) reported that vmPFC activity differentiated attractive faces from unattractive faces in male subjects but not in female subjects. These results raise the possibility of gender differences in the contribution of the vmPFC to the processing of positive reputation from the same and from the opposite gender. Thus, the second purpose of the present study was to determine whether the activity of the vmPFC (and other regions related to the processing of positive reputation) differs when male and female participants receive positive reputation from the same and opposite genders.

2. Materials and methods

2.1. Subjects

Twenty-eight healthy, young, heterosexual volunteers (14 males and 14 females; age range, 20–24 years; mean age, 21.1 years) with no history of neurological or psychiatric disease were paid to participate in this study. No pathological findings in the participants' brains were identified using MRI. All of the subjects were right-handed (Oldfield, 1971) and had normal or corrected-to-normal vision. After the subjects were given a detailed description of the study, they provided written informed consent in accordance with the Declaration of Helsinki and the guidelines approved by the Ethical Committee of Tohoku University.

2.2. Stimuli and tasks

Prior to the fMRI experiment, we prepared face photographs of male and female faces together with positive and negative words for creating experimental stimuli. To collect face photographs, we recruited 72 young male and 72 young female volunteers who did not participate in the fMRI study. To avoid a situation in which the subjects who participated in the fMRI experiment were acquainted with the individuals whose faces were used as the experimental stimuli, we collected these photographs in the Hokkaido prefecture, far from our laboratory. The volunteers were informed that the photographs would be used for research purposes only, and they provided written informed consent. The photographs were captured using a DMC-LX2 digital camera (Panasonic, Japan) with a flash and a resolution of 1920×1080 pixels. The volunteers were asked to present a neutral facial expression and to look directly into the camera. All of the images were then downloaded onto a computer and edited in Adobe Photoshop CS 5.1 and Adobe Illustrator CS 5.1 (San Jose, CA, USA) to produce greater uniformity across the photographs. Photographs were resized to 720×540 pixels.

A separate group of 10 young volunteers (5 males and 5 females; age range, 18–24 years; mean age 19.9 years) who did not participate in the fMRI study rated the 72 male and 72 female face photographs using a 10-point scale for emotional valence ranging from 1 (extremely negative) to 10 (extremely positive) and arousal ranging from 1 (not arousing at all) to 10 (extremely arousing). For each face, we calculated the average scores of emotional valence and chose 36 male (mean = 5.50, SD = 0.50, 95% confidence interval (CI) = 5.33–5.67) and 36 female (mean = 5.50, SD = 0.61, 95% CI = 5.29–5.71) face photographs that were rated as neutral. A paired t-test showed no significant difference between the emotional valence scores of the 36 male and 36 female face photographs ($t(35) = 0.09$, $p = 0.93$). We also calculated the average arousal scores for the 36 male (mean = 4.89, SD = 1.17, 95% CI = 4.49–5.29) and 36 female (mean = 4.71, SD = 0.96, 95% CI = 4.39–5.04) photographs. A paired t-test showed no significant difference ($t(35) = 0.73$, $p = 0.47$).

We also prepared 72 positive and 72 negative words, each of which represents a social reputation. Those words were chosen from Japanese articles investigating words that describe personality traits (Murakami, 2006; Ozeki and Oda, 1981; Sukigara, 2006). The same group of 10 young volunteers who rated the face photographs also rated the 72 positive and 72 negative words using a 10-point scale for pleasantness ranging from 1 (extremely unpleasant) to 10 (extremely pleasant) and a 10-point scale for arousal ranging from 1 (not arousing at all) to 10 (extremely arousing). For each word, we calculated the average pleasantness scores and chose 36 more positive (mean = 7.66, SD = 0.48, 95% CI = 7.49–7.82) and 36 more negative (mean = 2.29, SD = 0.36, 95% CI = 2.17–2.41) words. A paired t-test showed a significant difference between the pleasantness scores of 36 positive and 36 negative sentences ($t(35) = 138.63$, $p < 0.001$). We also calculated the average arousal scores for 36 positive (mean = 6.30, SD = 0.87, 95% CI = 6.01–6.60) and 36 negative (mean = 6.48, SD = 0.90, 95% CI = 6.17–6.78) words. A paired t-test showed no significant difference ($t(35) = 0.71$, $p = 0.48$).

Each experimental stimulus presented during the fMRI scan consisted of a face photograph and a sentence that included one of the 36 chosen positive or negative words (e.g., 'You are kind.'; 'You are unreliable.') below the face photograph (Fig. 1). The experimental stimuli were composed of a combination of two factors: the type of social reputation (positive or negative) and the gender of the face (male or female). Thus, four sets of experimental stimuli, each consisting of 36 stimuli, were prepared. The combinations of face and sentence were randomly determined and were fixed across the subjects. In addition, we prepared 72 neutral stimuli (the 36 male

Fig. 1. Schematic diagram of experimental design. During fMRI scanning, the subjects were presented with each stimulus sequentially. They were then asked to imagine a situation in which they were told the indicated comment by the individual whose face was presented and asked to rate the pleasantness of each stimulus using a 4-point scale ranging from 1 (very unpleasant) to 4 (very pleasant).

and 36 female face photographs with the sentences that instructed the subjects to press one of four buttons) (Fig. 1).

