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Modulation of the brain activity in outcome evaluation by interpersonal relationship: An ERP study

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ABSTRACT

Previous event-related potential (ERP) studies employing monetary gambling tasks have demonstrated that the brain responds differentially not only to one's own gain and loss but also to the others' gambling outcomes. Empathy and motivational significance are implicated in the processes of outcome evaluation. This study is to explore to what extent the brain activity is modulated by the interpersonal relationship between the individual and the other agent, who can be a friend or a stranger. Brain potentials were recorded while the participant observed reward feedback to his/her own, his/her friend's, or a stranger's performance in a gambling task. The magnitude and latency of the effect on an early ERP component, the FRN, did not differ between the friend- and the stranger-observation conditions, whereas a late component, the P300, was modulated not only by reward valence but also by the interpersonal relationship between the observer and the other agent. These findings suggest that brain responses in outcome evaluation may be divided into an earlier semi-automatic process and a later cognitive appraisal process and that the interpersonal relationship comes into play mostly in the late attention-sensitive stage.

1. Introduction

To perform efficiently in the environment, one has to be able to evaluate the outcome of his/her action as quickly as possible and use the positive or negative feedback to guide his/her future behavior. Outcome evaluation is an important ability for adaptive control of behavior and evolution may have forced the brain to develop special mechanisms to assess the valence, the magnitude, and other aspects of outcome, linking feedback information with subjective, motivational significance. Neurophysiological studies on outcome evaluation have found a special event-related potential (ERP) component that is particularly sensitive to the valence of outcome. This component, called feedback-related negativity (FRN), is a negative deflection at frontocentral recording sites that reaches maximum between 200 and 300 ms following the onset of feedback stimulus (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005; Hajcak, Moser, Holroyd, & Simons, 2006; Hajcak, Moser, Holroyd, & Simons, 2007; Holroyd & Coles, 2002; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; Holroyd, Larsen, & Cohen, 2004; Holroyd, Hajcak, & Larsen, 2006; Miltner, Braun, & Coles, 1997; Nieuwenhuis, Holroyd, Mol, & Coles, 2004; Yeung & Sanfey, 2004; Yeung, Holroyd, & Cohen, 2005; Yu & Zhou, 2006a; Yu & Zhou, 2006b). The FRN is more pronounced for negative feedback associated with unfavorable outcomes, such as incorrect responses or monetary losses, than for positive feedback. Another ERP component, the P300, which is the most positive peak in the period of 200–600 ms post-onset of feedback and which typically increases in magnitude from frontal to parietal electrodes, has also been found to be related to various aspects of outcome evaluation (Hajcak et al., 2005; Holroyd & Coles, 2002; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Sato et al., 2005; Wu & Zhou, 2009; Yeung & Sanfey, 2004; Yeung et al., 2005).

The FRN effect is commonly accounted for by the reinforcement-learning theory (Holroyd & Coles, 2002; Nieuwenhuis et al., 2004; Yeung, Botvinick, & Cohen, 2004), which suggests that the FRN reflects the coding of prediction error. According to this theory, the FRN reflects the impact of the midbrain dopamine signals on the anterior cingulated cortex (ACC). The phasic decreases in dopamine inputs elicited by negative prediction errors (i.e., "the result is worse than expected") give rise to the increased ACC activity that is reflected as larger FRN amplitudes. The phasic increases in dopamine signals elicited by positive prediction errors (i.e., "the result is better than expected") give rise to decreased ACC activ-

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ity that is reflected as smaller FRN amplitudes. These signals are used to guide action selection mediated by the ACC, through the reinforcement of action associated with positive reward and the punishment of action associated with negative outcomes. Recent studies showed that the prediction error can be defined not only in terms of the valence of outcome but also in terms of whether the outcome fits pre-established, non-valence expectancy (Jia et al., 2007). Wu and Zhou (2009), for example, found that when the amount of reward, whether positive or negative, is not consistent with expectancy towards reward magnitude established by a prior cue, the FRN effect is observed.

