

# Functional heterogeneity of perceived control in feedback processing

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## Abstract

Perceived control is a fundamental psychological function that can either boost positive affect or buffer negative affect. The current study addressed the electrophysiological correlates underlying perceived control, as exercised by choice, in the processing of feedback valence. Thirty-six participants performed an EEG choice task during which they received positive or negative feedback following choices made either by themselves or by a computer. Perceived control resulted in an enhanced reward positivity for positive feedback but increased theta power for negative feedback. Further, perceived control led to greater feedback P3 amplitude and delta power, regardless of feedback valence. These results suggest functional heterogeneity of perceived control in feedback processing as diverse as magnifying the reward signal, enhancing the need for control and increasing the motivational salience of outcome irrespective of valence.

**Key words:** perceived control; feedback valence; functional heterogeneity; EEG

## Introduction

Perceived control (typically exercised by choice) refers to a belief that one can exert control over environment, which constitutes a fundamental psychological function associated with human well-being (Bandura, 1977; Rodin, 1986; Ryan and Deci, 2000). The contribution of perceived control in promoting our well-being occurs in two aspects. On the one hand, the feeling of control can buffer the impacts of negative information, in that it can decrease neural responses to aversive events (Salomons *et al.*, 2004) and in the face of failure feedback (Murayama *et al.*, 2015). On the other hand, perceived control can boost the influences of positive information in that it can recruit the corticostriatal pathways shared by reward processing (O'Doherty *et al.*, 2004; Tricomi *et al.*, 2004; Wang and Delgado, 2019). Here, we focused on the electrophysiological correlates underlying perceived control in the processing of positive and negative feedbacks.

Feedback processing has been well investigated by the event-related potential (ERP) due to its fine-grained temporal resolution (Glazer *et al.*, 2018). Two relevant ERP components are the reward positivity (RewP) and the feedback P3 (fb-P3). The RewP (also known as the feedback-related negativity; Miltner *et al.*, 1997) is a frontocentrally positive-going deflection occurring between 250 and 350 ms following positive feedback, which is absent or suppressed following negative feedback (Holroyd *et al.*, 2008; Proudfit, 2015). This component is typically isolated from other ERP components by taking the difference between the ERPs to positive and negative feedbacks (Sambrook and Goslin, 2015). The RewP constitutes a well-established neural marker for reward processing because of its associations with self-report and behavioral measures of reward sensitivity (Bress and Hajcak, 2013) and neural activation in reward-related brain areas including the medial frontal cortex and ventral striatum

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(Carlson et al., 2011; Foti et al., 2011; Becker et al., 2014). Subsequent to the RewP, the fb-P3 is a centroparietal positivity peaking between 300 and 500 ms and is associated with motivational salience during feedback processing (Nieuwenhuis et al., 2005).

Recent ERP studies have demonstrated that both the RewP and the fb-P3 are larger when outcomes are delivered in a high perceived control condition than in a low perceived control condition (Yeung et al., 2005; Li et al., 2011; Meng and Ma, 2015; Muhlberger et al., 2017; Yi et al., 2018; Mei et al., 2018b). Whereas it is well established that the fb-P3 is increased as a function of perceived control, regardless of feedback valence (Yeung et al., 2005; Muhlberger et al., 2017; Yi et al., 2018; Mei et al., 2018b), most of previous RewP studies focused on the difference between positive and negative feedbacks, thus ignoring the effect of perceived control in processing feedback with different valences. To our knowledge, only two previous studies have addressed this issue but obtained inconsistent results (Meng and Ma, 2015; Muhlberger et al., 2017). Muhlberger et al. (2017) found the effect of perceived control during the period of the RewP for positive feedback (pictures of attractive men) but not for negative feedback (pictures of rocks). In contrast, Meng and Ma (2015) found that the effect of perceived control was more pronounced for negative feedback (unsuccessful performance) than positive feedback (successful performance). Therefore, it remains ambiguous about the roles that perceived control plays in the processing of positive and negative feedbacks. Addressing this topic is of great importance in understanding whether perceived control is driven by only a reward system (i.e. the perceived control effect appears only for positive feedback), only a punishment system (the perceived control effect appears only for negative feedback) or, in a more general sense, a motivational system (i.e. the perceived control effect appears across positive and negative feedback).

