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Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity

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Along with expanding the understanding of the human 'social brain', a new challenge for neuroscience is to elucidate the nature of individual differences in social competence. Here we report a neural index of gender difference in empathy-related processing in a complex social situation. Using electroencephalography, we measured the neural activity of perceptions to one's own and another's monetary gain or loss, while individuals played a 'competitive' two-person gambling game, in which one's monetary gain resulted in the other's loss. The medial-frontal negativity (MFN), a component within 300 ms latency reflecting an emotional categorization of the event, showed a significant gender difference in perceiving an opponent's, but not a self-performed outcome. When females perceive the opponent's outcomes, the MFN was elicited, indicating that another's loss was categorized as negative, even though it resulted in a benefit to them. On the contrary, the males did not elicit discernable MFN to the opponent's outcomes. Together with the fact that the affect score has a negative linear correlation with the MFN, this indicated that the MFN was sensitive to socio-emotional processing. These results suggest that individual differences in complex social behavior result from rapid neural activity in response to external stimuli.

Keywords: empathy; gender difference; competition; gambling task; event-related potentials (ERPs)

INTRODUCTION

In the field of cognitive neuroscience, studies have suggested that observing another person's emotion-related experience, particularly negative ones such as pain or unpleasant odors, activates a brain region that is also active when we encounter a similar experience ourselves (Wicker *et al.*, 2003; Keysers *et al.*, 2004; Gallese *et al.*, 2004; Singer *et al.*, 2004; Jackson *et al.*, 2005). This 'resonance' activity can be interpreted as a neural correlate and/or substrate of human empathy.

However, in real-life social situations, there are occasions in which a negative event experienced by another person evokes a *positive* emotional or motivational reaction in the observer. For example, in a competitive situation, an opponent's failures result in a positive outcome such as a win or gain for the self and thus should result in a positive mental reaction. In such a case, an empathetic (allocentric) evaluation of the other's performance seems opposed to utilitarian (egocentric) processing. However, the empathy-related neural activity in an adversarial situation, which was assumed to provide an anti-empathetic perception of the other's performance, has rarely been investigated (but also see Singer *et al.*, 2006). In order to develop a realistic model of human social behavior, our study examined the interplay between empathetic and non-empathetic processes in the brain. We conducted a 'competitive' two-person gambling task and measured the neural activity of participants while they perceived their own and the other's monetary outcomes. The task required two players to take turns at a lottery game, in which one participant played the game, while the other observed the player's performance (either monetary gain or loss). This game was arranged to be competitive, so that one's monetary gain meant the other's loss and vice versa.

As an index of the valence-related perception of outcomes, we recorded the electrophysiological activity of the participants. Previous studies have established an electrophysiological index of performance monitoring while conducting a one-player gambling game (Gehring and Willoughby, 2002; Nieuwenhuis *et al.*, 2004a; Yeung and Sanfey, 2004; Hajcak *et al.*, 2005; Yeung *et al.*, 2005). These studies showed that feedback of a participant's monetary loss elicited a more negative deflection of the event-related potential (ERP) on the medial-frontal site of the head surface, compared with the gain. This medial-frontal negativity (MFN) is assumed to reflect subjective judgments about whether an event has positive or negative value for the monitored individual (Gehring and Willoughby, 2002; Nieuwenhuis *et al.*, 2004a; Luu and Pederson, 2004). The source of the electrical current of this component is thought to be in the medial-frontal cerebral regions (Gehring and Willoughby, 2002; Garavan *et al.*, 2003; Luu *et al.*, 2003; Nieuwenhuis *et al.*, 2004b),

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in particular the anterior cingulate cortex (ACC), which is thought to be the center of the self-monitoring function (Bush *et al*., 2000; Ridderinkhof *et al*., 2004).

Crucially to this study, it has been suggested that this monitoring system is incorporated, not only in processing self-generated actions or decisions, but also in observing another individual's performance. The error-related negativity is an ERP component that is elicited in self-induced error. van Schie *et al.* (2004) showed that the visual perception of another's erroneous response in a choice reaction task elicits the error-related negativity as in the case of self-induced error. We have also confirmed that feedback stimuli which indicate the error of another person's response in a time estimation task elicited the MFN, just as the feedback for self-induced error (Fukushima and Hiraki, 2005). These findings suggest that comparable cognitive and neural processes occur in the observation of another's performance and in self-performance. In this study, we defined the MFN as an ERP component with a latency of 200–300 ms, on a difference wave between the losses minus gain for each player. That is, the MFN for the participant's personal performance ('self-MFN') was calculated as self-loss minus self-gain, while the MFN for the competitor's performance ('other-MFN') was calculated as the other's loss minus the other's gain. Given that the MFN reflects emotional or motivational categorization of two events, if the other-MFN was generated with the same polarity as the self-MFN, this implies that an individual perceived the other's monetary loss as more negative than a gain, in the same way to the self-outcomes. On the other hand, if the polarity of the MFN inverts by showing a positive peak, this would imply that the individual judged the gain as having a more negative impact than a loss. Therefore, we used the MFN component as an index to investigate the mental processing style of participants in perceiving self-and other's performances. In addition, we measured the participants' subjective ratings regarding the task and partners. This is based on Yeung *et al.* (2005), who reported that the MFN was elicited, but diminished, when a gambling game was performed in the absence of participant's choice or response. They also showed that the amplitude is associated with participants' subjective ratings of involvement in the tasks. Following the procedure in Yeung *et al.* (2005) we asked the participants their subjective ratings about the interest, attention and affect, as well as motivation (the will to earn) and relationship (familiarity) to the task partner, at the end of task, to test a correlation between the scoring and the MFNs.

