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Empathic responses to others' gains and losses: An electrophysiological investigation

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ABSTRACT

A growing number of studies in exploring empathic modulation have revealed the neural substrates of how social stimuli are represented in the human brain, especially the pain of others. The empathic response of observing other's gains and losses, however, remains not clearly characterized. In the current study, we carried out two experiments with a gamble task to investigate how the effects of interpersonal familiarity and self-participation work on modulating the temporal neural response towards gain and loss of a friend or a stranger using scalp-recorded event-related potentials (ERPs). The electrophysiological data show an increased amplitude of the P300 when observing a friend's performance compared to strangers playing the game in both two experiments. But the distinction of differentiated feedback-related negativity (d-FRN) between friends and strangers was only observed when the player was not involved in the game. These results indicated that the participants exerted more motivational relevance toward their friends than strangers, but the participants' empathic response toward friends was only salient when they were not involved in the gamble directly. Therefore, both familiarity and self-engagement are factors that influence the empathy towards others, complementing the recent research on empathic modulation.

Introduction

We, as human beings, have evolved to rapidly process social information. As a social creature, we are not only able to infer the intention of others' behavior, but our capability of empathy also lets us share the mental and emotional states of others (de Vignemont and Singer, 2006; Decety and Lamm, 2006; Frith and Singer, 2008; Hein and Singer, 2008; Kirman and Teschl, 2010; Singer, 2006; Singer and Lamm, 2009). A large literature of published empirical investigations is probing the neural mechanism of empathy (Singer and Lamm, 2009), most of which used the perception of concrete negative emotions. Taking pain, which gains the most attention in recent empathic research, as an example, the common conclusion is that the vicariously experienced pain recruits the largely overlapping neural circuits compared to experiencing the pain directly, thus supporting a capacity of "shared representations."

Previous experiments indicated that empathy was not merely a passive reflection of other's brain responses. It can also be modulated by contextual appraisal. For instance, Singer and colleagues (2006) explored how social attributes of others modulated the empathizer's empathic responses toward others in pain. Male participants differed in their affective responses toward those who betrayed them in a trust game when contrasted to those who behaved fairly. The nucleus accumbens was activated instead of empathy-related region like the anterior cingulate cortex (ACC) or anterior insula (AI) when seeing the betrayers suffering from pain (Singer et al., 2006). So the acquired moral character, as a typical social context factor, can modulate the empathic response toward others.

Applying electrophysiological methods, converging evidence implies that FRN(feedback-related negativity), a component distributed over the fronto-central recording sites, reaching a maximum at about 200–300 ms after the onset of the outcome feedback, is more prominent for outcome stimuli with unfavorable as opposed to favorable outcomes (Gehring and Willoughby, 2002; Nieuwenhuis et al., 2005). In addition to the reinforcement learning theory which suggests that FRN provides learning information about an action to guide subsequent behavior (Holroyd and Coles, 2002; Nieuwenhuis et al., 2004), the FRN has recently been reported to be related to the motivational significance of the outcomes in gambling tasks (Gehring and Willoughby, 2002; Yeung et al., 2005). In a pioneering work, Gehring adopted a binary choice gambling task in which subjects

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were asked to choose between a small and large number card, which may lead to a corresponding gain or loss, and both cards' results were revealed after the choice. Their work found FRN was sensitive to the loss gain difference of the outcome.

Several studies have extended such a phenomenon into social situation by exploring how the brain represents other's gains and losses in a passive observation. Yu and Zhou (2006) asked the subjects to perform a gambling task and observe another person's performance of an independent task on alternate trials and found FRN's negativity response toward other's loss was similar to that elicited by the loss of subjects themselves, both in morphology and scalp distribution. Fukushima and Hiraki (2009) extended such a task to elucidate how subjects empathize with different others, i.e., friends and a computer. Their study found that, compared to the computer, subjects presented stronger empathic responses toward their friend, which was represented by a similar FRN to the observer performing the gamble himself. Furthermore, the amplitude of this component was positively correlated to evaluation of empathy by a self-reported questionnaire. This is in line with the hypothesis that the FRN is a reflection of motivational/affective impact of outcome events (Gehring and Willoughby, 2002; Yeung et al., 2005).

In addition, like the empathic response to pain, the brain's empathic response towards monetary gains and losses of others has also been shown to be modulated by situational factors.

For example, in a recent fMRI study, the authors explored how people empathized with vicarious monetary rewards toward others (Mobbs et al., 2009). They found that the empathizer exhibited larger ventral striatal activation toward those who were socially desirable winning a gamble compared to those who were socially undesirable. In this study, a person's social desirability derived from his/her similarity to the empathizer. Such a result supported that the reaction to others' monetary gains and losses can also be modulated by social context in our brain, similar with the widely explored stimulus, pain.

Compared with Fukushima and Hiraki (2009)'s work mentioned above, the same authors (Fukushima and Hiraki, 2006) reported an empathic task where the subjects finished a gambling task in turn with their gender-match friend and were required to observe their friend performing the same task. The gambling task was competitive rather than independent, which means one's gain led to the other player's loss and vice versa. In general, this competitive task resulted in an absence of the FRN difference between gains and losses of their friends, although such an experiment found a gender difference on the empathic response toward friends similar to the recent fMRI study by Singer and colleagues (2006) mentioned above. These experiments show that different task manipulation, e.g., competitive vs. independent trials, could effectively change subjects' empathic response toward others, and FRN is a component that represents such a process.

Further supporting the hypothesis of the modulation of the FRN by social context, a study by Itagaki and Katayama (2008) adopted a task including both identical and reversed situations, which means the other's performance results in the observer's same or opposite income. They found that the FRN was adaptively modulated by the concrete situation. When the performer's loss led to the gain of the observer, the observer's brain potential presented a corresponding reversed FRN. This result supports the idea that the FRN is not a simple mirror of the outcome per se, but rather indicates a match, which evaluates whether the outcome is in favor or not for the observer. In addition to the motivational/affective impact of the FRN, this study implies that evaluational processes also play a role in FRN amplitude modulation.

