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Research report

I endeavor to make it: Effort increases valuation of subsequent monetary reward

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HIGHLIGHTS

- Effort, in general, could enhance subjective valuation toward gain–loss outcome.
- FRN and P300 represent modulated effect of varied efforts during outcome evaluation.
- P300 also exhibits the valence effect of feedback at the late stage of evaluation.

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ABSTRACT

Although it is commonly accepted that the amount of effort we put into accomplishing a task would exert an influence on subsequent reward processing and outcome evaluation, whether effort is incorporated as a cost or it would increase the valuation of concomitant reward is still under debate. In this study, EEGs were recorded while subjects performed calculation tasks that required different amount of effort, correct responses of which were followed by either no reward or fixed compensation. Results showed that high effort induced larger differentiated FRN responses to the reward and non-reward discrepancy across two experimental conditions. Furthermore, P300 manifested valence effect during reward feedback, with more positive amplitudes for reward than for non-reward only in the high effort condition. These results suggest that effort might increase subjective evaluation toward subsequent reward.

1. Introduction

According to our common knowledge, there is a close relationship between reward and effort, since we seldom get any reward without effort. Ecological theories assert that we would recognize the role prior effort plays when we process the subsequent outcome, due to the fact that a better comprehension would lead to better decisions in the future [1,2]. Quite often, we may judge whether a potential payoff is worth the effort it requires or not. There are two common propositions accounting for this effort effect. However, up to now, only a few empirical studies have addressed the effect of prior effort on the processing of the resulting reward.

One prevalent view holds that effort has disutility, according to which effort itself carries a negative value or cost. This negative connection between effort and reward is found in a series of theories, including social equity theory [3]. According to the effort discounting principle, the net value of a reward would be higher if it is comparatively easily obtained [4–6]. In effect, effort level stands as a reference point against the earned rewards, and more effort corresponds to a relatively higher reference point [7]. On the other hand, other previous literatures revealed that humans prefer conditioned rewards that are earned with greater effort [8]. It was discovered that actions taken beforehand could increase people's valuation of the following reward [9–11]. Compared with windfalls, people have decreased willingness to spend money from earned gains [12], which supported the view of effort valuation.

In recent years, there is increasing interest to probe into the neural mechanisms responsible for reward evaluation, which makes

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it possible for us to understand the role prior effort plays in the processing of the subsequent reward in a direct manner. For example, Hernandez et al. (2013) investigated how prior effort influences the valuation of different reward magnitudes using functional magnetic resonance imaging (fMRI) [13]. In their experiment, the subjects received monetary rewards of varied amount after they successfully performed calculation tasks that were difficult, easy or already solved. It was considered that as the difficulty of the task increases, people would have to make more effort to solve the problem. A forced donation stage was implemented subsequently, which caused a loss for the subject. Results showed that gain and loss magnitudes positively and parametrically modulate activation in NAcc and anterior insula respectively only after high effort, which suggested that increased effort leads to an accompanying increasing relevance of the outcomes. One possible limitation of this study is that reward and non-reward did not appear at the same stage of the experiment, which makes it difficult to directly compare people's perceptions to reward and non-reward with preceding effort.

To date, however, few studies have explored the temporal dynamics of how effort shapes people's valuation of subsequent reward. To investigate how such a cognitive process is implemented in the brain, we adopted event-related potentials (ERPs) to explore temporal substrates of the evaluation of reward and no-reward after effort. In ERPs studies concerning outcome evaluation and reward processing, FRN and the P300 are the most widely reported and examined ERP components.

Feedback-related negativity (FRN), which is the most negative deflection around the 250–350 ms period post-onset of feedback, shows maximal amplitude over medial frontal scalp locations. The amplitude of FRN is larger following negative feedback, which appears when facing an incorrect response, game failure, or monetary loss [14–17].

According to the reinforcement-learning theory of FRN [16,17], when people make a risky decision, the negative prediction errors induced by the unfavorable outcome would facilitate the release of dopamine in midbrain, which would reduce its inhibition function to dopaminergic projection areas ACC. This would subsequently result in an increased deflection of FRN at the frontal area of scalp and vice versa. Such a mechanism could explain why the unexpected losses would elicit a relatively larger FRN as compared to gains, which has been well established in the past decade [18]. Beyond that, in a recent study, Bellebaum et al. (2010) investigated the role of FRN through a probabilistic risky decision-making task and found that FRN is also sensitive to the violation of reward magnitude expectation, which indicated that, besides valence, the FRN could also represent the salience of the prior stimuli [19]. Correspondingly, in our current study, when people invest more effort into a task, their expectancy toward good results may increase. Thus, when this expectancy is violated, a stronger prediction error may occur [18,20].

