Self-reflection modulates the outcome evaluation process: Evidence from an ERP study

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Recent research demonstrated structural overlap between reward and self processing, but the functional relationship that explains how self processing influences reward processing remains unclear. The present study used an experimentally constrained reflection task to investigate whether individuals’ outcome evaluations in a gambling task are modulated by task-unrelated self- and other-reflection processes. The self- and other-reflection task contained descriptions of the self or others, and brain event-related potentials (ERPs) were recorded while 16 normal adults performed a gambling task. The ERP analysis focused on the feedback-related negativity (FRN) component. We found that the difference wave of FRN increased in the self-reflection condition compared with the other-reflection condition. The present findings provide direct evidence that self processing can influence reward processing.

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1. Introduction

The concepts of the self and reward are both important topics in the field of psychology. Great progress has been made recently in understanding how the self and reward are represented and processed in the human brain (Johnson et al., 2002; Schultz, 2006). The neural mechanisms of the self and reward have been investigated largely independently. However, neuroimaging studies have revealed neuronal networks that overlap in self and reward processing (for review, see Northoff and Brempoth, 2004; Northoff and Hayes, 2011), mainly in cortical middle structures (CMSs), including the anterior cingulate cortex (ACC), posterior cingulate cortex (PCC), precuneus, and especially ventromedial prefrontal cortex (vmPFC). In addition to structural overlap, recent studies on the self and reward have demonstrated that self-specific stimuli induce changes in neural activity in regions that are recruited during reward (deGreck et al., 2008; Enzi et al., 2009; Ersner-Hershfield et al., 2009; Tamir and Mitchell, 2012), including the vmPFC, ventral striatum (VS), and ventral tegmental area (VTA). The aforementioned findings raise the possibility that vmPFC’s processing of self-related content may reflect a valuation mechanism. Indeed, the vmPFC plays a broad role in affective and value-based processing (Phan et al., 2002; Roy et al., 2012). Some researchers have explicitly proposed that the vmPFC might signal the personal significance of self-related content. For example, Schmitz and Johnson (2007) proposed that the vmPFC subserves supramodal processes that contribute to monitoring the self-relevance of various types of stimuli. Northoff and Hayes (2011) proposed a reward-based view of the self and discussed three ways in which self-relevance and value-based processing are related. More relevant to the present study, D’Argembeau (2013) relied on the valuation hypothesis to explain the role of the vmPFC in self-processing. He proposed several lines of converging evidence to support this hypothesis. Increasing the psychological distance from self-representations leads to a decrease in vmPFC activation, and the magnitude of vmPFC activation linearly increases with the personal importance that is attributed to self-representations. However, the evidence reviewed by these authors mainly focused on either the self-relevance of external stimuli (e.g., pictures of emotional scenes or rewarding stimuli) or correlation between vmPFC activation and personal significance. Few studies have explored the ways in which self processing influences reward processing. To provide a better understanding of the interaction between self and reward, the present study employed the event-related potential (ERP) technique, combined the self-reflection task and a gambling task to investigate how self- and other-reflection influences the outcome evaluation process.

The self-and other-reflection task is an important approach that is used to assess the neural bases of self-related processes using functional neuroimaging methods (Christoff et al., 2011). This approach has addressed the relevance of trait adjectives with reference to oneself and compared brain activity to control conditions (e.g., the reference of trait adjectives that are related to close friends or others; van der Meer et al., 2010). The social neuroscience literature indicates that the evaluation of one’s own personality and the personalities of others...
recruits shared neural networks, mainly in the CMS regions (Modinos et al., 2011; Murphy et al., 2010; Qin and Northoff, 2011; Schmitz et al., 2004). Nonetheless, some self-specific structures can differentiate processing of the self and others. For example, four important meta-analyses investigated cortical activation that is relevant to self-specific regions (Northoff et al., 2011; Qin and Northoff, 2011; van der Meer et al., 2010). Results indicated four particular regions that are sensitive to self-specificity: pACC (Qin and Northoff, 2011), dorsal anterior cingulate cortex (dACC; van der Meer et al., 2010), vmPFC, and anterior insula (Af; Northoff et al., 2011). These regions have also been implicated in diverse aspects of reward processing (Ruff and Fehr, 2014). The engagement of these areas during both self-processing and reward processing may provide the basis for the possible interactions between them.

