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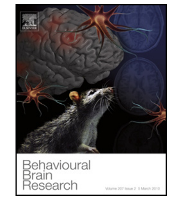

Research report

The sweet side of inequality: How advantageous status modulates empathic response to others' gains and losses

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HIGHLIGHTS

- Advantageous status modulates empathic response to monetary gains and losses.
- Feedback-related potential (FRN) could reflect empathic responses.
- FRN and P300 have dissociated roles in social decision making.

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ABSTRACT

In the past decade, considerable amounts of studies have explored the neural underpinnings of empathic response toward the positive and negative feelings of others, such as pain and social exclusion, in the field of neuroeconomics. In addition, empathic response of observing other's financial gains and losses have recently started to gain increasing attention in this interdisciplinary field. However, the effects of inequality-averse social preference on individuals' response toward other's gains and losses have not yet been clearly characterized. This work conducted an electrophysiological study with a simple gambling task to explore how inequality aversion matters in modulating neural temporal dynamics toward self and others' gains and losses using scalp-recorded event-related potentials (ERPs). The electrophysiological data demonstrated increased amplitude of P300 toward self's monetary gains and losses independent of advantageous and disadvantageous status. Intriguingly, subjects in the high pay group evoked more pronounced gain loss disparity of feedback-related negativity (FRN) amplitude toward others than themselves. Meanwhile, such a pattern was not observed among the subjects in the low pay group. Therefore, the current double dissociation results of FRN and P300 may indicate that advantageous status enhances subjects' empathic response toward others' pecuniary outcome, giving a direct electrophysiological evidence for the economic modeling on inequality aversion behavior.

1. Introduction

Human beings by nature are social creatures. In addition to caring about their own personal interests, individuals are also concerned with the fortune and misfortune of others in dynamic interpersonal interactions. Empathy, or the capability to experience and share with what others feel, is vital in the social context. Philosophers and psychologists have paid attention to this aspect for centuries. In addition, in the past decade, a growing number of studies have investigated its neural mechanism [1–4]. At present, numerous studies have paid close attention to the empathic response of pain and found that the passive observation of others in pain evoked a largely similar neural pattern compared to incurring the pain in a direct manner, indicating the "shared representations" of others' suffering. Similar with the empathic response toward the negative stimuli (i.e., pain), recent studies have also revealed that individuals empathetically respond to others' financial reward. For instance, a recent functional magnetic resonance imaging (fMRI) study investigated how individuals empathize with others' monetary reward [5]. They found that the subjects had greater reward region activation when they observe another subject who was socially similar with themselves win at gambling, as opposed to those who were socially dissimilar. Such results indicate that positive monetary reward could also be mirrored in the brain, which is analogous to electric-induced pain.

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In light of the modulatory factors of empathy, many social factors are involved in modulating the empathic response toward others, of which a very important one is inequality. In a pioneering study, Sanfey et al. asked the subjects to act as the recipient in a one-shot ultimatum game while their brain underwent scanning in fMRI [6]. They found that regions related with negative emotion, namely, anterior insula (AI), anterior cingulate cortex (ACC), were more responsive to unfair offers compared with fair offers from a proposer. Singer et al. (2006) extended the aforementioned study to examine how such unkind behavior from others modulated individuals' empathic response when they observed others experienced pain. They found that the subjects, especially males, had gloating attitudes toward those who treated them unfairly in a game before the empathic task. Instead of these empathic regions (i.e., AI, ACC), the reward-related region (i.e., the ventral striatum) was involved when they saw that the betrayers experienced electric shock [7]. Therefore, as an important situational context factor, this acquired social image modulates individuals' empathic response toward others.

However, most contemporary neuroeconomic studies have mainly centered on the neural response of individuals under disadvantageous inequality [6,8–11]. Only a few studies have focused on the instinct motivation of human beings to reduce the inequality of distributional outcome [12]. In the original inequality framework for economic modeling developed by Fehr and Schmidt [13], they posited that humans are inequality-averse and egalitarian; the coefficient "alpha" in the model indicates that the envy originated from disadvantageous inequality, and the coefficient "beta" embodies the guilt aversion from the advantageous status of the decision makers [14]. Adopting a simple and ingenious design, a recent study explored this possible neural evidence of inequality-averse social preference existing in the brain [15]. Paired subjects were recruited; at the beginning of the experiment, they randomly endowed one subject from each pair with a large amount of money from a lucky draw. Afterward, the paired subjects were asked to evaluate further monetary transfer to both subjects in the scanner using a dictator game. They found that although subjects from the high pay group scored their higher monetary transfer as more satisfactory in their self-reported ratings, the increased reward-related regions (the ventral medial prefrontal cortex and striatum) were recruited when they saw that their disadvantageous counterparts won a larger amount of money compared with the amount they received. This study was the first to provide direct evidence for the existence of advantageous inequality aversion in the brain. Inspired by this study, by adopting an electrophysiological approach, the present study intends to integrate status manipulation with a financial empathic paradigm to explore how advantageous status modulates subsequent empathic response to others' financial gains and losses.

With the rapid development of the interdisciplinary field of neuroeconomics, decision making under social context has also elicited considerable attention in electrophysiological studies. Two event-related potential (ERP) components, namely, feedback-related negativity (FRN) and P300, especially the former, are the key foci of studies under this theme. Mounting evidence indicates that FRN, a component distributed over the frontal area of the scalp and peaking at approximately 200–300 ms following the revelation of unfavorable feedback, reflects the correctness of the decision that subjects made [16,17]. In an early study, Gehring and Willoughby (2002) adopted a gambling task in which subjects were instructed to make a trade-off between options with small and large stakes, which may result in a corresponding win or loss; the uncertainty of both options was resolved as long as the choices were made by the subjects. They explored the stimuli-locked ERP amplitude at the stage of outcome revelation and found a prominent differentiated FRN (d-FRN) toward the loss–gain divergence of the results, reflecting the motivational and affective evaluation of the revealed outcome [18].

Moreover, recent scientific attempts have successfully extended the FRN exploration into social context. Electrophysiological studies revealed that the representation of vicariously experienced gains and losses is similar with experiencing their own wins and losses, comparable to those observed in the fMRI studies [5]. In a previous study, Yu and Zhou asked the subjects to perform a gambling task while observing the other subjects' performance of the same gambling task alternatively. They observed that the mere observation of others' performance also induced an increased loss–gain FRN discrepancy, with relatively smaller amplitude but similar morphology and scalp distribution as compared to the FRN divergence of the outcome for themselves [19].