Leng and Zhou (2010) extended the social contexts of empathy towards other's gain and loss by exploring the different electrophysiological responses to friends and strangers when the observer himself was also engaged in the gambling task. Their work found that observers presented a more pronounced P300 toward their friends compared to the stranger. This is consistent with past reports that the P300 is affected by the attentional allocation and motivational/affective salience (Nieuwenhuis et al., 2005). However, they failed to observe a differentiation of FRN responses in the two conditions, i.e., between friend and stranger observations. Their explanation is that the FRN may entail an automatic or semi-automatic process that is too early to differentiate observers' different brain response to other's gain–loss outcome, no matter friends' or strangers'. Nevertheless, as discussed above, it has to note that there is an alternative possibility that due to the confounding factor of self-involvement, the subjects weaken their empathic response toward their friends. Like pain, which could be modulated by the social context, the empathic response toward the monetary gain and loss of others could also be modulated by the situation.

Accordingly, in clarifying the potential possibility mentioned, the current study tried to address the temporal neural underpinnings of empathy modulation by interpersonal relationship or familiarity between individuals under two different situational contexts. We revised the classical Gehring and Willoughby (2002)'s gambling task and recruited groups of three gender-matched participants. In each group, two participants were friends and another one was a stranger to them. In experiment 1, each of the three participants played the gamble and each observed the two others playing the game when it was not his/her own turn. Namely, two gender-matched friends played the gamble and observed each others' as well as the other stranger's performance in the same game. Meanwhile, the event-related potentials were recorded from these paired friends. In experiment 2, the same gamble task was introduced but one of the two friends did not play the game and only observed the other two playing the game, one of whom was familiar with and the other was a stranger to him/her. Such a paradigm allowed us to explore how the friendship influenced the empathic response under two different contexts, one in which only observing other two confederates' monetary gains and losses as a beholder and the other not only observing others' performance but also joining the gamble personally.

Due to the different motivational salience of the outcome stimuli in current study, we predict that the P300 differs between the empathizer himself/herself and others, and further differs when observing friends' performance compared to strangers'. On the other hand, FRN, which is sensitive to the valence of the stimuli, should show differences between gain and loss under the self condition. Further, FRN differences between gains and losses under different agent conditions should depend on the empathic attitude under different social conditions. So we predict that the FRN difference under different agent condition is modulated by social context. The gain–loss distinction in observing the outcome of friends should be significant when the empathizer himself/herself is not involved in the game, but weaken or even reverse when he is participating.

Methods

Participants

Twelve gender-matched pairs who were self-reported good friends (7 female pairs; mean age 23 years, SD = 3.1) were recruited in experiment 1, and 23 same-gender pairs who were also self-reported good friends (10 female pairs; mean age 22.8 years, SD = 1.9) participated in experiment 2 from Zhejiang University. Another two students, one male and one female who were strangers to the paired friends, were recruited to join in the game as confederates. All participants were right handed, had normal or corrected to normal vision, and did not have any history of neurological or mental diseases. Informed consent was obtained from all participants in accordance with the guidelines and approvals of the Internal Review Board of Zhejiang University Neuomanagement Lab. Participants were given written instructions before Experiment began. They knew that at the end of the experiment, they were paid 30

RMB Yuan as a basic payment and an additional reward or punishment based on their performance, resulting in the earnings ranging from 20 to 40 Yuan (RMB).

Experiment1

In the first experiment, an experimental group is composed of two gender-matched friends and one same-gender stranger to the paired friends. The same-gender friends sat separately in two adjacent electrically shielded rooms, each in front of a 17-inch CRT display about 1 m away, with their EEG recorded simultaneously. The other participant sat in another room to finish the same task as the paired friends did except that his/her EEG data was not recorded (Fig. 1). All participants were informed that they would play the game individually and get reward or punishment independently from each other without social interaction. The participants were also told that their gain or loss according to performance in each round would be added or subtracted directly from the basic payment and were encouraged to earn as much as possible. In addition, the same-gender friends were instructed to pay attention to their own performance as well as the performances of their confederates, both friend and stranger.

Each of the three participants in a group began the experiment with their own name presented on the display first for 5 seconds and performed 20 consecutive trials as a round. Three participants joined in the gambling game in turns. Everyone was instructed to observe others' card selection as well as the feedback outcomes when they were not in their own turn to play (Fig. 2). The gambling task of each trial was adapted from Gehring and Willoughby's (2002) classical gamble task. Stimuli were presented sequentially in the center of the CRT computer screen. Each trial began with the display of the black background (7.5° × 5.4°) for a variable duration of 400–600 ms (mean duration 500 ms). Subsequently two squares (each subtended 1.6° × 1.6°, the visual angle between the centers of the two squares was 3°) with thin white border were laid out horizontally on the background for 400–600 ms variably, with the two possible alternative of 5 or 25 betting cards then displayed in them. Executing player in that round was asked to select one of the two cards with a key press, using the left hand to press the left button for the left card or the right hand for the right button for the right card. Once the card was selected, it would highlight for 800–1200 ms (mean duration 1 s) before the outcome feedback was displayed with red or blue color of the chosen card to index gain or loss including "+", "−" symbol to increase the salience of the stimulus which lasted 1 second. The inter-trial duration was 1 second. The color to signify the gain or loss of the card was counterbalanced across participants. "5" on a card represents 0.5 Yuan and "25" means 2.5 Yuan. After one participant finished a round of 20 trials, he or she was informed with the value of the outcome in this finished round from the screen. Of course, at the same time the other two participants could also see the result though it was not their turn. Unknown to the paired friends, the stranger's selection and outcome feedback were predetermined by a computer program. Four possible outcomes, +25, −25, +5, −5 had the equal frequencies of appearance.

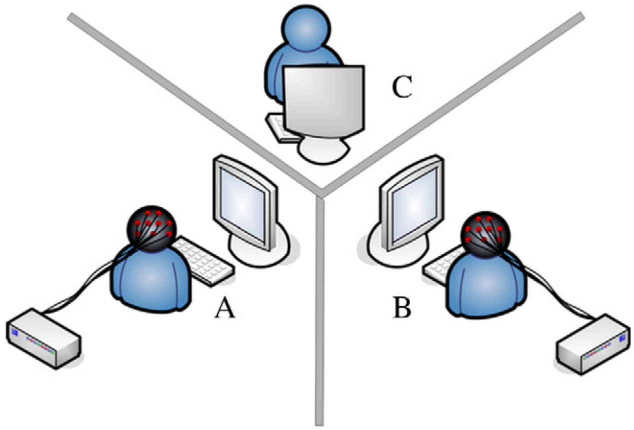

Fig. 1. Experimental schematic diagram. Three participants joined in the gamble task, one paired friends and a stranger. The paired friends' EEG was simultaneously recorded. Three participants play the gamble in turns. Everyone was instructed to observe others' card selection as well as the feedback outcomes when he/she was not in their own turn to play.

