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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

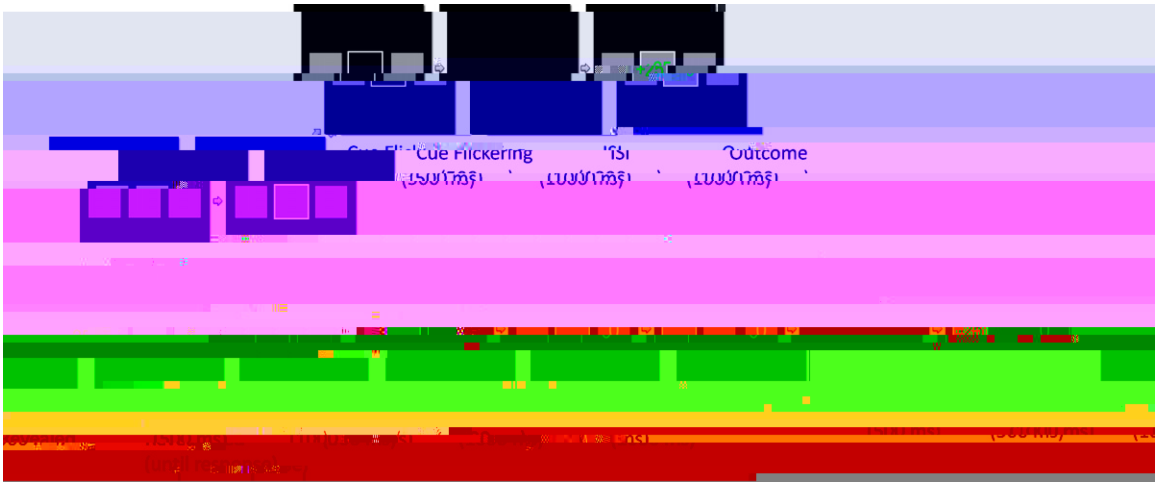

Fig. 1. Sequence of events for the filler trials (the upper part) and action/inaction trials (the lower part).

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 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.

2.4.

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)
34 participants	Immediate feedback		2.53 ± 0.61	0.59 ± 0.82	−1.76 ± 0.85
	"0" type	Action	2.36 ± 0.74		−1.91 ± 0.91
		Inaction	1.94 ± 1.17		−1.52 ± 1.34
	"+25" type	Action		1.24 ± 1.12	−1.79 ± 1.08
		Inaction		0.76 ± 1.15	−1.64 ± 0.96
	"−25" type	Action	2.06 ± 0.92	0.06 ± 1.20	
		Inaction	1.53 ± 1.28	−0.15 ± 1.31	
18 participants	Immediate feedback "0" type		2.50 ± 0.71	0.56 ± 0.86	−2.11 ± 0.68

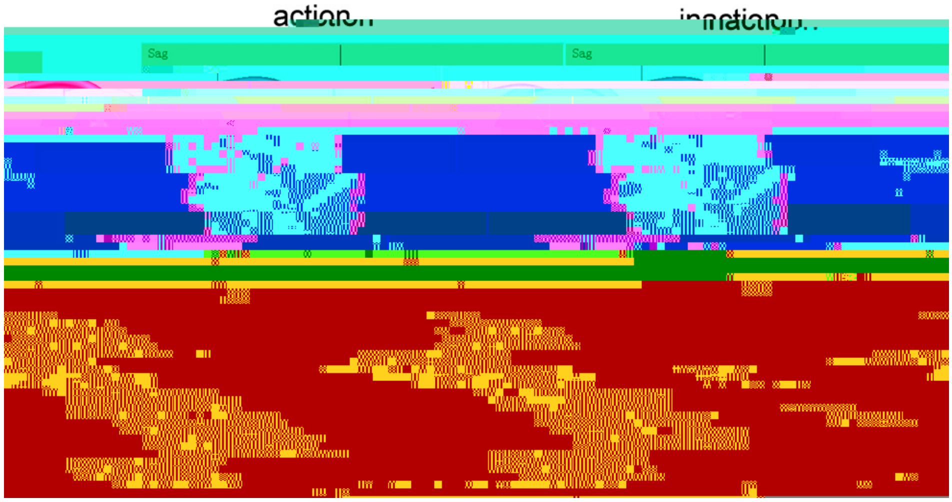

Fig. 4. Dipole source localization of the difference waves for the action and inaction trials. For the FRN, the time window selected for the difference waves was 210–260 ms post-onset. For the P300, the time window selected for the difference waves was 310–360 ms post-onset. Dipolar stereotaxic coordinates 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).

3.3.

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 he participant himselfh.comp99(h.co.comp99(h.(h.co.coj/F1(h.co.coj/F1(h.co.c ,9(E9.)-whichl27.49(a)-2

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 linRN effects

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