On the other hand, another popular theory deems that the motivational significance of the FRN could be an explanation for the FRN discrepancy toward gains and losses in risky decision-making. In a pioneering study, Gehring and Willoughby (2002) asked the subjects to make a selection from two available options and revealed the outcome instantly after their selection [15]. They found that the loss and gain divergence could invoke a negative deflection that originates from ACC, no matter whether the chosen option is inferior or superior to the alternative one. Beyond that, in a recent study, Zhou et al. (2010) reported that the mere confirmative action could prominently enlarge the amplitude of FRN at the feedback stage, which indicates that the heightened motivation could also modulate the deflection of FRN. By analogy, the additional effort that subjects put into the multiplication tasks could also augment the motivational significance of the accompanying reward and subsequently enlarge the amplitude of FRN discrepancy at the feedback stage [21].

Another component is the P300, which is the most positive deflection in the 200–600 ms period after the presentation of feedback information, which typically exhibits its maximum magnitude at parietal sites. Early research found that the P300 could encode the motivational/affective significance of the stimuli [22]. In its extension to risky decision-making, it was found that the P300 is sensitive to the magnitude of reward, which is consistent with its role to embody the subjective motivation toward stimuli in a general manner [23–25]. With respect to the role of P300 in encoding valence of the received outcome, early studies claimed that gain loss difference has no impact on the P300 [24,25]. However, several recent studies indicated that the P300 is also sensitive to the valence of feedback, which responds more positively to positive feedback than to neutral and negative feedback [26–28].

In the present experiment, we applied ERPs to investigate the integration of effort and outcome information in the human brain. Our objective was to test for a neural correlate of effort valuation. The calculation tasks were revised from the work of Hernandez et al. (2013) mentioned above [13]. We only recruited male participants for this experiment, mainly due to their more consistent performance in terms of accuracy rate. Each participant was asked to solve a certain number of multiplication and additive operation tasks. Once they provided the correct answer to a problem, they got 50% chance to win a fixed amount of monetary reward, and they would receive no reward under the rest 50% circumstances. This manipulation aimed to induce reward and non-reward at the same feedback stage, which differs from the previous fMRI experimental design. The subjects would not be compensated for their effort if they gave a wrong answer or failed to arrive at a solution to the problem within the time limit. The electroencephalography signals were recorded from the subjects throughout the experiment. Such a paradigm allowed us to explore how the previous effort affects subjects' neural responses toward the subsequent reward and non-reward.

Considering that differentiated FRN (d-FRN) toward the reward/non-reward divergence of the outcome reflects both the prediction error and the motivational/affective evaluation, we posit that the reward/non-reward FRN discrepancy in observing the resulting outcome of high effort would be more pronounced. Given that P300 is a reflection of the motivational salience, we postulate that the P300 would loom larger in the high effort condition than in the low effort condition.

2. Methods

2.1. Participants

Nineteen healthy, right-handed subjects aged 18–25 years ($M = 22.59$ years, $SD = 1.66$ years) participated in this study. All subjects were male students of Zhejiang University. They were native Chinese speakers, had normal or corrected-to-normal vision, and did not have any history of neurological disorders or mental diseases. This study was approved by the Internal Review Board of Zhejiang University Neuromanagement Lab. Informed consents were obtained from all participants before the experiment was formally started. Data from two subjects were discarded because of excessive recording artifacts, resulting in 17 valid subjects for the final data analysis.

2.2. Experiment procedure

The subjects were comfortably seated in a dimly lit, sound-attenuated and electrically shielded room. The stimuli were presented centrally on a computer screen at a distance of 100 cm. A keypad was provided for the subjects to make their choices. The experiment was consisted of 3 blocks, each containing 60 trials. During the experiment, subjects were presented with 90 multiplication tasks (high effort condition) and 90 additive operation tasks (low effort condition). All the addends and multipliers were two-digit figures, while all the provided options were three-digit.