The stimulus presentation, marker and response recording were controlled by E-prime software package (Psychology Software Tools, Pittsburgh, PA, USA). The experiment contains 4 blocks, and each block has 2 rounds of 20 trials each (Fig. 2). The playing order of three participants of a group in each block was arranged pseudo-randomly by the program. Practice trials were administered before the formal experiment.

Since 12 pairs of friends took part in the experiment, 24 participants were recorded with EEG. Three conditions were analyzed: self-execution, friend observation, and stranger observation. We called this factor briefly as agency (self, friend and stranger).

Experiment 2

Experiment 2 adopted a similar manipulation as in experiment 1, but one of each friend pair was asked to just observe other two participants playing the game. We called this participant observer. Since the observer did not perform the game, he/she had no chance to earn or lose money in the gambling game and got a fixed payment of 30 Yuan for taking part in this experiment. Each observer was asked to pay attention to the card selection and outcome feedback of the other two confederates, one of whom was his/her friend and another one the stranger. At the same time, the other one of the paired friends was asked to perform the game in his/her own turn and pay attention to the stranger's gains and losses performance. Only the observer's result was reported due to the purpose of this experiment, which was to compare the different conditions of ERP in observers. Therefore, there were 23 participants whose EEGs were analyzed in two conditions: friend observation and stranger observation. This factor was also referred to as agency (friend vs. stranger).

EEG data acquisition

Electroencephalogram (EEG) was recorded (band-pass 0.05–70 Hz, sampling rate 500 Hz) with Neuroscan Synamp2 Amplifier (Scan 4.3.1, Neurosoft Labs, Inc. Virginia, USA), using an electrode elastic cap with 64 Ag/AgCl electrodes according to the international 10–20 system. All electrodes were referenced to the vertex first and later digitally re-referenced to the linked mastoids reference. Vertical and horizontal electrooculograms (EOGs) were recorded with two pairs of electrodes, one pair placed above and below the left eye in parallel with the pupil and the other pair placed 10 mm from the lateral canthi. Electrode impedance was maintained below 5 kΩ throughout the experiment.

In off-line analysis, electrooculogram artifacts with ocular movements were corrected using the method proposed by Semlitsch et al. (1986). Electroencephalogram recordings were segmented for the epoch from 200 ms before onset of feedback to 824 ms after this onset with the pre-stimulus period as the baseline. Trials contaminated by amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ± 100 μV were excluded from averaging. About 10% of the recorded EEG trials were excluded under such a standard. The data were digitally low-pass filtered below 30 Hz (24 dB/Octave).

The data of 3 participants in experiment 1 and 1 participant in experiment 2 were excluded because of excessive recording artifacts. Thus, the primary analysis was conducted on data from 21 participants in experiment 1, and 22 in experiment 2.

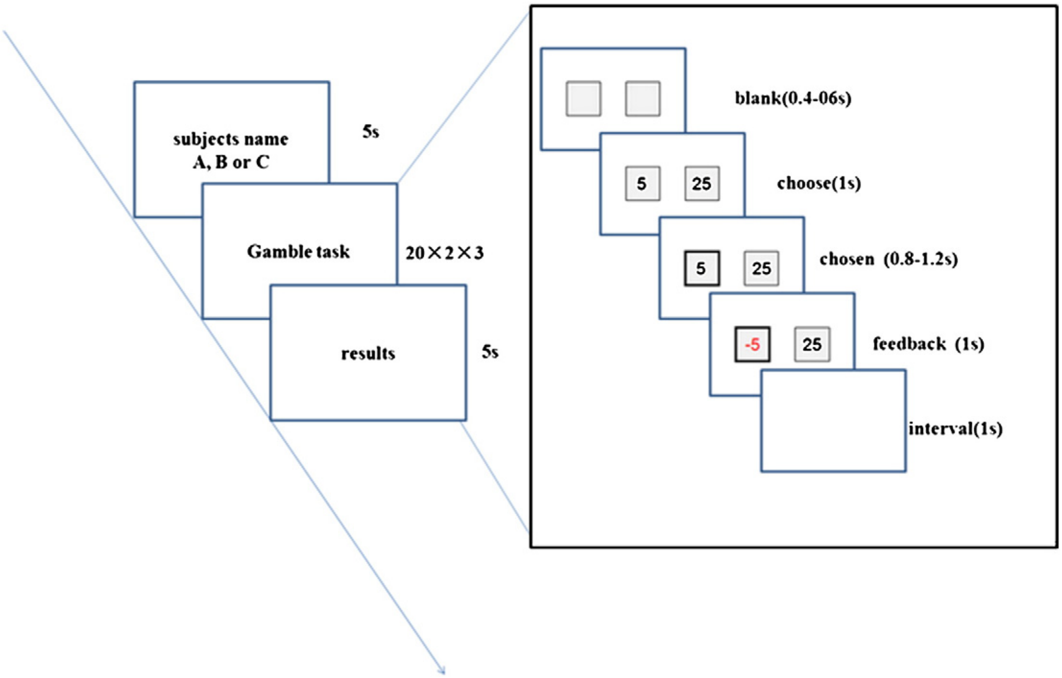

Fig. 2. Experimental design sketch. Subjects were informed whether it was his/her turn or not to play the gamble by presenting his/her name for 5 s at the start of each round. Then the informed subjects played the gamble game for 20 consecutive trials. In each block there were two rounds for each subjects. The experiments lasted three blocks in total.

The EEG epochs were averaged separately for agency(3) × valence (2) conditions (self gain, self loss, friend gain, friend loss, stranger gain and stranger loss) in experiment 1, and for agency(2) × valence(2) conditions (friend gain, friend loss, stranger gain and stranger loss) in experiment 2.

EEG data analysis

The ERP components analyzed in the two experiments include the FRN and P300. Based on visual observation, we analyzed the mean amplitude of the 300–380 ms after the onsets of the outcome for FRN in experiment 1 and 2. To minimize the effects of overlap of the FRN with positive ERP components, we further created difference waveforms separately for each of the three agency conditions (self, friend, stranger) in experiment 1 and for each of the two agency conditions (friend vs. stranger) in experiment 2 by subtracting the ERPs elicited by the gain trials from the ERPs elicited by loss trials. This FRN difference effects were defined as the mean value of the most negative component distributed on the anterior scalp over 280–380 ms in the two experiments. We referred to this component which reflected the FRN difference effect between loss and gain as d-FRN. The peak value of the P300 was detected as the most positive value in the 250–600 ms after feedback onset in both experiments on central-parietal electrodes. We selected 10 electrodes of CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2 and P4 in central-parietal area for P300, and 10 electrodes of F1, Fz, F2, FC1, FCz, FC2, F3, F4, FC3 and FC4 in frontal area for FRN in statistical analysis. The time windows for qualification of each component were based on the grand-average difference waveform of FRN, d-FRN and P300 as mentioned above (see Fig. 3).