To avoid two consecutive presentations of the same face and six consecutive presentations of one of the six conditions, each stimulus was presented in a predetermined pseudo-random order. During fMRI scanning, the participants were asked to imagine a situation in which they heard the indicated comments from the individual whose face was presented and to rate the pleasantness of each stimulus using a 4-point scale ranging from 1 (very unpleasant) to 4 (very pleasant). Each stimulus was presented for 3.0 s. The inter-stimulus interval, during which a fixation cross was constantly presented, ranged from 4.0 s to 10.0 s to maximize the efficiency of the event-related design (Dale, 1999). The entire fMRI task was divided into three consecutive runs, each of which lasted approximately 12 min.

2.3. Image acquisition

Whole-brain imaging was performed using a 3.0-tesla MRI scanner (MAGNETOM Trio, A Tim System; Siemens, Germany) equipped with a 12-channel head coil array for signal reception. A T2*-weighted echo planar imaging (EPI) sequence sensitive to blood oxygenation level-dependent (BOLD) contrast was used for functional imaging with the following parameters: repetition time (TR) = 2500 ms, echo time (TE) = 30 ms, flip angle = 90°, acquisition matrix = 80×80, field of view (FOV) = 240 mm, in-plane resolution = 3 mm × 3 mm, number of axial slices = 43, slice thickness = 3 mm, and interslice gap = 0.5 mm. We used an acquisition sequence tilted at 30° to the intercommissural (anterior commissure–posterior commissure) line to recover the magnetic susceptibility-induced signal losses due to the sinus cavities (Deichmann et al., 2003). A high-resolution (spatial resolution 1 mm × 1 mm × 1 mm) structural image was also acquired using a T1-weighted, magnetization-prepared rapid-acquisition gradient echo (MP-RAGE) pulse sequence. The subject's head motion was restricted using firm padding that surrounded the head. Visual stimuli were presented using magnet-compatible goggles (Visual Stim Digital, Resonance Technology, Inc., Los Angeles, USA). The responses were collected using a magnet-compatible response box. The EPI images were acquired in three consecutive runs. The first four scans in each run were discarded for T1 equilibration effects.

2.4. Preprocessing

Data preprocessing and statistical analyses were performed using SPM8 software (Wellcome Department of Imaging Neuroscience, London, UK). All of the volumes acquired from each subject were realigned to correct for small movements that occurred between scans. This process generated an aligned set of images and a mean image for each subject. The realigned images were then corrected for the different slice acquisition times. Each participant's T1-weighted structural MRI was coregistered to the mean of the realigned EPI images and segmented to separate the gray matter, which was normalized to the gray matter in a template image based on the Montreal Neurological Institute (MNI) reference brain (resampled voxel size 3 mm × 3 mm × 3 mm). Using the parameters from this normalization process, the EPI images were then normalized to the MNI template and smoothed using an 8-mm, full-width half-maximum Gaussian kernel.

2.5. Statistical analyses

The fMRI data were analyzed using two general linear models (GLMs). For each participant and on a voxel-by-voxel basis, the hemodynamic response to the stimulus onset for each event type was modeled via convolution using a canonical hemodynamic response function. At this time, six motion parameters of head movement were also included in the model as events of no interest. Events involving multiple responses or no response were also modeled as events of no interest. The first GLM was intended to explore the neural substrates specifically involved in the processing of positive and negative social reputations. This first GLM included the following regressors of interest: (1) the positive comments, (2) the negative comments, and (3) the neutral comments. The second GLM was intended to explore the gender differences associated with receiving positive and negative reputations from the same or opposite genders, and included the following regressors of interest: (1) positive comments from males, (2) positive comments from females, (3) negative comments from males, and (4) negative comments from females.

For the second GLM, events involving neutral comments were modeled as events of no interest. A high-pass filter of 1/128 Hz was used to remove low-frequency noise, and an AR (1) model was used to correct for temporal auto-correlations. For the whole-brain analyses, the threshold of significance was set at $p < 0.001$ at the voxel level (uncorrected for multiple comparisons) and $p < 0.05$ at the cluster level (FWE corrected for multiple comparisons). The peak voxels of clusters that exhibited reliable effects are reported in MNI coordinates. Activation is displayed on a surface-rendered standard brain using MRIcroN software (Rorden et al., 2007).

2.6. ROI definition and analyses

We used MarsBaR software to perform a region-of-interest (ROI) analysis (Brett et al., 2002). Each ROI was defined using the results of the first GLM (i.e., functional ROI), and the percentages of signal changes were calculated for the four conditions based on the results of the second GLM. The signal changes were averaged across all voxels in a given cluster (see the Results section for details). The purpose of this ROI analysis was to elucidate the patterns of signal changes in the ROI that varied depending on the gender of the subject (male and female) and the gender of the face in the stimulus (male and female), as well as the type of social reputation (positive and negative).

