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To do or not to do? Action enlarges the FRN and P300 effects in outcome evaluation

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to image an alternative (i.e., inaction) following action, negative outcomes following action would be regretted more than negative outcomes following inaction, whose counterfactual alternative (i.e., action) is relatively difficult to image. Action is thus associated with greater feelings of responsibility for the consequence.

Most of the previous studies presented participants with imaged scenarios and asked them to judge how the protagonists in scenarios would feel towards the outcome following action or inaction. It is not clear to what extent the participant's responses truly reflect the protagonist's feelings. How would participants respond to the outcome following action or inaction if they are situated in real scenarios? And how would the neurocognitive processes involved manifest in brain activity? In this study, we tried to answer these questions by asking participants in a gambling task to decide whether they themselves would react to the changing situation and make a new choice or stick to their previous one and do nothing. Specifically, participants were given choices between three boxes encoding different monetary consequences (winning 2.5 Chinese yuan, losing 2.5 yuan, or getting nothing). After participants made their first choice, the computer would open an unselected box and participants were given the option of switching to the third box or staying with their initial choice. The outcome of the finally selected box was then revealed. We measured EEG responses to the positive or negative outcome (i.e., wining or losing the amount of money contained in the finally selected box) following action (i.e., making a new choice) or inaction (i.e., sticking to the old choice) and focused on two ERP components that have been shown to be particularly sensitive to various aspects of outcome evaluation: the feedback-related negativity (FRN) and the P300. If action increases participant's emotional responses to the (negative) outcome following the action choice, as suggested by previous behavioral studies, it is possible that action would also enlarge the FRN and the P300 effects in outcome evaluation.

The FRN is a negative deflection at fronto-central recording sites and it peaks between 250 and 300 ms post-onset of outcome feedback (Gehring & Willoughby, 2002; Hajcak, Holroyd, Moser, & Simons, 2005; Hajcak, Moser, Holroyd, & Simons, 2007; Holroyd, Larsen, & Cohen, 2004; Miltner, Braun, & Coles, 1997; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004; Yeung, Holroyd, & Cohen, 2005). The FRN is more pronounced for negative feedback associate with unfavorable outcome, such as incorrect response or monetary loss, than for positive feedback. Source localization analysis showed that it is generated at the anterior cingulate cortex (ACC; Gehring & Willoughby, 2002; Miltner et al., 1997; Müller, Möller, Rodriguex-Fornells, & Münte, 2005; Yu & Zhou, 2009).

There are two major theories concerning the role of FRN in outcome evaluation. The reinforcement-learning theory (Holroyd & Coles, 2002; Nieuwenhuis et al., 2004) proposes that the FRN reflects the impact of midbrain dopamine signals upon 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 activity that is reflected as smaller FRN amplitudes. These signals are used to guide action selection mediated by ACC, through the reinforcement of action associated with positive reward and the punishment of action associated with negative outcomes. In contrast, the alternative theory suggests that the FRN 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 outcome events, i.e., the processes of putting subjective values onto outcomes (Gehring & Willoughby, 2002; Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006; Yeung et al., 2005; Yu, Luo, Ye, & Zhou, 2007). Previous studies have shown that the FRN effect could be elicited when participants passively watch feedback stimuli without making any choice or action (Donkers, Nieuwenhuis, & van Boxtel, 2005; Donkers & van Boxtel, 2005; Yeung et al., 2005). Moreover, the FRN effect is 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 (Itagaki & Katayama, 2008; Leng & Zhou, 2010; Yu & Zhou, 2006). The latter effect is presumably through empathetic processes involved in stranger observation.

Both theories predict that action choice may increase the FRN responses to the outcome. According to the reinforcement learning theory, action may increase expectancy towards a (good) outcome and violation of this expectancy may elicit a stronger prediction error (Hajcak et al., 2007; Holroyd et al., 2004; Wu & Zhou, 2009) and hence a larger FRN effect. According to the motivational account, action may augment the motivational/affective significance of the outcome. A previous study showed that the size of FRN effect varied according to whether the choice was made by a computer or by the gambler himself/herself, with a larger effect for the latter (Yeung et al., 2005).

The P300, which is the most positive peak in the 200–600 ms time window post-onset of feedback, has been shown to be sensitive to various aspects of outcome, including the magnitude of reward (Nittono, Otsuka, & Ullsperger, 2008; Sato et al., 2005; Yeung & Sanfey, 2004), the valence of reward (Hajcak et al., 2005, 2007; Wu & Zhou, 2009; Yeung et al., 2005), and interpersonal relationship in reward processing (Itagaki & Katayama, 2008; Leng & Zhou, 2010; Yu & Zhou, 2006).

