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Original article

Contextual valence modulates the effect of choice on incentive processing

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Abstract

Previous research has demonstrated that reward-related neural activity is enhanced for choice relative to no-choice opportunities in the gain context. The current event-related potential study examined whether this modulatory effect of choice can be observed in both the gain and the loss contexts across anticipatory and consummatory phases of incentive processing. Thirty-two participants performed a simple choice task during which choices were made either by themselves (a choice condition) or by a computer (a no-choice condition) during a gain context (gain *vs* nongain) and a loss context (nonloss *vs* loss). Behaviorally, participants reported a higher level of perceived control in the choice than the no-choice condition as well as in the gain than loss context. During the anticipatory phase, the choice relative to the no-choice condition elicited an increased cue-P3 in the loss context and an enhanced stimulus-preceding negativity in the gain context. During the consummatory phase, the choice condition elicited a larger reward positivity (ΔRewP) than the no-choice condition in the gain relative to the loss context but a comparable feedback P3 across contexts. These findings demonstrate that the crucial role of voluntary choice in reward processing is contingent upon contextual valence.

Key words: choice; contextual valence; stimulus-preceding negativity; reward positivity; P3

Introduction

All organisms, from pigeons to humans, prefer choice (Catania and Sagvolden, 1980; Bown *et al.*, 2003). By making choices, individuals can generate a sense of control over the environment, which is critical for emotion regulation and motivated behavior (Leotti *et al.*, 2010). The perception of control as exercised by choice is associated with agency (Haggard and Chambon, 2012), action–outcome contingency (Tricomi *et al.*, 2004) and decision effort (Sullivan-Toole *et al.*, 2017). Converging evidence has demonstrated a modulatory effect of choice on reward processing such that reward-related neural activity is enhanced when a choice opportunity is available compared to when it is unavailable in the context of potential gains (O'Doherty *et al.*, 2004; Tricomi *et al.*, 2004; Masaki *et al.*, 2010; Leotti and Delgado, 2011; Muhlberger *et al.*, 2017; Chen *et al.*, 2018).

Another line of evidence supports the contention that gain and loss do not function equally, which is known as the gain–loss asymmetry (Alves *et al.*, 2017). Behavioral studies have demonstrated that most people tend to be risk averse when gains are salient but risk seeking when losses are salient (Kahneman and Tversky, 1979), and discount gains more steeply than losses with delayed delivery (Benzion *et al.*, 1989) or reduced probability (Thaler, 1981). Moreover, a number of neuroimaging studies have identified discrete neural circuits responsible for gains (e.g. the medial orbitofrontal cortex and striatum) and losses (e.g. the lateral orbitofrontal cortex and anterior insula) (O'Doherty *et al.*, 2001; O'Doherty *et al.*, 2003). Finally, pharmacological studies

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have established that gains and losses may be mediated by dopamine and serotonin, respectively (Daw *et al.*, 2002; Zhong *et al.*, 2009). Thus, a question arises whether the modulatory effect of choice on reward processing can be observed in the context of potential losses, similar to that in the context of potential gains. One hypothesis is that perceived control as exercised by choice conveys motivational significance regardless of contextual valence (Leotti and Delgado, 2014). Alternatively, the value of choice may be discounted in the loss context because choice is undesirable when decisions are complex (Iyengar and Lepper, 2000) or emotionally demanding (Samuelson and Zeckhauer, 1988).

Only one recent study using functional magnetic resonance imaging (fMRI) has attempted to address this issue (Leotti and Delgado, 2014). In this study, participants were instructed either to choose between two keys or to accept a computer-selected key passively in a gain context during which monetary gains would be delivered or omitted or in a loss context during which monetary losses would be delivered or omitted. The authors found that activity in the ventral striatum, a core area of the reward system, was increased for cues predicting a choice opportunity compared to those predicting a no-choice opportunity. Importantly, the choice effect observed for cues was comparable across the gain and loss contexts, though more variable in the latter context (Leotti and Delgado, 2014). However, there are important issues that cannot be addressed with fMRI because of the sluggish characteristic of the BOLD signal. Most relevantly, studies using fMRI are not able to fully distinguish processing stages related to incentive processing, such as anticipatory and consummatory phases (Berridge and Robinson, 1998, 2003). Convergent evidence indicates that these phases are related but can also be dissociated (Berridge and Robinson, 1998; Knutson *et al.*, 2001; Waugh and Gotlib, 2008). In this regard, it remains unclear how mechanisms of the choice effect are modulated by contextual valence across anticipatory and consummatory phases of incentive processing, which constitutes the primary goal of the current study.