3. Results

3.1. Behavioral data

The experimental conditions consisted of the following: (1) a male-positive condition in which the participants received positive reputations from males, (2) a female-positive condition in which the participants received positive reputations from females, (3) a male-negative condition in which the participants received negative reputations from males, and (4) a female-negative condition in which the participants received negative reputations from females. Because we employed both male and female subjects, we classified the data for each experimental condition by subject gender (Fig. 2A and B).

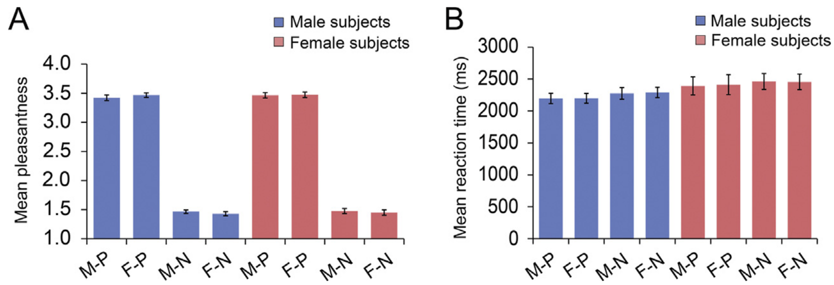

Fig. 2. (A) Mean scores of pleasantness rating and (B) mean reaction times. M-P, positive comments from males; F-P, positive comments from females; M-N, negative comments from males; and F-N, negative comments from females. The error bars represent the SEM.

The mean pleasantness scores from the male subjects were 3.42 (SD = 0.18, 95% CI = 3.32–3.53) for the male-positive, 3.47 (SD = 0.15, 95% CI = 3.38–3.55) for the female-positive, 1.46 (SD = 0.11, 95% CI = 1.40–1.53) for the male-negative, and 1.43 (SD = 0.14, 95% CI = 1.35–1.51) for the female-negative conditions. The mean pleasantness scores from the female subjects were 3.46 (SD = 0.18, 95% CI = 3.36–3.57) for the male-positive, 3.47 (SD = 0.18, 95% CI = 3.37–3.58) for the female-positive, 1.47 (SD = 0.16, 95% CI = 1.38–1.57) for the male-negative, and 1.45 (SD = 0.17, 95% CI = 1.35–1.55) for the female-negative conditions. We performed a three-way ANOVA, using the type of social reputation (positive and negative) and the gender of the face (male and female) as within-subject factors and the gender of the subject (male and female) as a between-subject factor. The ANOVA revealed a main effect of the type of social reputation (positive > negative) [$F(1, 26) = 2053.67$, partial $\eta^2 = 0.99$, $p < 0.001$], but there were no main effects of the gender of the face [$F(1, 26) = 0.03$, partial $\eta^2 = 0.001$, $p = 0.86$] or of the gender of the subject [$F(1, 26) = 0.28$, partial $\eta^2 = 0.01$, $p = 0.60$]. In addition, the ANOVA showed a significant two-way interaction between the type of social reputation and the gender of the face [$F(1, 26) = 8.51$, partial $\eta^2 = 0.25$, $p < 0.01$]. A post hoc t-test revealed that the difference in the pleasantness scores between the female-positive and female-negative conditions was greater than that between the male-positive and male-negative conditions ($t[27] = 2.90$, $p < 0.01$). We observed neither a significant three-way interaction nor significant two-way interactions between the type of social reputation and the gender of the subject or between the gender of the face and the gender of the subject (all p-values >0.1).

The mean reaction times in the male subjects were 2197.65 ms (SD = 304.77, 95% CI = 2021.68–2373.62) for the male-positive, 2199.01 ms (SD = 288.26, 95% CI = 2032.57–2365.44) for the female-positive, 2276.55 ms (SD = 344.18, 95% CI = 2077.82–2475.27) for the male-negative, and 2290.14 ms (SD = 305.07, 95% CI = 2114.00–2466.29) for the female-negative conditions. The mean reaction times in the female subjects were 2393.64 ms (SD = 524.87, 95% CI = 2090.59–2696.69) for the male-positive, 2413.24 ms (SD = 581.86, 95% CI = 2077.28–2749.20) for the female-positive, 2462.52 ms (SD = 462.84, 95% CI = 2195.28–2729.75) for the male-negative, and 2456.02 ms (SD = 453.06, 95% CI = 2194.43–2717.61) for the female-negative conditions. A three-way ANOVA revealed a significant main effect of the type of social reputation (positive < negative) [$F(1, 26) = 5.19$, partial $\eta^2 = 0.17$, $p = 0.03$] but showed no main effects of the gender of the face [$F(1, 26) = 0.19$, partial $\eta^2 = 0.01$, $p = 0.67$] or of the gender of the subject [$F(1, 26) = 1.52$, partial $\eta^2 = 0.06$, $p = 0.23$]. There was neither a three-way interaction nor any two-way interactions (all p-values >0.1).