One methodological issue of time-domain ERP analysis for feedback processing concerns component overlap, whereby it is often difficult to isolate the RewP from the preceding P2 and the subsequent P3 components. This issue could be in part overcome by extracting the time-frequency signals during the RewP and fb-P3 time window (200–500 ms) of feedback processing (Glazer et al., 2018). The most relevant signals consisted primarily of theta power (4–7 Hz) over frontocentral areas and delta power (1–3 Hz) over centroparietal areas. Theta power is usually increased for negative vs positive feedback and is sensitive to salient information such as conflict, error and novelty, possibly signaling a need for cognitive control (Cavanagh and Frank, 2014). In contrast, delta power is often enhanced for positive vs negative feedback and is associated with more elaborative processing of feedback stimuli such as outcome magnitude and prediction error (Bernat et al., 2015; Cavanagh, 2015). Therefore, decomposing theta and delta power during feedback processing may provide insights into mechanisms underlying perceived control in the processing of positive and negative feedbacks.

Together, the current study aimed to determine the modulatory effects of perceived control on feedback valence by using a multicomponent approach. Participants completed a simple choice task while their EEG was recorded. In this task, participants could obtain either positive or negative feedback each time after making a binary choice either by themselves (a choice condition during which a high level of perceived control would be experienced) or by the computer (a no-choice condition during which a low level of perceived control would be experienced). If perceived control influences reward evaluation specifically, electrophysiological signals would be enhanced in the choice vs no-choice condition for positive but not negative feedback; if

perceived control is associated with the buffering of the impacts of negative information, electrophysiological signals would be modulated by the choice vs no-choice condition for negative but not positive feedback. Otherwise, if this influence is motivational, electrophysiological signals would be enhanced in the choice vs no-choice condition for both positive and negative feedbacks.

## Materials and methods

### Participants

Thirty-six healthy, right-handed volunteers (18 females, 21.11 ± 2.30 years of age) were recruited. All had normal or corrected-to-normal visual acuity and received a base payment of ¥10 for their participation plus a performance-dependent bonus (¥50, see details below). All participants gave written informed consent, and this study was approved by the Dalian Medical University Institutional Review Board.

### Procedure

Participants were seated in a dimly lit and sound-attenuating room and performed a choice task. The choice task was adopted from the doors task (Proudfit, 2015) and modified for the current experiment. In this task, participants could earn an amount of points by choosing one of two doors correctly in either a choice condition or a no-choice condition. In the choice condition, participants were able to make a choice by themselves. In the no-choice condition, participants had to select the door indicated by the computer. Each trial (Figure 1) began with a task cue (1000 ms) signaling the upcoming trial type. Choice cues indicated that participants would have the opportunity to choose between two doors; no-choice cues indicated that participants would be forced to accept the door selected by the computer; uncertainty cues indicated that participants would perform either a choice trial or a no-choice trial with a probability of 50%. The uncertainty trial condition was included to avoid boredom, which would be decomposed into the choice and the no-choice conditions during following EEG analysis. Task cues were indicated by different symbolic shapes (a triangle, a circle, a square) using a Latin square design. After a randomly jittered interval (2000–2500 ms), two doors were shown at both sides of an arrow (either bidirectional for the choice condition or unidirectional for the no-choice condition) on the screen, allowing participants to choose one of the doors by pressing the corresponding button (the 'F' or 'J' key) with their left or right index finger. After their response, an additionally jittered interval (900–1100 ms) was shown and then was replaced by a number (either +10 or 0) indicating the outcome on that trial. The feedback stimulus remained on the screen for 1000 ms and was followed by a jittered intertrial interval (1200–1500 ms).

The task consisted of 240 trials (120 for the choice condition and 120 for the no-choice condition) divided into six blocks (40 trials each), with a break between blocks. Twelve practice trials were provided before the formal experiment to familiarize participants with the task. Participants were encouraged to use any strategies they wanted to earn as many points as possible, as the final points (including those earned in both the choice and the no-choice conditions) would be translated into the bonus money at the end of the experiment. Unbeknownst to the participants, the outcome of each trial was predetermined and pseudorandom with gain and nongain feedback occurring on 50% of the trials for each condition regardless of participants'

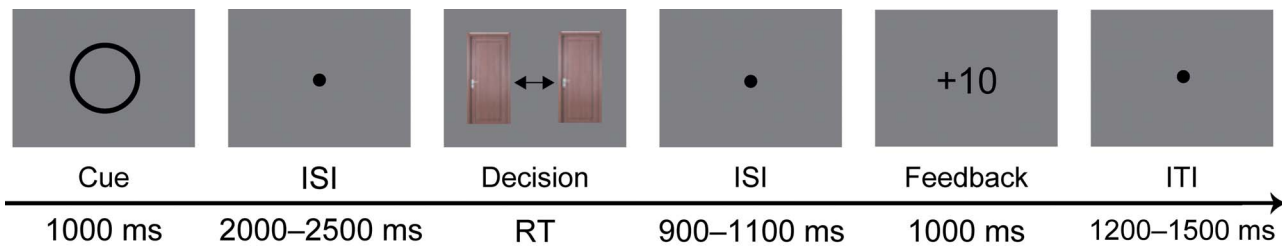


Fig. 1. Schematic representation of the choice task. RT = reaction time; ISI = interstimulus interval and ITI = intertrial interval.

responses. All participants therefore earned the same bonus money. Postexperimentally, participants rated the trial types in terms of perceived control, liking and attention on a nine-point Likert scale (1 = 'not at all'; 9 = 'very much').