Another issue that was examined in this study was the individual difference in social processing, for which a neuro-cognitive account has been relatively lacking (Blakemore and Frith, 2004; Decety and Jackson, 2004). In our previous study, the other-MFN for another person's performance showed a large variation in terms of gender difference (Fukushima and Hiraki, 2005). We assumed that the competitive context of the current study would result in an antagonistic relationship between empathetic and non-empathetic responses and thus may amplify individual variation in terms of the degree of empathetic processing involved in perceiving another's performance. Thus, it was expected that the other-MFN in this study would exhibit an evident gender difference, rather than show a consistent pattern among all participants. In order to account for possible individual differences in neural activities, we also measured self-report trait scores, the empathy quotient (EQ) and systemizing quotient (SQ) of participants (Baron-Cohen *et al*., 2003; Lawrence *et al*., 2003; Baron-Cohen and Wheelwright, 2004), to test the correlation of these measures with MFN amplitudes. Empathy, here, refers to one's concern, reading and reactive ability regarding the internal state of another person. Systemizing refers to one's concern, reading and reactive ability with regard to physical and objective systems, other than human mental issues. Baron-Cohen *et al.* (2003) claimed that the discrepancy between the two scores corresponds to the gender difference, in which typical females have EQ > SQ, whereas typical males have EQ < SQ (Baron-Cohen, 2004). Thus, it was expected that the possible correlation of the MFN amplitude with a discrepancy score between the two quotients (EQ minus SQ), as well as the unitary score of EQ and SQ would further elucidate the nature of gender effects in the MFN.

METHODS

Participants

Twenty-four gender-matched pairs [12 female (aged 18–29 years, mean 19.9, s.d. 2.5) and 12 male pairs (18–23 years, mean 19.1, s.d. 1.4)] participated in the experiment. All the pairs were acquaintances with each other; the mean period of acquaintances (s.d.) were 20.0 (27.3) months for females and 20.3 (23.7) months for males. There was no statistical difference between gender groups in terms of age and period of acquaintance [two-tailed *t*-test; age: $t_{46} = 1.35$, $P = 0.18$; period of acquaintance: $t_{46} < 1$]. The participants were healthy and right-handed undergraduate or graduate Japanese students. The handedness was assessed by using an abridged version of the Edinburgh Inventory (Oldfield, 1976). They were paid 1500 yen, with additional monetary awards paid according to the results of the task. Written informed consent was obtained from each participant before the experiment. The ethics committee of The University of Tokyo approved this study.

Apparatus and procedure

In an electrically shielded room, the participant pair was seated ~1 m in front of a 14-inch CRT display, and ~0.8 m apart from each other (Figure 1A). Each participant held a response box in their hands which had two buttons to select left or right 'cards' on the display. They were instructed to use the left hand to press the left button (for the left card), and the right hand for the right button. The task sequence is

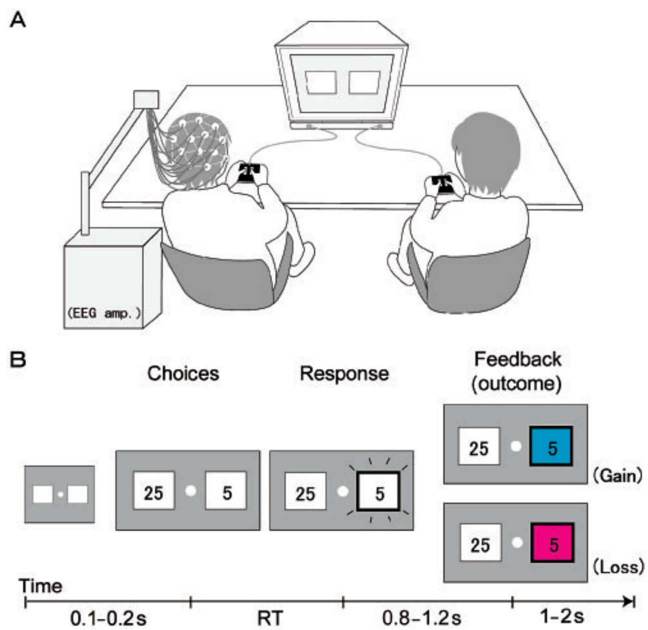

Fig. 1 Experimental setup (A) and task sequence (B) of the two-person gambling task. (A) Two players sat in front of a display and played a game. The EEG of one player was monitored during the game. While one (performer) played, the other (observer) observed the opponent's performance through the display. (B) In each trial, alternatives of 5 or 25 yen betting cards were displayed and the performer selected one of the cards (the example illustrates the selection of 5 yen card). After the response, the selected card changed into one of two colors, either cyan or magenta. Cyan indicated a gain for the performer (and a loss for the observer), while magenta indicated a loss for the performer (and a gain for the observer).

shown in Figure 1B. The alternatives of 5 or 25 yen betting cards were displayed, and a player selected one of the cards. After the response, the selected card changed into one of two colors, either cyan or magenta. Cyan indicated a gain for the player (and a loss for the observer), while magenta indicated a loss for the player (and a gain for the observer). Fifty percent of the trials were a gain and fifty percent were a loss for each participant. This sequence was based on Gehring and Willoughby (2002) with a minor modification such that the outcome of the non-selected card, which was shown in Gehring and Willoughby (2002), was not displayed in this experiment for simplicity. Participants were given two instructions regarding the task: (i) 'Maximize your individual outcome with any strategy' and (ii) 'Pay as much attention to your competitor's outcome as your own.' Players performed the game 10 times each in alternating blocks of 20 trials. Rest periods were allowed between each condition, the length of which was controlled by the players. During rest periods, the display informed the next player as 'A's turn' or 'B's turn'. A participant whose EEG was recorded and his/her competitor were assigned 'A' and 'B', respectively. After each block, the current scores of each player were shown on the display to help maintain their motivation. The session was preceded by 20 practice trials for each player and lasted for a total of 30–40 min.