3.2. Imaging data

The imaging results are shown in Table 1. First, we compared the positive with neutral conditions (positive vs. neutral) and the negative with neutral conditions (negative vs. neutral). Next, using the same t-map described above, we conducted a two-sample t-test to identify brain regions specifically involved in the processing of positive and negative reputations. The comparison between the positive vs. neutral conditions and the negative vs. neutral conditions revealed a significant activation in the left vmPFC (Fig. 3). We found no significant activation in the opposite comparison [i.e., (negative vs. neutral) vs. (positive vs. neutral)]. We also conducted an inclusive masking procedure to identify brain regions commonly activated for positive and negative reputations. Based on the conjunction null hypothesis, we employed a threshold of significance of $p < 0.001$ at the voxel level (uncorrected for multiple comparisons) and a significance of $p < 0.05$ at the cluster level (FWE corrected for multiple comparisons) for all contrast images (Friston et al., 2005; Nichols et al., 2005). We found significant activation of the left ventrolateral prefrontal cortex (extending to the bilateral amygdala), left supplementary motor area/dmPFC, left fusiform gyrus, bilateral posterior cingulate cortex, and right middle temporal gyrus.

To explore the possibility of gender differences in the activity patterns of the left vmPFC, we extracted signal changes in the clusters of the vmPFC identified in the subtraction analysis of [(positive vs. neutral) vs. (negative vs. neutral)] (i.e., functional ROI). The mean signal changes in the left vmPFC in the male subjects were 0.03 (SD = 0.10, 99.9% CI = −0.08 to 0.14) for the male-positive, 0.09 (SD = 0.09, 99.9% CI = −0.01 to 0.20) for the female-positive, −0.04 (SD = 0.12, 99.9% CI = −0.18 to 0.10) for the male-negative, and −0.04 (SD = 0.11, 99.9% CI = −0.16 to 0.08) for the female-negative conditions. The mean signal changes in the left vmPFC in the female subjects were 0.02 (SD = 0.08, 99.9% CI = −0.06 to 0.11) for the male-positive, 0.06 (SD = 0.09, 99.9% CI = −0.04 to 0.16) for the female-positive, −0.02 (SD = 0.13, 99.9% CI = −0.17 to 0.12) for the male-negative, and -0.06 (SD = 0.10, 99.9% CI = −0.18 to 0.06) for the female-negative conditions.

Using the same approach as for the behavioral analysis, we performed a three-way ANOVA, using the type of social reputation (positive and negative) and the gender of the face (male and

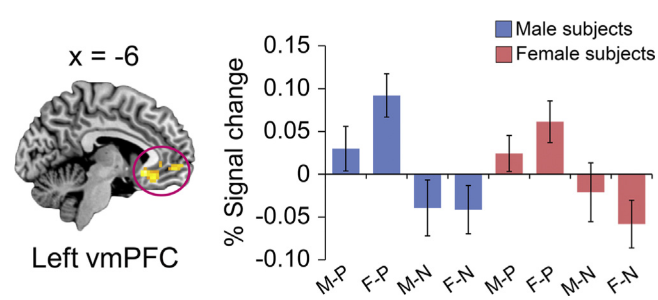

Fig. 3. Significant activation in the left vmPFC in the comparison of (positive vs. neutral) vs. (negative vs. neutral) and percentage signal changes of this cluster in each condition. M-P, positive comments from males; F-P, positive comments from females; M-N, negative comments from males; and F-N, negative comments from females. The error bars represent the SEM.

Table 1
Brain regions found in the present study.

Region (Brodmann's area)	MNI coordinates			Z value	Cluster size
	x	y	z		
Positive vs. Neutral					
Left ventrolateral prefrontal cortex (47)	−45	29	−11	Inf	7956
Left supplementary motor area (6)	−6	17	61	7.83	3511
Left angular gyrus (39)	−48	−61	25	5.29	72
Right middle temporal gyrus (21)	48	−34	1	4.35	80
Right cerebellum	3	−58	−32	4.46	105
Negative vs. Neutral					
Left ventrolateral prefrontal cortex (47)	−42	29	−8	7.05	5326
Left supplementary motor area (6)	−6	17	58	7.80	2255
Left precentral gyrus (6)	−48	2	52	4.79	85
Left posterior cingulate cortex (23/30)	−3	−49	25	4.94	84
Left inferior occipital gyrus (19)	−36	−73	−11	4.66	330
Right middle temporal gyrus (21)	48	−28	1	5.47	136
(Positive > Neutral) inclusively masked with (Negative > Neutral)					
Left ventrolateral prefrontal cortex (47) extending to bilateral amygdala	−45	29	−11	Inf	4696
Left supplementary motor area/dorsomedial prefrontal cortex (6/8/9/32)	−6	17	61	7.83	2173
Left fusiform gyrus (37)	−39	−61	−14	6.12	323
Bilateral posterior cingulate cortex (23)	0	−46	28	5.88	83
Right middle temporal gyrus (21)	48	−34	1	4.35	74
(Positive vs. *Neutral)* vs. *(Negative vs. Neutral)*					
Left ventromedial prefrontal cortex (25/11)	−6	23	−8	4.38	165
(Negative vs. Neutral) vs. (Positive vs. Neutral)					
No suprathreshold activation					

The threshold of significance was set at $p < 0.001$ at the voxel level (uncorrected) and a significance of $p < 0.05$ (FWE corrected for multiple comparisons) at the cluster level.