### Recording and analysis

The EEG was continuously recorded using an elastic cap embedded with 64 Ag/AgCl electrodes according to the extended International 10/20 system. Two additional pairs of electrodes were placed on the external canthi of each eye to monitor horizontal eye movements and above and below the left eye to detect blinks and vertical eye movements, respectively. EEG signals were amplified using a Neuroscan SynAmps<sup>2</sup> amplifier with a low-pass of 100 Hz in DC mode and were digitalized with a sampling rate of 500 Hz. The left mastoid electrode served as the reference. Electrode-to-skin impedances were kept below 5 K $\Omega$  throughout the experiment.

The EEG data were analyzed offline using EEGLAB toolbox (v13.1.1, Delorme and Makeig, 2004) and MATLAB 2014a (MathWorks, USA). The EEG signals were rereferenced to the mean of the activity at the left and right mastoids and were then filtered with a high-pass of 0.1 Hz (roll-off 6 dB/octave). Epochs were defined as 1500 ms prior to and 2000 ms relative to feedback onset, with the activity from -200 to 0 ms serving as the baseline. All epoched data were screened manually for artifacts and were then adopted an infomax independent component analysis (runica). Afterwards, individual components were inspected, and blink components were removed. Additionally, an automatic artifact detection was performed, discarding epochs with a voltage difference of more than 50  $\mu$ V between sample points, a voltage difference exceeding 200  $\mu$ V within a trial or a maximum voltage difference less than 0.5  $\mu$ V within 100-ms intervals. Finally, the cleaned epochs were averaged across trials for each condition for each participant. The RewP was first isolated using a difference wave approach by subtracting the nongain waveform from the gain waveform for the choice condition and the no-choice condition, respectively. The RewP was then measured as the mean activity of the difference waveforms from 220 to 320 ms post feedback onset at Fz and FCz. The fb-P3 was defined as the mean activity from 320 to 420 ms at Cz and CPz. These measure parameters were determined using the orthogonal selection approach (Luck and Gaspelin, 2017) and were consistent with our previous studies on perceived control (Yi et al., 2018; Mei et al., 2018b).

After removing artifacts described above, time-frequency decomposition was performed via complex Morlet wavelet convolution. Wavelet frequency increased from 1 to 50 Hz in 50 logarithmically spaced steps, with the number of wavelet cycles being set to 4. Following the convolution, individual epochs were cut in length (from -500 to 1000 ms) to account for edge artifacts. Power was normalized using a decibel (dB) conversion from a

baseline of 300–200 ms prior to feedback onset. Theta power was scored as the mean activity from 200 to 500 ms over 4–7 Hz post feedback onset at Fz and FCz, and delta power from 200 to 500 ms over 1–3 Hz at Cz and CPz.

A paired sample t-test was used to compare reaction times (RTs) between the choice and no-choice conditions. Rating data post the experiment were assessed using a repeated-measures analysis of variance (ANOVA) with trial type (choice, no-choice and uncertainty) as a within-subjects factor. RewP data were analyzed using a paired sample t-test. Data of fb-P3 and EEG (delta and theta) power were analyzed separately with a choice availability (choice, no-choice)  $\times$  feedback valence (gain, nongain) ANOVA. Greenhouse-Geisser epsilon correction was applied when necessary, and Bonferroni correction was used for post hoc comparisons.

## Results

### Behavioral and rating data

During the choice task, participants took a longer time to select a door in the choice condition ( $744.90 \pm 188.41$  ms) than in the no-choice condition ( $658.37 \pm 132.42$  ms),  $t(1, 35) = 4.46$ ,  $P < 0.001$ , Cohen's  $d = 0.74$ . Participants perceived a higher level of control for choice trials ( $7.17 \pm 1.78$ ) than for uncertainty trials ( $5.97 \pm 1.72$ ), which was in turn higher than no-choice trials ( $4.47 \pm 2.52$ ),  $F(2, 70) = 21.86$ ,  $P < 0.001$ ,  $\eta_p^2 = 0.38$ . However, they reported comparable scores in terms of liking,  $F(2, 70) = 0.22$ ,  $P = 0.784$ ,  $\eta_p^2 = 0.01$ , and attention,  $F(2, 70) = 0.14$ ,  $P = 0.844$ ,  $\eta_p^2 < 0.01$ , across trial types.

