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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