Other researchers suggest that the FRN effect does not reflect the cognitive processes of evaluating performance or detecting prediction errors *per se*, but rather, it reflects the processes of assessing the motivational/affective impact of the outcome events (i.e., the processes of putting subjective values onto the outcomes; Gehring & Willoughby, 2002; Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006; Yu, Luo, Ye, & Zhou, 2007). Yeung et al. (2005) demonstrated that the FRN can also be elicited by outcomes that are not contingent upon recent actions. This observation has been taken to suggest that the FRN reflects an evaluation of the motivational impact of outcomes and as such is associated with feedback signals in general instead of with feedback signals specifically related to recently executed actions. Recent studies also showed that the FRN effect can be observed not only in situations in which the individual himself/herself performs a task (e.g., gambling) and receives positive or negative feedback, but also in situations in which the individual observes another, unrelated stranger performing the task and receiving reward. Yu and Zhou (2006a), for example, asked the participant to play a game round-by-round, in alternation, with a stranger over the computer network. In the "self-execution" condition the participant made a selection from the presented cards and received monetary feedback concerning his performance; in the "observation" condition, the participant saw the other person's choice and the associated outcome. Rewards in the two conditions were independent, with the other's gain or loss having no impact upon the observer's own gain or loss. The differential FRN effect between the negative and positive feedback was found not only in the self-execution condition, but also in the observation condition. Moreover, these two effects were similar in terms of latency and morphology, although not in terms of magnitude (see also van Schie, Mars, Coles, & Bekkering, 2003). Itagaki and Katayama (2008) not only replicated but also extended these findings by showing that, when the stranger becomes an antagonist in the game and his gain produces a monetary penalty on the observer, the stranger's gain elicits a more negative-going FRN than his/her loss on the observer (see also Fukushima & Hiraki, 2006). The latter finding, consistent with Yeung et al. (2005), indicates that whether an outcome is regarded as positive or negative depends on its relevance to the self-interest of the observer. Hewig et al. (2008) extended this point by showing that the rejection of one's advice in a coaching situation elicits an FRN effect similar to the effect when one receives negative feedback concerning his/her own behavior.

It is clear from the above studies that the social relationship between the observer and the other person (stranger vs. antagonist, advisor vs. advisee) affects the pattern of the FRN effect, although it is not clear through what processes the FRN is modulated. To the reinforcement theory of the FRN, the ACC uses reward signal not only to reinforce representations of one's own actions (i.e., instrumental conditioning), but also to learn (or to attempt to learn) about contingencies in the external environment (i.e., observational learning). This covert learning allows the observer to learn without actually doing something or suffering from its negative consequences (Yeung et al., 2005; Yu & Zhou, 2006a). However, this theory would need additional assumption when explaining why observing an antagonist's performance would elicit a reversed pattern of the FRN effect as to observing a stranger's performance (Itagaki & Katayama, 2008). It has to assume that the antagonist's performance should not be evaluated by the direct positive or negative feedback (i.e., winning or losing money) presented on the screen, but by the relevance of the feedback to the observer' self-interests. The determination of the relevance involves empathetic or meta-cognitive processes that the reinforcement theory of the FRN may or may not want to get into. On the other hand, it is rather straightforward for the motivational account of the FRN to accommodate these findings. The reduced FRN effect in observing strangers' reward feedback (Itagaki & Katayama, 2008; Yu & Zhou, 2006a) or the reversed FRN effect in observing antagonists' reward feedback (Fukushima & Hiraki, 2006; Itagaki & Katayama, 2008) reflects simply the reduced or reversed motivational/affective significance of the others' outcomes to the observer. Although the observer may be empathetic to a stranger's loss in a game, observation of this person's performance does not elicit strong emotional responses in the observer when the observed performance and reward have no direct relationship with the observer's self-interest. In the same vein, to the observer, an antagonist's gain means his/her own loss while the antagonist's loss is music to his/her ears.

The main purpose of this study is to investigate further to what extent the event-related neurophysiological responses in outcome evaluation can be modulated by interpersonal relationship. Beyond the factors examined by previous studies, we introduced a new variable for the interpersonal relationship, i.e., the friendship between an observer and other agents in the monetary game. Similar to Yu and Zhou (2006a), the main participant in this experiment played a three-person gambling task with others round-by-round, in alternation. Although the gain and loss were assessed independently for each participant, the other person could be a close friend of the main participant or a total stranger. The empirical question is whether the brain responses, in particular the FRN and the P300, in observing feedback to the others' monetary reward, are modulated by the interpersonal relationship between the main participant and other persons.

On the basis of previous findings, we expected to observe a larger FRN effect and a larger P300 effect between negative and positive feedback in the self-execution condition than in the stranger-observation condition. The augment of the differential effects in the former condition can be related to the action of selecting cards and/or to the involvement of self-interest in assessing the motivational/affective significance of outcomes (Yeung et al., 2005). It is less straightforward, however, to make predictions for the comparison between the friend- and the stranger-observation conditions. If the interpersonal relationship comes into play very early in outcome evaluation, we would expect to see its impact upon both the FRN and the P300. After all, a friend's gain or loss is more pertinent to the observer's self-interest than a stranger's and would be more likely to incur affective/empathetic responses on the observer.