### EEG data

Figure 2 displays the time-domain ERP waveforms and time-frequency representations of EEG power in response to gain and nongain feedback, as well as the difference waveforms (gain minus nongain outcomes), as a function of choice. Figure 3 shows the topographic distribution maps for the RewP (220–320 ms), the fb-P3 (320–420 ms), theta power (4–7 Hz, 200–500 ms) and delta power (1–3 Hz, 200–500 ms). The data of each measure are shown in Figure 4. During the time domain, a RewP was evidenced as a positive-going deflection over frontocentral areas, followed by an obvious fb-P3 over centroparietal areas. During the time-frequency domain, feedback stimuli elicited an obvious enhancement of power in theta band over frontocentral areas and delta band over centroparietal areas.

### Time domain

The RewP was larger for the choice condition ( $M = 4.32$   $\mu$ V) than that for the no-choice condition ( $M = 2.41$   $\mu$ V),  $t(35) = 3.45$ ,  $P = 0.001$ , Cohen's  $d = 0.57$ . Given that the difference wave approach cannot disentangle the individual contributions of

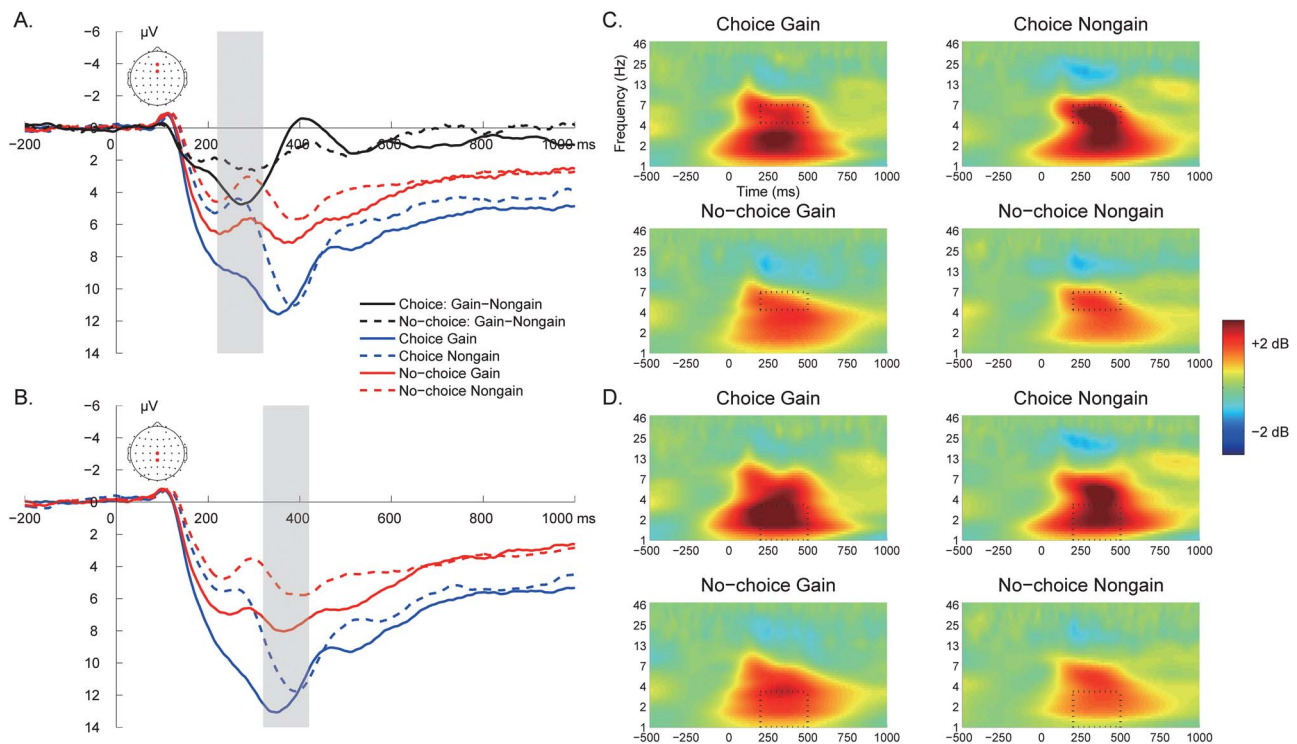


Fig. 2. Grand-averaged ERP waveforms over (A) frontocentral and (B) centroparietal areas in response to gain and nongain feedback as a function of choice. The difference waveforms (gain minus nongain outcomes) were also shown as a function of choice.