In addition, this socially induced FRN is also modulated by social factors. In a recent report, Marco-Pallarés et al. recruited three groups of paired subjects to participate in a gambling task [20]. In each pair, one subject was assigned as an observer and the other as an executor. The executors were asked to carry out the gambling task in all three pairs, whereas the observers were instructed to passively observe the gambling task in three different scenarios. The gain–loss outcome of the gamble from the executors would entail observers' neutral, parallel, or opposite earnings. They observed that the amplitudes of the FRN of the observers adaptively reacted to discrepant manipulated conditions. The gain–loss discrepancy of FRN was prominent in the neutral condition, which was similar with the FRN under parallel condition and those observed from the executor but not in the opposite condition. Therefore, they concluded that empathic and affective processes might be essential in neutral condition, which is consistent with the motivational theory of FRN [18,21].

Recent studies further confirmed that observation-induced d-FRN is related to the empathic response to others' gains and losses. Fukushima and Hiraki (2009) found that human outcome, rather than that obtained by computers, could evoke the gain–loss discrepancy of FRN toward non-self agent, and this differed FRN amplitude was positively correlated with the empathic traits of the subjects, as measured by a self-reported questionnaire [22]. To confirm this further, Leng and Zhou attempted to explore how the social contexts modulate electrophysiological response of empathy toward others' gain and loss with varied degree of familiarity [23]. In their study, subjects were engaged in a gambling task while they observed two others with differed familiarity perform the same gambling task. Their study revealed that observers exhibited a more prominent P300 toward their friends rather than toward strangers. Such results are in accordance with previous studies that P300 reflects the attentional allocation and motivational salience of the stimuli [24]. Moreover, although the own performance of the subjects induces a larger FRN compared with those of others, no obvious differentiation of FRN was found in the conditions between friend and stranger observation. Our recent study replicated their conclusion that P300 represented the agent difference among self, friend, and stranger [25]. Moreover, our study extended that the unobserved d-FRN difference might be due to the self-involvement of the empathizer. Although the observers themselves did not attend the gambling experiment, we observed a prominent d-FRN between their friends and strangers, and the difference of the P300 remained. Therefore, the amplitude of FRN could actively represent the decreases or increases of others' empathic response in a socially changing context. In general, converging studies indicate that the amplitude of FRN could be flexibly modulated by a specific social context, reflecting the motivational significance of the outcome.

Therefore, to address the potential role of advantageous inequality aversion in modulating the empathic response to others' pecuniary outcome, the present study attempted to explore the temporal mechanism of neural response to self and others' monetary gains and losses using ERP. We revised the classical 5–25 gambling task [18] and recruited groups of unacquainted male participants for this experiment. In each group, two paired participants were asked to choose a gamble with 50/50 probability before the start of the electrophysiological experiment, where one subject received RMB 50 while the other received nothing. Afterward, these two matched subjects passively observed the gamble played by the computer for themselves as well as for the paired subjects. The electroencephalography signals were recorded from the paired subjects simultaneously. Such a paradigm allowed us to explore how advantageous status affects the subjects' neural response toward the monetary wins and losses of themselves and of others.

Given the varying motivational salience of the outcome stimuli in the current study, we postulate that P300 differs between the empathizer and the other, and its amplitude would loom larger over self than others. On the other hand, the FRN between gains and losses under different agent conditions would depend on the manipulated social status. Increased empathy is caused by advantageous inequality. Thus, we posit that the gain–loss discrepancy in observing the outcome of others should be more pronounced than the discrepancy toward themselves when the empathizer himself is in an advantageous status.

2. Methods

2.1. Subjects

A total of 46 right-handed healthy undergraduate and graduate male students, aged 19–33 (mean age = 22.24 years, SD = 2.62) were enrolled. They were all native Chinese speakers, had normal or corrected-to-normal vision, and did not have any history of neurological disorder or mental disease. The participants were divided into two groups based on the results of a "lucky draw" before the ERP experiment started. Informed consent was obtained from all participants prior to the commencement of the experiment. The data of three subjects were discarded because of excessive artifacts. For symmetry, three of their paired subjects were eliminated as well, resulting in 40 valid subjects (20 pairs) for final data analysis.

2.2. Experimental procedure

In this experiment, an experimental group was composed of two paired male subjects who were not familiar with each other. As illustrated in Fig. 1, the paired subjects were initially asked to attend a "lucky draw" task before the ERP experiment. Two balls (one of which represents RMB 50 whereas the other represents RMB 0) were placed in a box in advance. The participants were instructed to draw a ball from the box; the one who drew the "win" ball would receive RMB 50 immediately from the experimenter whereas the other one would receive nothing. According to the outcome of the "lucky draw", the paired subjects were allocated into high pay group and low pay group separately. Afterwards, the two subjects were separately seated in two adjacent shield rooms. Each of them seated about 1 meter away from a computer-controlled CRT monitor. The participants were instructed to observe the computer playing gambles, regardless of whether the financial results of the gambles were related to their own income or that of their counterpart. They were also asked to minimize body and muscle movement throughout the experiment.

As illustrated in Fig. 2, the participants were shown one of their names for five seconds at the start of each round, which indicated the gambling results in this certain round would affect the income of the shown subject. The gambling task was adapted from the classical gamble task initially developed by Gehring and Willoughby [18]. Stimuli were presented sequentially in the center of the CRT computer screen. Each trial began with two blank squares (each subtended 1.6 × 1.6°, the visual angle between the centers of the two squares was 3°) of thin white borders over a black background (7.5 × 5.4°) for a variable duration of 800–1600 ms. Subsequently, two squares were filled with the two possible alternatives of 5 or 25 betting cards and were laid out horizontally on the background for 1000–2000 ms variably. Then, the computer automatically chose between the two alternatives; the chosen bet was highlighted for 800–1600 ms. The outcome feedback was displayed with red or blue color on the chosen card to index gain or loss by adding "±", "−" symbol to increase the salience of the stimulus for 2 s. The inter-trial interval lasted for 1000–1500 ms. The colors to signify the gain or loss of the card were counterbalanced across participants. "5" on a card represents RMB 0.5 and "25" indicates RMB 2.5. When the gamble task ended, the participants were informed about the value of both their