As illustrated in Fig. 1, at the beginning of each trial, a fixation appeared as a cue for 1000 ms on the black screen, which was followed by the calculation task to be performed. The calculation task might be either multiplication or additive operation, all of which were randomized by the program, which makes it impossible for the subjects to predict the type of the upcoming task. The participants were provided with three possible solutions for each task and had a maximum of 10 s to give their response by button press. After the participants made their choice, the chosen option was highlighted for 1000 ms, which would be skipped if no valid responses were given within 10 s.

Afterwards, visual feedback was displayed according to the previous choice (performance feedback). A trial would be deemed as unsuccessful if the given response was incorrect or the subject failed to make a choice within the time limit. In this circumstance, a red cross would be displayed for 1500 ms before the next trial started. If the response given within 10 s were correct (successful trial), a green check mark would be displayed for 1500 ms, indicating possible reward for the participants. 50% of the successful trials were accompanied with a reward of ¥ 10, while the participants would receive nothing in the other trials. The reward feedback stage lasted for 1500 ms before the end of each trial.

In a typical trial, the sequential stimuli were separated by blank screens that lasted for 500–800 ms. The between trial interval lasted for 1000–1500 ms. The subjects were informed that they would receive ¥ 20 as show up fee, in addition to which three trials would be randomly chosen to calculate their performance-based reward. The final reward a subject received equals to the sum of the show up fee and the performance-based reward. Because every trial has equal probability to be chosen, a rational subject would try his/her best to solve out every task in order to get larger rewards in the end. Ten practice trials were implemented before the start of the formal experiment. Stimuli, recording triggers, and responses were presented adopting E-Prime 2.0 software package (Psychology Software Tools, Pittsburgh, PA, USA).

2.3. EEG recordings

EEGs were recorded (band-pass 0.05–70 Hz, sampling rate 500 Hz) from 64 scalp sites with Neuroscan Synamp2 Amplifier. The left mastoid served as on-line reference. EEGs were off-line re-referenced to the average of the left and the right mastoids. The electrode on the cephalic region was applied as ground. Vertical Electrooculogram (EOG) was recorded supra and infra-orbitally at the left eye, while horizontal EOG was recorded at the left versus right orbital rim. Electrode impedance was maintained below 5 kΩ during the experiment.

2.4. Data analysis

For the analysis of behavioral data, paired *t*-test was adopted to compare the success rates across the two experimental conditions. During the offline EEGs analysis, ocular artifacts were removed, which is followed by digital filtering through a zero phase shift (low pass at 30 Hz, 24 dB/octave). Time windows of 200 ms before and 800 ms after onset of the stimulus were segmented, and the whole epoch was baseline-corrected by the 200 ms interval prior to stimulus onset. Trials containing amplifier clipping, bursts of electromyography activity, or peak-to-peak deflection exceeding ±100 μV were excluded. For each subject, recorded EEGs were separately averaged over each recording site under each experimental condition. During performance feedback, the EEG epochs were averaged for high effort versus low effort conditions.