Although there were arguments that the P300 encodes only the magnitude of reward in outcome evaluation, recent studies demonstrated that the P300 is sensitive to valence of reward as well (Hajcak et al., 2005, 2007; Leng & Zhou, 2010; Wu & Zhou, 2009). Given that the P300 is widely believed to be related to processes of attentional allocation and to high-level motivational/affective evaluation (see Olofsson, Nordin, Sequeira, & Polich, 2008 for review), it is possible that action would also enlarge the differential effect on P300 for positive and negative outcomes.

2. Method

Thirty-four undergraduate and graduate students (13 female; mean age 23.7 ± 1.5 years) recruited in Southeast University participated in the experiment. All the participants were right-handed and had normal or corrected-to-normal vision, and none of them had neurological or psychiatric disorders. They were told that they would get a basic payment of 30 Chinese yuan (about US $4.5) and then they would be awarded or penalized according to their performance in the gambling task, although in the end all the participants were paid extra 20 yuan on top of the basic payment. The study was approved by the Academic Committee of the Research Center for Learning Science, Southeast University, China.

On each trial, a participant was presented with three gray boxes, each box extending $1.3^\circ \times 1.3^\circ$ and the three boxes extending $5.0^\circ \times 1.3^\circ$ in visual angle. He/she was told that these boxes were associated with 2.5 (25 in number) yuan, 0 and −2.5 yuan, respectively (Fig. 1). The participant selected a target box by pressing the left or right button on a joystick, once or more times, with the left or right index finger. The first press would highlight a box (i.e., the outlines of the box being thickened) and a second press

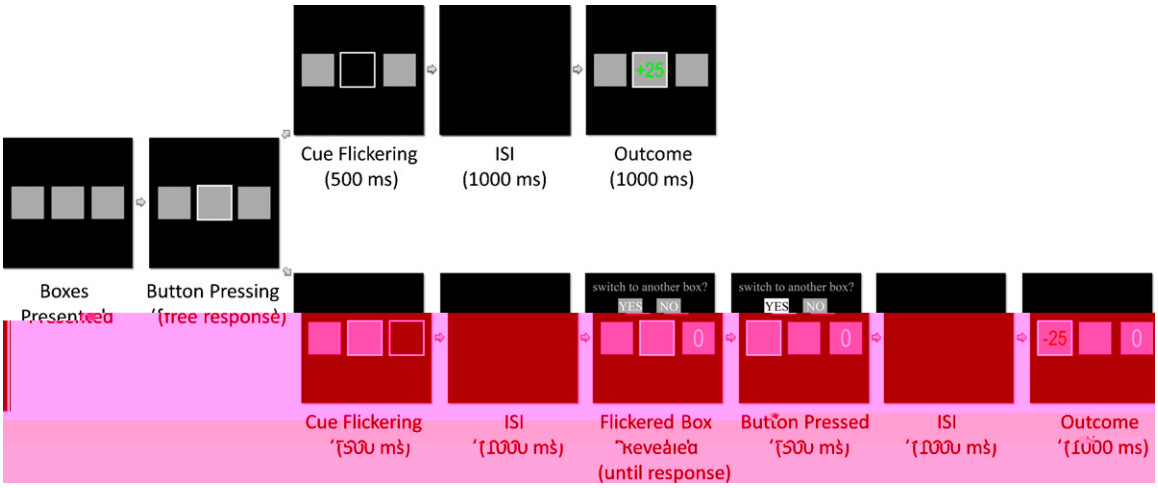

Fig. 1. Sequence of events for the filler trials (the upper part) and action/inaction trials (the lower part).

would highlight the next box, and so on. The participant confirmed the selection by pressing a third key using the right thumb. Then one of the three boxes flickered (i.e., with the background of the box turning to black or gray) for 500 ms to attract the participant's attention and the value (numeral) associated with this box, e.g., "+25" (win) in green, "0" (even) in white, or "−25" (loss) in red, would be presented after an interval of 1000 ms. The mappings between color and value were counterbalanced over participants. If the flickered box was the one that the participant had just selected, this value, presented for 1000 ms, was the final result of this trial and the participant would be, supposedly, awarded or penalized for this amount (see the upper part of Fig. 1). After another 1000 ms, a new round of gamble would start. This type of trials was considered as filler and was not analyzed. There were 150 (out of 650) trials like this, with 50 trials each for the three revealed values (i.e., "+25", "0", "−25").