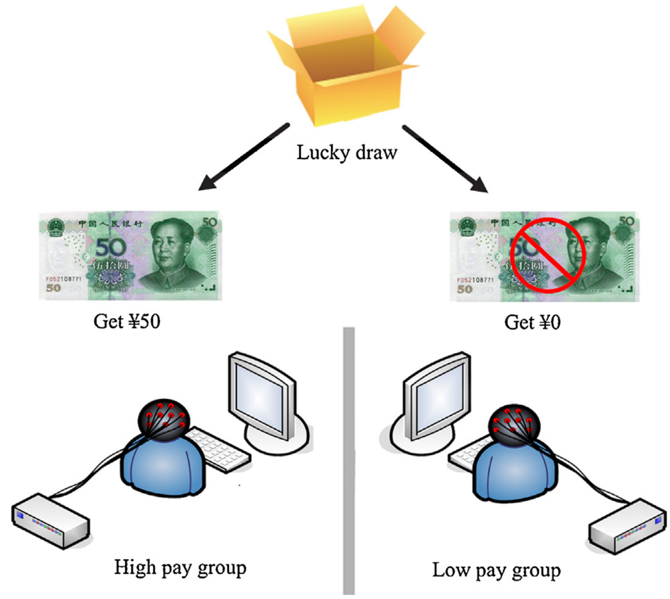

Fig. 1. Two stages of experiment. Two paired male subjects attended the game; in stage 1, each of them drew a ball from the box, where one gained a bonus of RMB 50 for a "win" draw whereas the other received RMB 0 for a "non-win" draw. At stage 2, both of them were instructed to observe the computer performed the gambling task for them alternatively while their EEGs were simultaneously recorded.

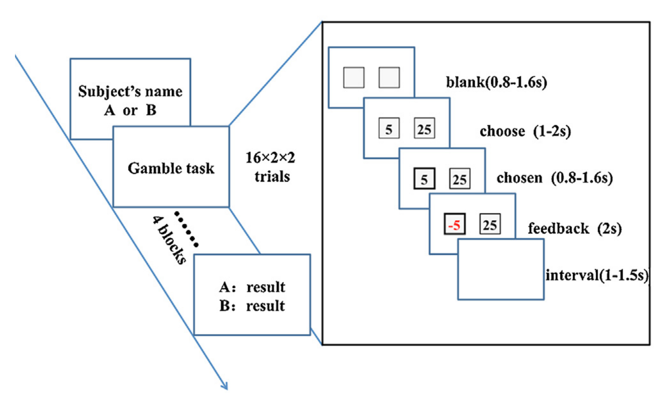

Fig. 2. Gambling task. At 2nd stage of the study, the paired subjects were informed whose gamble task by presenting one of their names for 5 s at the start of each round. Then computer performed the gamble game for 16 consecutive trials for him. In each block, there were 2 rounds of game for each subject. The experiments lasted 4 blocks in total.

outcomes on the screen for another five seconds. Four possible outcomes (i.e., ±25, −25, ±5, and −5) had independent equal frequencies of appearance for feedback presentation.

Stimuli, recording triggers, and response were presented and recorded using E-Prime 2.0 software package (Psychology Software Tools, Pittsburgh, PA, USA). The task consists of 4 blocks. Each block contains 2 rounds of 16 trials for each subject. Therefore, half trials were gambles that would influence the financial incomes of high pay group whereas the other two rounds were for their counterpart, the low pay group. The order of rounds in each block was randomized by the program. The formal experiment started after a pilot practice for both subjects. After the gambling task, the subjects were asked to complete an altruism subscale of Neuroticism Extraversion Openness Personality Inventory (NEO-PI).

2.3. Electroencephalogram (EEG) recordings and analyses

The 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 standard international 10–20 system. A cephalic (forehead) location was used for ground and left mastoid was chosen for reference. During offline analysis, all electrodes were digitally re-referenced to the linked mastoids reference. Electrooculogram (EOG) was recorded from electrodes placed at 10 mm from the lateral canthi of both eyes (horizontal EOG) and above and below the left eye (vertical EOG). The EOG artifacts were corrected off-line for all subjects in preprocessing. The experiment started only when the electrode impedances were maintained below 5 kΩ. The data were analyzed using Neuroscan 4.3.1. The EOG artifacts were corrected using the method initially proposed by Semlitsch et al. (1986) [26]. Trials containing amplifier clipping, bursts of electromyography activity, or peak-to-peak deflection exceeding ±100 μV were excluded for final analysis. The data were digitally filtered with a low pass filter at 30 Hz (24 dB/octave).

The EEG recordings were segmented for the epoch from 200 ms before the onset of target to 800 ms after the onset, with the first pre-targets of 200 ms as the baseline. The EEG epochs were averaged separately for agency (self/other) × outcome (gain/loss) conditions. Therefore, it results in four conditions, namely, self's gain, self's loss, other's gain and other's loss both for high and low pay groups. Based on visual observation of grand average waveforms and previous ERPs reports on feedback processing [23], two ERP components, namely, FRN and P300, were analyzed. We averaged the ERP amplitude of the time range of 230–330 ms and 360–460 ms for FRN and P300 analyses, respectively. According to the scalp distribution of FRN difference and the reports from previous studies [17,21], we selected six electrode sites, namely, F1, Fz, F2, FC1, FCz, and FC2 in frontal and central areas where it elicited the largest FRN amplitude for statistical analysis. In order to investigate the effect across groups, we run the four-way mixed repeated measures ANOVAs analysis for FRN and P300. The 2 (group: high and low pay) × 2 (agency: self and other) × 2 (outcome: win and loss) × 6 (electrodes) mixed-design ANOVAs analysis was conducted for FRN. To minimize the effects of overlap of the FRN with positive components and demonstrate the results more explicitly, differentiated-FRN (d-FRN), which was one's FRN in loss condition subtracted from the FRN in win condition, was also analyzed. We conducted 2 (group: high and low pay) × 2 (agency: self and other) × 6 (electrodes) mixed-design ANOVAs analysis for d-FRN. In a similar vein, we selected six electrode sites, namely, C1, Cz, C2, CP1, CPz, and CP2 in central and parietal areas for P300 analysis and also conducted 2 (agency: self and other) × 2 (outcome: win and loss) × 2 (group: high and low pay) × 6 (electrodes) mixed-design ANOVAs. Simple effect analysis was conducted when the interaction effect was significant. The Greenhouse–Geisser [28] correction was applied in all statistic analyses when necessary (uncorrected d*f* are reported with the ε and corrected *p* values). Independent sample *t* test was employed for the analysis of post-experiment altruism questionnaire difference across high and low pay groups and *Pearson* correlation analysis was conducted for the correlation between d-FRN for non-self agent and altruistic score measured by NEO subscale in high and low pay group separately.