EEG recording

Within each pair, one participant's EEG was recorded by random selection (Figure 1A). The EEG was recorded from 65 electrodes with a Geodesic Sensor Net (Tucker *et al.*, 1993) sampled at 250 Hz with a 0.1–100 Hz band-pass filter. All recordings were initially referenced to the vertex and later digitally re-referenced to the linked mastoids reference. Artifacts with ocular movement were corrected using an algorithm created by Gratton *et al.* (1983). A 20 Hz low-pass filter was re-applied in off-line analysis. All of the data were segmented into 1024 ms epochs, including a 200 ms pre-stimulus baseline period, based on time markers for the onset of the feedback stimuli. A total of 100 trials for each of the four conditions (self-gain, self-loss, other's gain and other's loss) were recorded from each participant. Only segments less than $\pm 100\,\mu V$ in each channel were analyzed and baseline-corrected.

Calculation of the MFN

ERPs were calculated from EEG segments and time-locked to each type of feedback stimulus (gain and loss by each player). The MFN was then detected, based on the difference waveform between loss and gain for each player. The MFN for the participant's personal performance ('self-MFN') was calculated as self-loss minus self-gain, while the MFN for the competitor's performance ('other-MFN') was calculated as the other's loss minus the other's gain. The MFN was quantified on the difference waves from the channels centered on the FCz site. Previous studies of the MFN observed that this component reached a maximum at the front central region, or the Fz or Cz sites (Nieuwenhuis *et al.*, 2004a; Gehring and Willoughby, 2002; Yeung *et al.*, 2005;

Muller *et al.*, 2005). Thus, we pooled seven electrodes around FCz as the midpoint of Fz and Cz (#3, 4, 5, 8, 9, 55 and 58 of a GSN64ch sensor array). This procedure was also used to increase the S/N ratio (Oken and Chiappa, 1986). The quantification was performed as a base-to-peak amplitude (Yeung and Sanfey, 2004), based on the difference between mean averages of the following three time windows: pre-MFN positivity (156–188 ms after the stimulus onset), MFN (220–280 ms) and post-MFN positivity (320–380 ms). The amplitude of MFN was calculated as the MFN −(pre-MFN + post-MFN)/2. The base-to-peak measurement was chosen as an 'initial dip' was evident in the self-MFN, which suggested that a considerable baseline shift had infiltrated the time window of the MFNs, possibly by an overlapping of the P3 component (Yeung and Sanfey, 2004) and/or early onset of frontal theta oscillation (Luu and Tucker, 2001; Gehring and Willoughby, 2004), in all conditions. The time windows for quantification were based on the grand-average difference waveform of the self-MFN. This was because polarity and latency of self-MFN was quite robust among participants, whereas there were notable individual differences in the pattern of the other-MFN.

Post-recording questionnaires

After the experimental session, participants were asked to rate their subjective intensities on 'interest' and 'motivation' to the task, 'attention' and 'affect' towards self-and other's outcomes, and 'familiarity' and 'period of acquaintance' with the partner. The scores were rated on a 15-point scale (0–14). For the rating of 'affect', for which participants were asked 'How did you feel when your (the other's) choice resulted in a gain (loss)?' zero was labeled 'very bad/sad' and 14 was 'very good/happy', without corresponding labels for the other scores. The affect scores for self-and other's outcomes were rated for gain and loss independently, and were calculated as a difference ('gain' minus 'loss') score for each performer. For the other questionnaires, scores 0 and 14 were labeled 'not at all' and 'very much', respectively (for further details of the questionnaires, see 'supplementary materials'). Participants also completed the Japanese version of EQ and SQ.

RESULTS

ERP results

Figure 2 illustrates the ERP waveforms averaged across all participants, for the feedback stimuli of gain and loss, in trials of self-performance and other's performance. In the self-performance trials, the difference between ERPs following loss *vs* gain feedbacks was characterized by an evident negative deflection for the loss feedback, termed self-MFN, which peaked 256 ms after the onset of feedback stimuli. The significance of this component was confirmed by analysis of variance ($F_{1,23} = 38.87$, $P < 0.001$). On the other hand, in trials for the observation of another's performance, the differentiation between gain and loss of an opponent was remarkably diminished, only reaching marginal statistical significance ($F_{1,23} = 3.74$, $P = 0.066$). This result indicated two possibilities regarding the participants' neural activities in perceiving opponent's outcomes: one is that all participants do not significantly generate the MFN in response to the outcomes of others; the other is that there was no universal tendency in the pattern among participants. In fact, Levine's test for equality of variance indicated that variance of amplitude in the grand-averaged ERP was greater in the time window of other-MFN compared with the self-MFN ($F = 5.468$, $P = 0.024$), suggesting the second possibility mentioned above. These results support our hypothesis of gender-related differences in MFN responses