Reward processing can be divided into two sub-processes: anticipation of reward and outcome evaluation (Schultz, 2006). The present study focused on the latter. In ERP studies, two ERP components are particularly sensitive to the processing of outcome feedback. Feedback-related negativity (FRN) is a medial frontal negative deflection of the visually evoked ERPs that peaks approximately 250 ms following feedback, indicating negative performance feedback compared with positive performance feedback and monetary loss or nonreward compared with monetary gain or reward (Gehring and Willoughby, 2002). Localization studies suggest that FRN is generated near the ACC (Nieuwenhuis et al., 2004), consistent with functional magnetic resonance imaging results that implicated the ACC and vmPFC in negative feedback processing (e.g., Nieuwenhuis et al., 2005). The most influential theories that have been proposed suggest that FRN reflects a reinforcement learning signal that is associated with prediction errors, especially when outcomes are worse than expected (Holroyd and Coles, 2002). However, recent accumulating evidence suggests the opposite viewpoint, in which the FRN amplitude is largely modulated by neural activity in gain trials. One proposal is that monetary gain feedback elicits a distinct positive-going deflection (Foti et al., 2014; Proudfit, 2015), and reward positivity directly reflects activity of the mesencephalic dopamine system (Foti et al., 2011), a neural network that is critically involved in reward processing (Schultz, 2006). The second component is the P3 or P300, which is a centro-parietal positivity that is often associated with allocation of cognitive resources, such that larger P3 amplitudes indicate more resources are allocated to the ongoing task (Polich, 2007; Molnár, 1999).

Self-reflection is not immune to the valence of the reflected content. According to the self positivity bias view, people have a need to view themselves positively (Mezulis et al., 2004). Cortical activity during self-reflection is also modulated by the valence of the content. For example, Moran et al. (2006) found that positive self-processing evoked larger vACC activity than negative self-processing. Given the anatomical proximity of the mPFC and vACC, a tempting speculation is that the self effect would be larger under positive reflection conditions than under negative reflection conditions.

Building on these aforementioned observations, in the present study, we used explicitly defined reflection task to determine whether self processing influences outcome evaluation. We predicted that the self-reflection task can influence the outcome evaluation process, and the modulatory effect will be manifested in FRN. Specially, the self-reflection evokes an enhanced vmPFC activity and it is generally thought that vmPFC is the source of the FRN, so we hypothesized that the FRN should be larger in the self-reflection condition than in the other-reflection condition. Further, we predicted the FRN should be larger in the positive reflection condition than in the negative reflection condition.

2. Methods

2.1. Participants

Sixteen college students (22.6 ± 0.8 years of age; range, 22–24 years; nine males) participated in the study. Informed consent was obtained prior to the experiment. All of the participants had normal or corrected-to-normal vision, and none of them had a history of neurological disease or brain injury. All of the participants were right-handed. The subjects were paid for their participation.

2.2. Self- and other-reflection task

Before the experimental task, each participant was asked to list eight positive and eight negative adjectives that best described themselves. Each word was used to form two sentences to describe a trait of the participant or a stranger (e.g., the word “brave” could be used to generate “I am brave” and “He/she is brave”). At the beginning of each trial, this sentence was presented on the screen for 3 s. When the sentence described the participants themselves, they were asked to reflect on the trait as mentioned in the sentence. If the subject of the sentence was a third person, then the participants were asked to reflect on someone who they did not know who possesses this trait.

Immediately after the reflection task, the subjects underwent the gamble task. The stimulus display and behavioral data acquisition were conducted using E-Prime 1.1 software (Psychology Software Tools). During the task, the participants sat comfortably in an electrically shielded room approximately 80 cm from a computer screen. Each trial began with the presentation of two white rectangles (2.5° × 2.5° of visual angle), in which two Arabic numerals (9 and 99) were individually presented to indicate two alternative options on the left and right sides of a fixation point. The positions of the two numbers were counterbalanced across trials. The participant was asked to make a selection by pressing the “F” or “J” key on the keyboard with the left or right index finger, respectively. The alternatives remained on the screen until the participant chose a rectangle, which was then highlighted by a thick red outline for 500 ms. Afterward, the outcome of the participant’s choice was presented such that its valence and magnitude were sequentially displayed, with a 500 ms interval between presentations (Fig. 1). The task had four possible outcomes: +9, +99, −9, and −99. Each outcome indicated the number of points the participant won (when the valence of the outcome was positive [+]) or lost (when the valence of the outcome was negative [−]) in the current trial. The formal task consisted of four blocks with 64 trials each. Unbeknownst to the participant, the outcomes were provided according to a predetermined pseudorandom sequence, and each participant received exactly 64 of each kind of outcome.

Before the experiment, each participant was informed about the rules and meaning of the symbols in the task. The participants were also told that the gain or loss was unrelated to the reflection task. Additionally, the participants were encouraged to respond in a way that would maximize the total score. The participants were told that higher scores would result in more bonus money that they would receive at the end of the experiment. However, after the participant finished the task, he/she was briefed that there was no optimal strategy in the task. Each participant was paid 50 Chinese Yuan (approximately $8) for participation.