With its fine-grained temporal resolution, the event-related potential (ERP) technique is uniquely suited to address the neural dynamics of the interface between choice and contextual valence. Several ERP components have been linked to anticipatory and consummatory phases during incentive processing. The most relevant anticipatory ERP components are the cue-P3 and the stimulus-preceding negativity (SPN). The cue-P3 is a positive deflection peaking between 300 and 500 ms over parietal areas following cue presentation (Goldstein *et al.*, 2006). This component is reliably enhanced for incentive (reward and punishment) cues relative to neutral cues (Broyd *et al.*, 2012; Pornpattananangkul and Nusslock, 2015; Schmitt *et al.*, 2015; Zhang *et al.*, 2017) and is related to activation in the ventral striatum during incentive anticipation (Pfabigan *et al.*, 2014). As isolated from the contingent negative variation (Walter *et al.*, 1964), the SPN is a slow, nonmotoric, negative-going wave that builds in size as a feedback display draws near (Damen and Brunia, 1987; Brunia, 1988). It has been found to be enhanced prior to incentive *vs* neutral stimuli (Chwilla and Brunia, 1991; Kotani *et al.*, 2003; Masaki *et al.*, 2010; Zheng *et al.*, 2017), and convergent evidence has identified the right anterior insula as the main source of the SPN (Bocker *et al.*, 1994; Kotani *et al.*, 2009).

In contrast, two ERP components, the reward positivity (RewP) and the feedback P3 (fb-P3), are associated with the consummatory phase. The RewP (also referred to as the feedback-related negativity) is a relative positivity peaking approximately 300 ms after the receipt of feedback over frontocentral areas, which occurs in response to positive feedback and is suppressed for negative feedback (Holroyd *et al.*, 2008; Proudfit, 2015). Initially, the RewP was believed to reflect a reward prediction error signal, tracking whether outcomes are better or worse than expected (Holroyd and Coles, 2002; Mulligan and Hajcak, 2018). Recent studies, however, highlighted that this component may index a salience prediction error, discriminating events with high salience from those with low salience, regardless of outcome valence (Talmi *et al.*, 2013; Soder and Potts, 2018). Alternatively, the RewP has been linked to affective and motivational processing of feedback stimuli (Gehring and Willoughby, 2002; Yeung *et al.*, 2005). Following the RewP, the fb-P3 is a positivity peaking 300–600 ms after feedback presentation over parietal areas (Sutton *et al.*, 1978; Yeung and Sanfey, 2004). It has been proposed to reflect the motivational salience of outcome stimuli during incentive processing (Nieuwenhuis *et al.*, 2005; San Martin *et al.*, 2010).

Recent ERP studies have demonstrated that incentive processing is sensitive to perceived control, as exercised through choice behavior, during both anticipatory and consummatory phases (Yeung *et al.*, 2005; Bellebaum *et al.*, 2010; Masaki *et al.*, 2010; Meng and Ma, 2015; Chen *et al.*, 2018; Yi *et al.*, 2018). Particularly, both the RewP and SPN are enhanced under a choice condition during which a high level of perceived control was experienced compared to a no-choice condition during which a low level of perceived control was experienced (Masaki *et al.*, 2010; Meng and Ma, 2015; Chen *et al.*, 2018; Yi *et al.*, 2018). This choice effect is observed even for people experiencing an illusion of control (Muhlberger *et al.*, 2017). Similarly, another line of evidence indicates that both anticipatory and consummatory ERP components are modulated by the context in which they occur. On the one hand, the cue-P3 is enhanced during a gain relative to loss context (Santesso *et al.*, 2012; Pfabigan *et al.*, 2014; Zheng *et al.*, 2017), and the SPN is more sensitive to a gain than loss context (Ohgami *et al.*, 2006; Zheng *et al.*, 2015; but see Zheng *et al.*, 2017). On the other hand, the RewP is enhanced for positive *vs* negative feedback in a gain context but is diminished in a loss context (Holroyd *et al.*, 2004; Kujawa *et al.*, 2013; Zheng *et al.*, 2015; Zheng *et al.*, 2017). Similarly, fb-P3 amplitudes have been found to be larger in a gain than loss context (Kujawa *et al.*, 2013; Pfabigan *et al.*, 2015; Mei *et al.*, 2018).