If the flickered box was not the one that the participant just selected, when the value associated with the flickered box was presented, the question "to switch to another box?" in Chinese was also presented above the boxes (see the lower part of Fig. 1). The revealed value, although having nothing to do with the participant's win or loss in this trial, would let the participant know what the two remaining, unrevealed values were. The question indicated to the participant that he/she had a second chance to decide either to switch to the third, unmarked box or to stick with his/her initial choice. There were two small rectangle boxes between the question and the boxes, with the left one having the English word "YES" inside and the right one having "NO" inside. The participant was told to press the left key to switch to the third box or to press the right key to maintain his/her initial choice. The finally chosen box, i.e., the unmarked box for the "Action" choice or the maintained box for the "Inaction" choice, was highlighted with thickening of box outlines for 500 ms. The screen went blank for 1000 ms, and then the three boxes were presented again and the value associated with the finally chosen box was revealed and presented for 1000 ms. A new round of gamble would start after another interval of 1000 ms.

There were 300 trials in which the value for the flickered box was "0". These "0" type trials were the critical ones that allow us to examine to what extent the participant would change his/her mind and switch to the third box. We used an adaptive procedure that gave the participant the win feedback (i.e, "+25") in half of the "action" trials and in half of the "inaction" trials. For the remaining trials, the revealed value associated with the flickered box was either "+25" (100 trials) or "−25" (100 trials). Although these trials were included in the analysis of behavioral data, they were considered as fillers and were excluded in the EEG analysis.

Before the formal test, participants were given detailed task instructions and a practice block consisting of 20 trials. The 650 trials for the formal test were pseudo-randomized with the restriction that no more than 4 consecutive trials were of the same type. All trials were then divided into 13 test blocks and participants could take a break after each block. Participants were told that they could adopt whatever strategies to maximize their rewards. After the EEG test, participants were required to indicate, on a 7-point Likert scale (−3, very unpleasant; 3, very pleasant), their feelings towards all the 15 possible outcomes they experienced in the experiment.

Participants were seated comfortably about 1.5 m in front of a computer screen in a dimly lit and electromagnetically shielded room. The task was administered on a Pentium IV computer with a Dell 22 in. CRT display, using Presentation software (Neurobehavioral System Inc.) to control the presentation and timing of stimuli. All the stimuli were presented at the center of the screen against black background. The numerals "+25" and "−25" were presented in either green or red, on the gray box and the numeral "0" was always presented in white. The feedback stimulus "+25" or "−25" extended approximately $0.8^\circ \times 0.8^\circ$ in visual angle.

EEGs were recorded from 64 scalp sites using Ag/AgCl electrodes embedded in an elastic cap (NeuroScan Inc., USA) according to the international 10-20 system, with the reference to the right mastoid. Eye blinks were recorded from 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. The EEGs were re-referenced offline to the linked mastoids. All electrode impedances were maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05–70 Hz bandpass and continuously sampled at 500 Hz/channel for offline analysis.

EEG epochs of 1000 ms (with 200 ms pre-stimulus baseline) were extracted offline for ERPs time-locked to the onset of feedback stimuli (i.e., the presentation of value associated with the finally chosen box). Ocular artifacts were corrected with an eye-movement correction algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986). All trials in which EEG voltages exceeded a threshold of ±75 μV during the recording epoch were excluded from further analysis. The EEG data were low-pass filtered at 30 Hz with a FIR digital filter. ERPs were baseline corrected by subtracting from

each sample the average activity of that channel during the baseline period.

Based on visual inspection of waveforms (Fig. 3A), we first analyzed the mean amplitudes in the time window of 200–280 ms post-onset of the outcome feedback. The peak value of the P300 was detected as the most positive value in the 250–600 ms time window on each electrode. For the purpose of statistical analysis, we focused on the FRN responses on the anterior frontal midline electrodes (Fz) and the P300 responses on the central midline electrodes (Cz), since the FRN and P300 effects were the largest on these electrodes, respectively. Effects over the whole scalp are depicted in Fig. 3B. Repeated-measures analysis of variance (ANOVA) was conducted separately for the FRN data and the P300 data, with feedback valence (win vs. loss) and action choice (action vs. inaction) as two within-participant factors. The Greenhouse–Geisser correction for repeated measures was applied where appropriate.

Brain Electric Source Analysis (BESA, version 5.2) with a four-shell ellipsoidal head model was used to carry out estimation of dipole source location of ERP components (Scherg & Berg, 1990). ERP data were high-pass filtered (0.5 Hz) to remove slow drifts and low-pass filtered (8 Hz) to increase the signal to noise ratio. Source models were derived for the FRN effect (loss minus win difference wave) in a time window of 210–260 ms and for the P300 effect (win minus loss difference wave) in a time window of 310–360 ms. Principal component analysis (PCA) was employed in this interval for the ERP components in order to estimate the minimum number of dipoles.