The within-subject repeated measures ANOVA were performed with three factors: agency (self, friend and stranger), valence (gain, loss), and electrodes for P300 and with two factors: agency and electrodes for d-FRN in experiment 1. A similar ANOVA was conducted in experiment 2 except that there were only two levels for agency factor: friend and stranger. The Greenhouse-Geisser correction was applied for the violation of sphericity assumption in ANOVA where appropriate, and Bonferroni correction was used for multiple comparisons.

ERP results

Experiment 1

The statistical result for FRN with three factors (agency, valence and electrode) revealed a main effect for agency ($F(2,40) = 33.697$, $p < 0.001$), post hoc pairwise comparison with Bonferroni correction showed the comparisons of self-execution with friend observation and with stranger observation were significant respectively ($p_{\text{self, friend}} < 0.001$, $p_{\text{self, stranger}} < 0.001$), whereas the comparison between friend- and stranger observation was not ($p = 0.054$). A significant main effect of valence indicated that the mean amplitude of FRN across loss trials (12.98 μV) was smaller than that across gain trials (14.11 μV) ($F(1,20) = 11.38$, $p = 0.003$). Additionally, the interaction effect between agency and valence was also significant ($F(2,40) = 11.38$, $p = 0.003$,), suggesting that gain–loss effect was inconsistent among the three agency conditions (self, friend and stranger). In further simple effect analysis at the FCz electrode where the FRN showed the largest negativity indicated that the difference between gains and losses was only significant under the self-execution condition ($F(1,20) = 25.75$, $p < 0.001$); the differences between gains and losses in the remaining two agency conditions—friend vs. stranger observation were not statistically significant, i.e., $F(1,20) = 0.32$, $p = 0.581$ for the friend observation condition and $F(1,20) = 0.18$, $p = 0.673$ for the stranger observation condition, respectively. The main effect of the electrode also reached significance ($F(9,180) = 8.201$, $p < 0.001$). In terms of d-FRN's statistical analysis, it produced a significant main effect of agency ($F(2,40) = 14.373$, $p < 0.001$). Bonferroni-corrected post hoc *t*-test showed the self-execution condition differed significantly from both friend ($p = 0.001$) and stranger observation ($p < 0.001$) conditions, whereas the latter two conditions did not differ ($p = 1.000$).

As shown in Fig. 3, the grand-averaged ERP of the P300 was larger for the self-execution condition than for friend observation. Within-

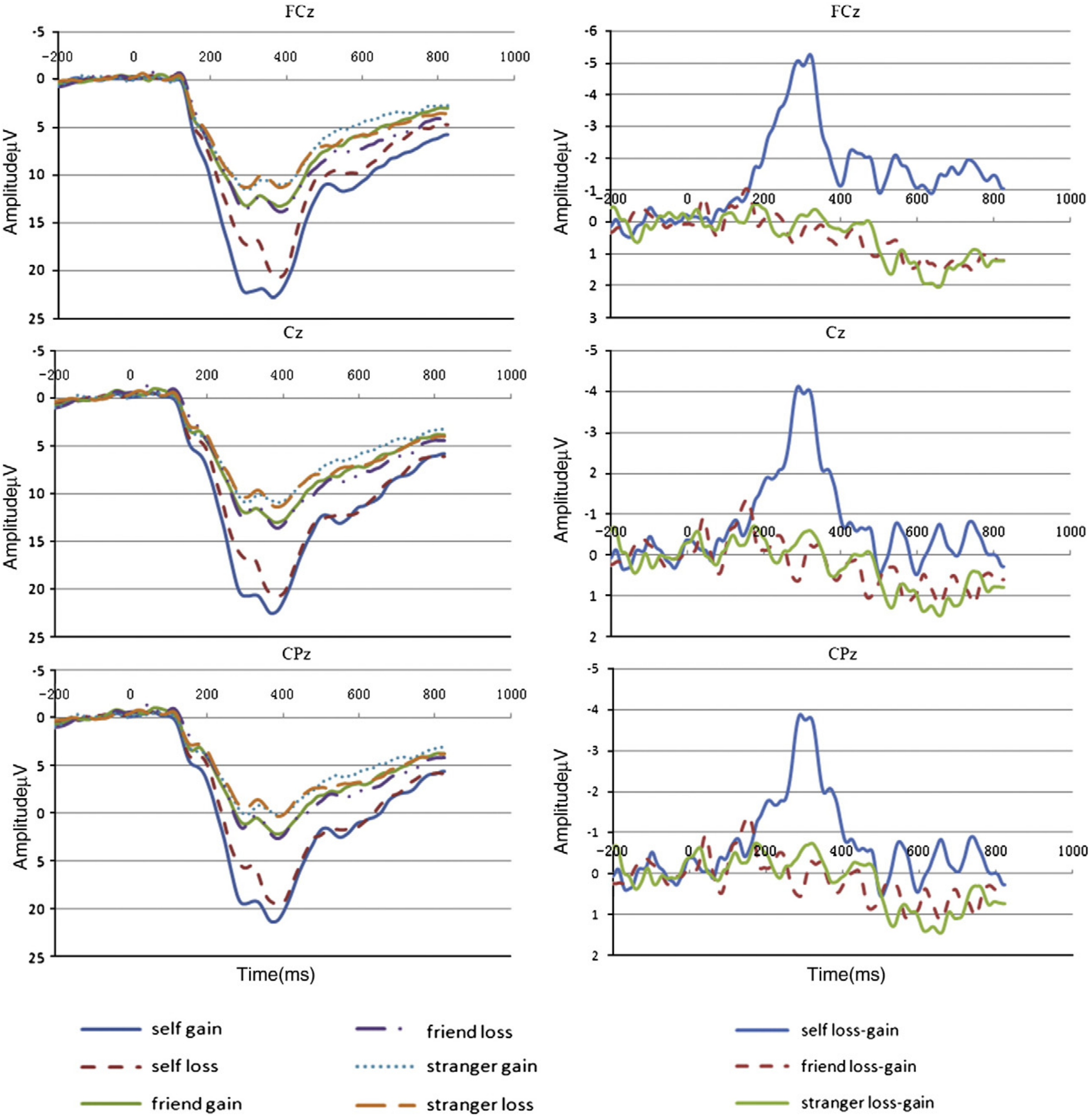

Fig. 3. Experiment 1 results. Grand-average ERP waveforms from channel FCz, Cz, CPz as a function of agency (self-execution, friend observation and stranger observation) and valence (gains and losses) of feedback outcomes (left), and the FRN difference waveform comparison among agency (right) in experiment 1.