If, on the other hand, outcome evaluation entails both automatic (reflexive) and intentional (attentional) processes, the interpersonal relationship may be able to affect the later, attention-sensitive process of outcome evaluation and the associated neural activity, as indexed by the P300, but not the early semi-automatic process, as possibly indexed by the FRN. Such distinction between automatic and controlled evaluative processes has been incorporated into behavioral theories on attitude and social evaluation (Devine, 1989; Fazio, 2001; Greenwald & Banaji, 1995; Greenwald et al., 2002; Wilson et al., 2000; see Cunningham & Zelazo, 2007 for a new formulation). A number of fMRI and ERP studies on social evaluation, empathy, and friendship provide evidence from brain activity supporting this distinction (Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003; Cunningham, Raye, & Johnson, 2004; Fan & Han, 2008; Goubert et al., 2005; Winston, Stranger, O'Doherty, & Dolan, 2002). Fan and Han (2008), for example, presented the participant with pictures or cartoons of hands that were in painful or neutral situations and manipulated top-down attentional set by requiring the participant to perform either a pain judgment task or a finger counting task. They found that an early effect over the frontal lobe (starting at 140 ms after stimulus presentation) was modulated by contextual reality of stimuli, but not by top-down attention to the pain cues, although this effect correlated with subjective reports of the degree of perceived pain of others and of self-pleasantness. It is possible that the FRN is related to an initial, coarse evaluation for motivational/affective significance which may distinguish between the "self" and others but which may not distinguish between a friend and a stranger. This coarse evaluation is followed by more elaborative evaluation, in which the allocation of the observer's attentional resources could be affected by the interpersonal relationship in a top-down controlled manner. The P300, which is sensitive to the allocation of attentional resources, could then be modulated by this relationship, with the friend-observation condition producing more positive ERP responses than the stranger-observation condition.

2. Methods

2.1. Participants

Fourteen pairs of graduate students (6 female pairs and 8 male pairs) were recruited through the University intranet. Members of each pair were self-reported good friends. The mean age of the main participants undergoing the EEG test was 23.5 years, ranging between 23 and 28 years. They were paid 40 Chinese yuan (about $6) as basic payment, with additional monetary rewards paid depending on their performance in the gambling task. Two graduate students (1 female and 1 male, aging 23 and 24 years respectively), who were strangers to the friend pairs, were recruited as confederates. All the participants were right-handed and had normal or corrected-to-normal vision. They had no history of neurological or psychiatric disorders. Informed consents were obtained from them before the experiment, which was approved by Academic Committee of the Research Center for Learning Science, Southeast University, China.

2.2. Apparatus and procedure

When a pair of same-sex friends came to the laboratory, they decided by themselves which one of them underwent the EEG test. They were told that they would play a game and get reward individually and independently but would see the other's as well as a stranger's performance through the computer network. While the EEG participant would sit inside a sound-and-electronically shielded chamber, his/her friend and a same-sex stranger, played by a confederate, would sit in other rooms, playing the game through the computer network. Thus the experiment had two main factors: agency (self, friend, or stranger) and valence of reward (gain or loss). The EEG participant was asked to pay attention to his/her own as well as the others' performance. He/she was informed that the value of the outcome in each round of gamble would be added to or subtracted from the basic payment awarded to him/her, and he/she should earn as much as possible by using whatever strategies he/she could appeal to.

The EEG participant was seated about 1 m in front of a Dell 22-in. CRT display (screen resolution: 1024×768, refresh rate: 120 Hz, color quality: highest 32 bit). Each trial began with the presentation of one of the three participant's name above a fixation sign (a white dot subtended 0.4° of visual angle) against black background (see Fig. 1). After 500 ms, two gray cards (each subtended $2.3 \times 3.2°$, separated for 3.7° between the centers of the cards) were presented on the left and the right side of the fixation sign, respectively. After another 500 ms, the numeral 5 and 25 (white and size 28, font Courier, bold) appeared at the center of the gray cards, respectively. The numerals here represented the amount of money involved in the current round of gamble, with "25" representing 2.5 yuan and "5" representing 0.5 yuan. The named participant was asked to press one of the two buttons on the joystick to select one number and his/her choice was highlighted by the thickening of the white outlines of the card. After further 500 ms, the background of the selected card turned red or green for 1000 ms, to indicate whether the named participant had gained or lost the amount of money indicated by the chosen numeral. The assignment of the two colors as "gain" and "loss" was counterbalanced over participants. To emphasize the valence and the magnitude of outcome and to attract the participant's attention, the "+" or "−" symbol was added before the numeral to represent the gain/loss statue of the outcome.

The EEG participant was asked to pay attention to the selection of cards as well as to the monetary feedback in each round of gamble even if this round was for his/her friend or for the stranger. In fact, without the participant's knowledge, the friend's or the stranger's selection of card and the outcome feedback were predetermined by a computer program, such that the four types of outcomes (+25, +5, −5, −25) had equal frequencies of appearance for both the friend- and the stranger-observation conditions. The gain/loss status of the participant's chosen numeral was also determined by a pre-specified pseudorandom sequence, with half the times gaining and another half losing.