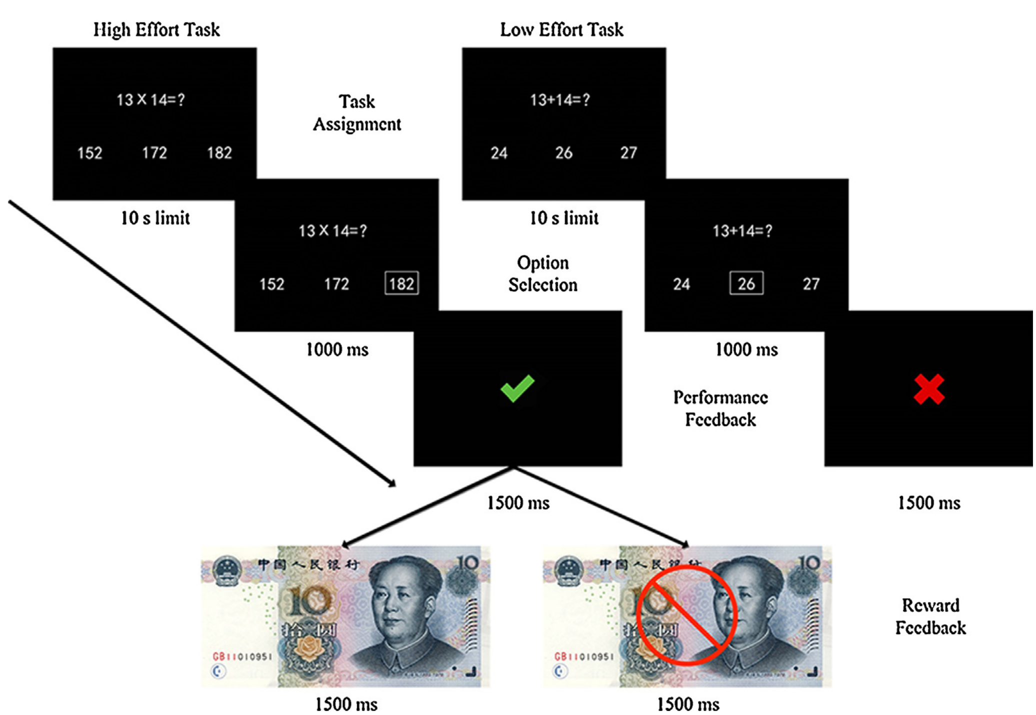

Fig. 1. Experimental task. Participants were instructed to accomplish both high effort and low effort tasks. They were provided with three options and had a maximum of 10 s to make their choice. The correctness of their responses was revealed during performance feedback. In a successful trial, the actual reward for that trial was presented during reward feedback. EEGs were recorded from the subjects throughout the experiment.

During reward feedback, the EEG epochs were separately averaged for effort (high effort/low effort) × valence (reward/non-reward) conditions, which resulted in a total of four conditions.

Given that the maximum P300 amplitudes were observed at parietal sites, data from the electrode sites C1, Cz, C2, CP1, CPz, CP2, P1, Pz and P2 were analyzed, and we averaged the ERP amplitude of the time range 330–430 ms post-onset of the feedback. Since we are interested in the role effort plays in the processing of the subsequent reward, only data from successful trials were analyzed. Taking into consideration that the reward feedback might be either reward or non-reward, P300 data went into a 2 (effort) × 9 (electrode) repeated measures ANOVA during performance feedback, while a 2 (effort) × 2 (valence) × 9 (electrode) repeated measures ANOVA was applied during reward feedback. Considering that the maximal FRN amplitudes appeared at frontal sites, data from the electrode sites F1, Fz, F2, FC1, FCz and FC2 were analyzed. Mean amplitudes in the 230–330 ms time window post-onset of feedback, defined through visual inspection, went into a 2 (effort) × 2 (valence) × 6 (electrode) repeated measures ANOVA. Simple effect analysis was conducted when the interaction effect was significant. The Greenhouse–Geisser correction was applied in all statistical analyses when necessary.

3. Results

Accuracy was 83.70% (SD = 0.110) in the high effort condition and 98.10% (SD = 0.039) in the low effort condition, which demonstrated a significant condition effect on accuracy ($t = 5.420$; $p < 0.001$). Average reaction time was 5881.1 ms (SD = 835.6) in the high effort condition and 2146.7 ms (SD = 421.6) in the low effort condition, yielding a significant condition effect on average reaction time ($t = 17.764$; $p < 0.001$). Across all subjects, since the lowest number of correct responses was 59 in the high effort condition, there was sufficient number of events for following ERP analysis under both conditions. As have been outlined above, reward processing and outcome evaluation are mainly reflected in FRN and the P300. All the following analyses refer to brain activity evoked by presentation of feedback information (stimulus-locked), including feedback about the correctness of the choice (performance feedback) and feedback about the received reward (reward feedback).

3.1. Performance feedback

As can be observed in Fig. 2, the ANOVA analysis for the P300 revealed main effects of effort ($F_{1,16} = 16.641$; $p = 0.001$) and electrode ($F_{1,8} = 3.647$; $p = 0.040$) during performance feedback, indicating larger amplitude in the high effort condition than in the low effort condition.