neural responses to gains and nongains, a following choice availability  $\times$  feedback valence ANOVA was performed to evaluate the choice effect on gain and nongain outcomes, respectively. The ANOVA revealed that the neural response was enhanced in the choice ( $M=7.18 \mu\text{V}$ ) vs the no-choice ( $M=4.83 \mu\text{V}$ ) condition,  $F(1, 35)=37.10$ ,  $P<0.001$ ,  $\eta_p^2=0.52$ , and following gain ( $M=7.69 \mu\text{V}$ ) vs nongain ( $M=4.33 \mu\text{V}$ ) outcomes,  $F(1, 35)=110.44$ ,  $P<0.001$ ,  $\eta_p^2=0.76$ . Importantly, there was a significant interaction between choice and valence,  $F(1, 35)=11.88$ ,  $P=0.001$ ,  $\eta_p^2=0.25$ . Post hoc comparisons revealed that although the choice effect was significant for both outcomes, it was more pronounced for gain outcomes ( $\Delta M=3.30 \mu\text{V}$ ) than for nongain outcomes ( $\Delta M=1.40 \mu\text{V}$ ).

Similarly, the fb-P3 was larger in the choice condition ( $M=11.68 \mu\text{V}$ ) than in the no-choice condition ( $M=6.57 \mu\text{V}$ ),  $F(1, 35)=71.85$ ,  $P<0.001$ ,  $\eta_p^2=0.67$ , and following gain outcomes ( $M=10.09 \mu\text{V}$ ) than following nongain outcomes ( $M=8.16 \mu\text{V}$ ),  $F(1, 35)=23.95$ ,  $P<0.001$ ,  $\eta_p^2=0.41$ . In contrast to the RewP, the interaction between choice and valence was not significant,  $F(1, 35)=2.07$ ,  $P=0.16$ ,  $\eta_p^2=0.06$ , indicating that they were encoded independently during the time window of the fb-P3.

### Time-frequency domain

Theta power was higher in the choice condition ( $M=2.50 \text{ dB}$ ) than the no-choice condition ( $M=1.60 \text{ dB}$ ),  $F(1, 35)=23.58$ ,  $P<0.001$ ,  $\eta_p^2=0.40$ , following nongain outcomes ( $M=2.28 \text{ dB}$ ) than following gain outcomes ( $M=1.83 \text{ dB}$ ),  $F(1, 35)=4.50$ ,  $P=0.041$ ,  $\eta_p^2=0.11$ . Critically, the interaction between choice and valence was significant,  $F(1, 35)=5.16$ ,  $P=0.029$ ,  $\eta_p^2=0.13$ . Post hoc comparisons revealed that although theta power exhibited a choice effect for both gain and nongain outcomes, it was more pronounced for nongain outcomes ( $\Delta M=1.18 \text{ dB}$ ) than for gain outcomes ( $\Delta M=0.62 \text{ dB}$ ).

Analysis of delta power showed higher delta power in the choice condition ( $M=2.43 \text{ dB}$ ) than in the no-choice condition ( $M=1.50 \text{ dB}$ ),  $F(1, 35)=34.93$ ,  $P<0.001$ ,  $\eta_p^2=0.50$ , and following gain outcomes ( $M=2.14 \text{ dB}$ ) than following nongain outcomes ( $M=1.80 \text{ dB}$ ),  $F(1, 35)=7.36$ ,  $P=0.010$ ,  $\eta_p^2=0.17$ . In contrast to theta power, the interaction between choice and valence failed to reach significance,  $F(1, 35)=1.65$ ,  $P=0.207$ ,  $\eta_p^2=0.05$ , indicating independent effects of choice and valence on delta power.

In sum, we observed an interaction between choice and valence for both the RewP and theta power such that the choice effect was more pronounced for gains in terms of the RewP but for nongains in terms of theta power. Further, choice and valence were encoded independently at both the fb-P3 and delta-band levels.

### Discussion

In this study, we investigated the electrophysiological correlates of perceived control, as exercised by choice, in the processing of positive and negative feedbacks. We found that perceived control resulted in an enhanced RewP for positive feedback but increased theta power for negative feedback, indicating that the feeling of control plays different roles in terms of feedback valence. Further, perceived control led to greater fb-P3 amplitude and delta power, regardless of feedback valence, suggesting a generally motivational influence. These results suggest both common and distinct effects of perceived control on the processing of positive and negative feedbacks.

In the current study, the RewP, when isolated as the difference between positive and negative feedbacks, was enhanced when choice opportunity was available compared to when it was unavailable, which is consistent with previous research using the difference wave approach (Yeung et al., 2005;