2.3. Electrophysiological recording and measurement

Electroencephalographic (EEG) activity was recorded from 63 scalp sites using tin electrodes that were mounted in an elastic cap (Brain Products) with online reference to the middle at Cz and Fz (FCz) and offline algebraic re-reference to the average of the left and right mastoids. Horizontal electrooculograms (HEOGs) were recorded from an electrode that was placed at the outer canthi of the right eye. Vertical electrooculograms (VEOGs) were recorded from an electrode that was placed above the left eye. All inter-electrode impedance was maintained at <10 kΩ. Electroencephalographic and EOG signals were amplified with a bandpass from 0.01 to 100 Hz and continuously sampled at 500 Hz/channel.
Offline analysis of the EEG was performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). The first step in data pre-processing was the correction of ocular artifacts using Independent Component Analysis of the continuous data using Brain Vision Analyzer software (Brain Products, Munich, Germany). The ocular-artifact-free EEG data were low-pass-filtered below 30 Hz (12 dB/oct) and high-pass-filtered above 0.5 Hz (12 dB/oct). Separate EEG epochs of 1000 ms (200 ms baseline) were extracted offline for the stimuli. Error trials were discarded from all of the analyses. All of the trials in which EEG voltages exceeded a threshold of ± 75 μV during the recording epoch were excluded from the analysis.

According to previous studies, the FRN amplitude can be calculated in essentially two ways: using grand-averaged waveforms or creating a difference wave between error and correct trials (Holroyd et al., 2008). The main advantage of the difference wave approach is the minimization of overlap between FRN and other ERP components, including P3 (for detailed discussions, see Hajcak et al., 2007; Holroyd and Krigolson, 2007). Indeed, the application of the difference wave method generates clear FRN. To minimize the effects of overlap among FRNs with positive ERP components, we also created difference waves (dFRN) by subtracting the ERP responses in gain trials from the ERP responses in loss trials within the 220–320 ms window. The electrode at which the FRN reached a maximum was detected along the frontal midline (Fz and Cz). After examining the parieto-occipital regions, in which the P3 associated with outcome evaluation process can modulate reward processing. The self process is involved in the evaluation process. The present results are consistent with these views, suggesting that the self and reward networks have a tight relationship and extend previous results explored the functional relationships between self processing and reward processing. The present FRN results support the view that the self and reward networks have a tight relationship and extend previous results explored the functional relationships between self processing and reward processing.

### 3. Results

#### 3.1. Behavioral results

We defined the choice of “9” as the risk-avoidant choice in our experiment, predicting that participants would make this choice to avoid the possibility of a large loss (“−99”). However, by making this choice, they also gave up the opportunity to receive the larger reward (“+99”). In contrast, the choice of “99” was defined as the risky choice (high-risk or high-return).

For the purpose of investigating the influence of reflection type and reflection valence on risk-avoid behavior, the average level of risk-avoidant choices that were made by each participant were entered into a 2 (reflection type: self and other) × 2 (reflection valence: positive and negative) ANOVA test. The main effects and interaction were not significant ($p > 0.05$, self positive: $M = 31$; self negative: $M = 34$, other positive: $M = 31$; other negative: $M = 32$).

#### 3.2. ERP results

For the dFRN amplitudes, repeated-measures analyses of variance revealed no main effect was significant ($p > 0.05$). The interaction between emotional valence and reflection type was significant ($F_{1,15} = 6.32, p = 0.024, \eta^2 = 0.296$). Simple effect analysis revealed that self-reflection ($M = −2.398 \mu V, SD = 1.50$) evoked a larger dFRN than in the other-reflection ($M = −1.418 \mu V, SD = 1.36$) in the positive condition ($p = 0.019$) but not in the negative condition. All other interactions were not significant ($ps > 0.05$).

For the P3 amplitudes, repeated-measures analyses of variance revealed a main effect of emotional valence ($F_{1,15} = 7.52, p = 0.015, \eta^2 = 0.334$). P3 was larger in the positive reflection condition ($M = 3.67 \mu V, SD = 2.66$) than in the negative reflection condition ($M = 3.14 \mu V, SD = 2.14$). The main effect of outcome valence was also significant ($F_{1,15} = 12.30, p = 0.003, \eta^2 = 0.451$). P3 was larger in the win condition ($M = 3.09 \mu V, SD = 2.37$) than in the loss condition ($M = 3.72 \mu V, SD = 2.33$). The main effect of reflection type and all the interactions were not significant ($ps > 0.05$).