Each experimental block began with a trial for the stranger, followed by a trial for the friend, finally a trial for the EEG participant. Then this sequence was repeated to the end of this block. The experiment task was administered on a Pentium IV computer, with Presentation software (Neurobehavioral System Inc.) to control the presentation and timing of stimuli. The experiment consisted of 16 blocks of 60 trials each. Each block had 20 trials for the "self-execution", "friend-observation" and "stranger-observation" conditions respectively. The current state of reward was communicated to the EEG participant at the end of each block. A practice block was administered before the formal test.

2.3. EEG recording and analysis

EEGs were recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc. Herndon, Virginia, USA) according to the international 10–20 system, with the reference on the left mastoid. Eye blinks were monitored with electrodes located above and below the right eye. The horizontal electro-oculogram (EOG) was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. All electrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05–70 Hz band-pass and continuously sampled at 500 Hz for offline analysis.

Separate EEG epochs of 700 ms (with 100 ms pre-stimulus baseline) were extracted offline, time-locked to the onset of feedback stimuli. Epochs were re-referenced offline to the linked mastoid electrodes. Ocular artifacts were corrected with an eye-movement correction algorithm which employs a regression analysis in combination with artifact averaging (Semlitsch, Anderer, Schuster, & Presslich, 1986). Epochs were baseline-corrected by subtracting from each sample the average activity of that channel during the baseline period. All trials in which EEG voltages exceeded a threshold of $\pm 60\ \mu V$ during recording were excluded from further analysis. The EEG data were low-pass filtered below 30 Hz.

The analyzed ERP components included the FRN, P300, and a late positivity. To minimize the overlap between the FRN and other ERP components, we created difference waves for the three agency conditions by subtracting the ERP responses to the gain trails from the loss trials. According to their manifestations in the difference waves, the FRN effects for the three agency conditions were defined as the most negative values on the anterior electrodes in the 200–400 ms time window. The peak value of the P300 component on the posterior electrodes was detected as the most positive value in the 250–600 ms time window. The late positivity effect was defined as the difference between mean amplitudes of the gain and loss trials within the 550–650 ms time window. For statistical analyses, we focused on 10 anterior electrodes, F3, F1, Fz, F2, F4, and FC3, FC1, FCz, FC2, FC4, on which the FRN was the greatest, and 10 posterior electrodes, CP3, CP1, CPz, CP2, CP4, and P3, P1, Pz, P2, P4, on which the P300 was the greatest. Analysis of variance (ANOVA) was conducted with four within-participant factors: agency (self, friend, stranger), valence (gain, loss), and two electrode position factors (laterality and row). The reward magnitude was not treated as a factor in this study because in the preliminary analysis it showed neither the main effect nor interaction with experimental factors in the selected time windows. The Greenhouse–Geisser correction for violation of the ANOVA assumption of sphericity was applied where appropriate. Bonferroni correction was used for multiple comparisons.

3. Results

3.1. Behavior results

Participants gained on average 2.3 yuan for extra monetary reward at the end of experiment. For the self-execution condition, the distribution of the participants making their bets and getting rewards was as following: gain "25" (28.31%, SD = 5.48%), loss "25" (27.50%, SD = 5.06%), gain "5" (22.07%, SD = 5.09%), loss "5" (22.12%, SD = 2.76%). Analysis of variance (ANOVA) on the proportion of the selected bet (i.e., reward magnitude: 5 vs. 25) and the valence of outcome (gain vs. loss) as two within-participant factors revealed only a main effect of magnitude, $F(1, 13) = 5.10$, $p < .05$. Neither the main effect of valence nor the interaction between magnitude and valence reached significance, $p > .1$. Clearly participants on average tended to select the bigger bet but chances of win and loss were equivalent for either the bigger or the smaller bet. All of the participants reported orally after the experiment that they paid attention to their own as well as to their friends' and the stranger's performance.

