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Woulda, coulda, shoulda: the Evaluation and the Impact of the Alternative Outcome

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Abstract

The alternative outcome refers to the outcome of the unselected option in decision-making tasks, which has significant influence on the chosen outcome evaluation. Most paradigms have presented the alternative outcome either after or simultaneous with the chosen outcome, which complicates the observation on the brain activity associated with the alternative outcome. To circumvent this perceived shortcoming, we modified the classic paradigm designed by Yeung & Sanfey (2004) such that the alternative outcome was presented before the chosen outcome in each trial while electroencephalographic (EEG) was recorded. The feedback-related negativity (FRN) elicited by the positive alternative outcome was larger than that elicited by the negative alternative outcome, suggesting that the participants evaluated the positive alternative outcome as negative feedback. Moreover, the FRN and the P3 elicited by the chosen outcome were influenced by the valence of the alternative outcome. The current study reveals that the alternative outcome is treated as important information even though it is economically neutral.

Descriptors

decision making; outcome evaluation; alternative outcome; feedback-related negativity (FRN); logic error; counterfactual thinking

Introduction

We judge new events according to our knowledge. That is, the process of outcome evaluation is based on the comparison of available information (Nieuwenhuis, Heslenfeld et al., 2005). For instance, neuroscience studies suggest that outcome value is coded as the difference between expected and actual outcomes in the brain (Ernst & Paulus, 2005; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). Moreover, if the alternative outcome is known to the decision-maker, the chosen outcome evaluation depends also on the value of alternative outcome, rather than only the chosen outcome per se (Kahneman & Miller, 1986; see also Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004).

The influence of the alternative outcome is prevalent in daily life. During economic gambling, people would be disappointed from a gain if it turns out that the outcome

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associated with the alternative option is even better (Camille et al., 2004; Nieuwenhuis, Yeung et al., 2004). Likewise, investors in financial markets often make poor economic decisions for irrational reasons, possibly to avoid the resultant feeling that their wealth could have been higher with a foregone alternative decision (Muermann, Mitchell, & Volkman, 2006). A study on the alternative outcome evaluation could bring new understanding to how people make a comparison between ‘what has happened’ and ‘what might have happened’ (see also Goyer, Woldorff, & Huettel, 2008).

A study by Yeung & Sanfey (2004), which used a monetary gambling task with electroencephalographic (EEG) recording, provides important knowledge about the neural mechanisms underlying the alternative outcome evaluation. In each trial, the participants chose between two arbitrary options, and then were shown the outcome of their choice (chosen outcome), as well as the alternative (unselected) outcome. Two ERP components were used as the biomarkers for the process of outcome evaluation: the feedback-related negativity (FRN) and the P3. Both components are of great significance to ERP research on outcome evaluation (Christie & Tata, 2009; Li et al., 2010; Polezzi, Sartori, Rumiati, Vidotto, & Daum, 2010; Wu & Zhou, 2009). The FRN is suggested to indicate a binary categorization of the outcomes as either ‘good’ or ‘not good’ (Holroyd, Hajcak, & Larsen, 2006), while the P3 is linked with the motivational significance of the outcome (Bellebaum & Daum, 2008; Hajcak, Moser, Holroyd, & Simons, 2007; Martin & Potts, 2004).

Yeung & Sanfey (2004) found that (1) for the chosen outcome, the FRN was sensitive to reward valence but insensitive to reward magnitude while the P3 showed the opposite pattern, and that (2) for the alternative outcome, the FRN was insensitive to the features of alternative outcomes, while the P3 amplitude increased with outcome magnitude. Accordingly, they believe that the alternative outcome is processed in a similar way as the chosen outcome, regardless of whether it is associated with rewards and penalties. In addition, they propose an ‘independent coding model’ which suggests that the coding of outcome valence and that of outcome magnitude are separate in the brain, which are related to the FRN and the P3, respectively.