female) as within-subject factors and the gender of the subject (male and female) as a between-subject factor. The ANOVA revealed a main effect of the type of social reputation (positive > negative) [$F(1, 26) = 27.16$, partial $\eta^2 = 0.51$, $p < 0.001$], but there were no main effects of the gender of the face [$F(1, 26) = 1.74$, partial $\eta^2 = 0.06$, $p = 0.20$] or of the gender of the subject [$F(1, 26) = 0.07$, partial $\eta^2 = 0.003$, $p = 0.79$]. In addition, the ANOVA showed a significant two-way interaction between the type of social reputation and the gender of the face [$F(1, 26) = 13.93$, partial $\eta^2 = 0.35$, $p < 0.001$]. A post hoc t-test revealed that the difference in the activity between the female-positive and female-negative conditions was greater than that between the male-positive and male-negative conditions ($t[27] = 3.80$, $p < 0.001$). There was neither a significant three-way interaction nor a significant two-way interaction between the type of social reputation and the gender of the subject or between the gender of the face and the gender of the subject (all p-values >0.1).

4. Discussion

In the present study, behavioral data showed that the pleasantness score was significantly higher in the positive reputation condition than in the negative reputation condition but did not differ on the basis of the gender of the face or of the subject. In addition, the ANOVA showed a significant two-way interaction between the type of social reputation and the gender of the face; both male and female subjects showed greater differences in the pleasantness score between the female-positive and female-negative conditions than between the male-positive and male-negative conditions. The imaging data revealed that the left vmPFC specifically contributed to the processing of positive reputation. The pattern of vmPFC activity corresponded to the interaction found in the behavioral data; both male and female subjects showed greater differences in vmPFC activity between the female-positive and female-negative conditions than between the male-positive and male-negative conditions.

The behavioral data showing that the pleasantness score was significantly higher in the positive reputation condition than in the negative reputation condition are consistent with the results of Ito et al. (2011). Moreover, both male and female subjects showed greater differences in the pleasantness score between the female-positive and female-negative conditions than between the male-positive and male-negative conditions. That is, the male subjects showed a greater difference in the pleasantness score between the positive and negative reputations from the opposite gender (female) than from the same gender (male), whereas the female subjects showed a greater difference in pleasantness score in the conditions showing faces of the same gender (female) than in those showing faces of the opposite gender (male). Our results suggest that male subjects are sensitive to social reputation from the opposite gender and female subjects are sensitive to social reputation from the same gender, although the precise reason for this gender difference in behavior requires further exploration.

We also found that the subjects responded faster for positive reputation than for negative reputation, regardless of the gender of the giver or the subject. This finding is partially consistent with a previous study showing that subjects made faster responses when they received highly positive reputations than when they received modestly positive reputations (Izuma et al., 2008). Increased subjective pleasantness induced by social reputation may cause faster responses, not only within the processing of positive reputation but also across the processing of positive and negative reputations.

The imaging results showed that the left vmPFC is specifically associated with the higher pleasantness induced by positive reputation. Our experimental paradigm, in which we employed the neutral condition as well as positive and negative conditions, enables us to formally test which regions are specifically associated with positive reputation.

Our results decisively confirm previous findings that indicate an important role for the vmPFC in processing positive reputation (Ito et al., 2011). Previous studies have shown that the vmPFC is associated with the processing of subjective values using various types of stimuli (Bray et al., 2010; Chib et al., 2009; Ishizu and Zeki, 2011; Kim et al., 2011; Lebreton et al., 2009; Levy and Glimcher, 2012; Lin et al., 2012; Plassmann et al., 2008; Tsukiura and Cabeza, 2011a,b). Specifically, using various stimuli within the experimental paradigm, several studies showed that the vmPFC is commonly associated with the representation of subjective values of different types of stimuli (Chib et al., 2009; Kim et al., 2011; Lin et al., 2012), supporting the idea of a "neural common currency." These prior results, as well as those of the present study, suggest that the subjective values of different types of targets, including social reputation from others, are computed in a common neural system within the vmPFC.

Both male and female subjects showed greater differences in vmPFC activity between the female-positive and female-negative conditions than between the male-positive and male-negative conditions. This finding demonstrates that the pattern of vmPFC activity corresponds to gender differences in behavior during the processing of social reputation. The vmPFC might be regarded as a final (or nearly final) computational site in a stream of value-based decision-making processes. In fact, Levy and Glimcher (2012) suggested that value-related information converges on the vmPFC before moving on to the choice-related motor circuitry. As mentioned above, vmPFC activity in response to attractive faces of the opposite gender was greater in male subjects than in female subjects (O'Doherty et al., 2003), and vmPFC activity differentiated attractive faces from unattractive faces in male subjects but not in female subjects (Cloutier et al., 2008; O'Doherty et al., 2003). These findings demonstrate gender differences in vmPFC activity. However, our findings did not show such a difference; instead, our findings indicated that vmPFC activity can explain gender differences in value-based decision-making. Future studies must consider how subjective values are created by the combination of several factors, including pleasantness, attractiveness, and other affective factors, and then explore which factors lead to gender differences in both behavior and brain activity, including vmPFC activity.