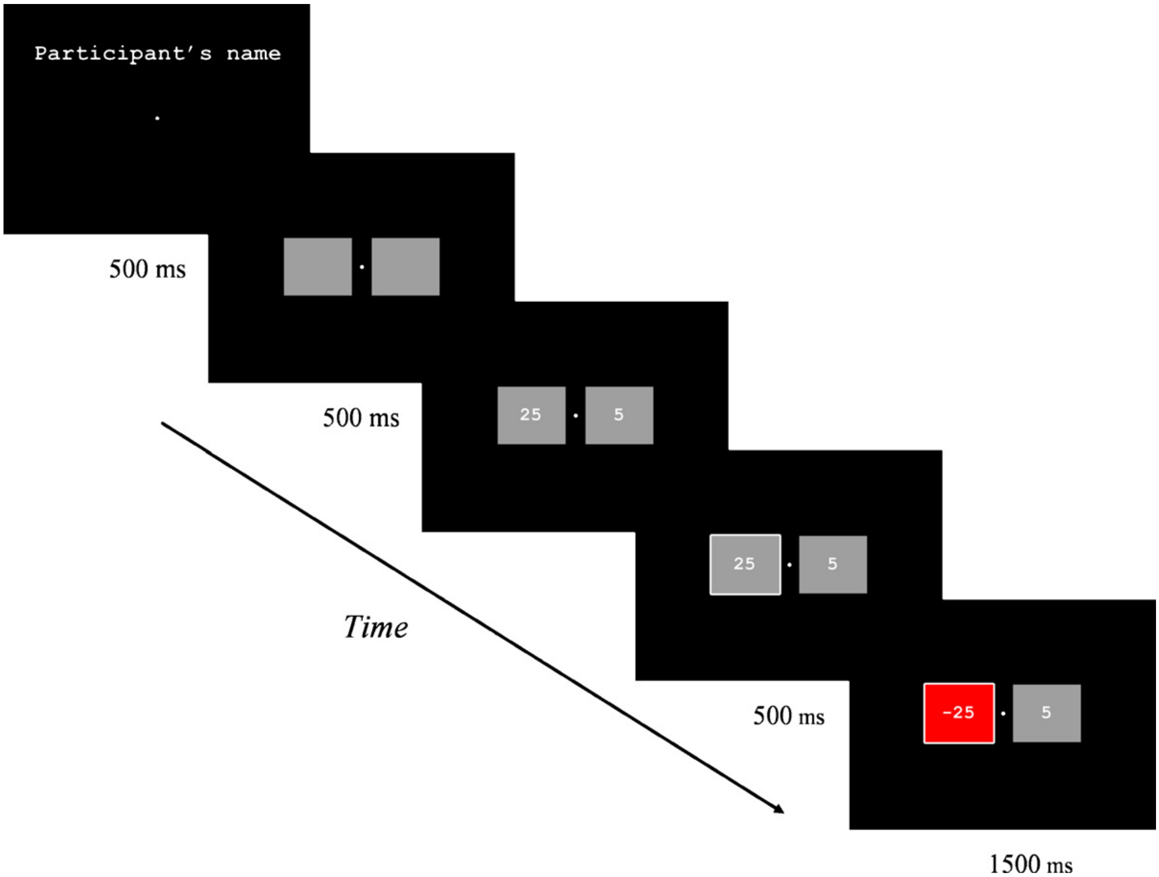

Fig. 1. Sequence of events in a single trial. The participant was presented on each trial with the name of a gambler printed above the fixation sign.

3.2. The FRN effects

There are different ways to measure the FRN or the FRN effect. We first measured the mean amplitudes in the 200–240 ms time window for the three agency conditions (see Fig. 2). ANOVA with agency (self, friend, stranger), reward valence (win, loss), laterality (midline, and two electrode positions further away from the midline, to the left and the right respectively; see the Method section) and row (Fz row, FCz row) as four within-participant factors found a significant main effect of valence, $F(1, 13) = 21.30$, $p < .001$, with ERP responses being more negative-going after the loss feedback (7.63 μV) than after the gain feedback (9.69 μV). There was also a significant main effect of agency, $F(2, 26) = 48.81$, $p < .001$, with ERP responses to one's own performance being the most positive (14.31 μV), followed by responses to the friend's performance (6.16 μV) and to the stranger's performance (5.51 μV). The difference between the latter conditions did not reach significance ($p > 0.1$). Importantly, the interaction between agency and valence was significant, $F(2, 20) = 6.38$, $\varepsilon = 0.78$, $p < .01$, suggesting that the sizes of the FRN effects differed between the conditions. Test of the simple effect showed that there was a significantly larger FRN effect (−4.13 μV) in the self-execution condition relative to the friend- or the stranger-observation conditions (−1.17 and −0.87 μV, respectively; $p < .05$). To check whether the FRN effects differed between the friend- and the stranger-observation conditions, we conducted ANOVA over the two conditions and obtained a significant main effect of valence, $F(1, 13) = 8.32$, $p < .05$, but no interaction between valence and agency, $F(1, 13) < 1$, nor a main effect of agency, $F(1, 13) = 2.98$, $p > .01$. These findings indicate that ERP responses to the friend's and the stranger's performance were similar, with the FRN effect being only slightly larger in the friend-observation condition than in the stranger-observation condition.