3. Results

3.1. Behavioral results

The statistical analysis of altruism subscale indicated that no difference was found in the degree of altruism between the two groups of participants ($t(38) = 0.21$, $p \geq 0.5$). Pearson correlation analysis indicated that there were no correlations between d-FRN for others and altruistic scores both in high ($r = -0.069$, $p = 0.779$) and ($r = 0.282$, $p = 0.229$) low pay groups.

3.2. ERPs results

3.2.1. FRN

A mixed-design ANOVAs analysis for FRN showed significant main effects for agency ($F(1,38) = 37.39$, $p \leq 0.001$), outcome ($F(1, 38) = 8.12$, $p = 0.007$) and electrodes ($F(5,190) = 14.42, \varepsilon = 0.526$, $p \leq 0.001$). Moreover, the interaction effect between agency and valence was also significant ($F(1,38) = 5.21$, $p = 0.028$) and so was the interaction effect among agency, outcome and group ($F(1,38) = 4.73$, $p = 0.036$). Therefore, we ran further ANOVAs analysis on both high and low pay groups separately.

For the high pay group, the grand-averaged ERP evoked by the feedback observation for self and other collapsed across gains and losses was illustrated in Fig. 3 (top). We found significant main effects for agency ($F(1,19) = 22.48$, $p \leq 0.001$), outcome ($F(1,19) = 8.98$, $p = 0.007$), and electrode sites ($F(5,95) = 12.28$, $p \leq 0.001$, $\varepsilon = 0.601$). In general, outcome for self (9.748 μV) evoked smaller FRN (negative polarity, larger voltage means smaller amplitude) amplitude than those for others (7.104 μV). Loss outcome (7.966 μV) induced larger FRN than wins (8.886 μV). Notable interaction effect over agency and outcome was also observed ($F(1,19) = 8.45$, $p = 0.009$). Further analysis showed that no significant FRN amplitude difference exists between their own gains and losses ($F(1,19) \leq 0.01$, $p \geq 0.1$). However, significant difference was found for paired other subjects' gains and losses ($F(1,19) = 17.36$, $p \leq 0.001$), the high pay group evoked larger FRN amplitude toward losses (6.193 μV) than for wins (8.015 μV) for their counterparts.

Analysis for the low pay group showed significant main effects for agency ($F(1,19) = 15.22$, $p < 0.001$) and electrode sites ($F(1,19) = 5.25$, $p = 0.009$, $\varepsilon = 0.421$). As indicated in Fig. 3 (bottom), in general, for the participants in low pay group, their own results (11.341 μV) evoked smaller FRN amplitude than that of others (9.191 μV). However, the main effect of outcome ($F(1,19) = 1.91$, $p > 0.1$) was not significant. Interaction effect between agency and outcome was also not observed ($F(1,19) < 0.01$, $p > 0.1$).

For the d-FRN data, ANOVAs analysis showed that the main effect of agency was significant ($F(1,38) = 5.21$, $p = 0.028$), d-FRN for others (−1.225 μV) elicited prominently larger amplitude that that for themselves (−0.300 μV). However, the main effect of electrodes was not notable ($F(5,190) = 0.49$, $p \geq 0.1$). Moreover, the interaction effect between agency and group was also significant ($F(1, 38) = 4.73$, $p = 0.036, \varepsilon = 0.760$). Therefore, further analysis was conducted in both two groups respectively. For subjects in high pay group, agency effect was significant ($F(1,19) = 8.45$, $p = 0.009$). It revealed that gain loss discrepancy of others (−1.822 μV)