subject ANOVA for P300 in four factors (agency, valence and electrode) of parietal-central electrodes revealed a significant main effect for agency ($F(2,40)=46.98$, $p<0.001$, $\varepsilon=0.741$), confirming that the mean amplitude of P300 was larger for the self-execution (20.07 µV) than for friend observation (12.87 µV, $p_{\text{self, friend}}<0.001$), which in turn was larger than that for stranger observation (11.14 µV, $p_{\text{friend, stranger}}=.0042$) after Bonferroni correction. The mean amplitude of gains (15.10 µV) only showed a trend for a significant difference from the loss conditions (14.29 µV; $F(1,20)=3.47$, $p=0.077$)) The interaction between valence and agency was also significant ($F(2,40)=4.56$, $p=0.016$). Further simple effect analysis of the Pz electrode on which the P300 was maximal across the scalp revealed the self gain induced a larger positive deflection than the self loss ($F(1,20)=4.57$, $p=0.045$), but this gain–loss difference of the P300 was not observed in the other two conditions, $F(1,20)=0.01$, $p=0.911$ for friend observation and $F(1,20)=2.29$, $p=0.146$ for stranger observation condition. For the effect of the electrode, $F(9,180)=13.58$, $p<0.001$.

Experiment 2

Fig. 4 illustrates the grand-averaged ERP evoked by the feedback stimuli for friend and stranger observation separately in trials of gains and losses. The ANOVA for the FRN resulted in a significant main effect for agency ($F(1,21)=10.932$, $p=0.003$); friend observation induced a larger FRN(10.92 µV) than that of stranger observation (8.94 µV). The main effect for valence was also significant ($F(1,21)=12.77$, $p=0.002$),and we observed a significant interaction between agency and valence ($F(1,21)=9.45$, $p=0.006$). Simple effect analysis for valence at FCz revealed that the difference between gains and losses

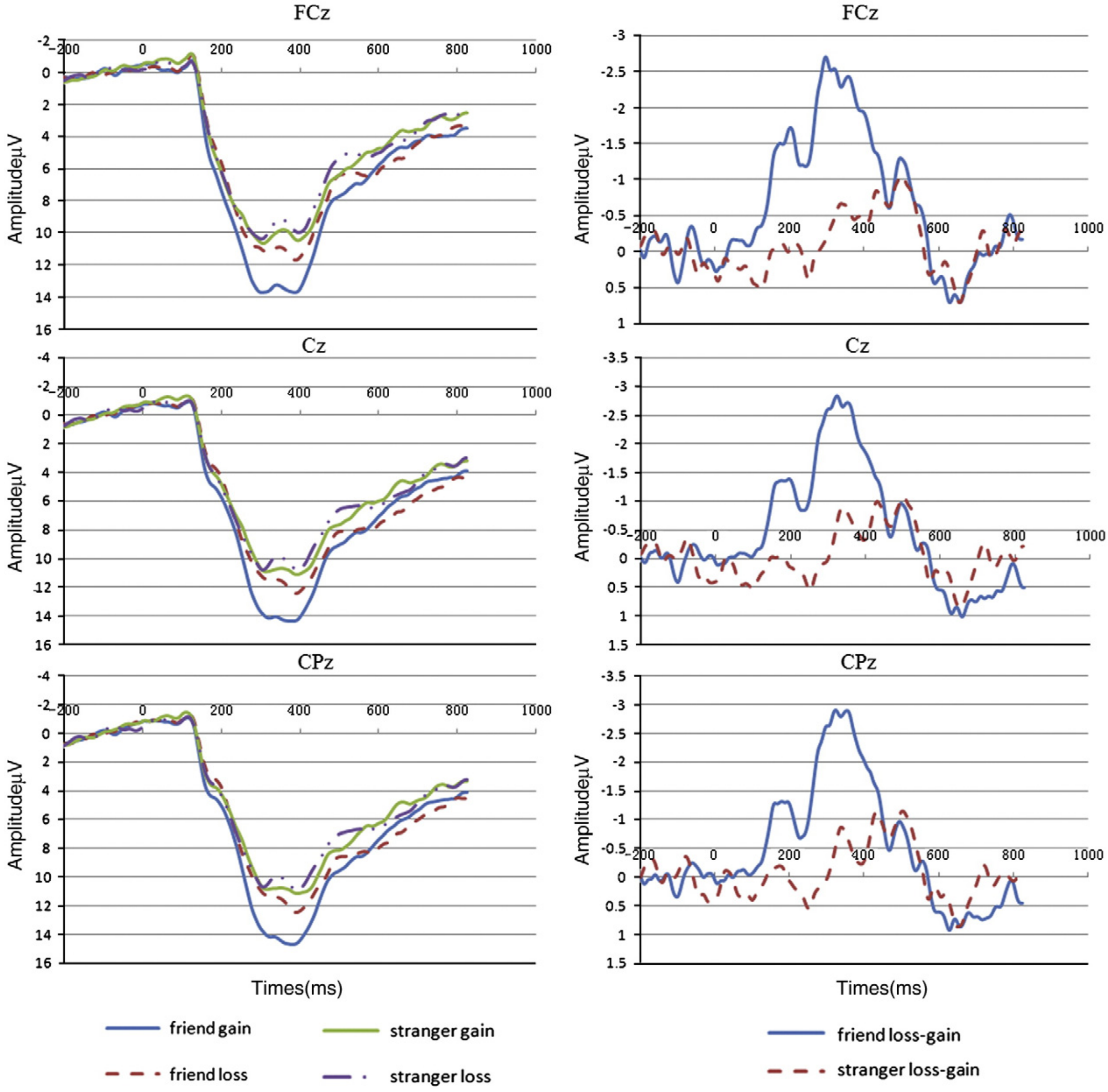

Fig. 4. Experiment 2 results. Grand-average ERP waveforms from channel FCz, Cz, CPz as a function of agency (friend vs. stranger) and valence (gain vs. loss) of feedback outcomes (left), and the FRN difference waveform comparison among agency (right) in experiment 2.

was significant under friend observation condition ($F(1,21) = 29.30$, $p < 0.001$), whereas it was not under stranger observation condition ($F(1,21) = 0.64$, $p = 0.431$). Electrode effect was also reach significant, $F(9,189) = 17.07$, $p < 0.001$.