A potential problem with the above analysis of the FRN effect is that the computation of mean amplitudes for different experimental conditions could have been affected by the following P300. To minimize the potential confound and to get convergent evidence, we computed the loss-minus-gain differences for different agency conditions and used the peak values of the difference waves in the 200–400 ms time window (Fig. 2) as measures of the FRN effect (Cohen & Ranganath, 2007; Hajcak et al., 2005, 2007). ANOVA with agency, row, and laterality as three within-participant factors found a significant effect of agency, $F(2, 24) = 7.33$, $\varepsilon = .906$, $p < .05$. Bonferroni-corrected pairwise comparisons showed that the FRN effect for one's own performance (−6.32 μV) was significantly stronger ($p < .05$) than the effect for his/her friend's (−3.50 μV) or the stranger's performance (−3.26 μV), with no difference between the latter two ($p > .1$). These results replicated the main findings in the above analysis. It should be noted that the same pattern of the anterior FRN effects were observed when we filtered the EEG data with a 2–20 Hz bandpass to remove further the potential confounding from the P300 (Donkers, Nieuwenhuis, & van Boxel, 2005; Heldmann, Rüsseler, & Münte, 2008; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). The same pattern of the FRN effects were also observed when we measured the FRN effects in terms of mean amplitudes in different time windows for the three agency conditions (i.e., 200–280 ms for the self-execution condition and 260–360 ms for the friend-observation and the stranger-observation conditions; see Fig. 2).

Additional analysis was also conducted for the peak latencies of the FRN effects shown in the difference waves in the 200–400 ms time window (Fig. 2), with agency, laterality, and row as three