However, in their paradigm, the chosen outcome and the alternative outcome are represented in a fixed sequence: after the participants select one of the options, they are always presented with the chosen outcome first, and then the alternative outcome (Yeung & Sanfey, 2004). In each trial, participants could not judge whether they have made the optimal decision upon the presentation of the chosen outcome, since the alternative outcome is not yet known (Wu & Zhou, 2009). Thus, this task design might not be optimal when investigating the influence of the alternative outcome on the chosen outcome evaluation.

Most previous studies about the neural mechanism of outcome evaluation have presented the chosen outcome either before (e.g., Yeung & Sanfey, 2004) or at the same time as the alternative outcome (e.g., Goyer et al., 2008; Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006; Sailer et al., 2007). For the latter set, it is reasonable to presume that the evaluation of the chosen outcome and that of the alternative outcome would happen simultaneously. Therefore, it would be difficult, if possible, to dissociate neural signals secondary to the alternative outcome from those secondary to the chosen outcome. The current study aims to resolve this issue.

In order to examine alternative options better, we modified Yeung & Sanfey’s (2004) study such that the alternative outcome was presented **before** the chosen outcome. Rigoni et al.’s (2010) task design approximates our idea. However, they focused on outcome evaluation in social context while the issue of alternative outcome was omitted in their report (Rigoni, Polezzi, Rumiati, Guarino, & Sartori, 2010). To the best of our knowledge, the influence of

the alternative outcome on the chosen outcome evaluation has not yet been investigated in the way we suggest.

In light of Yeung & Sanfey's (2004) research, we aimed to use the amplitude of the FRN (a negative-going component which peaks 200–300 ms following the presentation of feedback) and the P3 (a centro-parietal positivity approximately 300–600 ms post-stimulus) as objective measures of the process of outcome evaluation. The paradigm was replicated from Yeung & Sanfey (2004) apart from two major modifications. First, the chosen outcome was preceded by the alternative outcome in each trial, as described above. Second, the factor of outcome magnitude was excluded in the current study, so as to simplify the task and the analysis. According to Yeung & Sanfey (2004)'s independent coding model, we hypothesized that the FRN should be sensitive to the alternative outcome and the chosen outcome, being larger after losses than after wins. Meanwhile, the P3 should be indifferent to either kind of outcome, since the factor of magnitude was omitted in the current study.

Materials and methods

Participants

25 right-handed students (16 females; mean age 19.6 years [S.D. = 1.3]) from Beijing Normal University participated in the experiment. All subjects were free of regular use of medication or other nonmedical substances that might influence the central nervous system. All had normal vision (with or without correction); none had history of neurological disease. All subjects gave their informed consent prior to the experiment. The experimental protocol was approved by the Local Ethics Committee (Beijing Normal University). None of the subjects had knowledge about the Cyrillic alphabet according to their report.

Experimental tasks and procedure

During the task, the subject sat approximately 100 cm from a computer screen in an electrically shielded room. Each trial began with the presentation of two options for the subject to choose. The two alternatives were represented as two Cyrillic letters ('д' and 'ю' respectively), each of which was presented inside a white rectangle (2.5 degree $\times$ 2.5 degree of visual angle) appearing on either side of a fixation point. The positions of these two letters were counterbalanced across the trials. The subject could select one of the two alternatives by pressing the 'F' or 'J' keys on the keyboard with his/her left or right index finger ('F' for the alternative on the left, and 'J' for the other one on the right). The alternatives remained on the screen until the subject chose a rectangle; the selected rectangle was outlined in red for 500 ms. After that, the 'alternative outcome' was presented in the unselected rectangle for 1000 ms simultaneously with the disappearance of the two letters. Then the alternative outcome disappeared, leaving the rectangles and the fixation point onscreen for 500 ms. Finally, the 'chosen outcome' was presented in the chosen rectangle for 1000 ms (see Fig. 1). The formal task consisted of two blocks of 128 trials each. Stimulus display and behavioral data acquisition were conducted using E-Prime software (Version 1.1, Psychology Software Tools, Inc.).