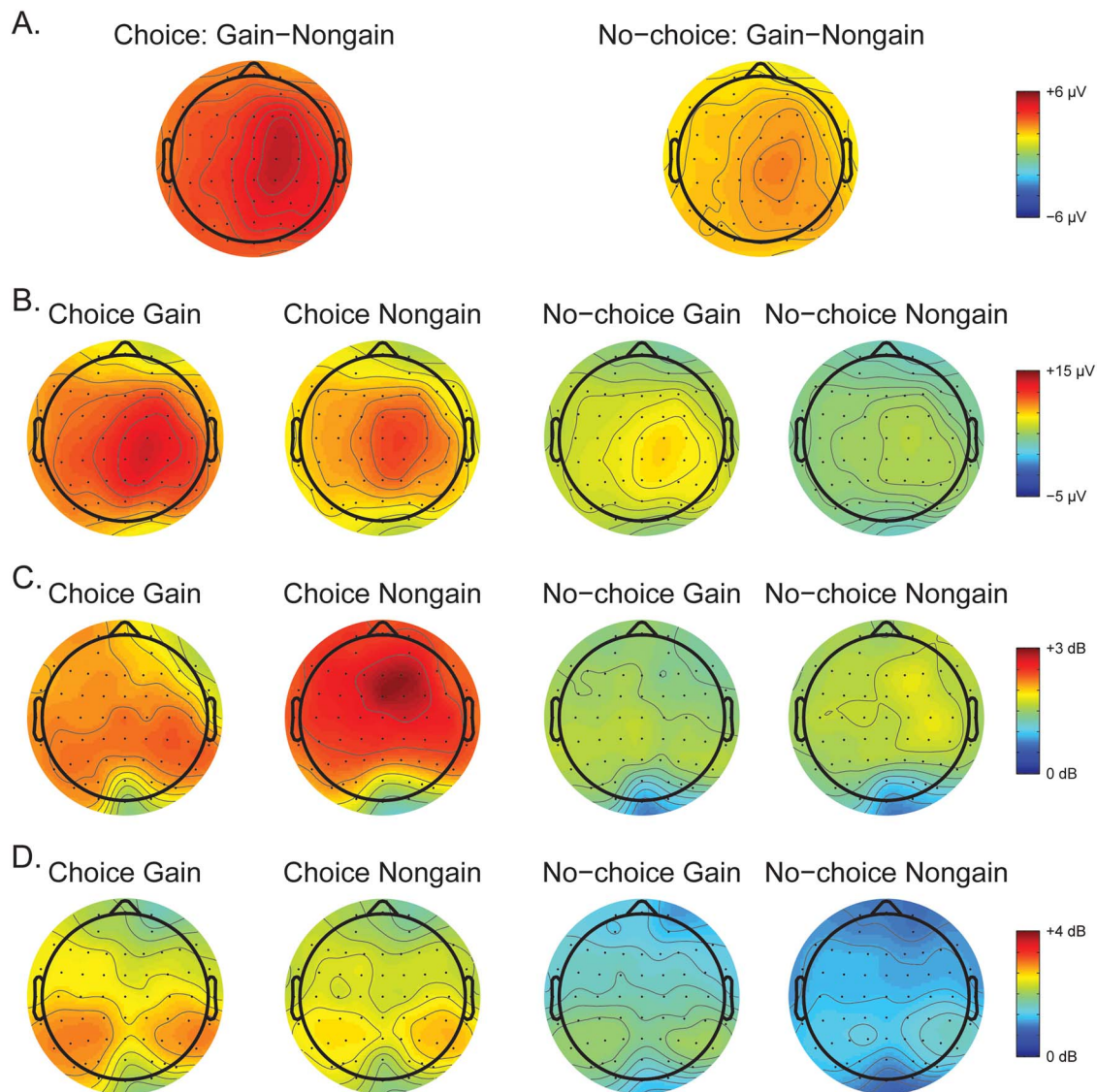


Fig. 3. Topographic distribution maps for (A) the RewP (220–320 ms), (B) the fb-P3 (320–420 ms), (C) theta power (4–7 Hz, 200–500 ms) and (D) delta power (1–3 Hz, 200–500 ms).

Li et al., 2011; Meng and Ma, 2015; Muhlberger et al., 2017; Yi et al., 2018; Mei et al., 2018b). Given that the RewP reflects reward-specific responses originating from striatal areas as well as the medial frontal cortex (Carlson et al., 2011; Foti et al., 2011; Becker et al., 2014), the finding of the increased RewP as a function of choice indicates common neural circuitry shared by reward-related processes and perceived control. This interpretation was further supported by the following evaluation of the choice effect on positive and negative feedbacks, respectively. Specifically, although the choice effect was observed for both positive and negative feedbacks, it was more than twice when feedback was positive ( $\Delta M = 3.30 \mu\text{V}$ ) as large as when feedback was negative ( $\Delta M = 1.40 \mu\text{V}$ ). This pattern is consistent with a previous study (Muhlberger et al., 2017) but at odds with another research (Meng and Ma, 2015). This discrepancy between our findings and those reported by Meng and Ma may be due to the use of performance feedback (intrinsic motivation) in that study and the use of externally monetary feedback (extrinsic motivation) in our study. Together, the choice-related enhancement of RewP

for positive feedback is compatible with the idea that perceived control (exercised by choice) can boost the influences of positive information and is even rewarding in and of itself (Leotti et al., 2010; Ly et al., 2019).

