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Diminished choice effect on anticipating improbable rewards

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ABSTRACT

Previous research found that the neural substrates underlying perceived control highly overlap those of reward system, especially during reward anticipation stage. The current event-related potential study examined whether the experience of choice by which individuals exercise control is modulated by reward probability during reward anticipation stage as indexed by the stimulus-preceding negativity (SPN). Thirty participants performed a cued gambling task during which choices could be made either by themselves (a choice condition) or by a computer (a no-choice condition) with three levels of reward probability (low, medium, and high) while their EEG was recording. As expected, the participants perceived higher control during the choice compared to no-choice condition. Correspondingly, the SPN was enhanced in the choice condition than the no-choice condition. Critically, the SPN choice effect was present when reward probability was high and medium, but was diminished when reward probability was low. These findings suggest that the perceived control as exercised by choice is associated with reward anticipation, which may be sensitive to the fundamental properties of reward.

1. Introduction

Perceived control refers to a belief of one's ability to exert control over the environment through choices and to produce desired outcomes (Leotti et al., 2010). The perception of control constitutes one of the four basic needs (Grawe, 2007) and plays a critical role in individual well-being (Bandura et al., 2003; Ryan and Deci, 2006; Shapiro et al., 1996). For example, perceived control can buffer the negative emotional response to aversive pain (Salomons et al., 2007) and increase the tolerance of pain and aversive noise in behavioral performance (Thompson, 1981). On the other hand, a lack of perceived control can elicit the feeling of helplessness and has shown to be related to depression, anxiety and mood disorders, eating disorders, and substance abuse (Mineka and Hendersen, 1985; Shapiro et al., 1996).

Recent neuroimaging research has demonstrated that perceived control as elicited by choice possesses an inherent reward value, especially during the anticipatory phase of reward processing (Leotti et al., 2010). A previous fMRI study found stronger brain responses in the ventral striatum during the anticipation of a choice relative to no-choice opportunity to obtain monetary gains (Leotti and Delgado, 2011). Similarly, another fMRI study observed that adolescents' reward anticipation was influenced by the subjective illusion of control in an uncertain situation such that ventral striatal activation during reward anticipation was enhanced among individuals experiencing an illusion of control relative to those reporting no such illusion of control (Lorenz et al., 2015). Given the intimate relationship between perceived control and reward anticipation, it is reasonable to hypothesize that the perception of control should be modulated by reward parameters such as valence, magnitude, and probability. For example, a recent research found that perceived control was modulated by reward valence such that ventral striatal responses were larger on trials involving potential rewards than on those involving potential losses (Leotti and Delgado, 2014). Here, we aimed to examine whether the perception of control during reward anticipation is modulated by another reward parameter, that is, reward probability.

The stimulus-preceding negativity (SPN) is characterized as a slow, nonmotor negative potential over frontal and parietal areas with its amplitude increasing gradually as a motivational stimulus arrives (Brunia et al., 2011; Hackley et al., 2014). This component is usually larger over the right versus left hemisphere and appears to be generated in the right anterior insular cortex (Bocker et al., 1994; Brunia et al., 2000; Kotani et al., 2009). Recent evidence has established the SPN as a reliably electrophysiological index of reward anticipation (Foti and Hajcak, 2012; Mattox et al., 2006; Zhang et al., 2017; Zheng et al., 2017). Despite a considerable amount of research on the neural correlates of perceived control during reward anticipation, a few studies have focused on the neurophysiological signature of this processing. Using a gambling task, Masaki et al. (2010) found that the SPN was larger under a choice condition during which participants made a decision between two options than a no-choice condition during which

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only one option was available. Similarly, Meng and Ma (2015) observed that the SPN was enhanced when a cognitive task could be actively chosen than when the same task was passively assigned. Finally, Muhlberger et al. (2017) has demonstrated that the SPN was larger in a condition with high perceived control during which rewards were perceived as controllable events than a condition with low perceived control during which rewards were regarded as random events. Taken together, these previous ERP research has demonstrated that the SPN is associated with the perception of control. Similarly, previous research has linked the SPN to reward probability (Catena et al., 2012; Fuentemilla et al., 2013; Megias et al., 2017; Umemoto and Holroyd, 2017). Using probabilistic learning tasks, two previous studies found that the SPN was increased as reward probability decreased (Fuentemilla et al., 2013; Umemoto and Holroyd, 2017). However, other studies observed that the SPN was enhanced on trials with high uncertainty during which outcomes were unpredictable than those with low uncertainty during which outcomes were predictable (Catena et al., 2012; Megias et al., 2017). To the best of our knowledge, it remains unclear whether perceived control is modulated by reward probability during reward anticipatory stage as indexed by the SPN.

To address this issue, the present study devised a cued gambling task during which choices could be made either by participants (a choice condition) or by a computer (a no-choice condition) with three levels of reward probability (low, medium, and high). We were interested in the effect of choice and thus perceived control on the SPN under different levels of reward probability. Given the similar neural correlates underlying perceived control and reward anticipation (Leotti and Delgado, 2011, 2014), and reduced ventral striatal activation during reward anticipation observed on trials with low reward probability (Abler et al., 2006) or negative expected value (Leotti and Delgado, 2014), we hypothesized that the inherent reward value of choice should be diminished once the desired outcomes become improbable in the low reward probability condition. Specifically, the SPN would be increased in the choice versus no-choice condition when reward probability was high. Importantly, the SPN choice effect would be reduced or disappeared when reward probability was low.