There were two kinds of outcomes: positive outcome (represented as the symbol '+', indicating that the subject gained one point in the current trial) and negative outcome (represented as the symbol '-', indicating that the subject lost one point in the current trial). Unbeknownst to the subject, no matter which option was chosen, the probability of receiving a positive or a negative 'chosen outcome' in each trial was equal. Moreover, there was also an equal probability of receiving a positive or a negative 'alternative outcome'. The valences of the chosen outcome and the alternative outcome were independent from each other.

Before the experiment, the subject was instructed about the rules and the meaning of the symbols in the task. In addition, he/she was encouraged to respond in a way that would maximize the total score amount. However, after the subject finished the task, he/she was briefed that the outcomes were pre-determined and that there was no optimal strategy for the task. Each subject was paid 60 Chinese Yuan (about \$ 10) for their participation.

EEG recordings and data analysis

The electroencephalogram (EEG) activity was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc.), with an online reference to the right mastoid and off-line algebraic re-reference to the average of the left and right mastoids. Horizontal electrooculogram (HEOG) was recorded from electrodes placed at the outer canthi of both eyes. Vertical electrooculogram (VEOG) was recorded from electrodes placed above and below the left eye. All inter electrode impedance was maintained at $< 5 \text{ k}\Omega$. EEG and EOG signals were amplified with a 0.05–100 Hz bandpass filter and continuously sampled at 1000 Hz/channel.

During the offline analysis, ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software (Semlitsch, Anderer, Schuster, & Presslich, 1986). Any trials in which EEG and EOG voltages exceeded a threshold of $\pm 100 \mu\text{V}$ during the recording epoch were excluded from the analysis. The EEG was averaged in 1000 ms epochs (200 ms baseline) time-locked to the outcome stimulus. These averages were digitally filtered with a 30-Hz low-pass filter and were baseline-corrected by subtracting from each sample the average activity of that channel during the baseline period.

The FRN has been reported to be maximal at the fronto-central area of the scalp (Holroyd & Krigolson, 2007; Oliveira, McDonald, & Goodman, 2007), while the P3 has been reported to be maximal at the centro-parietal area (Lust & Bartholow, 2009; Nieuwenhuis, Aston-Jones, & Cohen, 2005). In this study, the amplitude of the FRN was measured as the mean value within the 200–300 ms window following the presentation of outcome averaged between five midline electrodes (Fz, FCz, Cz, CPz, Pz) in the fronto-central-parietal regions. The amplitude of the P3 was similarly measured as the mean value within the 300–500 ms window following the presentation of outcome averaged between five midline electrodes (Cz, CPz, Pz, Poz, Oz) in the centro-parietal- occipital regions.

For all the analyses listed below, the significance level was set at 0.05. Greenhouse–Geisser correction for ANOVA tests was used whenever appropriate.

RESULTS

Behavioral results

The average percentage of choosing alternative 'д' was $49.55 \pm 9.64 \%$. For 'ю', this number was $50.45 \pm 9.64 \%$. The average time for decision-making was 0.99 ± 0.46 seconds. Since there was no optimal strategy for the participants during the task, the behavioral data was not analyzed further.

ERP Results

Alternative Outcomes

FRN: The mean amplitude of the FRN was entered into a 2 (alternative outcome: positive vs. negative) $\times$ 5 (electrode: Fz, FCz, Cz, CPz, Pz) ANOVA test to compare the FRN associated with different kinds of alternative outcomes. The main effect of the alternative outcome was significant ($F(1, 24) = 10.040, p = 0.004$); the FRN was greater in response to positive alternative outcomes than in response to negative alternative outcomes (5.26 ± 0.69

μV vs. $6.61 \pm 0.74 \mu\text{V}$). This result is particularly worth noting (see Fig. 2) because the classic FRN is consistently larger following negative feedback than positive feedback (Gehring & Willoughby, 2002; Holroyd et al., 2006; Nieuwenhuis, Holroyd et al., 2004). The main effect of electrode was also significant ($F(4, 96) = 10.148, p = 0.001$); the FRN associated with alternative outcomes was greatest at the frontal area of the scalp at electrode Fz ($5.09 \pm 0.67 \mu\text{V}$). The alternative outcome $\times$ electrode interaction was not significant ($F(4, 96) = 2.516, p = 0.114$).