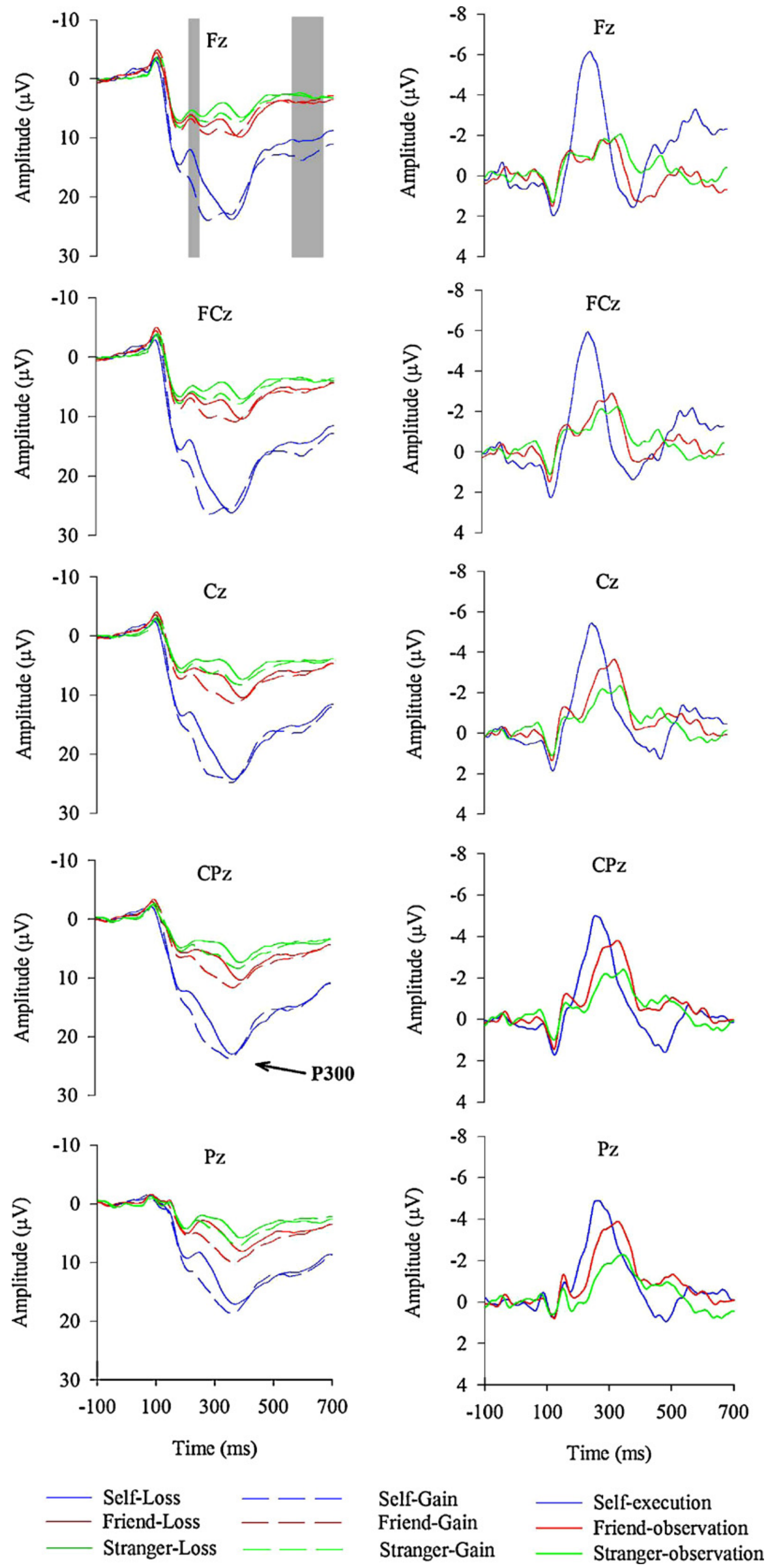

Fig. 2. Grand average waveforms and the ERP difference waves collapsed over reward magnitudes at 5 midline electrodes: Fz, FCz, Cz, CPz, Pz, post-onset of the feedback stimuli. The left lane: grand-average ERP responses to loss trials (solid line) and gain trials (dash line), in the self-execution condition (blue lines), the friend-observation condition (red lines), and the stranger-observation condition (green lines). The gray shaded areas indicate FRN analysis window (200–240 ms) for mean amplitudes and the late positivity analysis window (550–650 ms), although other time windows were also selected for the measurement of the FRN effects (see text). The P300 was measured as the most positive peak value in the 250–600 ms time window. The right lane: the ERP difference waveforms (loss-minus-gain) for the self-execution (blue line), the friend-observation (red line), and the stranger-observation (green line) conditions.

within-participant factors. There was only a significant main effect of agency, $F(2, 23) = 141.85$, $\varepsilon = .896$, $p < .001$. Bonferroni-corrected pairwise comparisons showed that the FRN effect reached its peak earlier in the self-execution condition (234 ms post-onset) than in the friend-observation (336 ms) or the stranger-observation (343 ms) condition, $p < .001$, whereas the difference between the latter conditions two did not reach significance, $p > .1$

3.3. The P300 effects

ANOVA with the four within-participant factors (agency, valence, laterality and row of posterior electrodes) revealed a significant main effect of agency, $F(2, 26) = 155.86$, $p < .001$, indicating that the mean peak amplitude of the P300 was larger for the self-execution condition (20.89 μV) than for the friend-observation condition (11.51 μV) or the stranger-observation condition (8.64 μV; see Fig. 2). The differences between conditions were all significant in the Bonferroni-corrected pairwise comparisons, $p < .001$. The main effect of valence was also significant, $F(1, 13) = 5.52$, $p < .05$, with the P300 being more positive for the gain trials (14.34 μV) than for the loss trials (13.02 μV). The interaction between valence and agency was not significant, $F(2, 26) < 1$, indicating that the valence effects were equivalent across the three conditions.

3.4. The late positivity effect

It is clear from Fig. 2 that, for the self-execution condition, the gain and loss trials differed in the ERP responses and this difference was most apparent at the frontal electrodes. Mean amplitudes in the 550–650 ms time window were entered into ANOVA, with reward valence and positions of anterior electrodes as within-participant factors. The main effect of valence was indeed significant, $F(1, 13) = 5.15$, $p < .05$, with the gain trials (13.24 μV) more positive than the loss trials (11.14 μV). When mean amplitudes over the entire 500–700 ms time window were entered into ANOVA, with agency, valence, laterality and row as four within-participant factors, we observed an interaction between valence and agency, $F(2, 26) = 3.28$, $p = .054$. Further tests showed that while there was no valence effect for either the friend- or the stranger-observation condition, $F < 1$, ERP responses to the gain trials (12.83 μV) were more positive than to the loss trials (10.99 μV) for the self-execution condition, $F(1, 13) = 4.02$, $p = .066$. This late, frontal positivity effect is rarely reported in previous studies on outcome evaluation. It is possible that this effect reflects a re-appraisal process in which the individual's own gain and loss are motivationally attended and assessed against the background of other agents' gain and loss, although further studies are needed to address this speculation.

4. Discussion

This study provides insight into whether the brain potentials in outcome evaluation can be modulated by the interpersonal relationship between the observer and other agents. Results revealed that the anterior FRN showed the feedback valence effect for all the self-execution, friend- and stranger-observation conditions; however, although the effect was larger for the self-execution condition than for the other two conditions, the size of this effect, with different measurements of the FRN, did not differ between the friend- and stranger-observation conditions; in addition, the peak of the FRN effect (i.e., the differential loss-minus-gain ERP responses) occurred much earlier in the self-execution condition than in the friend- and stranger-observation conditions, which did not differ either. In contrast, the posterior P300 showed both the feedback valence effect and the agency effect, with gain trials constantly eliciting more positive P300 than loss trials and trials in the friend-observation condition eliciting more positive P300 than trials in the stranger-observation condition. Moreover, a late frontal positivity starting from 500 ms post-onset of feedback was observed for the gain vs. loss trials in the self-execution condition, but not in the other two conditions. In the following paragraphs, we discuss the implications of these findings on the FRN and the P300 respectively.