The further analysis for d-FRN showed a significant main effect for agency ($F(1,21) = 4.99$, $p = 0.024$); friend observation condition (−2.467 μV) evoked an obviously negative deflection compared with the stranger observation condition (−0.587 μV). This result is different from the results in experiment 1, where the d-FRN elicited by friend observation did not differ from stranger observation (Fig. 5).

The P300 revealed a significant main effect for agency ($F(1,21) = 18.15$, $p < 0.001$), indicating that the mean amplitude of the P300 elicited by friend observation (13.714 μV) was larger than that of the stranger observation (11.835 μV). The main effect of valence also reached significance ($F(1,21) = 21.56$, $p < 0.001$). The interaction effect reached a marginal significance ($F(1,21) = 3.48$, $p = 0.076$). Further analyses at Pz revealed a larger P300 elicited by feedback indicating monetary gain under the friend observation condition (17.002 μV) than under stranger observation (14.224 μV, $F(1,21) = 16.84$, $p = 0.001$). P300 demonstrated marginal difference in valence under stranger observation condition ($F(1, 21) = 4.03$, $p = 0.058$). In addition, the electrode location effect was significant, $F(9,189) = 18.08$, $p < 0.001$.

Discussion

The results of the present study show that self-involvement influences our perceptions of others' gains and losses. This study is in concordance with two recent studies applying similar paradigm but with important extensions (Fukushima and Hiraki, 2009; Leng and Zhou, 2010).

As can be seen from the results, FRN under friend observation is inconsistent among different situational context in the two experiments. This is concordant with the recent advance on the role of social situation that modulates the magnitude of FRN as mentioned in the introduction (Fukushima and Hiraki, 2006; Itagaki and Katayama, 2008; Fukushima and Hiraki, 2009). For example, in a recent experiment, Marco-Pallares et al. (2010) recruited three groups of

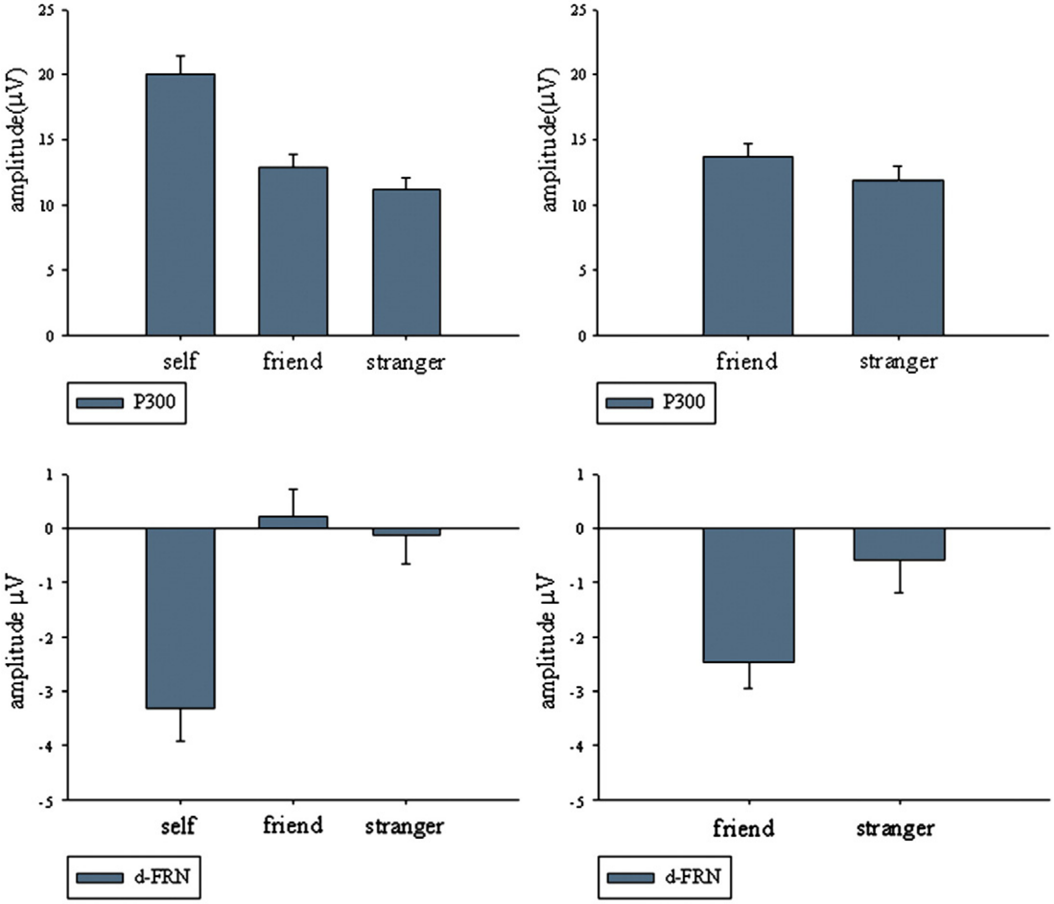

Fig. 5. Comparison of ERP amplitude in two epxeriments. Means and standard errors of the amplitude of the P300 and d-FRN of the selected electrodes for ERP statistics in the three condition (self, friend and stranger) in experiment 1 (left) and the two condition (friend vs. stranger) in experiment 2 (right).

paired subjects to attend a gambling task. In each pair, one was designated as a performer and the other as an observer. The performers were required to perform a gambling task and the instruction to the observers was different in the three situations with a between-subject experimental manipulation. That is, the gamble results of the performer would result in the observer's neutral, identical or reversed income respectively. The authors found that the FRN of the observer is adaptively changed under different situations. The FRN difference between gain and loss in the neutral condition was observed, similar with the d-FRN revealed in the identical payoff condition and similar to that recorded from the performer. The authors inferred that emotional/empathic impact plays a role in the observer's FRN in the neutral condition, consistent with the motivational theory of the FRN (Gehring and Willoughby, 2002; Yeung et al., 2005). This is also consistent with a recent general hypothesis that the empathic response could be interpreted as a mirror of what happened in the performer's brain (de Vignemont and Singer, 2006; Decety and Lamm, 2006; Mobbs et al., 2009). As can be seen from our study, the FRN difference between the gain and loss of the observer is obvious in the friend observation condition, which resembles those reported in Fukushima and Hiraki (2009). Current and the mentioned previous studies indicate the FRN is an indicator of empathic response toward observer's friends. On the other hand, in Marco-Pallares et al. (2010)'s results under the reversed condition, the FRN difference between gains and losses was also correspondingly reversed, which means the gain of the performer induced a larger FRN as opposed to losses. The authors assumed that, in addition to the empathic/emotional reason, the evaluative process was also involved, similar to the Itagaki and Katayama (2008)'s results in the modulation of the magnitude of FRN. In our current study, when the observer self engaged in the gamble game as a performer in alternate blocks in experiment 1, the FRN difference between gains and losses disappeared, which is similar with the stranger observation condition. And further, there is no d-FRN discrepancy between friend- and stranger observation conditions.