P3: The mean amplitude of the P3 was entered into a 2 (alternative outcome: positive vs. negative) $\times$ 5 (electrode: Cz, CPz, Pz, Poz, Oz) ANOVA test. The main effect of the alternative outcome was not significant ($F(1, 24) = 2.185, p = 0.152$). The main effect of electrode was significant ($F(4, 96) = 23.290, p < 0.001$); the P3 was largest at the parietal area of the scalp at electrode Pz ($11.16 \pm 0.95 \mu\text{V}$). The alternative outcome $\times$ electrode interaction was not significant ($F(4, 96) = 1.079, p = 0.351$).

Chosen Outcomes

FRN—In order to investigate the influence of the alternative outcome on the chosen outcome evaluation, the valence of the alternative outcome was added into the analysis as a within-subject factor. Consequently, the mean amplitude of the FRN was entered into a 2 (chosen outcome: positive vs. negative) $\times$ 2 (alternative outcome: positive vs. negative) $\times$ 5 (electrode: Fz, FCz, Cz, CPz, Pz) ANOVA test. The main effect of the chosen outcome was significant ($F(1, 24) = 10.980, p = 0.003$); the FRN was greater in response to negative chosen outcomes than in response to positive chosen outcomes ($7.00 \pm 0.76 \mu\text{V}$ vs. $8.14 \pm 0.78 \mu\text{V}$). The main effect of the alternative outcome was also significant ($F(1, 24) = 28.850, p < 0.001$); the FRN to the chosen outcome was smaller when alternative outcomes were positive as opposed to when they were negative (positive: $9.39 \pm 0.88 \mu\text{V}$; negative: $5.75 \pm 0.77 \mu\text{V}$). The main effect of electrode was significant ($F(4, 96) = 10.376, p = 0.001$); the FRN associated with chosen outcomes was greatest at the frontal area of the scalp at electrode Fz ($6.52 \pm 0.83 \mu\text{V}$; see Fig. 3a).

Neither the chosen outcome $\times$ alternative outcome interaction ($F(1, 24) = 0.551, p = 0.465$) nor the chosen outcome $\times$ electrode interaction ($F(1, 24) = 1.868, p = 0.177$) could reach significance. The alternative outcome $\times$ electrode interaction was significant ($F(4, 96) = 4.501, p = 0.030$). Simple effect analysis on this interaction revealed that the impact of the alternative outcome on the FRN was significant at all of the electrodes, except at Pz ($F(1, 49) = 3.03, p = 0.088$). The chosen outcome $\times$ alternative outcome $\times$ electrode interaction was significant ($F(4, 96) = 16.119, p < 0.001$). Further analysis indicated that the chosen outcome $\times$ alternative outcome interaction was significant at the parietal area, at electrode Pz ($F(1, 24) = 5.581, p = 0.027$) but not at other sites. Since the classical FRN is source localized at the frontal area (Hajcak, Holroyd, Moser, & Simons, 2005), we suggest this interaction was not actually associated with the FRN.