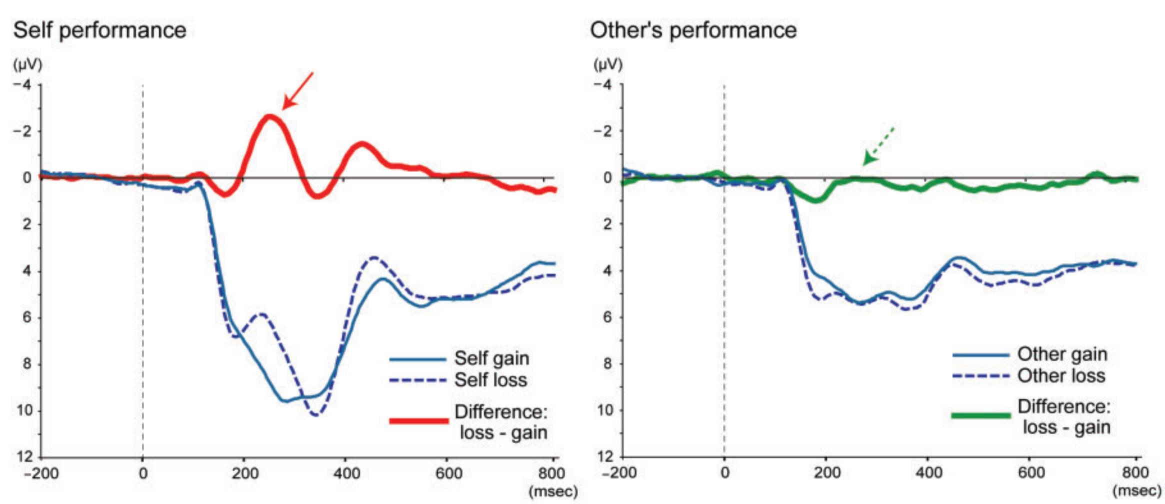

Fig. 2 The grand-averaged ERP waveforms aligned at the onset of feedback stimuli for self-and other's performances (recorded from the FCz site). The left panel shows the ERPs in self-performance trials. The bold line indicates a difference waveform of loss minus gain. A negative component termed self-MFN appeared at 200–300 ms, as indicated by the arrow. The right panel shows the ERPs in observation of the opponent's performance. A difference wave (bold line) displays no evident component of the other-MFN, as indicated by the dotted arrow.

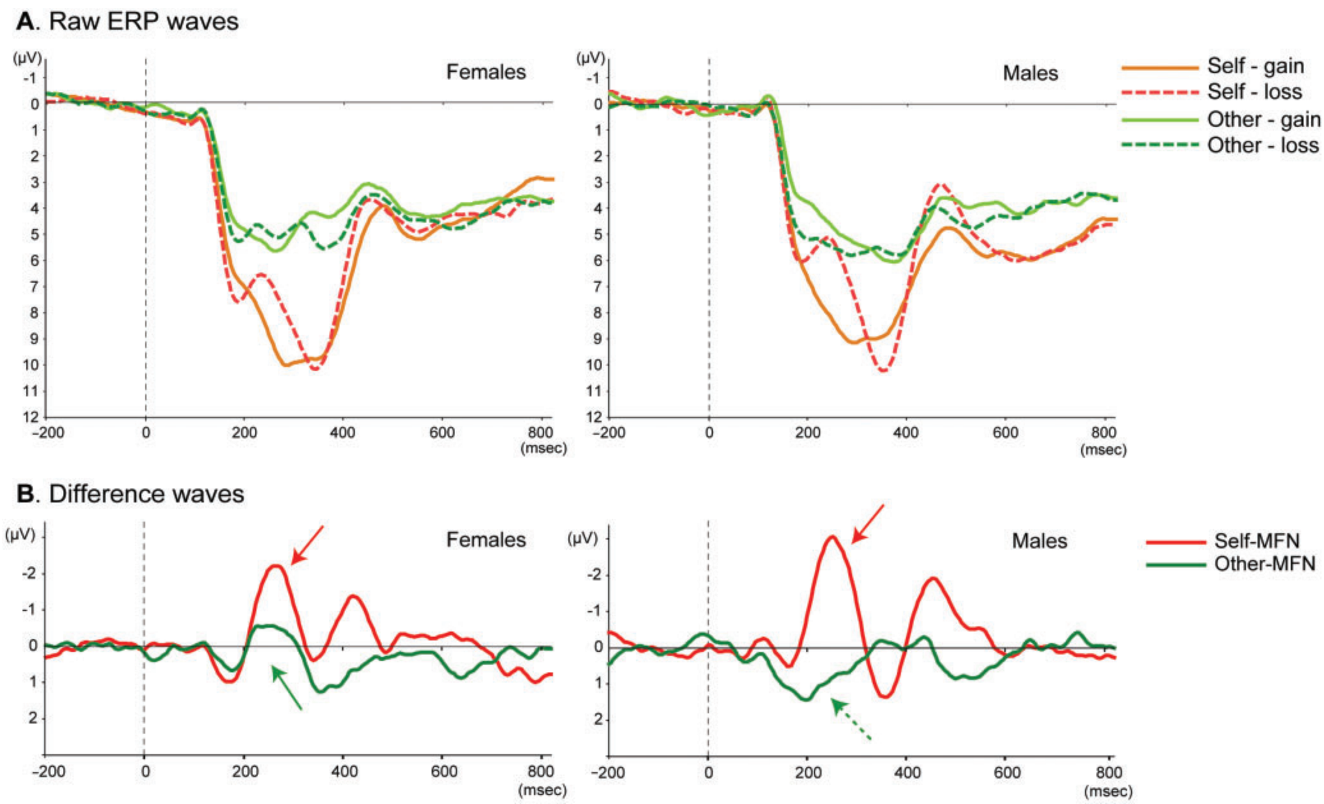

Fig. 3 The raw and different waveforms for each gender. (A) Grand-averaged raw ERP waveforms for each condition, and for females (left) and males (right). (B) Difference waveforms (loss minus gain) for self-and other's trials for females (left) and males (right).

towards others. Thus, further analyses were dedicated to examining the individual variance, particularly gender difference.