To explain the inconsistency of the FRN in these two experiments, we focused on the modulation factors involved in empathy. As outlined earlier, situational context is a factor involved in the modulation process of empathy and self-involvement is the one implicated in the current study.

Past studies in the field of empathy research found that pain could involuntarily induce the capability to share the experience of others, thus automatically activating neural circuits in observing the process of pain in others overlapping with brain activity when the observer experiences the pain directly. A recent study using laser-evoked potentials (LEP) explored the neural activation when participants observed another person suffering from both painful and non-painful stimuli in addition to experiencing pain themselves. It was found that the N1/P1 LEP component, which is probably related to the activation of the sensory cortex, was only correlated with the pain intensity of observer self, rather than that of other person (Valeriani et al., 2008). The authors concluded that empathizers in pain themselves biased their neural empathic reaction toward others in an egocentric manner (Hein and Singer, 2008; Valeriani et al., 2008). This was further confirmed by a subsequent study on the normal subjects' perception of pain toward those who experienced algesia (Lamm et al., 2010). Taken these results together, it seems that self-involvement in pain regulates the empathic responses to others. So it could also be the case that a more egocentric attitude is active in a paradigm involving monetary gains when oneself is involved in contrast with just being in an observer position. Empathizers may consciously or unconsciously experience a competition in experiment 1 because dominance seeking is an instinct desire for individuals in social context (Rustichini, 2008). Probably for the reason of social comparison in experiment 1, participants exerted a selfish manner rather than a selfless one in experiment 1, which weakened their empathy toward the friend and made them treat the other two agents' similarly, or not different enough though they paid more attention to their friends than others and treated friends' outcome seriously (see below). So a possible explanation for the FRN effect discrepancy is the endogenous desire of dominance seeking, which may lead the participants to treat self and others differently and also treating friends and strangers similarly, as long as they are involved in performing the same monetary task.

Moreover, our finding of FRN modulation is also a direct support for the early appraisal model of top-down control of people's empathy toward others. de Vignemont and Singer (2006) suggested two routes for the modulation of the empathic processing, an early and a late appraisal model. The early appraisal model proposes that the emotional stimulus is evaluated in a context of external and internal information. Hence, the outcome of the appraisal process determines whether the empathic response might be elicited or not. The late appraisal model, however, suggests the default rule for empathic response is an automatic activation by the perception of an emotional cue, and the empathic modulation takes effect at a later stage through inhibition or amplification of the involuntarily elicited empathy. The recent work by Fan and Han (2008), to some extent, supported the later model. Their work found that the early effect over the frontal lobe at about 140 ms after sensory stimulation was modulated by the contextual reality of stimuli (pain pictures vs. cartoons), while the late component P300 over the central–parietal regions after 380 ms was task dependent and modulated by top-down attention to the pain cues. In our work, the FRN which reflected an early evaluation of outcomes (gain or loss) was modulated by different social situations of the participant, whether they themselves were engaged in the gamble or not. Such a result could support the early appraisal model which suggested the former evaluation could have determined our empathy toward others. The lack of consistency between the attention modulation in Fan and Han (2008)'s study and the currently reported modulation appear to be at odds with each other. However, we should note that it could be attributed to the very different paradigms, especially the different features or characteristics of the stimuli, e.g., pain photos vs. money sign, as above mentioned. Empathic response for monetary gains or losses of others in the current research, which belongs to neither primary nor secondary emotion (de Vignemont and Singer, 2006), could be modulated by the early appraisal that primarily depend on pre-established emotional response tendencies before the onset of an empathic process. On the other side, primary emotions like pain probably induce an automatic empathy at the early stage and could only be modulated at the late stage of empathy appraisal process. Our results probably complement Fan and Han's report, implicating that both early and late appraisal play a role in the empathy process and taking an initial step to distinguish the modulation stage of the empathic processing.

Congruent with the recent work of Leng and Zhou (2010), the P300 components presented an obvious difference among different agents: self, friend and stranger in experiment 1 and friend and stranger in experiment 2. Such a result indicates that the motivational salience could be represented by the P300, a component regarded to represent motivational/affective and allocation of mental resources (Nieuwenhuis et al., 2005).

Although there is no valence diversity of d-FRN in experiment 1, there is still a clear distinction of the P300 between friend and stranger observation. This d-FRN and P300 disparity in experiment 1 indicates that while the FRN which was sensitive to the valence of the stimuli exhibited an empathic favor for friend compared to stranger as confirmed in experiment 2, P300 registers participants' motivational relevance toward their friends compared to those who they were not familiar with.

Moreover, the P300 was also modulated by valence of the monetary feedback in the self-execution condition in experiment 1 and friend observation condition in experiment 2. Recent work has found that gain feedback elicits a larger P300 than loss in outcome evaluations of risky gambles (Polezzi et al., 2010; Rigoni et al., 2010; Wu and Zhou, 2009), although the inner mechanism was not well disentangled. Our current result is partially supporting such a result. Gain–loss differentiation was observed under self-execution in experiment 1 and friend observation condition in experiment 2. Besides, it is interesting to note that the valence distinction of the P300 appeared simultaneously with the d-FRN difference in the two experiments and especially their concurrent absence in friend observation condition of experiment 1 and presence in experiment 2. We inferred that this agent-specific valence effect of the P300 observed in the current study further corroborated P300's role in coding the motivational significance of reward. We hypothesize that the valence effect of the positive components P300 might also reflect to what extent participants empathize with others. We have to take such a speculation cautiously since little work is performed on this effect in the past. Still we note here that this valence differentiation was an interesting finding that might be pursued in future research to unravel the underlying mechanism.