3. Result

. Depending on whether the revealed value associated with the flickered box was "0", "+25" or "−25", the action/inaction trials can be categorized into different types (Table 1). For the "0" type, the mean percentage of inaction trials was 70.6% (SD = 19.0%), which was significantly larger than the percentage of action trials, (33) = 6.32, < 0.001. For the "+25" type, the mean percentage of inaction trials was 66.9% (SD = 15.2%), which was significantly larger than the percentage of action trials, (33) = 6.47, < 0.001. For the "−25" type, the mean percentage of inaction trials was 75.0% (SD = 19.3%), which was significantly larger than the percentage of action trials, (33) = 7.57, < 0.001. Thus for all the three types of trials we observed the "inaction bias", i.e., participants sticking with their old choices rather than changing mind and switching to the third box; this finding replicates previous studies using imaged scenarios (Baron & Ritov, 1994; Ritov & Baron, 1990, 1992, 1995). Moreover, one-way ANOVA over the percentages of inaction in the three types of trials found a significant main effect of type, (2, 66) = 10.0, < 0.001, with the percentage for the "−25" type larger than percentages for the other two types. This may indicate that participants were more likely to stick with their old choices when these choices would lead to relatively good and safe outcomes (i.e., either winning 2.5 yuan or losing nothing).

The post-experiment questionnaire was applied for scaling participant's feelings towards outcomes following action or inaction choice. For the "0" type of trials, it is clear from Table 1 that while the win feedback elicited positive emotional responses, the loss feedback elicited negative responses, (1, 32) = 203.12, < 0.001. Moreover, both the win feedback and the loss feedback elicited stronger (positive and negative, respectively) emotional responses following action choice than following inaction choice, (1, 32) = 7.03, < 0.05. Furthermore, ANOVA over types ("+25" type vs. "−25" type) and choice (action vs. inaction) found that the "0" (even) outcome in the "+25" type of trials elicited more positive emotional responses than the "0" outcome in the "−25" type of trials, (1, 32) = 11.21, < 0.005, suggesting that emotional responses to the same outcome could be different depending on the context.

. For the purpose of ERP analyses (see below), we excluded 16 (out of 34) participants. Among them, 13 had chosen inaction in over 80% of the critical action/inaction (i.e., the "0" type) trials, leaving less than 60 action (including both the "win" and the "loss") trials, which would not be sufficient for EEG averaging. One participant chose inaction in about 16% of the trials. The other two participants were excluded due to excessive artifacts in EEG recording.

For the remaining 18 ERP participants, the mean percentages of choosing inaction was 60.4% (SD = 10.3), 62.0% (SD = 11.0), and 64.3% (SD = 13.4) respectively for the "0", "+25", and "−25" types of trials. The inaction bias observed for all participants was still present even after the extreme participants were excluded. This inaction bias was also present in reaction time: it took longer to change mind and take action than to decide to stay with the initial choice: 1735 ms (SD = 637) vs. 1620 ms (SD = 633) for the "0" type of trials, 2187 ms (SD = 764) vs. 2057 ms (SD = 622) for the "+25" type of trials, and 2106 ms (SD = 886) vs. 1812 ms (SD = 626) for the "−25" type of trials. Two-way repeated-measures ANOVA over action choice and type of trials found a significant main effect of choice, (1, 17) = 7.12, < 0.05, and a significant main effect of stimulus type, (2, 34) = 24.85, < 0.001, but no interaction between them, (2, 34) = 1.12, > 0.1. Analyses of the subjective ratings of feeling towards outcomes found the same pattern as for the whole group analyses (see Table 1 and Fig. 2A).

Each of the 18 participants had at least 36 trials in each condition for EEG averaging. EEG waveforms from electrodes Fz and Cz are depicted in Fig. 3A. Topographic distributions of the difference waves between ERP responses to the loss vs. win outcome feedback in the 200–280 ms time window (for FRN) and between the most positive responses to the win vs. loss outcome feedback in the 250–600 ms time window (for P300) are depicted in Fig. 3B. The two-way repeated-measures ANOVA over feedback valence (win vs. loss) and action choice (action vs. inaction) revealed a main effect of valence for the mean ERP responses on the electrode Fz in the 200–280 ms time window (Fig. 3A), (1, 17) = 22.07, < 0.001, with ERP responses more negative to the loss feedback (9.70 μV) than to the win feedback (11.91 μV). The main effect of action choice was not significant, (1, 17) = 2.62, > 0.1. Importantly, this effect interacted with action choice, (1, 17) = 6.61, < 0.05, indicating that the FRN effect had different manifestations following action or inaction (see Fig. 2B).