Figure 3 illustrates that MFN waveforms were isolated as the difference between loss and gain for male and female groups separately. Self-MFN was evident in both gender groups (females, $F_{1,11} = 31.18$; males, $F_{1,\ 11} = 11.63$; both $P < 0.01$), there was no difference between gender groups ($F_{1,22} = 1.27$; $P = 0.27$). By contrast, a significant gender difference was evident in the other-MFN ($F_{1,\ 22} = 14.17$; $P = 0.0010$). In the female group, the other-MFN was generated significantly ($F_{1,11} = 55.38$, $P < 0.001$) with the same polarity as the self-MFN, indicating the comparable neural activities in observing the opponent's performance as that of own one. On the other hand, in the male group, the other-MFN was not elicited; instead, a positive deflection appeared in a period comparable to the self-MFN. Although this positivity was not significant with the current quantification ($F_{1,11} = 0.55$; $P = 0.47$), other statistics (successive two-tailed t-test, df = 11) showed significance of this deflection in latency at 132–216 ms. This indicated that the male participants did differentiate the other's gain and loss. These results indicate that the neural activities of male and female groups responded to the other's outcomes in different directions of valence, in terms of whether gains or losses are more negative for the self. Consequently, the other-MFN in the grand-averaged waveform averaged out to be virtually absent.

Psychological measurements and association with the MFN

The participants' subjective ratings about the task and their partners were also tested in terms of gender difference and correlation with MFN (Table 1). A significant gender difference was found in three scales: 'attention to self outcome', 'affect to self outcome' and 'affect to other's outcome'. Among these factors, significant correlation with the MFN was only found in the 'affect to other's outcome'. The 'affect' score was determined as the difference between rating for gain and loss. All participants rated the scores 'affect to self-outcomes' as plus (i.e. self-gain was evaluated more positively than self-loss) and 'affect to other's outcome' as minus (other's gain was evaluated more negatively than other's loss). This result confirms that all participants performed the task with the appropriate motivation to win monetary rewards. Absolute values of 'affect' scores for both self- and other's outcomes were greater in males than in females (self-outcome: $t_{11} = 2.93$, $P = 0.0082$, other's outcome: $t_{11} = 2.19$; $P = 0.040$). The factor 'affect to other's outcome', but not 'affect to self-outcome', also showed significant negative correlation with the other-MFN ($r = -0.55$; $P = 0.0078$) indicating that the more participants

Table 1 Results of psychological measurements: gender difference and correlations with the MFN amplitude

	Gender difference			Correlation coefficients with the MFN					
	Scores (s.d.)		t-value	Self-MFN			Other-MFN		
	Males	Females		Total	Males	Females	Total	Males	Females
EQ	35.3 (9.9)	39.5 (14.2)	<1	0.01	−0.31	0.13	−0.19	−0.14	−0.10
SQ	27.5 (12.4)	19.1 (8.4)	1.95†	−0.35†	−0.69*	0.20	0.45*	0.39	−0.01
EQ−SQ	7.8 (13.6)	20.4 (11.0)	2.49*	0.29	0.40	0.02	−0.54**	−0.46	−0.12
Motivation	11.7 (2.4)	10.3 (2.2)	1.41	0.07	−0.19	0.47	0.37	0.37	0.00
Interest	11.9 (2.2)	11.2 (1.8)	<1	0.08	−0.13	0.69*	−0.18	−0.38	−0.37
Attention to S's outcome	13.1 (1.3)	11.6 (1.1)	3.05**	0.03	0.40	−0.02	–	–	–
Attention to O's outcome	11.6 (1.9)	10.8 (1.5)	1.07	–	–	–	0.14	−0.07	0.19
Affect to S's outcome	8.6 (2.4)	5.0 (3.2)	2.93*	0.00	0.07	0.16	–	–	–
Affect to O's outcome	−5.9 (2.9)	−2.6 (4.0)	2.19	–	–	–	−0.55**	−0.74*	−0.11
Familiarity	9.7 (1.2)	10.6 (2.3)	1.11	0.31	0.20	0.33	−0.26	−0.07	−0.32
Period of acquaintance	20.3 (23.7)	20.0 (27.3)	<1	0.37†	0.59*	0.22	−0.05	0.02	−0.25
Total monetary outcome	272.9 (368.9)	147.9 (235.8)	<1	0.20	0.27	0.27	−0.17	−0.48	−0.11

SQ, systemizing quotient; EQ, empathy quotient; S's outcome, self outcome; O's outcome, other's outcome.
†$P < 0.1$.
*$P < 0.05$.
**$P < 0.01$.

had felt affect to the opponent's outcome, the less the other-MFN diminished, or emerged in positive polarity. This correlation was also significant within male groups, whereas not significant in female groups. There was no systematic gender difference in ratings for task-involvement ('interest' and 'motivation') and relationship with the opponent ('familiarity').

Possible associations between MFN and participants' traits scores, EQ and SQ, were also examined. As shown in Table 1, a significant linear correlation with the other-MFN, as well as the marginal gender difference, was found for SQ score, but not for EQ. In accordance with our prediction, a significant linear correlation between ERP amplitude and the EQ–SQ discrepancy score was found for other-MFN (Pearson's $r = -0.54$; $P = 0.0062$), whereas the correlation was not significant for self-MFN ($r = 0.29$; $P = 0.16$) as plotted in Figure 4.

DISCUSSION

In this study, we examined neural activity in participants who were observing self-and another person's monetary gain and loss in a competitive situation, in which participants' interests contradicted that of the other person. The ERP results indicate that there was a gender-related difference in the rapid neural activity generated in observing another person's outcome, termed as the other-MFN. Perception of the opponents' performances elicited a small but significant other-MFN in female participants, but not male participants. Assuming that MFN reflects emotional or motivational judgment (Gehring and Willoughby, 2002; Luu and Tucker, 2004), the other-MFN elicited here can be explained as the early performance-monitoring system categorized the other's loss as a more negative impact than the other's gain. Together with the fact that there was no systematic difference in self-MFN, we suggest that the other-MFN is related to valence representation in a social context, that is, to empathetic processing.