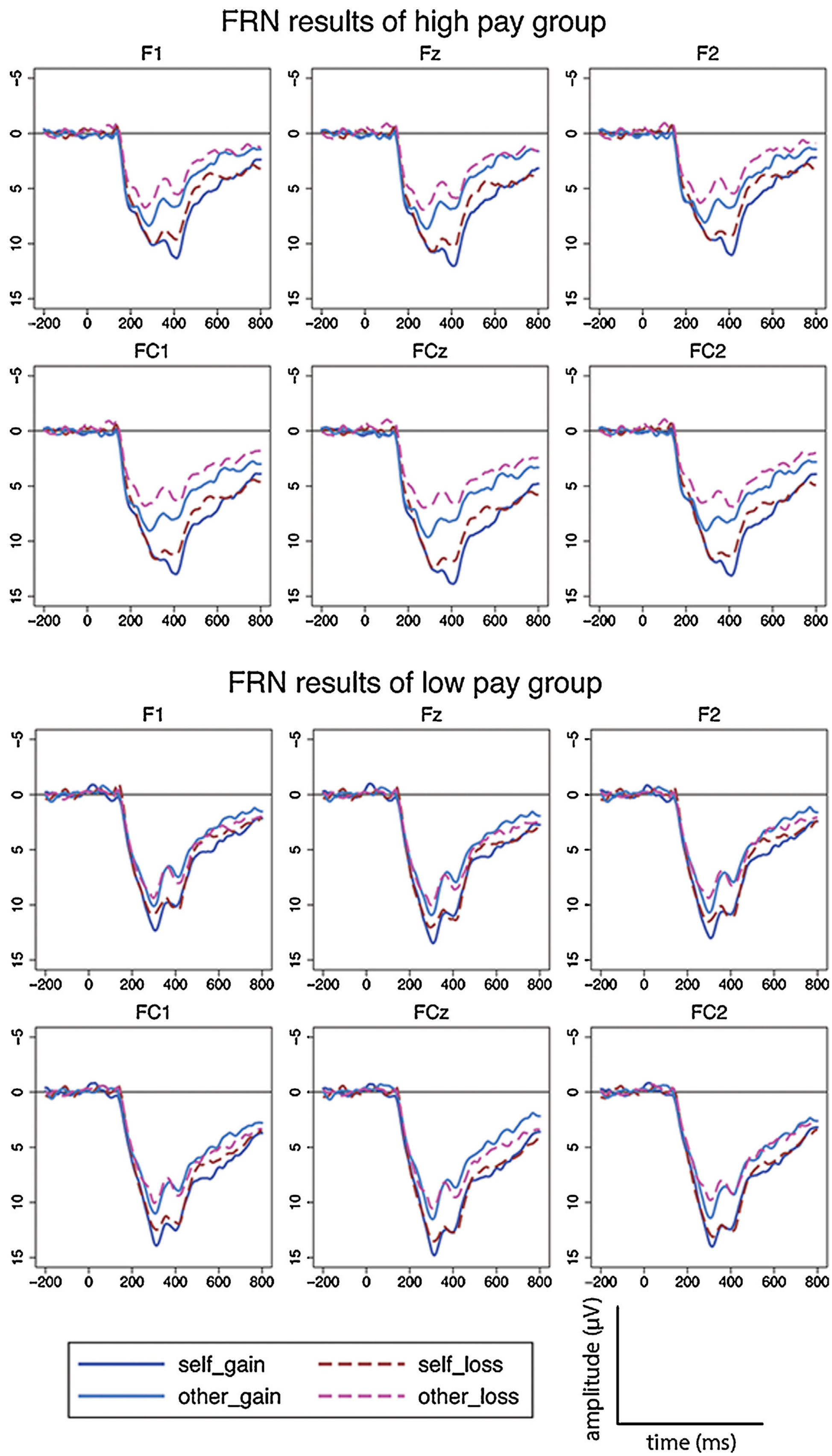

Fig. 3. FRN results. Grand-average ERP waveforms from 6 frontal electrodes (F1, FZ, F2, FC1, FCZ, FC2) as a function of agency (self and other) and outcome (gain and loss) of feedback for high (top) and low pay groups (bottom).

generated larger d-FRN amplitude than those for their own outcome (−0.584 μV). For the low pay group, we failed to find a prominent difference across agencies ($F(1,19) \leq 0.01$, $p \geq 0.1$).

3.2.2. P300

For the positive component P300, we found significant main effects for agency ($F(1,38) = 72.38$, $p \leq 0.001$), outcome ($F(1,38) = 5.95$, $p = 0.019$) and electrodes ($F(5,190) = 5.25, \varepsilon = 0.528$, $p = 0.003$) by adopting similar mixed-design ANOVAs analysis as what we did for FRN. However, the interaction effect between agency and outcome ($F(1,38) = 0.14$, $p \geq 0.1$), and the interaction effect between agency and group ($F(1,38) = 2.20$, $p \geq 0.1$) were not significant, and neither was the interaction effect among agency, outcome and group ($F(1,38) \leq 0.01$, $p \geq 0.1$). The interaction effect between outcome and group ($F(1,38) = 4.41$, $p = 0.042$) was significant. Therefore, we ran further ANOVAs analysis on both high and low pay groups separately.

As shown in Fig. 4 (top), the ANOVAs analysis revealed a main effect for agency ($F(1,19) = 44.63$, $p \leq 0.001$) for high pay group, their own outcome induced larger amplitude of P300 (13.111 μV) than that for others (8.319 μV). The main effect of outcome ($F(1,19) = 10.93$, $p = 0.004$) and electrodes ($F(5,95) = 17.16$, $p \leq 0.001$) was also significant, while the interaction effect between subjects and outcome ($F(1,9) = 0.14$, $p \geq 0.1$) was insignificant. The gain outcome (11.450 μV) elicited larger P300 amplitude than that of loss outcome (9.980 μV).

For the low pay group, as illustrated in Fig. 4 (bottom), the repeated ANOVAs analysis revealed a main effect for agency ($F(1,19) = 27.98$, $p \leq 0.001$), similar with those observed in the high pay group, their own outcome evoked larger amplitude of P300 (11.705 μV) than that for others (8.599 μV). The main effect of electrodes was not significant ($F(5,95) = 1.32$, $p \geq 0.1$, $\varepsilon = 0.393$). Moreover, the main effect of outcome ($F(1,19) = 0.05$, $p \geq 0.1$) and the interaction effect between agency and outcome ($F(1,19) = 0.03$, $p \geq 0.1$) were also insignificant.

4. Discussion

This study aimed to investigate the electrophysiological basis of pro-social behavior, more specifically, how inequality-averse social preference modulates the empathic response toward vicarious financial outcome. We hypothesized that inequality aversion would increase the empathy-related brain response of high pay group subjects when witnessing others' financial gains and losses.

In line with our prediction, for subjects in high pay group, the FRN discrepancy between gains and losses for others was prominent. However, it failed to evoke a discrepant FRN toward their own financial outcome observation over gains and losses. Moreover, the d-FRN amplitude was larger for others than those revealed amplitude toward high pay group themselves. Nevertheless, a few recent studies have reported the modulated role of FRN toward others' gains and losses [20,22,23,29]. Therefore, subjects in high pay group are more concerned about their counterparts who are in a disadvantageous situation. To the best of our knowledge, this study is the first to report the more prominent d-FRN for others as compared to those evoked for individuals themselves. As mentioned in the introduction, FRN has been reported to be involved in reflecting the motivational significance of the stimuli and has been linked to represent the increased empathic response to others' misfortunes. Additionally, these effects have also been observed in fMRI investigations. For example, in a recent study, Krach et al. (2011) found that ACC, the source of FRN, is activated by the invoked empathy for vicarious feeling of others in social pain, and such increased brain activation is positively correlated with their trait empathy [30]. Therefore, the markedly increased d-FRN in the advantageous group might indicate an increased empathic response toward others' gain–loss discrepancy due to the inequality concern, indicating the existence of egalitarianism for economics.

In neoclassical economics, economists put forward a pure self-interest maximization framework to explain the economic behavior of human beings. However, the collected data from experimental and field studies reveal that humans, in general, are willing to sacrifice a certain amount of money to defend egalitarianism of monetary distribution. This, however, concurs with Adam Smith's assertion in "the theory of moral sentiment" that "fellow-feeling" derived from egalitarianism concern can augment human beings' degree of empathic response toward others [12,31]. Therefore, the utility concern for others' incurred financial loss under low pay status is a possible explanation for the increased d-FRN toward others in a disadvantageous status. At an electrophysiological level, our results for the d-FRN of high pay group presented a further corroboration for the existence of disutility for advantageous inequality aversion, which has been integrated in behavioral economic models [13,32,33].