To the best of our knowledge, however, it remains unclear how contextual valence modulates the neural dynamics underlying perceived control as exercised by choice. To address this issue, we used a simple choice task during which participants could choose between two doors (a choice condition) or accept a computer-selected door passively (a no-choice condition). Both conditions, however, led to equal outcomes. This choice task was performed in two contexts with different valence, which were defined in terms of expected value. Monetary rewards were either delivered or omitted in a gain context (resulting in positive expected values), whereas monetary losses were either delivered or omitted in a loss context (resulting in negative expected values). Based on previous research, we hypothesized that both anticipatory and consummatory ERP components would be enhanced in the choice condition *vs* the no-choice condition. Importantly, these choice effects would be more pronounced in the gain context than in the loss context.

Materials and methods

Participants

Thirty-two undergraduates (16 females, 20.9 ± 1.76 years) with normal or corrected-to-normal visual acuity were recruited for

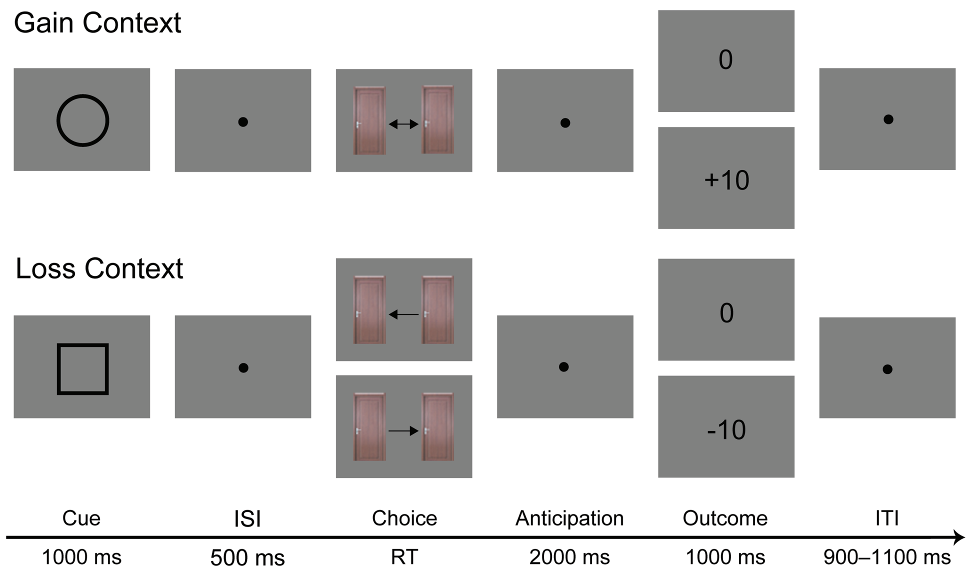

Fig. 1. Schematic representation of a choice trial in the gain context (top) and a no-choice trial in the loss context (bottom). RT = reaction time; ISI = interstimulus interval; ITI = intertrial interval.

participation. All participants were right-handed and reported no history of psychological or neurological disorders. Each signed a written informed consent form before the experiment and received a base payment of ¥10 plus a bonus of ¥40. This study was approved by the Dalian Medical University Institutional Review Board.

Procedure

A simple choice task adapted from our previous study (Yi *et al.*, 2018) was performed in a gain context and a loss context. During both contexts (Figure 1), each trial began with a symbolic cue (either a square or a circle) for 1000 ms to indicate whether participants had an opportunity for choice on the current trial. The types of cues were counterbalanced across participants. Following the cue, a fixation dot appeared for 500 ms and was then replaced by two doors shown at both sides of an arrow, which remained on the screen until the participants chose one of the doors by pressing one of two buttons (the 'F' or 'J' key) with either their left or right index finger. The arrow on the choice trial was bidirectional, indicating that participants could choose the door at will; the arrow on the no-choice trial was either a left- or right-pointing one, indicating that they had to choose the door according to the arrow direction, which was determined by the computer. After their response, a fixation dot was presented for 2000 ms, and thereafter, an outcome appeared for 1000 ms. Each trial ended with an intertrial interval varying randomly from 900 to 1100 ms.