In sum, the current study investigated the neural mechanism of how social factors modulate empathy towards others in gamble tasks involving monetary gains and losses. When the participants played the gambles and observed their friends and strangers performing the game at the same time, they did not react differently to friends and strangers. However, when the experimental manipulation excluded the participants from playing the gamble themselves, the d-FRN differentiation between friend- and stranger observation conditions appeared and the former condition evoked a larger d-FRN than the latter one. These results indicate that the participants had a greater empathy towards socially closer persons when they themselves were not personally involved in the game. Self-participation may induce social dominance seeking and weaken the empathy toward friends. P300 components were distinct from each other under different agents' condition in both experiment 1 and experiment 2, which mainly reflected the familiarity with different agents. The disparity between the P300 and d-FRN under friend observation condition in experiment 1 together with the contrast of the d-FRN difference in the friend observation condition between experiment 1 and experiment 2 underline that both familiarity and self-engagement are factors in modulating the empathic response towards others. Our results also have implications for the recent dispute on whether empathy could be regarded as an intrinsic trait or disposition, or if it is context dependent. Our results give direct support for the viewpoint put forward in a recent review (Kirman and Teschl, 2010) where the authors advocated that empathy was dependent on both social interaction and context.

Many neuroeconomic studies in recent years try to refute the ideally defined hypothesis that people are generally maximizing their self-interest in traditional economics, and have put forward plenty of direct demonstrations on the level of neuroscience, pointing out that people are social creatures and other-regarding in social situation (Fehr and Camerer, 2007). But according to the results of our experiments, to some extent, people are indeed self-interested. People's social preference is at least partly context dependent.

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References

de Vignemont, F., Singer, T., 2006. The empathic brain: how, when and why?.. Trends Cogn. Sci 10, 435–441.

Decety, J., Lamm, C., 2006. Human empathy through the lens of social neuroscience. Sci World J 6, 1146–1163.

Fan, Y., Han, S., 2008. Temporal dynamic of neural mechanisms involved in empathy for pain: an event-related brain potential study. Neuropsychologia 46, 160–173.

Fehr, E., Camerer, C.F., 2007. Social neuroeconomics: the neural circuitry of social preferences. Trends Cogn Sci 11, 419–427.

Frith, C.D., Singer, T., 2008. The role of social cognition in decision making. Philos Trans R Soc Lond B Biol Sci 363, 3875–3886.

Fukushima, H., Hiraki, K., 2006. Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. Soc Cogn Affect Neurosci 1, 149–157.

Fukushima, H., Hiraki, K., 2009. Whose loss is it? Human electrophysiological correlates of non-self reward processing. Soc Neurosci 4, 261–275.

Gehring, W.J., Willoughby, A.R., 2002. The medial frontal cortex and the rapid processing of monetary gains and losses. Science 295, 2279–2282.

Hein, G., Singer, T., 2008. I feel how you feel but not always: the empathic brain and its modulation. Curr Opin Neurobiol 18, 153–158.

Holroyd, C.B., Coles, M.G., 2002. The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychol Rev 109, 679–709.

Itagaki, S., Katayama, J., 2008. Self-relevant criteria determine the evaluation of outcomes induced by others. NeuroReport 19, 383–387.

Kirman, A., Teschl, M., 2010. Selfish or selfless? The role of empathy in economics. Philos Trans R Soc Lond B Biol Sci 365, 303–317.

Lamm, C., Meltzoff, A.N., Decety, J., 2010. How do we empathize with someone who is not like us? A functional magnetic resonance imaging study. J Cogn Neurosci 22, 362–376.

Leng, Y., Zhou, X., 2010. Modulation of the brain activity in outcome evaluation by interpersonal relationship: an ERP study. Neuropsychologia 48, 448–455.

Marco-Pallares, J., Kramer, U.M., Strehl, S., Schroder, A., Munte, T.F., 2010. When decisions of others matter to me: an electrophysiological analysis. BMC Neurosci 11, 86.

Mobbs, D., Yu, R., Meyer, M., Passamonti, L., Seymour, B., Calder, A.J., Schweizer, S., Frith, C.D., Dalgleish, T., 2009. A key role for similarity in vicarious reward. Science 324, 900.

Nieuwenhuis, S., Yeung, N., Holroyd, C.B., Schurger, A., Cohen, J.D., 2004. Sensitivity of electrophysiological activity from medial frontal cortex to utilitarian and performance feedback. Cereb Cortex 14, 741–747.

Nieuwenhuis, S., Aston-Jones, G., Cohen, J.D., 2005. Decision making, the P3, and the locus coeruleus-norepinephrine system. Psychol Bull 131, 510–532.

Polezzi, D., Sartori, G., Rumiati, R., Vidotto, G., Daum, I., 2010. Brain correlates of risky decision-making. Neuroimage 49, 1886–1894.

Rigoni, D., Polezzi, D., Rumiati, R., Guarino, R., Sartori, G., 2010. When people matter more than money: an ERPs study. Brain Res Bull 81, 445–452.

Rustichini, A., 2008. Dominance and competition. J Eur Econ Assoc 6, 647–656.

Semlitsch, H.V., Anderer, P., Schuster, P., Presslich, O., 1986. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology 23, 695–703.

Singer, T., 2006. The neuronal basis and ontogeny of empathy and mind reading: review of literature and implications for future research. Neurosci Biobehav Rev 30, 855–863.

Singer, T., Lamm, C., 2009. The social neuroscience of empathy. Ann NY Acad Sci 1156, 81–96.

Singer, T., Seymour, B., O'Doherty, J.P., Stephan, K.E., Dolan, R.J., Frith, C.D., 2006. Empathic neural responses are modulated by the perceived fairness of others. Nature 439, 466–469.

Valeriani, M., Betti, V., Le Pera, D., De Armas, L., Miliucci, R., Restuccia, D., Avenanti, A., Aglioti, S.M., 2008. Seeing the pain of others while being in pain: a laser-evoked potentials study. Neuroimage 40, 1419–1428.

Wu, Y., Zhou, X., 2009. The P300 and reward valence, magnitude, and expectancy in outcome evaluation. Brain Res 1286, 114–122.

Yeung, N., Holroyd, C.B., Cohen, J.D., 2005. ERP correlates of feedback and reward processing in the presence and absence of response choice. Cereb Cortex 15, 535–544.

Yu, R., Zhou, X., 2006. Brain responses to outcomes of one's own and other's performance in a gambling task. Neuroreport 17, 1747–1751.