Separate analyses were conducted for the FRN responses following action or inaction (Fig. 2B). Following the action trials, the main effect of feedback valence was significant, (17) = 5.11, < 0.001, with ERP responses more negative-going following the loss feedback (8.78 μV) than following the win feedback (12.01 μV). For the inaction trials, the main effect of feedback valence was marginally significant, (17) = 2.00, = 0.061, with ERP responses more negative-going following the loss feedback (10.62 μV) than following the win feedback (11.82 μV). On the other hand, it is clear from Fig. 2B that while ERP responses to the win feedback did not differ following action or inaction, (17) < 1, ERP responses to the loss feedback were less positive following action than following inaction, (17) = 3.13, < 0.01.

Similar analysis was also conducted for the peak values of P300 on the electrode Cz. The main effect of valence was significant,

Table 1
Post-experiment ratings of feeling towards the 15 possible outcomes on a 7-point scale, with "3" indicating "very pleasant" and "−3" indicating "very unpleasant".

	Feedback type		+25 (win)	0 (even)	−25 (loss)
	Immediate feedback		2.53 ± 0.61	0.59 ± 0.82	−1.76 ± 0.85
34	"0"	Action	2.36 ± 0.74		−1.91 ± 0.91
par-	type	Inaction	1.94 ± 1.17		−1.52 ± 1.34
tic-	"+25"	Action		1.24 ± 1.12	−1.79 ± 1.08
i-	type	Inaction		0.76 ± 1.15	−1.64 ± 0.96
pants	"−25"	Action	2.06 ± 0.92	0.06 ± 1.20	
	type	Inaction	1.53 ± 1.28	−0.15 ± 1.31	
	Immediate feedback		2.50 ± 0.71	0.56 ± 0.86	−2.11 ± 0.68
18	"0"	Action	2.61 ± 0.50		−2.17 ± 0.62
par-	type	Inaction	1.89 ± 1.23		−1.67 ± 1.14
tic-	"+25"	Action		1.12 ± 1.36	−2.29 ± 0.92
i-	type	Inaction		0.59 ± 1.37	−1.71 ± 0.85
pants	"−25"	Action	2.28 ± 0.75	0.00 ± 1.46	
	type	Inaction	1.67 ± 1.24	0.06 ± 1.47	

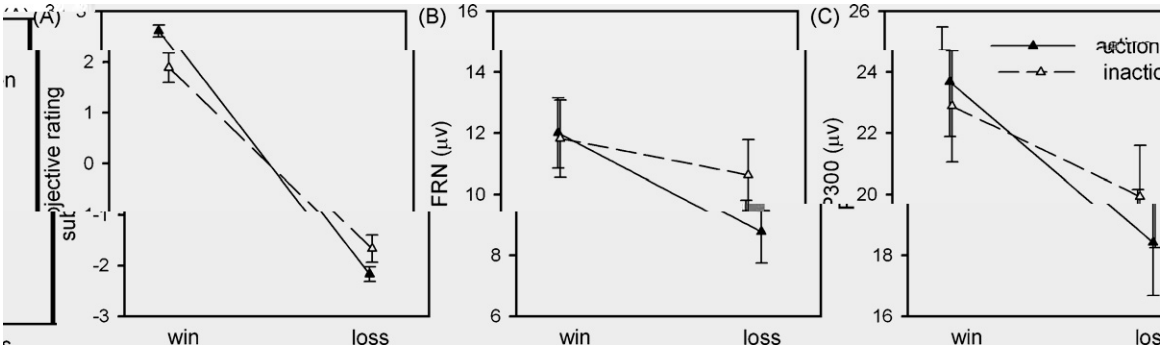

Fig. 2. (A) Post-experiment subjective ratings of feeling towards the win and the loss outcomes in the critical action/inaction (i.e., the "0" type) trials; (B) mean ERP amplitudes in the 200–280 ms time window to the win and the loss outcomes in the critical action/inaction trials on Fz; (C) P300 responses to the win and the loss outcomes in the critical action/inaction trials on Cz.