It should also be noted that functional couplings between the vmPFC and the other regions might have a key role in these processes. Recent studies have shown that the functional connectivities between the vmPFC and several regions including frontal, temporal, and parietal regions play a critical role in the processing of subjective value (Hare et al., 2010; Janowski et al., 2013; Smith et al., 2014; van den Bos et al., 2013).

We did not find the involvement of the amygdala in the processing of negative reputation. On the contrary, we found that the amygdala was associated with both positive and negative reputations compared with the neutral condition. This result seems inconsistent with the findings of previous studies showing that the amygdala is associated with the processing of negative reputation compared with positive reputation (Ito et al., 2011). However, because Ito et al. (2011) did not employ a neutral condition, their study did not examine whether the activity of the amygdala increases for positive and negative conditions compared with a neutral condition. Previous studies showed a non-linear response profile of the amygdala in response to social stimuli, including faces (Said et al., 2009; Winston et al., 2007). Furthermore, in the present study, the mean valence scores of the positive comments were significantly higher than those of the negative comments, whereas the mean arousal scores of the positive comments and negative comments were rated as similar. Thus, there is a possibility that the amygdala is involved in the processing of arousal rather than emotional valence induced by positive and negative social reputations, and this view is consistent with previous literature (Anderson et al., 2003; Brooks et al., 2012).

The present study also showed that the dmPFC was associated with the processing of social reputation regardless of the emotional valence. One possibility is that the dmPFC, as well as the amygdala, is involved in the processing of arousal information. Another possibility is that the dmPFC may contribute to valence-independent self-referential processes rather than valence-related processing per se. Previous studies highlighted the role of the dmPFC in the processing of one's own reputation (Amodio and Frith, 2006; Eisenberger et al., 2011; Frith and Frith, 2008; Izuma, 2012; Izuma et al., 2008, 2010b; Kawamichi et al., 2013). Furthermore, the dmPFC has been shown to be involved in both positive (Izuma et al., 2008) and negative reputation (Eisenberger et al., 2011). Future studies are required to explore whether and how the dmPFC is associated with self-referential processes and whether the activity of the dmPFC is modulated by arousal.

Investigating how the source of social information affects our behavior and brain activation is highly important. For example, social feedback from close friends and unfamiliar individuals has different effects on patterns of vmPFC activity (Sip et al., 2015). Furthermore, positive and negative social reputations from old acquaintances whom the subjects liked were rated more pleasant compared with those from old acquaintances whom the subjects disliked (Ito et al., 2011). Although we employed unfamiliar faces in the present study to control for the familiarity of faces, future studies are required to explore how differences between the sources of social information are associated with the neural underpinnings of social reputation.

Three further limitations of the present study should be mentioned. First, our results regarding gender differences are based on the comparison of data from 14 females and 14 males. Previous studies have suggested that a small sample size might lead to a lack of statistical power (Button et al., 2013; Yarkoni, 2009). In particular, the power to detect between-subject effects is typically much lower than the power to detect within-subject effects of an equivalent magnitude (Yarkoni, 2009). Second, we employed two GLMs; the first GLM was intended to explore the neural substrates specifically involved in the processing of positive and negative social reputations and the second GLM to explore the gender differences associated with receiving positive and negative reputations from the same or opposite genders. We isolated the cluster of the left vmPFC based on the results of the first GLM and explored the gender differences of the patterns of percentage signal changes corresponding to each condition in the second GLM. Although these GLMs were employed for different purposes, the regressors used in these GLMs were not completely independent. Previous literature indicated that "double dipping", the use of the same data for selection and selective analysis, can cause some degree of bias (Kriegeskorte et al., 2009, 2010). In the present study, regressors used in the first and second GLMs were different but not completely independent. Third, in the present study, positive or negative comments were always presented with a neutral face. Therefore, the comparison of the difference between positive vs. neutral conditions and negative vs. neutral conditions cannot reflect the effects of faces. In other words, brain activations found in the present study might reflect a simple word positivity/negativity effect. We therefore report the present results with great caution; further studies are required to demonstrate whether some or all of the results can be replicated. Despite these limitations, our results provide novel insight into how social reputation is processed in the human brain, especially within the vmPFC.

5. Conclusions

Consistently with previous findings, our behavioral data showed that positive reputation was perceived to be more pleasant than negative reputation. In addition, both male and female subjects showed a greater difference in pleasantness scores between the female-positive and female-negative conditions than between the male-positive and male-negative conditions. The imaging data demonstrated that the left vmPFC specifically contributed to the processing of positive reputation. Moreover, the pattern of vmPFC activity corresponded to gender differences in behavior during the processing of social reputation. These results suggest that the vmPFC has an important role in representing the subjective value of social reputation (especially positive reputation) and that this region might be a final computational site in a stream of value-based decision-making processes.

Acknowledgments

We are grateful to Tatsuo Nagasaka, Kazuomi Yamanaka, Hironobu Sasaki, Yohei Inaba, Tomoyoshi Kimura, Hisanobu Fukuda, and Hitoshi Nemoto for their assistance in collecting the data. This work was partly supported by JSPS KAKENHI Grant Number 21300101 (Grant-in-Aid for Scientific Research (B) to T.F.) and 24300102 (Grant-in-Aid for Scientific Research (B) to T.F.).