On the other hand, our RewP findings also provide important implications for understandings of the reinforcement learning theory. The RewP is thought to reflect the receipt of reward prediction error (RPE) signals carried by the midbrain dopamine system to the anterior cingulate cortex, tracking whether outcomes are better or worse than expected (Holroyd and Coles, 2002; Holroyd and Umemoto, 2016). According to the standard reinforcement learning model, the RPE is determined by the contingency between the action people take and the outcome they receive. However, this theory does not make a specific prediction about perceived control. In this regard, our finding of the effect of perceived control on the RewP contributes to a more nuanced understanding of the reinforcement learning theory, and thus the theory should be expanded to incorporate perceived control more explicitly. Indeed, it has been shown

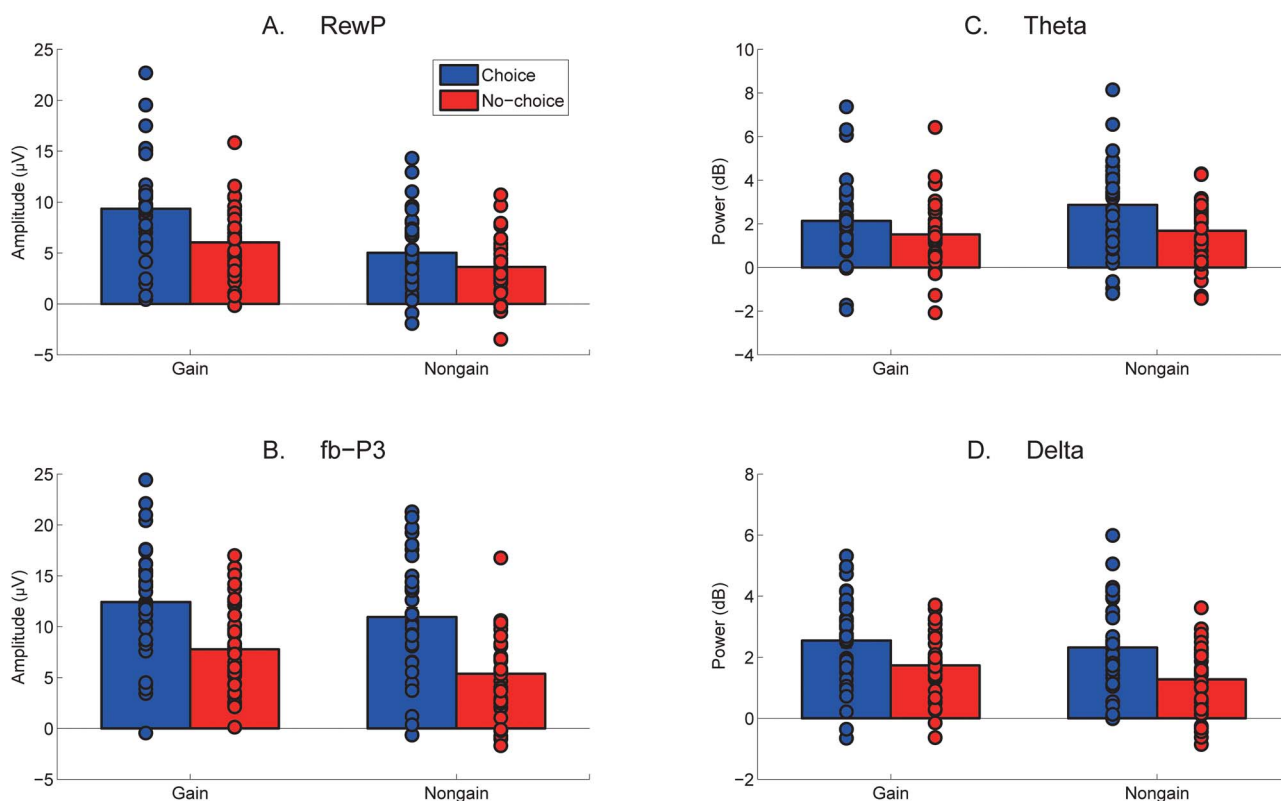


Fig. 4. Stripcharts for the data of (A) RewP amplitude, (B) fb-P3 amplitude, (C) theta power, (D) delta power in response to gain and nongain feedback as a function of choice.

in a previous study that perceived control exercised by choice amplified positive RPE specifically (Cockburn *et al.*, 2014). Future research should employ reinforcement learning tasks to investigate the relationship between the RPE (as indexed by the RewP) and perceived control more directly.