P3—Similar to the analysis on the FRN, the mean amplitude of the P3 was entered into a 2 (chosen outcome: positive vs. negative) $\times$ 2 (alternative outcome: positive vs. negative) $\times$ 5 (electrode: Cz, CPz, Pz, Poz, Oz) ANOVA test. The main effect of the chosen outcome was not significant ($F(1, 24) = 0.432, p = 0.517$). The main effect of the alternative outcome was significant ($F(1, 24) = 10.184, p = 0.004$); the P3 to the chosen outcome was larger when alternative outcomes were positive as opposed to when they were negative (positive: $14.43 \pm 0.92 \mu\text{V}$; negative: $12.84 \pm 0.82 \mu\text{V}$; see Fig. 4a). The main effect of electrode was also significant ($F(4, 96) = 42.680, p < 0.001$); the P3 associated with chosen outcomes was largest at the parietal area of the scalp at electrode Pz ($15.21 \pm 0.90 \mu\text{V}$).

The chosen outcome $\times$ alternative outcome interaction was significant ($F(1, 24) = 19.800, p < 0.001$). Simple effect analysis on this interaction revealed that the influence of the alternative outcome on the P3 associated with the chosen outcome was significant when the chosen outcome itself was positive ($F(1, 124) = 156.10, p < 0.001$), but not significant when the chosen outcome was negative ($F(1, 124) = 0.16, p = 0.691$). A positive chosen outcome following a positive alternative outcome could elicit a larger P3 than that following a negative alternative outcome ($15.43 \pm 0.91 \mu V$ vs. $12.10 \pm 0.78 \mu V$).

The alternative outcome $\times$ electrode interaction was significant ($F(4, 96) = 19.954, p < 0.001$). Simple effect analysis on this interaction revealed that the effect of the alternative outcome was not significant at electrode POz ($F(1, 49) = 2.18, p = 0.146$) or electrode Oz ($F(1, 49) = 1.43, p = 0.237$). The chosen outcome $\times$ electrode interaction was significant ($F(4, 96) = 3.754, p = 0.036$). Simple effect analysis on this interaction revealed that the effect of the chosen outcome was largest at electrode Cz ($F(1, 49) = 1.66, p = 0.204$), while smallest at electrode POz ($F(1, 49) = 0.10, p = 0.749$). The chosen outcome $\times$ alternative outcome $\times$ electrode interaction failed to reach significance ($F(4, 96) = 3.254, p = 0.057$).

Discussion

The Evaluation of the Alternative Outcome

The most interesting and somewhat surprising result of this study is the ERP response to the alternative outcome: the amplitude of the FRN was greater following positive alternative outcomes than it was following negative outcomes. A few other studies have reported similar phenomenon: in certain conditions, the feedback in positive valence could evoke a larger FRN than that in negative valence (Itagaki & Katayama, 2008; Marco-Pallares, Kramer, Strehl, Schroder, & Munte, 2010). However in their tasks, that kind of 'positive' feedback actually indicated monetary loss to the participants themselves. In contrast, the alternative outcome in our task is monetary neutral, regardless of its valence. Our finding supports the idea that the FRN is not simply sensitive to reward and punishment/lack of reward in a binary manner (Holroyd et al., 2006; Nieuwenhuis, Holroyd et al., 2004), but also sensitive to task/response context (Holroyd, Larsen, & Cohen, 2004). Accordingly, the process of outcome evaluation indexed by the FRN amplitude would respond not only to economic value but also to context information (Sharot, Shiner, & Dolan, 2010).

Previous studies suggest that the FRN responds to the alternative outcome in the same way as the chosen outcome (Goyer et al., 2008; Nieuwenhuis, Yeung et al., 2004; Rigoni et al., 2010). Nevertheless, in previous research, the presentation of the alternative outcome was either after (Yeung & Sanfey, 2004), or at the same time with the chosen outcome (Goyer et al., 2008; Nieuwenhuis, Yeung et al., 2004). Consequently, the evaluation of alternative outcomes was likely influenced by the features of chosen outcomes in these studies. We thereby suggest that our study might provide a better perspective of the alternative outcome evaluation.