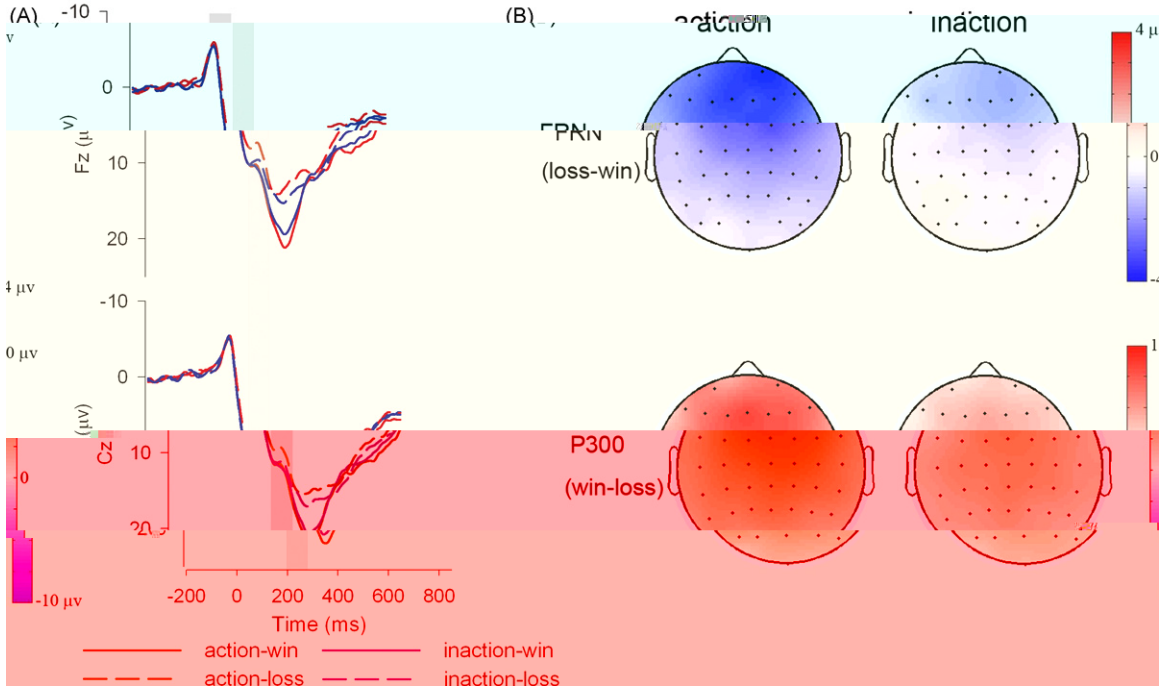

Fig. 3. (A) ERP responses on Fz and Cz to the win and loss outcomes in the critical action/inaction trials. The shaded 200–280 ms time window was for the calculation of the FRN effects. The P300 was measured as the most positive value in the 250–600 ms time window; (B) scalp topographies of the difference waves between ERP responses to the loss vs. win outcomes in the 200–280 ms time window (the upper panels) and between the peak responses to the win vs. loss outcomes in the 250–600 ms time window (the lower panels).

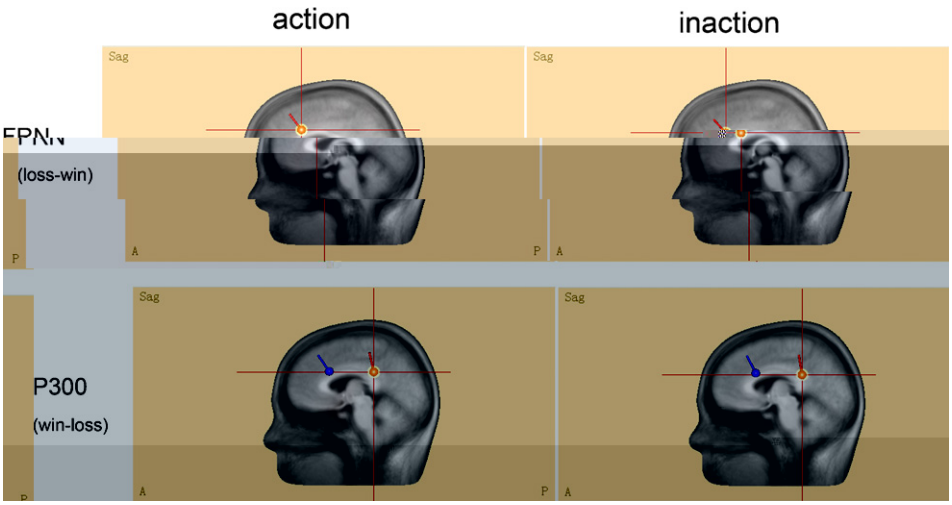

Fig. 4. Dipole source localization of the difference waves for the action and inaction trials. For the FRN, the time window selected for the difference waves was 210–260 ms post-onset. For the P300, the time window selected for the difference waves was 310–360 ms post-onset. Dipolar stereotaxic coordinates are transferred on a magnetic resonance imaging brain atlas.

(1, 17) = 20.00, < 0.001, with ERP responses more positive to the win feedback (23.28 μV) than to the loss feedback (19.18 μV; see Fig. 2C). The main effect of action choice was not significant, (1, 17) < 1. The interaction between valence and action choice was significant, (1, 17) = 4.50, < 0.05. These interactions indicated that the P300 effect may have different patterns following action or inaction.