2. Materials and methods

2.1. Participants

Participants were 30 right-handed volunteers (13 females and 17 males; $M = 19.77$ years; $SD = 1.60$) recruited from the Dalian Medical University. All participants had normal or corrected-to-normal visual acuity and were free of psychological or neurological disorders. Each signed a written informed consent and was offered a base payment of ¥10, plus a bonus of ¥50 based on their earnings in the task. This study was approved by the local ethics committee.

2.2. Procedure

The participants were seated approximately 80 cm away from a computer monitor in a dimly lit and sound-attenuating chamber. On each trial, the participants could earn 10 points by correctly choosing one of four doors presented horizontally in a graphic either by themselves (the choice condition) or by the computer (the no-choice condition). Each trial commenced with either a green or a red number ("1","2", or "3") for 1000 ms. The "1", "2" and "3" cues informed the participants how many doors hid a reward, thus corresponding to the probability of reward on the current trial: low (.25), medium (.50), and high (.75), respectively. The color of the number informed the participants whether the door could be chosen by themselves or by the computer. In the choice condition, the participants could choose a door that they thought hid a reward by pressing one of four buttons (the "D", "F", "J", and "K" keys), corresponding to the location of the chosen door, with either their left or right index or middle finger. In the no-choice condition, the participants could not choose the door freely but had to start the computer to make a choice for them by pressing a button (the "SPACE" key) with either their left or right thumb finger. The color of the number and response fingers were counterbalanced across the participants. Following their response, a fixation appeared in the middle of the screen for 2000 ms and, thereafter, a feedback was presented for 1500 ms to indicate whether the chosen door had a reward (+10 points) or not (+0 points). Each trial ended with an intertrial interval varying from 900 to 1200 ms.

The task included 576 trials divided into six blocks (96 trials each), with a short break provided between blocks. A practice block with six trials was used before formal experiment for familiarizing the participants with the procedure. Prior to the experiment, the participants were told that the higher the points they earned, the more bonus money they would get, and that the final points included those earned in both the choice condition and the no-choice condition. The exchange rate was not provided until the end of the experiment. Moreover, unbeknownst to the participants, the outcome of each trial was predetermined and pseudorandom, which was identical between the choice and no-choice conditions.

After the formal experiment, the participants were asked to complete a 7-point, Likert-scale questionnaire adapted from a previous research (Tricomi et al., 2004). The participants rated their degree of sense of control, subjective involvement including attention and interest, as well as certainty about reward pattern in the choice and no-choice conditions, respectively.

2.3. Recording and analysis

EEG was recorded with a set of 64 sintered Ag/AgCI electrodes embedded on an elastic cap, according to the extended 10–20 system. The signals were recorded using a left mastoid reference electrode and then re-referenced offline to the average of the activity of the left and right mastoids. Horizontal electrooculogram (EOG) was recorded from a pair of electrodes placed at the left and right outer canthi to monitor horizontal eye movements. Vertical EOG was recorded via a pair of electrodes placed above and below the left eye to detect blinks and vertical eye movements. All electrode impedances were maintained below 5 KΩ throughout the experiment. The EEG and EOG were amplified via a Neuroscan SynAmp^2 amplifier with a low-pass of 100 Hz in DC acquisition mode and digitalized with a sampling rate of 500 Hz.

EEG data were preprocessed and analyzed using MATLAB 2014a (MathWorks, US) and EEGLAB toolbox (v13.1.1, Delorme and Makeig, 2004). The original EEG signals were first filtered with a low-pass at 20 Hz and then were segmented into epochs from −2000 to 500 ms relative to feedback onset with the activity from −2000 to −1800 ms serving as the baseline. The epoched data were screened manually for artifacts and then were processed with an informax independent component analysis (runica). After that, blink components were identified and removed. Moreover, a semi-automated procedure was used to remove additional artifacts (Foti et al., 2011), with artifacts defined as a step more than 50 μV between sample points, a voltage difference exceeding 200 μV within a trial, or a maximum voltage difference less than 0.5 μV within 100-ms intervals. Finally, the epoched data were averaged across trials for each condition. For figures, the SPN data were filtered with a low-pass cutoff at 7 Hz, as implemented in the ERPLAB toolbox (Lopez-Calderon and Luck, 2014).

According to the grand average ERP waveforms and topographic maps (Figs. 1 and 2), the SPN was extracted from −200 to 0 ms relative to feedback onset at laterofrontal electrodes (FT7/8, F7/8, and T7/8) where the SPN was maximal (Zheng et al., 2017; Zheng and Liu, 2015). The SPN data were analyzed with a Reward probability (low, medium, high) × Choice (choice, no-choice) × Hemisphere (left, right) × Site (FT7/8, F7/8, T7/8) repeated-measures analysis of variance (RMANOVA). Greenhouse-Geisser epsilon (G-GE) correction was adopted for factors with more than two levels. The Bonferroni procedure was