Furthermore, for subjects in the low pay group, we failed to find a disparity between the d-FRN comparison of self and others. The altruistic scale score comparison and its correlation with d-FRN for others indicate such a discrepancy with the d-FRN observed for high pay group is not due to the varied altruistic traits of the subjects. At first glance, this seems contrary to the previous assumptions of other-regarding preference discussed in the model by Fehr and Schmidt (1999) that subjects are more sensitive to disadvantage than advantage inequality. One possible explanation might be the lack of intentionality or responsibility from their counterpart. In a situation such as an ultimatum game, the unkind offers from the proposer induce a strong unfair experience for the responder in a disadvantage position. However, for an exact same unfair offer from the proposer but with a kind intention, such a reaction was remarkably reduced [34]. A similar reduced behavioral and brain response was observed when the computer, instead of the proposer, proposes an unfair offer [6]. In the current experiment, the status manipulation was simply fulfilled by a fair lucky draw. Thus, the subjects in the low pay group might not have a strong sense of perceiving the disadvantage situation, and hence did not exert gloating and envious attitudes toward the subjects with an advantageous status. However, as discussed above, the subjects in the high pay group who received extra money from the first stage might naturally induce altruistic empathy to seek the egalitarian distribution across the group, which is consistent with the previous evidence that participants preferred monetary transfers that can narrow down inequality in the distribution of income [35]. Therefore, both electrophysiological results of high and low pay groups indicate pro-social traits of subjects in such a social decision-making context.

In addition, the FRN modulation observed in the present study also provided evidence for the proposed models on the modulation stage of empathy. In a review paper published in 2006, de Vignemont and Singer put forward a potential framework for empathic modulation toward others' suffering and fortune [4]. They proposed two possible models, namely, an early appraisal and a late evaluation model. In the early appraisal model, the empathic stimuli are assessed based on their internal and external contexts. Therefore, appraisal per se determines whether the empathic response would occur. The late appraisal model indicates that the passive viewing of vicarious target spontaneously induces empathic response. The empathic modulation only takes effect at a subsequent stage by enhancing or weakening the automatically elicited empathy at the previous stage. Recent empathic studies on pain supported both of the proposed frameworks. Fan and Han (2008) [36] found that only a late component P300 was modulated by top–down attention allocation to others in pain at

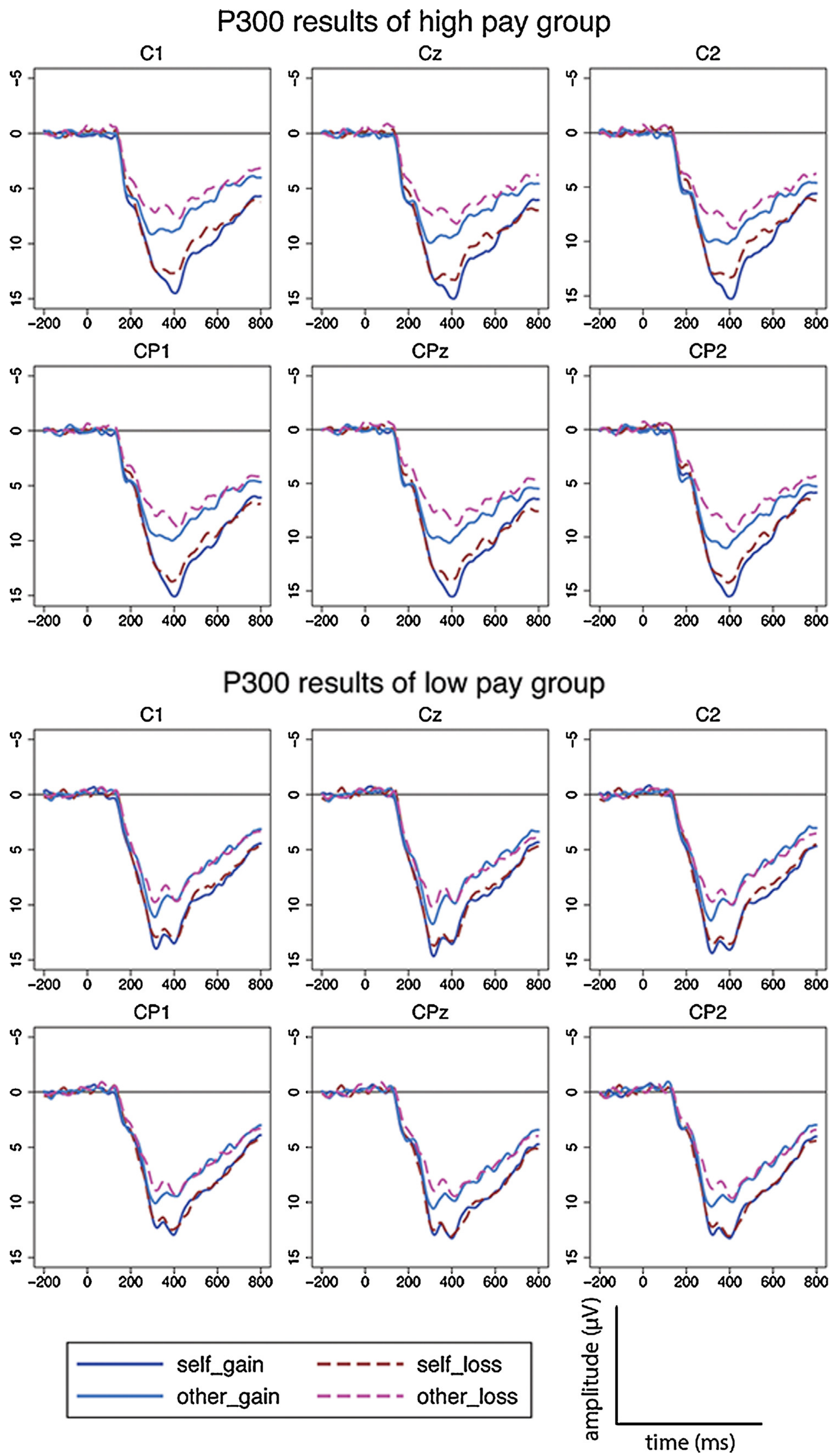

Fig. 4. P300 results. Grand-average ERP waveforms from 6 centro-parietal electrodes (C1, CZ, C2, CP1, CPZ, CP2) over agency (self and other) and outcome (gain and loss) of feedback for high (top) and low pay groups (bottom).