Separate analyses were conducted for P300 following action or inaction. For the action trials, the main effect of valence was significant, (17) = 4.51, < 0.001, with ERP responses more positive to the win feedback (23.68 μV) than to the loss feedback (18.43 μV). For the inaction trials, the main effect of valence was also significant, (17) = 3.08, < 0.01, with ERP responses more positive to the win feedback (22.88 μV) than to the loss feedback (19.93 μV). Clearly the P300 effect was larger following action than following inaction (see also Fig. 2C).

For the FRN effects, one dipole was fitted in the model and the initial PCA indicated that one principal component was able to explain more than 97% of the variance in the data for each difference wave. The location of the dipole for the FRN component was = 5.0, = 27.6, = 21.6 (Talairach coordinates), with residual variance (RV) of 7.81% for the action choice. The location was = 3.7, = 28.7, = 20.1, with RV of 8.72% for the inaction choice. The two dipoles were located in the ACC (the upper panels of Fig. 4), consistent with previous studies showing that the FRN was generated mainly by a region located near the ACC (see also Gehring & Willoughby, 2002; Miltner et al., 1997; Müller et al., 2005; Yu & Zhou, 2009).

For the P300 effects, two dipoles were fitted in the model and the PCA indicated that one principal component was able to explain more than 97% of the variance in the data for each different wave. For the action choices, the location of the first dipole was = −4.0, = −35.9, = 27.5, and the location of the second dipole was = −2.8, = 17.3, = 28.3, with residual variance (RV) of 4.33%. The first location was at the posterior cingulate cortex (PCC) and the second location was at the ACC (the lower panels of Fig. 4). Similarly, for the inaction choices, the location of the first dipole was = −4.7, = −39.4, = 24.8, and the location of the second dipole was = −3.7, = 15.7, = 26.8, with residual variance (RV) of 5.36%. The first location was at the PCC and the second location was at the ACC. These results were consistent with previous studies (Luu, Shane, Pratt, & Tucker, 2009; Luu, Tucker, & Stripling, 2007; Mulert et al., 2004).

4. Discussion

This study investigated to what extent brain responses to outcomes in decision making would be modulated by action or inaction choice. The choice of action is associated with heightened subjective emotion. ERP results demonstrate further that action increases the brain activity in outcome evaluation, with responses to positive outcomes more positive and responses to negative outcomes more negative (or less positive; see Fig. 2). In the following paragraphs, we explore the possible mechanisms underlying the modulatory effect of action.

The finding of a general FRN effect for the loss and win feedback and its generator in the ACC replicated many previous studies. Importantly, we found that action enlarged the size of the FRN effect, although this modulation took place mainly on ERP responses to the loss feedback, not on ERP responses to the win feedback. The augmentation of the FRN effect by action choice replicated and extended Yeung et al. (2005) who observed a larger FRN effect for outcomes following gambling choices made by the participant himself than following choices made randomly by the computer. As we suggested in Section 1, this modulatory effect by action/inaction could be accommodated by both the reinforcement learning theory and the motivational/emotional account of the FRN.

Previous studies have demonstrated that unexpected outcomes elicit larger FRN effects than expected outcomes, suggesting that the FRN is sensitive to the prediction error (Donkers & van Boxtel, 2005; Hajcak et al., 2007; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003; Wu & Zhou, 2009). It has been argued that unfavorable outcomes after action are more unexpected than unfavorable outcomes after omission/inaction (Kahneman & Miller, 1986; Ritov & Baron, 1994). Action may change the strength of expectancy towards the positive outcome or the desire to obtain the reward. Violation of this stronger expectancy, indicated by the negative feedback, would give rise to a stronger prediction error, leading to stronger brain responses. By this view, action would change the release of midbrain dopamine signals acting upon ACC, which generates the FRN. However, it is also possible that action (or changing mind) affects ACC activity and enhances the FRN responses directly, as ACC has been found to be involved in volitional action (Karch et al., 2009; Mulert et al., 2008; Nunez, Casey, Egner, Hare, &

Hirsch, 2005; Winterer, Adams, Jones, & Knutson, 2002; Yu & Zhou, 2009). Studies on the reinforcement learning theory of the FRN usually manipulate the degree of prediction error (or the degree of expectedness of the outcome) by explicitly varying the objective probability of certain outcomes. The present study suggests that increasing the subjective expectancy towards (positive) outcomes through action or active choice can also influence the FRN responses. Although we did not measure the expectancy online, we did find that the enlarged the FRN effect following action choice was mainly due to more negative-going ERP response to the loss outcome, not due to more positive-going response to the win outcome. This finding was consistent with the argument of increased expectancy, as the FRN may reflect the detection of conflict between expectancy and the actual outcome, irrespective of what attribute the expectancy is built upon (e.g., Wu & Zhou, 2009).