In support of this emotional account of the MFN, the individual difference in the participants' subjective ratings about the task and partner revealed that there were significant gender differences in the ratings for affective feelings; male participants rated their affect to self-and other's monetary outcomes higher than female participants did. Furthermore, the affect to the other's outcome showed a negative linear correlation with the amplitude of the other-MFN. In other ratings such as task-involvement (motivation and interest to the game) and social relationship within pairs (familiarity to the partner and period of acquaintance), there was neither gender difference nor correlation with the other-MFN. As for self-performance, self-MFN was not associated with the participants' affective ratings. These results suggest that the MFN, particularly elicited in observing other's performance, was sensitive to socio-emotional processing. Furthermore, considering that the current task was set in a competitive situation, the other-MFN would reflect an antagonistic relation between empathetic and non-empathetic, or utilitarian, processing in terms of which of these was relatively dominant to the other. It may be the case that the other-MFN was generated when the empathetic process dominated over the non-empathetic one, and disappeared when the non-empathetic process was dominant. In fact, the other-MFN and the affect score to the other's outcome were negatively correlated, indicating that the stronger participant had a more competitive feeling towards the other's outcome, the more the other-MFN diminished. Moreover, males

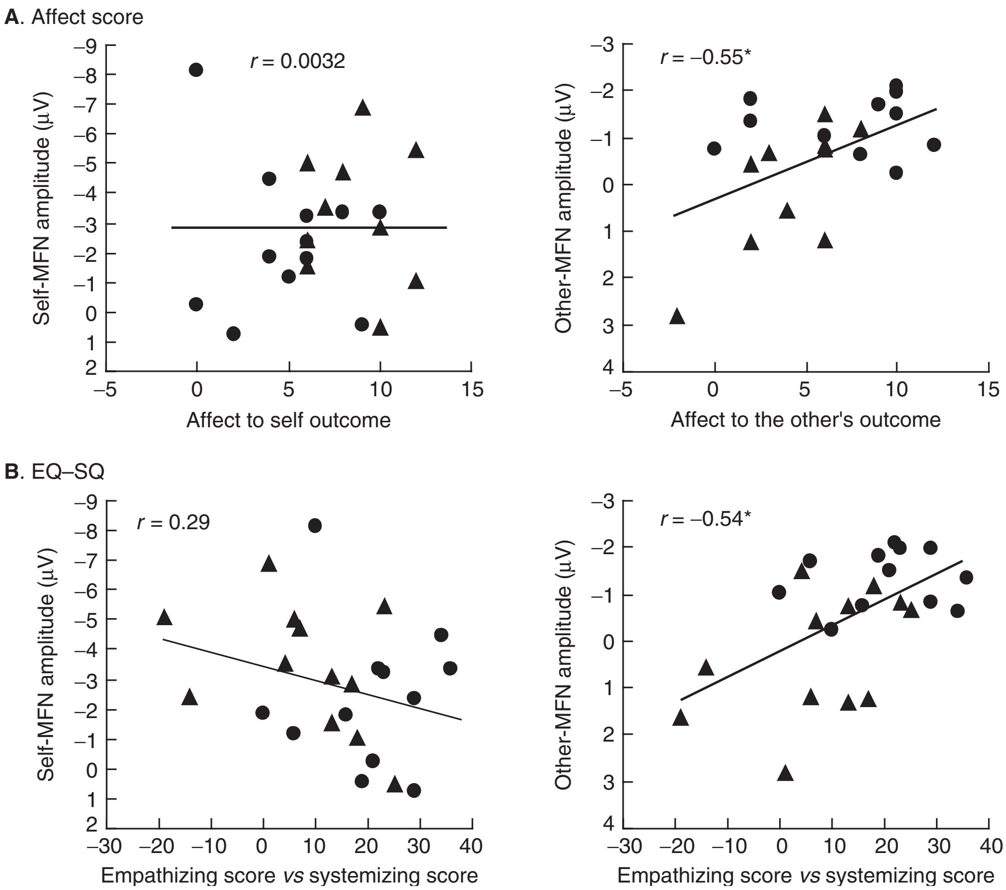

Fig. 4 The correlation between psychological measurements and MFN. (A) The *x*-axis indicates participants' ratings of affect for the outcomes. (B) The *x*-axis indicates the discrepancy between EQ and the SQ, representing an imbalance between the two characteristics. For both measurements, the *y*-axis of the left panels show the amplitude of the self-MFN and of the right panels show the other-MFN. The overlaid lines represent the best linear fit. Triangles represent female data and circles represent male data.

differentiated the other's loss and gain in *opposite* polarity to that of self-performance, although it was not identified as the MFN in the current quantification (Figure 3). This phenomenon suggests that the monitoring system in the male brain perceives their competitors' losses of more positive impact than their competitors' gains, in a manner consistent with explicit income for the self. This can be interpreted as a case that the utilitarian process dominates the empathetic function.

We also examined if there was any association between the MFN and empathetic trait of participant, and the discrepancy score between the EQ and SQ, which corresponded with daily social and non-social abilities (Baron-Cohen, 2004). In consistent with former reports (e.g. Baron-Cohen, 2004), the score EQ minus SQ was higher in females than males. Furthermore, it was correlated with the polarity and amplitude of the other-MFN. This result supports the view that the empathy-related function would contribute to the evaluative function reflected by the MFN. However, the fact that SQ, rather than EQ, provides a greater contribution to the correlation (Table 1) indicates that non-empathetic processes may be driving this effect; for example, an ability to switch good/bad judgment for the outcomes of gambling depends on whether it is performed by the self or the opponent. In addition, the discrepancy score and the other-MFN showed no significant correlation within each gender, remaining a possibility of spurious correlation. Therefore, although the trait score and ERP showed clear gender differences, the association between trait scores and the ERPs still needs to be elucidated.