References

Amodio, D.M., Frith, C.D., 2006. Meeting of minds: the medial frontal cortex and social cognition. Nat. Rev. Neurosci. 7, 268–277.

Anderson, A.K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D.G., Glover, G., Gabrieli, J.D., Sobel, N., 2003. Dissociated neural representations of intensity and valence in human olfaction. Nat. Neurosci. 6, 196–202.

Bray, S., Shimojo, S., O'Doherty, J.P., 2010. Human medial orbitofrontal cortex is recruited during experience of imagined and real rewards. J. Neurophysiol. 103, 2506–2512.

Brett, M., Anton, J.L., Valabregue, R., Poline, J.B., 2002. Region of interest analysis using an SPM toolbox. Presented at the 8th International Conference on Functional Mapping of the Human Brain, Sendai, Japan, June 2–6, 2002. NeuroImage 16 (2), Available on CD-ROM (abstract).

Brooks, S.J., Savov, V., Allzen, E., Benedict, C., Fredriksson, R., Schioth, H.B., 2012. Exposure to subliminal arousing stimuli induces robust activation in the amygdala, hippocampus, anterior cingulate, insular cortex and primary visual cortex: a systematic meta-analysis of fMRI studies. NeuroImage 59, 2962–2973.

Button, K.S., Ioannidis, J.P., Mokrysz, C., Nosek, B.A., Flint, J., Robinson, E.S., Munafo, M.R., 2013. Power failure: why small sample size undermines the reliability of neuroscience. Nat. Rev. Neurosci. 14, 365–376.

Chib, V.S., Rangel, A., Shimojo, S., O'Doherty, J.P., 2009. Evidence for a common representation of decision values for dissimilar goods in human ventromedial prefrontal cortex. J. Neurosci. 29, 12315–12320.

Cloutier, J., Heatherton, T.F., Whalen, P.J., Kelley, W.M., 2008. Are attractive people rewarding? Sex differences in the neural substrates of facial attractiveness. J. Cogn. Neurosci. 20, 941–951.

Dale, A.M., 1999. Optimal experimental design for event-related fMRI. Hum. Brain Mapp. 8, 109–114.

Deichmann, R., Gottfried, J.A., Hutton, C., Turner, R., 2003. Optimized EPI for fMRI studies of the orbitofrontal cortex. NeuroImage 19, 430–441.

Edelson, M., Sharot, T., Dolan, R.J., Dudai, Y., 2011. Following the crowd: brain substrates of long-term memory conformity. Science 333, 108–111.

Eisenberger, N.I., Inagaki, T.K., Muscatell, K.A., Byrne Haltom, K.E., Leary, M.R., 2011. The neural sociometer: brain mechanisms underlying state self-esteem. J. Cogn. Neurosci. 23, 3448–3455.

Friston, K.J., Penny, W.D., Glaser, D.E., 2005. Conjunction revisited. NeuroImage 25, 661–667.

Frith, C.D., Frith, U., 2008. Implicit and explicit processes in social cognition. Neuron 60, 503–510.

Garbarini, F., Boero, R., D'Agata, F., Bravo, G., Mosso, C., Cauda, F., Duca, S., Geminiani, G., Sacco, K., 2014. Neural correlates of gender differences in reputation building. PLOS ONE 9, e106285.

Hare, T.A., Camerer, C.F., Knoepfle, D.T., Rangel, A., 2010. Value computations in ventral medial prefrontal cortex during charitable decision making incorporate input from regions involved in social cognition. J. Neurosci. 30, 583–590.

Ishizu, T., Zeki, S., 2011. Toward a brain-based theory of beauty. PLoS ONE 6, e21852.

Ito, A., Fujii, T., Ueno, A., Koseki, Y., Tashiro, M., Mori, E., 2011. Neural basis of pleasant and unpleasant emotions induced by social reputation. Neuroreport 22, 679–683.

Izuma, K., 2012. The social neuroscience of reputation. Neurosci. Res. 72, 283–288.

Izuma, K., Adolphs, R., 2013. Social manipulation of preference in the human brain. Neuron 78, 563–573.

Izuma, K., Saito, D.N., Sadato, N., 2008. Processing of social and monetary rewards in the human striatum. Neuron 58, 284–294.

Izuma, K., Saito, D.N., Sadato, N., 2010a. Processing of the incentive for social approval in the ventral striatum during charitable donation. J. Cogn. Neurosci. 22, 621–631.

Izuma, K., Saito, D.N., Sadato, N., 2010b. The roles of the medial prefrontal cortex and striatum in reputation processing. Soc. Neurosci. 5, 133–147.

Janowski, V., Camerer, C., Rangel, A., 2013. Empathic choice involves vmPFC value signals that are modulated by social processing implemented in IPL. Soc. Cogn. Affect. Neurosci. 8, 201–208.

Kawamichi, H., Sasaki, A.T., Matsunaga, M., Yoshihara, K., Takahashi, H.K., Tanabe, H.C., Sadato, N., 2013. Medial prefrontal cortex activation is commonly invoked by reputation of self and romantic partners. PLOS ONE 8, e74958.