In the motivational account of the FRN (Gehring & Willoughby, 2002; Masaki et al., 2006; Yeung et al., 2005), action may increase the motivational/affective significance of the outcome and this stronger motivational significance may lead to stronger FRN responses. In a gambling task, Yu and Zhou (2009) asked participants to decide whether to bet or not to bet in the current trial by pressing a response button. They found that ERP responses locked to the "bet" decision was more negative than responses locked to the "not to bet" decision. The authors suggested that this so called ERN (error-related negativity) effect reflects an early warning function of ACC, which generates the ERN signals and alerts the brain to prepare for the potential negative consequences associated with risky actions. In the present study, ERP responses locked to the "switch" decision were indeed more negative (by 1.84 μV, <0.005) than responses associated with the "stay" decision, and this increased ERN responses may augment the motivational/affective significance of the outcome later on. Moreover, outcomes of self-executed actions elicited larger FRN effects than outcomes of actions performed by other persons or by the computer (Itagaki & Katayama, 2008; Leng & Zhou, 2010; Yeung et al., 2005; Yu & Zhou, 2006), suggesting again that the linking of outcome evaluation with self-execution may augment the motivational/affective significance of the outcome. This suggestion is consistent with previous behavioral results showing that action is associated with stronger feeling of responsibility towards the outcome (Ritov & Baron, 1990; Spranca et al., 1991; Zeelenberg et al., 2002), and the feeling of responsibility for current negative outcome might be the primary cause of regret (Zeelenberg et al., 2002). It has been shown, for example, that people who cause harm by acting, compared with people who cause the same harm by not acting, are judged to be more personally responsible and are more likely to be perceived as a causal agent (Ritov & Baron, 1990; Spranca et al., 1991).

Thus, it may be argued that responsibility mediates individuals' emotional response (e.g., regret) to outcomes and as a consequence, the FRN amplitude. This explains both the differential FRN effects in receiving outcomes following active choice making or following choices randomly made by the computer (Yeung et al., 2005) and the differential FRN effects following action or inaction. Although action or inaction choices in this study can be categorized as "active" given that the choices were made by the participants themselves, having a second thought and making another choice may increase the participants' subjective feeling of being more responsible for the outcome. A recent study that manipulated the degree of responsibility by asking the participant to execute a task himself or to complete the task with two partners indeed observed enhanced FRN effect when the responsibility was high (Li et al., 2010).

The finding of generally more positive P300 responses to the win feedback than to the loss feedback replicated previous studies (Hajcak et al., 2005, 2007; Leng & Zhou, 2010; Wu & Zhou, 2009; Yeung et al., 2005). Importantly, we found that the differential effect between win and loss was larger following action than following inaction. 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 affective/social evaluation (Leng & Zhou, 2010; Nieuwenhuis, Aston-Jones, & Cohen, 2005; Yeung & Sanfey, 2004), it is possible that, as for the FRN, action increases the affective/social significance of the outcome (Kahneman & Miller, 1986). Indeed, the pattern of interaction between action choice and feedback valence (Fig. 2C) was very similar to the pattern of interaction between action choice and subjective rating of feeling towards the outcome, consistent with the argument that the P300 is linked with high-level affective evaluation of the outcome. Note that, although outcome evaluation can be considered as composed of an earlier semi-automatic process and a later cognitive/affective appraisal process (Leng & Zhou, 2010) and the motivational/affective evaluation in the earlier stage could be more primitive than the later attention-sensitive, more elaborated appraisal, the two processes may nevertheless be closely linked. We found that the difference between the FRN effects following action and inaction correlated with the difference between the P300 effects following action and inaction, $(18) = 0.54$, < 0.05. This correlation suggest that action may impact upon the early stage, as reflected by the FRN, and the late stage, as reflected by the P300, of outcome evaluation in concert. The finding that the FRN and the P300 effects had a similar source generator in the anterior cingulate cortex (ACC), according to the source localization analysis, may be taken to support this argument, although further studies are needed to address this issue.

To conclude, by using a gambling task in which participants were given opportunities to decide whether they would change their initial choice (i.e., action) or not (i.e., inaction), the present ERP study demonstrated that action may increase the expectancy towards the outcome and/or the motivational/emotional significance of the outcome, and that this action effect can be found in both the FRN and the P300 of electrophysiological responses, with larger differential responses to the win and the loss feedback following action than following inaction.

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