Here, the novel finding of the present study was that choice effect was potentiated for negative relative to positive feedback during theta band. Contrasting voluntary and passive choice processing, the theta choice effect almost doubled for negative feedback ( $\Delta M = 1.18$  dB) vs positive feedback ( $\Delta M = 0.62$  dB). Theta power plays a specific role in situations wherein cognitive control is needed, including error commission (Cavanagh *et al.*, 2012), conflicting stimulus-response requirement (Nigbur *et al.*, 2012), novel information (Jiang *et al.*, 2019), as well as negative feedback as reported here. The present finding dovetails with a previous study finding that perceived control promoted behavioral performance by increasing the amplitude of the error-related negativity (Legault and Inzlicht, 2013), an ERP component originating from the medial frontal cortex and reflecting endogenous error monitoring (Gehring *et al.*, 1993). These results provide converging evidence that one possible mechanism underlying the perception of control in the face of negative feedback is associated with improved performance monitoring in order to treat negative feedback informatively (Murayama *et al.*, 2015).

Positive feedback elicited a larger fb-P3 as well as greater delta power than negative feedback, which may be associated with motivational salience (Nieuwenhuis *et al.*, 2005; Mei *et al.*, 2018a). Besides choice-related activity for the RewP and theta, significant effects were also found for the fb-P3 and delta-band activity in response to choice vs no-choice feedback. However,

these results emerged in a conjunction across feedback with different valences. Whereas the observed fb-P3 effect of perceived control across positive and negative feedback is well established in previous studies (Yeung *et al.*, 2005; Muhlberger *et al.*, 2017; Yi *et al.*, 2018; Mei *et al.*, 2018b), this is the first study to report that delta power contributed to electrophysiological mechanisms underlying perceived control. Furthermore, the effect of perceived control on delta power was comparable between positive and negative feedbacks, indicating its role in enhancing motivational relevance and salience of feedback stimuli (Knyazev, 2007; Glazer *et al.*, 2018). On the other hand, it is a little unexpected that delta power results were in contrast to the RewP results, given that delta power has also been associated with the RewP in recent research (Bernat *et al.*, 2015; Foti *et al.*, 2015). However, it should be noted that delta power in those studies associating these two measures was actually phase consistent (evoked), which was determined from the averaged ERP activity (Hajhosseini and Holroyd, 2013). In contrast, delta power reported here was obtained from trial-level data, thus corresponding to the sum of the evoked and induced (phase inconsistent) theta powers (Tallon-Baudry and Bertrand, 1999). Together, the fact that these electrophysiological indices did not come out in the difference between positive and negative feedbacks suggests a motivational effect of perceived control on feedback processing. To go a further step, perceived control and feedback valence may operate simultaneously but independently from each other during the more elaborative stage indexed by both the fb-P3 (Donchin and Coles, 1988; Nieuwenhuis *et al.*, 2005) and delta-band activity (Bernat *et al.*, 2015).

Our results indicate a two-stage model of perceived control during feedback processing. In the first stage as indexed by the

RewP and theta-band activity, synergistic effects of perceived control and feedback valence emerge as a reliable interaction between choice and feedback valence. The roles that perceived control plays depend on the valence of feedback such that the perception of control can add value in the face of positive outcomes and increase the need of cognitive control in the face of negative outcomes. In the second stage as indexed by the fb-P3 and delta-band activity, perceived control enlarges the motivational salience of feedback, irrespective of valence. The two-stage model proposed here provides intriguing insights into the potential role of perceived control in human well-being. Despite its great significance, mechanistic understandings of perceived control in feedback processing have been established previously in separate lines of research either highlighting its roles in generating positive affect (O'Doherty et al., 2003; Bjork and Hommer, 2007) or emphasizing its role in blunting negative affect (Legault and Inzlicht, 2013; Murayama et al., 2015). To our knowledge, the current study is the first to demonstrate the manifold influences of perceived control in feedback processing with a simple choice paradigm. On the other hand, abnormal perceived control has been found among various psychiatric disorders as diverse as depression (Liu et al., 2015), anxiety disorders (Gallagher et al., 2014) and pathological gambling (Orgaz et al., 2013). In future investigations, it will be of interest to determine the specific mechanism underlying perceived control. For example, the lack of perceived control in depression, according to our model, might be attributable to the dysfunctionality in producing positive affect, signaling the need of cognitive control or generating motivational saliency.

To conclude, our findings suggest a heterogeneous response profile of perceived control during feedback processing in a simple choice task. The RewP findings reflect that the perception of control can be rewarding in and of itself, whereas theta power results suggest that the feeling of control can increase the need for control following receipt of negative feedback. Furthermore, both the fb-P3 and delta power findings indicate that perceived control enhances the motivational salience of outcome irrespective of valence.

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## Conflict of interest

All authors have declared that no competing interests exist.

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