Since the valence of the alternative outcome and that of the chosen outcome were independent from each other, we could reasonably expect the participants to be indifferent to the alternative outcome. However, the FRN results indicate that the participants might evaluate the positive alternative outcome as negative information given the context. They might have held this opinion because they falsely assumed that there existed a relationship between the alternative and the chosen outcomes. In daily life, human beings often show a tendency to infer underlying relations between independent events (Ahn & Bailenson, 1996). Consider the 'conjunction fallacy' situation: when people read a story which contains two unrelated factors, they are prone to overestimate the probability of a 'conjunctive explanation' of the story, which assumes that the two factors are actually linked with each

other (Hertwig & Gigerenzer, 1999; Tversky & Kahneman, 1983). We suggest that in our task, the subjects might assume that the valence of the alternative outcome and that of the chosen outcome opposed each other. The knowledge of zero-sum games ('you win, I lose'; see Marco-Pallares et al., 2010; Messick, 1967) might encourage participants to make this interpretation. Therefore to the participants, the positive alternative outcome might have implied that the valence of the chosen outcome would be negative. This would generate a larger FRN accordingly.

However, this theory is based on the assumption that throughout the task, most participants failed to recognize that the alternative outcome and the chosen outcome were independent from one another. As an alternative, the FRN associated with the alternative outcome might be a reflection of counterfactual thinking. 'Counterfactual thinking' indicates the process of thinking about 'what might have been' if a different decision had been made (Coricelli, Dolan, & Sirigu, 2007; Pierro et al., 2008). Individuals often engage in spontaneous counterfactual thinking after encountering negative events (Pierro et al., 2008). In our study, when participants received the alternative outcome, the valence of the chosen outcome was not yet known. If the alternative outcome is positive, there is a 50% possibility for the chosen outcome to be worse than the alternative outcome. Thus, we propose that when subjects saw the positive alternative outcome, they would feel disappointed in not having made the alternative choice. A classic larger FRN response appeared in this situation. In contrast, the negative alternative outcome implied that the participants' choice could not have been worse than the alternative option, so it was more favorable for the participants.

The Evaluation of the Chosen Outcome (The Impact of the Alternative Outcome)

Consistent with prior research (Gehring & Willoughby, 2002; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003), the FRN elicited by the chosen outcome was larger when its valence was negative. Moreover, we found that the main effect of the alternative outcome was significant, indicating that the FRN elicited by the chosen outcome was influenced by the valence of the alternative outcome, which was presented before the chosen outcome in each trial. Specifically, the FRN amplitude was larger if the chosen outcome was preceded by a negative alternative outcome.

In our opinion, the FRN following chosen outcomes fits well with our understanding of the FRN following alternative outcomes. The FRN could be profoundly influenced by outcome expectation (Bellebaum & Daum, 2008; Hajcak et al., 2007), which might be modulated by the alternative outcome in our study. If the participants made a logic error in assuming that the valence of the alternative outcome and that of the chosen outcome opposed each other, they would be more likely to expect a positive chosen outcome after receiving a negative alternative outcome. Otherwise, if the participants were influenced by counterfactual thinking, they might falsely believe that they had already made a correct choice after receiving a negative alternative outcome. In either case, we suggest that the participants would underestimate the risk of a negative chosen outcome after receiving a negative alternative outcome (see the 'risk-as-feeling' hypothesis in Loewenstein, Weber, Hsee, & Welch, 2001). Thus, the negative chosen outcome would be evaluated as more unacceptable by the participants after a negative alternative outcome presentation. Consequently, a larger FRN would be elicited in this situation. Our results are consistent with the view that the influence of the alternative outcome on the FRN elicited by the chosen outcome might be better explained as changes in outcome expectation (Bellebaum & Daum, 2008; Rushworth & Behrens, 2008).