Each context included 160 trials divided into four blocks (40 trials each), and a rest break was given between blocks. A practice block was provided prior to each context for familiarization. Participants were told that in the gain context, one of the two doors contained a gain of 10 points and the other was empty (nongain), whereas in the loss context, one of the two doors contained a loss of 10 points and the other was empty (nonloss). All participants were asked that they should choose the door determined by the computer in the no-choice condition. If they chose the 'wrong' door (i.e. either pressing the 'J' key for a left-pointing arrow or pressing the 'F' key for a right-pointing arrow), they would obtain 0 points in the gain context or lose 10 points in the loss context. The gain context was performed first for half of the participants and the loss context first for the remainder. In addition, the gain context was unknown for participants who performed the loss context first and vice versa. Participants began the task with 1600 points in the loss context and were encouraged to maximize their points in the gain context and to avoid losing points in the loss context. Participants were informed of the number of points they earned after each context and that their final points would consist of those earned on both the choice and no-choice trials across contexts. Unbeknownst to participants, however, they would get 800 points in the gain context and saved 800 points in the loss context because the outcome of each trial was predetermined and pseudorandom such that participants succeeded and failed on exactly 50% of trials under each condition. The total 1600 points were converted into ¥40 at the end of the experiment, but the exchange rate was not provided until the end of the experiment.

Following each context, participants were asked to complete a 9-point Likert scale to rate the level of perceived control (1 = totally out of control and 9 = totally under control), interest (1 = disliked a lot and 9 = liked a lot), attention (1 = ignored and 9 = paid close attention) and regularity (1 = no pattern and 9 = absolutely a pattern to the 'correct' responses) for the choice and no-choice trials in that context.

Recording and analysis

Continuous electroencephalography (EEG) was recorded using an elastic cap with a set of 64 Ag/AgCl electrodes mounted based on the extended 10–20 system. The signals were referenced online to the left mastoid electrode and rereferenced offline to the mean of the activity at the left and right mastoids. Horizontal electrooculogram (EOG) was recorded from a pair of electrodes placed on the left and right external 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. The EEG and EOG data were amplified and digitalized with a Neuroscan SynAmps[2] amplifier at a rate of 500 Hz with a low-pass of 100 Hz in DC acquisition mode.