3.2. Reward feedback

As presented in Fig. 3, the ANOVA analysis for the FRN revealed main effects of valence ($F_{1,16} = 4.613$; $p = 0.047$) and electrode ($F_{1,5} = 3.611$; $p = 0.041$). However, the main effect of effort is not significant ($F_{1,16} = 0.434$; $p = 0.520$). The main effect of valence shows more negative FRN responses to the neutral feedback than to the positive feedback. This effect interacted with effort ($F_{1,16} = 15.143$; $p = 0.001$), with the FRN being more negative for the neutral feedback than for the positive feedback in the high effort condition ($F_{1,16} = 17.832$; $p = 0.001$), but not in the low effort condition ($F_{1,16} = 0.064$; $p = 0.804$). We further examined the effect of effort in the non-reward and reward conditions respectively. The main effect of effort on the non-reward condition is significant ($F_{1,16} = 5.420$; $p = 0.033$) but not in the reward condition ($F_{1,16} = 2.016$; $p = 0.175$).

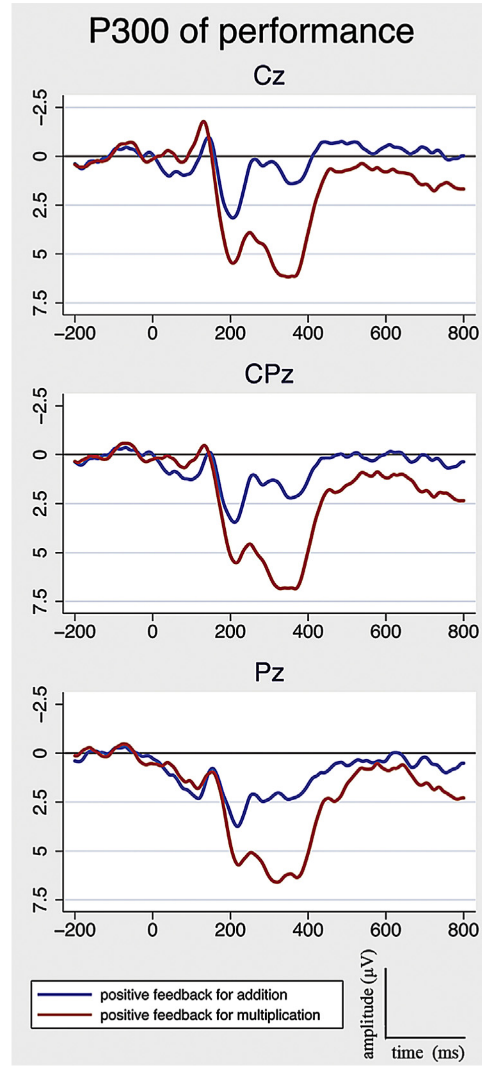

Fig. 2. P300 results during performance feedback. For illustrative purpose, grand-averaged ERP waveforms of the P300 from 3 midline parietal electrodes (Cz, CPz, Pz) were shown over effort (high effort and low effort).

The ANOVA analysis for the P300 revealed main effects of valence ($F_{1,16} = 11.212$; $p = 0.004$) and electrode ($F_{1,8} = 5.906$; $p = 0.008$). However, the main effect of effort is not significant ($F_{1,16} = 0.625$; $p = 0.441$). The main effect of valence shows more positive P300 responses to the positive feedback than to the neutral feedback, which interacted with effort ($F_{1,16} = 7.044$; $p = 0.017$), with the P300 being more positive for the positive feedback than for the neutral feedback in the high effort condition ($F_{1,16} = 16.213$; $p = 0.001$), but not in the low effort condition ($F_{1,16} = 0.977$; $p = 0.338$). We further examined the effect of effort in the reward and non-reward conditions respectively. The main effect of effort is significant ($F_{1,16} = 7.762$; $p = 0.013$) in the reward condition, but not in the non-reward condition ($F_{1,16} = 0.451$; $p = 0.511$).