In this report, we have assumed that the MFN in the gambling task reflects valence-related processing of stimuli and, as discussed above, the current data support this view. However, there have been several other accounts of the ERPs in performance monitoring (Yeung, 2004), such as error or conflict detection (Botvinick *et al.*, 2001; Holroyd and Coles, 2002), negative reward prediction error in a learning process (Holroyd and Coles, 2002; Nieuwenhuis *et al.*, 2004a) and expectation violation (Donkers *et al.*, 2006; Luu and Tucker, 2004; Potts *et al.*, 2006). These processing may also be reflected in the MFN in the current gambling game. Monetary 'loss' could be perceived as 'error' in the preceding choice, and thus, error detection process may be activated (Nieuwenhuis *et al.*, 2004b). Some learning function and expectation-violation should also be recruited, as it is possible that participants examined the opponent's (as well as the self) performance while trying to determine possible rules in the choice–outcome relation. However, we believe that these cognitive accounts do not fully explain the individual difference in the other-MFN found here. Theory of expectation violation would explain the evident other-MFN in females as it reflects the females' greater expectation of the other's failures than the males. However, the females scored lower affective impact than males, which is inconsistent with this account. Theory of reward prediction error may explain the result as females explored the pattern of the game more than the males. Nevertheless, in post-task debriefing, the majority of females reported that they were not attentive to the pattern of choice–outcome relation in the opponent's performance, although they did attend to the consequences. In addition, participants' reports on 'Attention to the other's outcome' did not show gender difference or correlation with the other-MFN. These results do not support the account by reward prediction error. Finally, the process of conflict monitoring (i.e. reflection of internal conflict among several possible responses) is unlikely to be reflected in the MFN here, which is a kind of feedback-related ERP evoked by delayed stimuli after a response. Therefore, even though the cognitive accounts should be incorporated into the other-MFN elicited in the current experiment, we consider that the main factor of the individual difference was the emotional or motivational processing of monetary outcomes.

In the literature of ethnology and social psychology, gender-based differences in social cognition, particularly empathetic behavior and ability, have been widely reported (e.g. Hoffman, 1977; Hall, 1984; Wagner and Buck, 1993; Baron-Cohen, 2004; but also see Ickes, 2003). However, in the field of cognitive neuroscience, gender effects in empathetic neural activity have rarely been reported until recently (Decety and Jackson, 2004). Singer *et al.* (2006) found a gender difference in the empathy-related activation of the ACC and the anterior insula ('pain network' in the cortex) while observing another person's pain experience. By manipulating the participant's subjective impression of the model in a pre-scan game, they showed that this effect was modulated by the participants' feelings of 'fairness' or sense of like or dislike for the other. Consequently, both genders showed resonant neural activity in response to a person, who was rated as fair and preferable. However, a gender difference was detected when pain was perceived to be inflicted on an unfair and dislikable person; in this case, the empathy-related activity almost disappeared in males, whereas it remained evident in female participants. In accordance with Singer *et al.* (2006), our study also examined the interaction between empathetic and non-empathetic processing, and showed robust empathetic activity in female participants, along with strong context dependency in males.

Although the present data exhibited significant gender effects on neural activity, we do not suggest that there is a gender difference in empathetic *ability* itself, as the present gambling task did not require either an explicit empathetic processing or an emotional judgment from the participants. It is possible that neural activity would not show any systematic individual differences if the tasks involved an explicit empathetic judgment. Similarly, Singer *et al.* (2006) did *not* show a gender difference when participants perceived pain experiences on a fair and likeable person or, in other words, when subjective impressions of the model was not contradictory with empathy. Together with the fact that a gender-related difference in empathy has rarely been reported in neuroscience, it is suggested that individual differences in empathetic neural processing may exist selectively in interactions between empathetic and non-empathetic mental operations.

Based on our findings, we conclude that the individual difference in empathetic neural activity is best illustrated in terms of the ratio, or imbalance, between empathetic and non- (or anti-) empathetic functions, although its association with social traits is still unclear. We consider that the gender-related difference found here is based on the allocation between empathetic and utilitarian processings in the perception of an external event, rather than in a difference in the unitary capacity for empathy, or the skill at empathy. In brief, our results suggest that females, in comparison with males, perceive another's performance in a more empathetic manner, although it is still unclear whether it is related to their social and non-social traits.

SUPPLEMENTARY MATERIAL

Post-task questionnaires

Subjective ratings (about the task, stimuli and partner). After the experimental session, participants were asked to rate questions listed below using a 15-point scale, where scores were: 1 = 'not at all'; 15 = 'very much', except question #4, where 1 = 'very bad/sad'; 15 = 'very good/happy'. The difference score ('loss' scores were subtracted from the 'gain' scores for each performer) was calculated. The statistical test of these scores for gender difference and correlation with the MFN amplitude are listed in Table 1.

(i) Interest: 'How much you were interested in the game?'
(ii) Motivation: 'How much did you feel "I want to get money, or win the game?"'
(iii) Attention to self-(other's) outcome: 'How much attention did you pay to the outcome of your (the other's) choice?'
(iv) Affects towards self-(other's) gain (loss): 'How good (bad) did you feel that your (the other's) choice resulted in a gain (loss)?'
(v) Intimacy to the partner: 'How much intimacy did you feel for your partner today?'
(vi) Familiarity with the human partner: 'How much do you think you know about your partner?'

(vii) Concern for the human partner: 'How much concern did you feel about the existence of your human partner during the task?'
(viii) How long it was since you have met your partner first time?

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Corrigendum

Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity

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The authors wish to apologise for two errors in the above article. One error appeared in Table 1, where two entries had incorrect asterisks, and the other error was in the legend to Figure 4. The corrected table and figure legend are given as follows.