approximately 380 ms. However, a recent study found that early frontal–central ERP was also modulated by the down-regulated empathic response of physicians toward others in pain [37]. In current study, the dynamic change of the FRN amplitude at approximately 300 ms after the onset of the stimuli may support the early appraisal model, in accordance with recent reports that the early FRN amplitude was modulated by the perceived favor of the outcome under a different social context [25,38]. Therefore, in addition to the observed modulation effect for the primary stimuli [36,37], further studies are necessary to further resolve the exact stage for the modulation effect of empathic perception for the secondary stimuli and monetary gain and loss in the financial domain.

Meanwhile, although we observed a diversified pattern of FRN under different social contexts, a clear and stable distinction of the P300 was found between self and others, regardless of whether the participants are in high or low pay group. While majority of the studies which investigated the electrophysiological basis of social decision making mainly focused on the role of FRN and it's source region ACC (see [39,40] for latest reviews), few has paid a close attention to the exact role of P300 in such interactive settings. The FRN is regarded to reflect the subjective valuation of the valence of the outcome as we discussed above, whereas past studies indicate that the P300 mainly embodies stimulus evaluation, which are related to the motivation of the stimuli or the electrophysiological response to target stimuli in oddball task [24]. For instance, Yeung and Sanfey (2004) [27] reported that although FRN is sensitive to the valence of stimuli, P300 responds to the magnitude of the results. However, in general, we also observed a prominent P300 discrepancy between gain and loss. Such a result is in accordance with the recent studies that P300 reflects the valence of stimuli [41–43]. Therefore, to a certain extent, P300 shares an analogous role with the function of FRN over outcome evaluation.

However, the independent agency-specific effect of P300 implies that it still has special role over the salient and affective evaluation of the outcome, which is also consistent with several recent studies. For example, as mentioned in the introduction, in an recent study by Leng and Zhou [23] on the modulating role of friendship over monetary outcome, while there is no obvious differentiated FRN difference between friend and stranger, they still observed a prominent P300 discrepancy across different agents: self, friend and stranger. Such a behavioral pattern was also observed in our recent study adopting a similar experimental paradigm (2011). Moreover, both Itagaki and Katayama (2008) [44] and Fukushima and Hiraki (2006, 2009) [22,29] observed more pronounced P300 amplitude for self compared with other condition although they either didn't report the data explicitly in their results or didn't pay attention to it in their discussion. Particularly for Itagaki and Katayama's (2008) study, they observed a reversal of the FRN difference under different experimental manipulation in two experiments. However, in both experiments, there was still a stable and prominent P300 toward self rather than for their counterparts [44]. P300 results observed in current study over outcome processing in high and low pay groups are generally compatible with such results and, to some extent, go beyond that. Unlike what Itagaki and Katayama's (2008) did, other's gain and loss wouldn't impact self's monetary reward or punishment directly. Additionally, different from recent studies mentioned above, the gain/loss outcome for self was determined by computer's selection rather than from direct self-execution. One explanation of such an observed effect might be that, human, by its nature, are self-centered, no matter in self-execution or passive observation context. For instance, in a latest review on the EEG basis of self-referential processing, Knyazev summarized that disparities between self- and other-related information is mainly associated with the P300 component [45]. Subjects' own face or self-relevant pronouns could elicit significantly larger P300 than non self-relevant information. By incorporating the results that gain loss discrepancy was also prominent for P300, we suggest that the P300 might, in general, demonstrate participants' overall evaluation of the outcome at the relatively late stage of outcome evaluation. Therefore, current findings are in line with the several previous studies and extend them into social settings that P300 played a dissociated role from FRN during outcome evaluation [21,46].

5. Conclusion

In summary, this study investigated the neural mechanism of how inequality-averse social preference modulates empathy toward others in gambling tasks involving financial gains and losses. When the participants were in high pay group, we observed an enhanced FRN toward others' gains and losses. Meanwhile, when the participants were in low pay group, they demonstrate a similar reaction toward their own and others' financial outcome. P300 components, however, were larger for themselves than for others regardless of their social status, indicating a more conspicuous egocentric salience for self. Therefore, using simple economic status manipulation, this study indicates that advantageous status enhances FRN's response toward others' monetary gains and losses. This finding has empirical and theoretical significance in confirming the existence of utilitarian-seeking and complements recent advancement on research on inequality aversion. One limitation of present study is that we only recruited the male subjects for experimental investigation. Therefore, further studies on both male and female subjects are necessary to extend current findings into general population.

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References

[1] Bernhardt BC, Singer T. The neural basis of empathy. Annu Rev Neurosci 2012;35:1–23.
[2] Frith CD, Singer T. The role of social cognition in decision making. Philos Trans R Soc B Biol Sci 2008;363:3875–86.
[3] Hein G, Singer T. I feel how you feel but not always: the empathic brain and its modulation. Curr Opin Neurobiol 2008;18:153–8.
[4] de Vignemont F, Singer T. The empathic brain: how, when and why. Trends Cogn Sci 2006;10:435–41.
[5] Mobbs D, Marchant JL, Hassabis D, Seymour B, Tan G, Gray M, et al. From threat to fear: the neural organization of defensive fear systems in humans. J Neurosci 2009;29:12236–43.
[6] Sanfey AG, Rilling JK, Aronson JA, Nystrom LE, Cohen JD. The neural basis of economic decision-making in the ultimatum game. Science 2003;300: 1755–8.
[7] Singer T, Seymour B, O'Doherty JP, Stephan KE, Dolan RJ, Frith CD. Empathic neural responses are modulated by the perceived fairness of others. Nature 2006;439:466–9.
[8] Fliessbach K, Weber B, Trautner P, Dohmen T, Sunde U, Elger CE, et al. Social comparison affects reward-related brain activity in the human ventral striatum. Science 2007;318:1305–8.
[9] Haruno M, Frith CD. Activity in the amygdala elicited by unfair divisions predicts social value orientation. Nat Neurosci 2010;13:160–1.
[10] Gospic K, Mohlin E, Fransson P, Petrovic P, Johannesson M, Ingvar M. Limbic justice-amygdala involvement in immediate rejection in the ultimatum game. Plos Biol 2011;9:e1001054.
[11] Wright ND, Symmonds M, Fleming SM, Dolan RJ. Neural segregation of objective and contextual aspects of fairness. J Neurosci 2011;31: 5244–52.