4. Discussion

In this study, we intended to investigate to what extent reward processing would be modulated by prior effort. ERP results during both performance and reward feedback demonstrated that effort indeed influences the brain activity in the subsequent outcome evaluation. During performance feedback, we observed prominently greater P300 amplitude in the high effort condition than in the low effort condition. During reward feedback, larger FRN

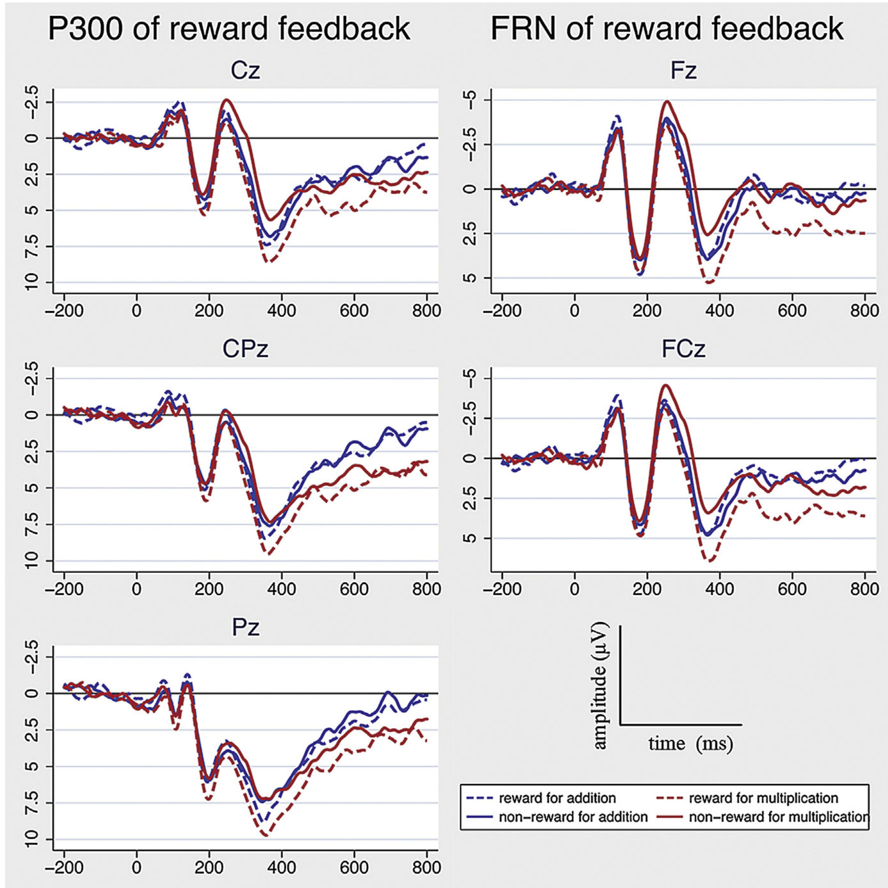

Fig. 3. FRN and P300 results during reward feedback. For illustrative purpose, grand-averaged ERP waveforms of FRN from 2 midline frontal electrodes (Fz, FCz) were shown over effort (high effort and low effort) and final outcome (reward and non-reward). In a similar vein, grand-averaged ERP waveforms of P300 from 3 midline parietal electrodes (Cz, CPz, Pz) were shown as a function of effort (high effort and low effort) and final outcome (reward and non-reward).

discrepancies between reward and non-reward were observed under high effort than under low effort. Furthermore, the P300 response was significantly more positive to reward than non-reward outcome only in the high effort condition. In general, we found that when subjects were assigned tasks of varied difficulties, they are more likely to treasure the same reward that they subsequently received if more effort has been made for the task. Therefore, our current findings may support the notion that effort enhances people's evaluation of the subsequent reward.

In the present study, we found a general FRN effect for reward and non-reward, which was in accordance with previous findings that the FRN represents the valence of the outcome [15,29]. Notably, we also found that effort enlarges the size of the FRN effect. From visual inspection, we conjectured that the enlarged FRN effect following high effort was mainly due to more negative-going ERP response to non-reward, instead of less negative-going ERP response to reward, and this speculation has been verified statistically, with a significant main effect of effort in the non-reward condition, but not in the reward condition. Such a finding indicates that non-reward induces a larger FRN deflection in the high effort condition than in the low effort condition.

As has been mentioned in the introduction, reinforcement-learning theory deems that FRN is sensitive to the negative prediction error. Thus, unanticipated unfavorable outcomes, which lead to a larger negative prediction error, would elicit a larger FRN effect than expected outcomes [20,28,30,31]. In the present study, previous effort may reinforce the expectancy to achieve the positive outcome. People would have a greater desire to obtain the reward once they have put a lot of effort into the task. Because the FRN monitors the detection of conflict as reflected by the discrepancy between the expectancy and the actual outcome, the neutral feedback indicating violation of a stronger expectancy would lead to a stronger prediction error and subsequently stronger FRN deflection. Hence, the present study suggests that manipulating the effort required to accomplish a task would change the subjective expectancy toward the positive outcome and subsequently influence the FRN responses.