### 4. Discussion

The aim of the present study was to determine the effects of a self- and other-reflection task on the outcome evaluation process during a gambling task. After a decision was made that was unrelated to the reflection process, the participants received negative or positive feedback after they made a choice in a gambling task. Feedback-related negativity was larger in the self-reflection condition than in the other-reflection condition (Fig. 2A). These results indicate a significant influence of the self- and other-reflection task on the outcome evaluation process and provide additional support for a close link between the self and reward networks.

The present results appear to have important implications for the relationship between the self and reward networks. Northoff and Hayes (2011) proposed three relationship models to explain the relationship between self and reward: integration, segregation, and parallel processing. These relationship models mainly rely on overlapping structures between the self and reward networks. Few studies have explored the functional relationships between self processing and reward processing. The present FRN results support the view that the self and reward networks have a tight relationship and extend previous results by showing that the self process can functionally modulate reward processing. Schmitz and Johnson (2007) proposed that self-appraisal underlies the processing of fear, reward, emotion, pain, and others. The present FRN results provide direct evidence that the reflection process can modulate reward processing. The self process is involved in value assignment. The present results are consistent with these views, demonstrating that self-reflection can directly modulate the outcome evaluation process.
Self processing is proposed to reflect activation of the long-term value system, and outcome evaluation reflects activation of the short-term value system (Northoff and Hayes, 2011). The present results indicate that the activation of self-relevant information has an important impact on reward processing, supporting the view that activation of the long-term value system can modulate short-term reward processing. What mechanisms might account for the observed long-term value system's modulation of outcome evaluation? Given the nature of the self-reflection task that was used in the present study, a tentative explanation of our results may be based on some form of the modulation of the long-term value system can modulate short-term reward processing, supporting the view that activation of the long-term value system (Northoff and Hayes, 2011). The present results indicated that the participants devoted more attentional resources are recruited in a top-down, controlled manner.

In addition to the reinforcement-learning explanation of FRN, some researchers have also stressed the motivational/affective significance of FRN. Supporting the motivational/affective interpretation of FRN, much evidence has indicated that interpersonal relationships in reward processing (Leng and Zhou, 2010), responsibility (Li et al., 2010), and the extent to which others are included in the “self” concept (Kang et al., 2010) can modulate FRN. For example, a recent study manipulated the degree of responsibility by asking participants to execute a task themselves or to complete the task with two partners (Li et al., 2010). They found that FRN was enhanced when responsibility was high. The common feature of these factors is that they are all related to self-involvement in the task. Previous studies showed that FRN amplitudes are correlated with the degree to which participants feel involved in the task (Yeung et al., 2005). The present results provide insights into how the self-involvement factor influences FRN. We propose that the common feature of these factors is that they all contain a certain level of self-processing. Near social distance, a higher level of relevance, a higher proportion of responsibility, have all been shown to involve more in-depth processing than their respective control conditions. The in-depth processing of the self activates the reward network, leading to larger FRN in these conditions than in control conditions. Nonetheless, these are only speculations, and further research is needed to address the issue of such self-related modulation of FRN.

Self-reflection evoked a larger dFRN than other-reflection only in the positive condition and not in the negative condition (Fig. 2B). As mentioned in the Introduction above, self positivity bias makes people tend to view themselves positively (Mezulis et al., 2004). Therefore, participants were more likely involved in positive self-reflection than in negative self-reflection. Consistent with this possibility, a previous study reported a positive correlation between vmPFC activity and scores on a questionnaire that assessed one’s interest in self-reflection (D’Argembeau et al., 2014).

Consistent with previous studies, the P3 could be differentiated between the loss and win conditions (Fig. 2C). Previous studies showed that positive feedback elicited a larger P3 amplitude than negative feedback (Hajak et al., 2007; Wu and Zhou, 2009). P3 was larger in the positive condition than in the negative condition. Importantly, it was not modulated by the self-reflection type. P3 has been proposed to reflect a more elaborate evaluation, in which factors that affect the allocation of attentional resources are recruited in a top-down, controlled manner. The present results indicated that the participants devoted more attention resources in the positive condition than in the negative condition. P3 was insensitive to self-reflection priming, indicating that the self-reflection priming effect occurred at an earlier semiautomatic outcome evaluation stage.

The experimental task in the present study consisted of a sentence that indicated the trial type, a period for mental reflection with no need for a response, and then a gambling task. To investigate the effects of self-reflection on outcome evaluation, the subjects were instructed to generate self-reflective cognition when presented with a sentence that contained a trait word that described themselves. The other-reflection
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References