[12] Dawes CT, Loewen PJ, Schreiber D, Simmons AN, Flagan T, McElreath R, et al. Neural basis of egalitarian behavior. Proc Natl Acad Sci USA 2012;109:6479–83.
[13] Fehr E, Schmidt KM. A theory of fairness, competition, and cooperation. Q J Econ 1999;114:817–68.
[14] Krajbich I, Adolphs R, Tranel D, Denburg NL, Camerer CF. Economic games quantify diminished sense of guilt in patients with damage to the prefrontal cortex. J Neurosci 2009;29:2188–92.
[15] Tricomi E, Rangel A, Camerer CF, O'Doherty JP. Neural evidence for inequality-averse social preferences. Nature 2010;463:U1089–99.
[16] Holroyd CB, Coles MGH. The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychol Rev 2002;109:679.
[17] Nieuwenhuis S, Yeung N, Holroyd CB, Schurger A, Cohen JD. Sensitivity of electrophysiological activity from medial frontal cortex to utilitarian and performance feedback. Cereb Cortex 2004;14:741–7.
[18] Gehring WJ, Willoughby AR. The medial frontal cortex and the rapid processing of monetary gains and losses. Science 2002;295:2279–82.
[19] Yu R, Zhou X. Brain responses to outcomes of one's own and other's performance in a gambling task. Neuroreport 2006;17:1747.
[20] Marco-Pallares J, Kramer UM, Strehl S, Schroder A, Munte TF. When decisions of others matter to me: an electrophysiological analysis. BMC Neurosci 2010;11:1–8.
[21] Yeung N, Sanfey AG. Independent coding of reward magnitude ad valence in the human brain. J Neurosci 2004;14:6258–64.
[22] Fukushima H, Hiraki K. Whose loss is it? Human electrophysiological correlates of non-self reward processing. Soc Neurosci 2009;4:261–75.
[23] Leng Y, Zhou XL. Modulation of the brain activity in outcome evaluation by interpersonal relationship: an ERP study. Neuropsychologia 2010;48:448–55.
[24] Nieuwenhuis S, Aston-Jones G, Cohen JD. Decision making, the p3, and the locus coeruleus–norepinephrine system. Psychol Bull 2005;131:510–32.
[25] Ma QG, Shen Q, Xu Q, Li DD, Shu LC, Weber B. Empathic responses to others' gains and losses: an electrophysiological investigation. Neuroimage 2011;54:2472–80.
[26] Semlitsch HV, Anderer P, Schuster P, Presslich O. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology 1986;23:695–703.
[27] Yeung N, Holroyd CB, Cohen JD. ERP correlates of feedback and reward-processing in the presence and absence of response choice. Cereb Cortex 2005;15:535–44.
[28] Greenhouse SW, Geisser S. On methods in the analysis of profile data. Psychometrika 1959;24:95–112.
[29] Fukushima H, Hiraki K. Perceiving an opponent's loss: gender-related differences in the medial-frontal negativity. Soc Cogn Affect Neurosci 2006;1:149–57.
[30] Krach S, Cohrs JC, Loebell NCD, Kircher T, Sommer J, Jansen A, et al. Your flaws are my pain: linking empathy to vicarious embarrassment. PLoS ONE 2011;6:e18675.
[31] Smith A. The theory of moral sentiments. London: A Millar; 1759.
[32] Bolton GE, Ockenfels AERC. A theory of equity, reciprocity, and competition. Am Econ Rev 2000;90:166–93.
[33] Camerer CF, Fehr E. When does "economic man" dominate social behavior. Science 2006;311:47–52.
[34] Falk A, Fehr E, Fischbacher U. Testing theories of fairness – intentions matter. Games Econ Behav 2008;62:287–303.
[35] Loewenstein GF, Thompson L, Bazerman MH. Social utility and decision making in interpersonal contexts. J Pers Soc Psychol 1989;57:426–41.
[36] Fan Y, Han SH. Temporal dynamic of neural mechanisms involved in empathy for pain: an event-related brain potential study. Neuropsychologia 2008;46:160–73.
[37] Decety J, Yang CY, Cheng YW. Physicians down-regulate their pain empathy response: an event-related brain potential study. Neuroimage 2010;50:1676–82.
[38] Kang SK, Hirsh JB, Chasteen AL. Your mistakes are mine: self-other overlap predicts neural response to observed errors. J Exp Soc Psychol 2010;46:229–32.
[39] Thoma P, Bellebaum C. Your error's got me feeling – how empathy relates to the electrophysiological correlates of performance monitoring. Front Hum Neurosci 2012;6:135.
[40] Lavin C, Melis C, Mikulan E, Gelormini C, Huepe D, Ibañez A. The anterior cingulate cortex: an integrative hub for human socially-driven interactions. Front Neurosci 2013;7:64.
[41] Polezzi D, Sartori G, Rumiati R, Vidotto G, Daum I. Brain correlates of risky decision-making. Neuroimage 2010;49:1886–94.
[42] Rigoni D, Polezzi D, Rumiati R, Guarino R, Sartori G. When people matter more than money: an ERPs study. Brain Res Bull 2010;81:445–52.
[43] Wu Y, The Zhou XL. P300 and reward valence, magnitude, and expectancy in outcome evaluation. Brain Res 2009;1286:114–22.
[44] Itagaki S, Katayama J. Self-relevant criteria determine the evaluation of outcomes induced by others. Neuroreport 2008;19:383–7.
[45] Knyazev GG. EEG correlates of self-referential processing. Front Hum Neurosci 2013;7:264.
[46] Sato A, Yasuda A, Ohira H, Miyawaki K, Nishikawa M, Kumano H, et al. Effects of value and reward magnitude on feedback negativity and P300. Neuroreport 2005;16:407–11.