In addition to that, previous research showed that different motivational/emotional significances could well explain the discrepancy in FRN electrophysiological responses [21,32]. Yeung et al. (2005) adopted monetary gambling tasks in which either participants made active choices, were forced to press a button to start a gamble, or the gamble started on its own. The differences in FRN amplitude across the three scenarios were correlated with changes in participants' subjective ratings of involvement, suggesting that FRN is sensitive to the motivational significance of ongoing events [32]. In another study, Li et al. (2010) manipulated subjects' responsibility levels in performing a gambling task. While a low-responsibility condition refers to a gamble performed alone, a high-responsibility condition refers to a gamble performed together with other people [33]. It was discovered that, the outcome revelation of FRN effect augments to a greater extent under high responsibility. Although the current study did not explicitly manipulate the responsibility level, similar results were arrived at. The increased amplitude of FRN might indicate the increased motivation derived from more effort invested.

As elaborated in the introduction, from the previous studies, it was reported that the P300 could represent the motivational/affective significance of the stimuli and recent studies also indicated its role in gain loss differentiation [22,26,28]. In the current study, we did not find a prominent P300 difference between the two effort levels. Instead, there is a pronounced P300 discrepancy between reward and non-reward in the high effort condition but not in the low effort condition, manifesting a moderation effect of effort on the valence effect of the P300 observed, which suggested that effort might be a significant influencing factor of the electrophysiological responses of P300.

Such a finding is in accordance with recent studies. For instance, in one of our recent studies adopting a gambling task in the social context, although we found that, independent of FRN, there is a general P300 divergence across agents of different degrees of closeness to the subjects, P300 diverged toward reward and non-reward only when there was a corresponding FRN discrepancy [34]. Therefore, the valence effect of P300 could bear motivational implication of the outcome. Discoveries of Zhou et al. (2010) also contributed to this proposition [21]. In the current study, as subjects invest considerable amount of effort into fulfilling the task, they would assign more affective significance to the upcoming outcome. Thus, the final outcome that is either positive or neutral becomes more motivationally significant to the subjects, increasing the electrophysiological discrepancy between the positive and neutral outcome in the high effort condition. The current P300 results might give some clues to explain the conflicting reports on the role of the P300 in outcome evaluation [24,26,28]. Because the valence effect of the P300 might be moderated by the motivational significance of the stimuli, this effect might be exhibited only when it is accompanied with high motivation. Moreover, since reward with high effort elicited the highest amplitude of the P300 compared with the rest conditions in the current study, it is suggested that the valence effect of the P300 might be mainly reflected in its more positive response to reward with high effort, in contrast to the discovery that FRN mainly responds to non-reward with high effort, which has been explained above.

Therefore, similar with the previous fMRI findings that reward-related brain regions NAcc and negative emotion-related brain region insula respectively encoded for the outcome evaluation with effort manipulation in the gain and loss domain, we also found a dichotomic result pattern in current study. Applying the ERP technique, it was discovered that FRN and the P300 reflect the modulation effect of effort on the reward processing in different domains. Under high effort, there is a significant deflection of FRN for non-reward, while a prominent positive deflection of the P300 was observed for reward. Therefore, the current study well complements the fMRI findings from the temporal dynamics perspective, which further demonstrated that effort modulation of the following reward processing could be encoded both in the reward and non-reward domain.

5. Conclusion

To conclude, ERP results of current study demonstrated that reward and non-reward processing in the human brain critically depends on how the reward was arrived at, and that effort increases the corresponding brain activity during outcome evaluation. Applying calculation tasks that require either high or low effort, current study revealed that varied effort would exert a modulation effect on FRN, with larger discrepant responses to valenced feedback following high effort than following low effort. Beyond that, in the high effort condition, the P300 responded more positively for reward than the feedback without reward. In general, such findings imply that intensive effort would lead to increased subjective evaluation of subsequent outcome.

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