Kim, H., Shimojo, S., O'Doherty, J.P., 2011. Overlapping responses for the expectation of juice and money rewards in human ventromedial prefrontal cortex. Cereb. Cortex 21, 769–776.

Kim, J.W., Choi, E.A., Kim, J.J., Jeong, B.S., Kim, S.E., Ki, S.W., 2008. The role of amygdala during auditory verbal imagery of derogatory appraisals by others. Neurosci. Lett. 446, 1–6.

King-Casas, B., Tomlin, D., Anen, C., Camerer, C.F., Quartz, S.R., Montague, P.R., 2005. Getting to know you: reputation and trust in a two-person economic exchange. Science 308, 78–83.

Kriegeskorte, N., Lindquist, M.A., Nichols, T.E., Poldrack, R.A., Vul, E., 2010. Everything you never wanted to know about circular analysis, but were afraid to ask. J. Cereb. Blood Flow Metab. 30, 1551–1557.

Kriegeskorte, N., Simmons, W.K., Bellgowan, P.S., Baker, C.I., 2009. Circular analysis in systems neuroscience: the dangers of double dipping. Nat. Neurosci. 12, 535–540.

Lebreton, M., Jorge, S., Michel, V., Thirion, B., Pessiglione, M., 2009. An automatic valuation system in the human brain: evidence from functional neuroimaging. Neuron 64, 431–439.

Levy, D.J., Glimcher, P.W., 2012. The root of all value: a neural common currency for choice. Curr. Opin. Neurobiol. 22, 1027–1038.

Lin, A., Adolphs, R., Rangel, A., 2012. Social and monetary reward learning engage overlapping neural substrates. Soc. Cogn. Affect. Neurosci. 7, 274–281.

Meshi, D., Morawetz, C., Heekeren, H.R., 2013. Nucleus accumbens response to gains in reputation for the self relative to gains for others predicts social media use. Front. Hum. Neurosci. 7, 439.

Murakami, Y., 2006. A collection of basic personality trait words. Jpn. J. Pers. 11, 35–49 (in Japanese).

Nichols, T., Brett, M., Andersson, J., Wager, T., Poline, J.B., 2005. Valid conjunction inference with the minimum statistic. NeuroImage 25, 653–660.

O'Doherty, J., Winston, J., Critchley, H., Perrett, D., Burt, D.M., Dolan, R.J., 2003. Beauty in a smile: the role of medial orbitofrontal cortex in facial attractiveness. Neuropsychologia 41, 147–155.

Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9, 97–113.

Ozeki, M., Oda, T., 1981. A Study of Personality Trait Words. I. Bulletin of Aichi Institute of Technology Part B., pp. 61–79 (in Japanese).

Plassmann, H., O'Doherty, J., Shiv, B., Rangel, A., 2008. Marketing actions can modulate neural representations of experienced pleasantness. Proc. Natl. Acad. Sci. U. S. A. 105, 1050–1054.

Rorden, C., Karnath, H.O., Bonilha, L., 2007. Improving lesion-symptom mapping. J. Cogn. Nurosci. 19, 1081–1088.

Said, C.P., Baron, S.G., Todorov, A., 2009. Nonlinear amygdala response to face trustworthiness: contributions of high and low spatial frequency information. J. Cogn. Neurosci. 21, 519–528.

Sip, K.E., Smith, D.V., Porcelli, A.J., Kar, K., Delgado, M.R., 2015. Social closeness and feedback modulate susceptibility to the framing effect. Soc. Neurosci. 10, 35–45.

Smith, D.V., Clithero, J.A., Boltuck, S.E., Huettel, S.A., 2014. Functional connectivity with ventromedial prefrontal cortex reflects subjective value for social rewards. Soc. Cogn. Affect. Neurosci. 9, 2017–2025.

Sukigara, M., 2006. Does a personality descriptive word with its antonym imply a bipolar personality dimension, another words unpolar ones? Stud. Humanit. Cult. 4, 31–46 (in Japanese).

Tsukiura, T., Cabeza, R., 2011a. Remembering beauty: roles of orbitofrontal and hippocampal regions in successful memory encoding of attractive faces. NeuroImage 54, 653–660.

Tsukiura, T., Cabeza, R., 2011b. Shared brain activity for aesthetic and moral judgments: implications for the Beauty-is-Good stereotype. Soc. Cogn. Affect. Neurosci. 6, 138–148.

van den Bos, W., Talwar, A., McClure, S.M., 2013. Neural correlates of reinforcement learning and social preferences in competitive bidding. J. Neurosci. 33, 2137–2146.

Winston, J.S., O'Doherty, J., Kilner, J.M., Perrett, D.I., Dolan, R.J., 2007. Brain systems for assessing facial attractiveness. Neuropsychologia 45, 195–206.

Yarkoni, T., 2009. Big correlations in little studies: inflated fMRI correlations reflect low statistical power – commentary on Vul et al. (2009). Perspect. Psychol. Sci. 4, 294–298.

Zaki, J., Schirmer, J., Mitchell, J.P., 2011. Social influence modulates the neural computation of value. Psychol. Sci. 22, 894–900.