The influence of the alternative outcome on the P3 elicited by the chosen outcome is also worth noting. Specifically, the P3 elicited by the chosen outcome was larger when it was preceded by a positive alternative outcome. In addition, this effect reached significance only

when the valence of the chosen outcome itself was positive. Previous studies have revealed that the P3 is larger following favorable feedback than when following unfavorable feedback (Gu, Ge, Jiang, & Luo, 2010; Hajcak et al., 2005). In the current study, the positive alternative outcome was regarded as disadvantaged information by the participants, which weakened the outcome expectation. In this situation, a positive chosen outcome would be unexpected and could be evaluated as more favorable, indicated by an enhanced P3 (for the relationship between the P3 and outcome expectation, see Bellebaum & Daum, 2008; Hajcak et al., 2007; Holroyd et al., 2004).

Yeung & Sanfey (2004) have suggested that valence and magnitude, the two fundamental features of outcome signal, are evaluated independently in the brain. The FRN is sensitive to valence but insensitive to magnitude, while the P3 shows the opposite pattern (see also Sato et al., 2005). In general, the results of our study support this idea: the FRN, but not the P3, sensitively responded to the valence of the outcome that was being evaluated (either the alternative or the chosen one). However, the P3 elicited by the chosen outcome was sensitive to the valence of the alternative outcome, indicating that this component is not indifferent to outcome valence. One possible explanation is that the P3 is actually sensitive to the comparison between different outcomes, rather than the features of the outcome per se. This viewpoint finds support from Yeung & Sanfey (2004)'s report, which found out that the P3 was sensitive to the relative value of the alternative outcome compared with the chosen outcome. Thus, one might suggest that the evaluation system indicated by the FRN and P3 is more complicated than an independent coding model (see also Goyer et al., 2008). Further investigation into this issue is needed.

To sum up, by presenting the alternative outcome upfront in the task, the FRN showed a different response pattern from the classical studies. The results of the current study provide new insights into the process of outcome evaluation, which is reflected by the ERP components FRN and P3. The valence of the alternative outcome not only influenced the FRN elicited by the alternative outcome, but also influenced the FRN and the P3 elicited by the chosen outcome. The results suggest that, even though the alternative outcome is economically neutral and independent of the chosen outcome, the participants still tried to take the alternative outcome into consideration when predicting future events. In addition, these results broaden knowledge about the cognitive function indexed by the FRN and the P3, which would be of interest for future research.

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Figure 1. Example trial: subjects were presented on each trial with a choice of two alternatives, one of which they were asked to select using their left or right index finger
 Their choice would be immediately highlighted with a thick red border. After 500 ms, they were shown the alternative outcome (which indicated what they would get if they made the alternative choice) for 1000 ms. After an additional 500 ms, they were shown the chosen outcome. In this trial, both the alternative outcome and the chosen outcome are positive. RT: response time.

Alternative Outcome (FRN)

Figure 2. (a) Grand-average ERPs evoked by the presentation of alternative outcomes at the Fz recording site, where the FRN in response to alternative outcomes reached its maximum; (b) the scalp topography of each condition

The time point '0' indicates the onset time of the alternative outcome presentation. The gray shaded area indicates the 200–300 ms analysis window in which the mean amplitude of the FRN was measured.

Chosen Outcome (FRN)

Figure 3. (a) Grand-average ERPs evoked by the presentation of chosen outcomes at the Fz recording site, where the FRN in response to chosen outcomes reached its maximum; **(b)** the scalp topography of each condition

The time point '0' indicates the onset time of the chosen outcome presentation. The gray shaded area indicates the 200–300 ms analysis window for the FRN.

Positive (after Positive): positive chosen outcomes, presented after positive alternative outcomes. **Positive (after Negative):** positive chosen outcomes, presented after negative alternative outcomes. **Negative (after Positive):** negative chosen outcomes, presented after positive alternative outcomes. **Negative (after Negative):** negative chosen outcomes, presented after negative alternative outcomes.

Chosen Outcome (P3)

Figure 4. (a) Grand-average ERPs evoked by the presentation of chosen outcomes at the Pz recording site, where the P3 in response to chosen outcomes reached its maximum; (b) the scalp topography of each condition

The gray shaded area indicates the 300–500 ms analysis window for the P3. The meaning of each condition is consistent with which in Figure 3.