Table 1 Results of psychological measurements: gender difference and correlations with the MFN amplitude

	Gender difference		*t*-Value	Correlation coefficients with the MFN					
	Scores (s.d.)			Self-MFN			Other-MFN		
	Males	Females		Total	Males	Females	Total	Males	Females
EQ	35.3 (9.9)	39.5 (14.2)	<1	0.01	−0.31	0.13	−0.19	−0.14	−0.10
SQ	27.5 (12.4)	19.1 (8.4)	1.95†	−0.35†	−0.69*	0.20	0.45*	0.39	−0.01
EQ-SQ	7.8 (13.6)	20.4 (11.0)	2.49*	0.29	0.40	0.02	−0.54**	−0.46	−0.12
Motivation	11.7 (2.4)	10.3 (2.2)	1.41	0.07	−0.19	0.47	0.37	0.37	0.00
Interest	11.9 (2.2)	11.2 (1.8)	<1	0.08	−0.13	0.69*	−0.18	−0.38	−0.37
Attention to S's outcome	13.1 (1.3)	11.6 (1.1)	3.05**	0.03	0.40	−0.02	–	–	–
Attention to O's outcome	11.6 (1.9)	10.8 (1.5)	1.07	–	–	–	0.14	−0.07	0.19
Affect to S's outcome	8.6 (2.4)	5.0 (3.2)	2.93**	0.00	0.07	0.16	–	–	–
Affect to O's outcome	−5.9 (2.9)	−2.6 (4.0)	2.19*	–	–	–	−0.55**	−0.74*	−0.11
Familiarity	9.7 (1.2)	10.6 (2.3)	1.11	0.31	0.20	0.33	−0.26	−0.07	−0.32
Period of acquaintance	20.3 (23.7)	20.0 (27.3)	<1	0.37†	0.59*	0.22	−0.05	0.02	−0.25
Total monetary outcome	272.9 (368.9)	147.9 (235.8)	<1	0.20	0.27	0.27	−0.17	−0.48	−0.11

SQ, systemizing quotient; EQ, empathy quotient; S's outcome, self outcome; O's outcome, other's outcome.
$^{\dagger}P < 0.1$; $^{*}P < 0.05$; $^{**}P < 0.01$.

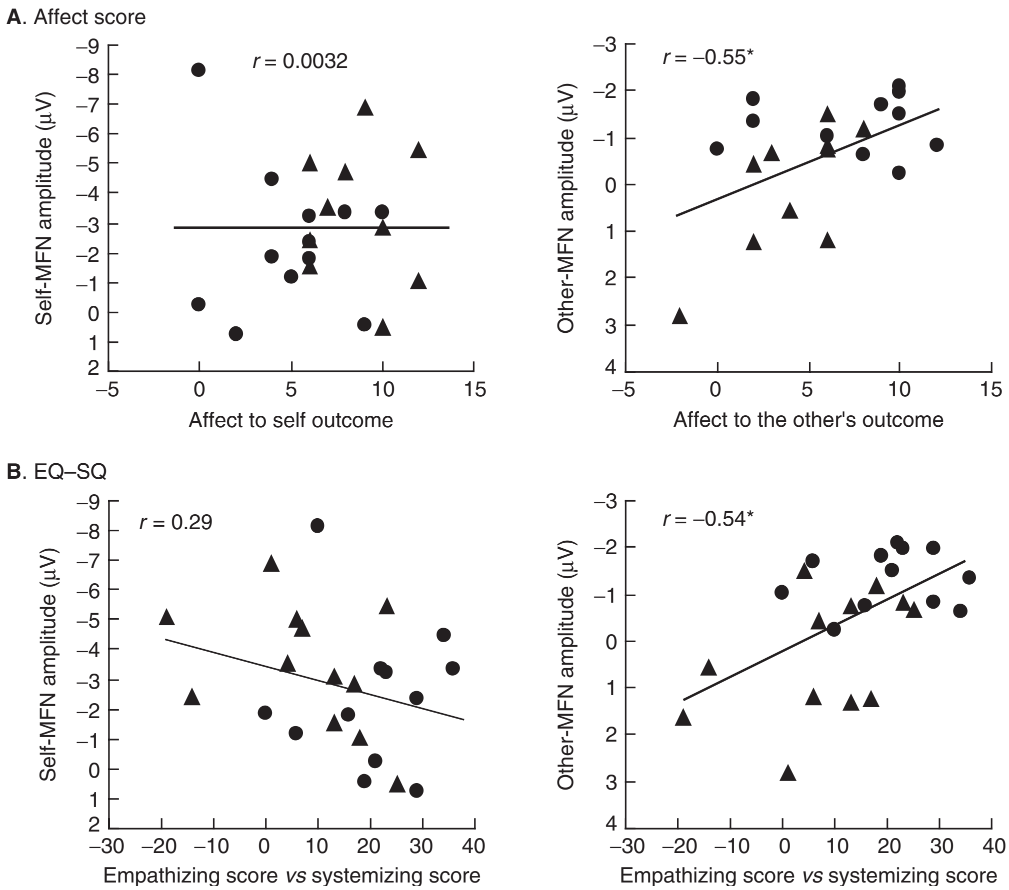

Fig. 4 The correlation between psychological measurements and MFN. (**A**) The *x*-axis indicates participants' ratings of affect for the outcomes. (**B**) The *x*-axis indicates the discrepancy between EQ and the SQ, representing an imbalance between the two characteristics. For both measurements, the *y*-axis of the left panels show the amplitude of the self-MFN and of the right panels show the other-MFN. The overlaid lines represent the best linear fit. Circles represent female data and triangles represent male data.