4.1. The FRN is sensitive to feedback valence but it is not modulated by interpersonal relationship

The generally more positive FRN responses for the self-execution condition than for the two observation conditions and the larger FRN effect for the former than for the latter replicated and extended previous studies (Itagaki & Katayama, 2008; Yu & Zhou, 2006a). This enlargement of the FRN responses for the self-execution condition is possibly related to the action of selection and/or the activation of self-interest. The size of FRN effect varies as a function of whether the choice is made by a computer or by the gambler himself, with a larger FRN effect between the loss and gain trials for the latter (Yeung et al., 2005). The linking of outcome evaluation with self-action may augment the motivational/affective significance of the outcome.

Crucially, we found no difference in the FRN responses between the friend- and stranger-observation conditions in different measurements of the FRN. This null effect may suggest that the interpersonal relationship between the observer and other agents does not affect the early brain responses to the consequences of action when they are not directly related to his/her self-interests. This finding is perhaps surprising given that previous studies have shown that observing an antagonist's gain could actually elicit a more negative-going shift, as if receiving information concerning the observer's own loss (Fukushima & Hiraki, 2006; Itagaki & Katayama, 2008). However, in these studies the other person's gain and loss had a direct impact upon the observer's own gain and loss, while in this study the monetary rewards are independent between different agents. It is possible that, without the involvement of self-interest, the early brain responses to feedback to the others' performance are primitive and (semi-)automatic. This initial evaluation is sensitive to the basic valence of reward, but not to the more complex social relationship between the observer and the agent.

In other words, in the early stage of outcome evaluation, humans distinguish instinctively oneself from others. This strong individualism is perhaps important for survival in evolution. But they may not distinguish further friends from strangers in the early process. This argument is consistent with theories differentiating automatic and controlled processes in attitude activation and social evaluation (Devine, 1989; Fazio, 2001; Greenwald & Banaji, 1995; Greenwald et al., 2002; Wilson et al., 2000).

4.2. The P300 is independently modulated by feedback valence and interpersonal relationship

In contrast to the FRN, we found that the P300 was modulated by both reward valence and interpersonal relationship. Given that the P300 is generally thought to be related to processes of attentional allocation (Gray, Ambady, Lowenthal, & Deldin, 2004; Linden, 2005) and/or to high-level motivational/affective evaluation (Nieuwenhuis et al., 2005; Yeung & Sanfey, 2004), it is not surprising that the monetary feedback to one's own performance elicited the strongest P300 responses. More importantly, observing feedback to a friend's performance elicited stronger P300 responses than observing feedback to a stranger's performance, suggesting that the involvement of attentional/affective processes in evaluating others' gambling performance is influenced by the interpersonal relationship between the observer and the agent. Indeed, it is possible that the differential P300 responses as a function of interpersonal relationship may be related to the empathy processes sharing other's experience and feeling (Fan & Han, 2008). A friend's pain or gain would elicit stronger empathetic responses on the observer than a stranger's.

Nevertheless, modulation of the P300 by interpersonal relationship is independent from modulation by feedback valence. Although it has been claimed that the P300 encodes only the magnitude of reward feedback, not the valence of feedback (Sato et al., 2005; Yeung & Sanfey, 2004), several studies have demonstrated otherwise (e.g., Hajcak et al., 2005, 2006, 2007; Holroyd et al., 2003, 2006; Wu & Zhou, 2009). A large number of human brain imaging studies have identified orbitofrontal cortex, medial prefrontal cortex, amygdala, and striatum as critical regions involved in reward processing (see McClure, York, & Montague, 2004 for a review). Among them, dorsal striatum is found to be related to the processing of reward valence (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Delgado, Locke, Stenger, & Fiez, 2003; Knutson, Westdorp, Kaiser, & Hommer, 2000). Moreover, compared to interaction with other peers, interaction with friends is associated with specific activity in amygdala, hippocampus, ventro-medial prefrontal cortex, and the nucleus accumbens (Guroglu et al., 2008). Each of these brain structures has been linked to empathy and emotion regulation and/or to reward processing. It is thus for further studies why the shared neural systems for reward processing and for interaction with friends modulate the P300 in monetary outcome evaluation independently.

5. Conclusion

By asking the main participant to observe monetary feedback to others' performance in a monetary gambling task and by manipulating the interpersonal relationship between the observer and other agents, this study found that the FRN responses make a distinction between the self and the others, but not between a friend and a stranger. In contrast, the P300 responses are modulated by both feedback valence and the interpersonal relationship, although these modulatory effects are independent from each other. These findings suggest that outcome evaluation may be composed of two processes with differential neural bases: an early semi-automatic evaluation for motivational/affective significance and a later, top-down controlled process that is sensitive to factors affecting the allocation of attentional resources.

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