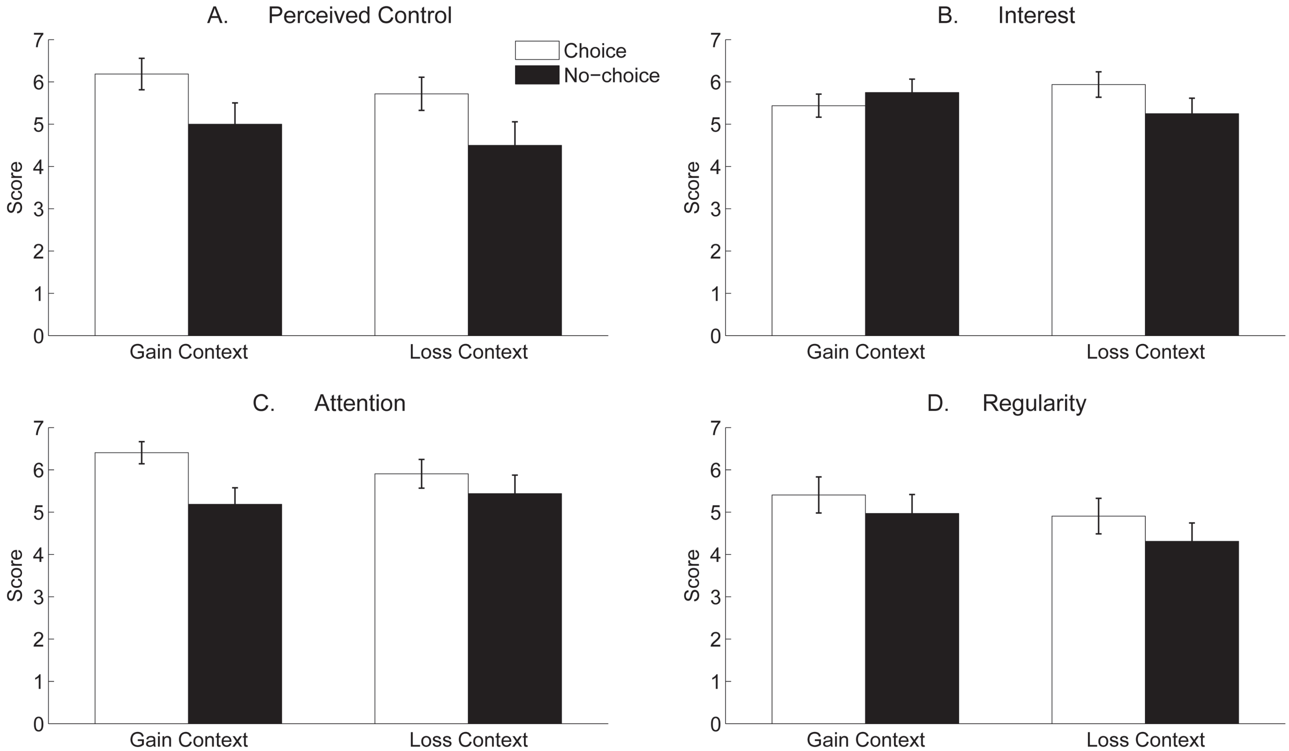

Fig. 2. Subjective rating data of perceived control (A), interest (B), attention (C) and regularity pattern (D) for the choice and no-choice conditions as a function of context. Error bars represent standard errors of the means.

Electrode impedances were kept under 5 KΩ throughout the experiment.

The EEG data were analyzed with MATLAB 2014a (MathWorks, Natick, MA, USA) and EEGLAB toolbox (v13.1.1; Delorme and Makeig, 2004). For cue-P3, RewP and fb-P3 analyses, the raw EEG was filtered with a bandpass of 0.1 and 30 Hz (roll-off 6 dB/octave) and then epoched from −1000 to 1500 ms relative to cue (the cue-P3) or feedback (the RewP and fb-P3) onset, with the activity from −200 to 0 ms serving as the baseline. For SPN analysis, the raw EEG was filtered with a low-pass of 30 Hz (roll-off 6 dB/octave) and then epoched from −5000 to 2000 ms relative to feedback onset, with the activity from −1900 to −1700 ms serving as the baseline. The epoched data were screened manually for artifacts (e.g. spikes, drifts and nonbiological signals) and then were subjected to an infomax independent component analysis (runica; Delorme and Makeig, 2004). Individual components were then inspected, and blink components were removed. To remove additional artifacts, epochs containing a voltage difference of 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 were automatically rejected. Finally, the cleaned data were averaged across trials for each condition for analysis. For the 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).

Consistent with previous studies (Fuentemilla *et al.*, 2013; Zheng *et al.*, 2015; Zheng *et al.*, 2017), the SPN was measured as the mean activity from −200 to 0 ms before feedback onset over frontal areas (F7, Fz, F8). The cue-P3 was measured as the mean activity from 400 to 550 ms following cue onset over parietal areas (P1, Pz, P2), the RewP from 220–320 ms following feedback onset over frontocentral areas (FC1, FCz, FC2) and the fb-P3 from 320–470 ms following feedback onset over parietal areas (P1, Pz, P2). All the ERP data were analyzed with a repeated measures analysis of variance (ANOVA) separately. Statistical analyses were implemented in SPSS v23 (IBM, Armonk, NY, USA). Greenhouse–Geisser epsilon correction was used when necessary. *Post hoc* comparisons were corrected by applying the Bonferroni procedure, and the partial eta-squared (ηp^2) was reported as a measure of effect size.

Results

Behavioral and rating data

A context (gain *vs* loss) × choice (choice *vs* no-choice) ANOVA performed for reaction times (RTs) revealed a significant main effect of choice, $F(1, 31) = 18.49$, $P < 0.001$, $\eta p^2 = 0.37$, with slower RTs for the choice condition ($M = 948.12$ ms, s.d. $= 469.93$) than the no-choice condition ($M = 720.20$ ms, s.d. $= 253.80$). No other effects reached significance ($P = 0.414$–0.731).

Figure 2 shows the rating data from the choice and no-choice conditions across contexts. As expected, participants perceived a higher level of control in the choice than in the no-choice condition, $F(1, 31) = 6.78$, $P = 0.014$, $\eta p^2 = 0.18$, and in the gain than loss context, $F(1, 31) = 4.78$, $P = 0.037$, $\eta p^2 = 0.13$. With respect to interest, there was a significant interaction of context × choice, $F(1, 31) = 7.40$, $P = 0.011$, $\eta p^2 = 0.19$. *Post hoc* comparisons revealed that participants were more interested in the loss than gain context when they had a choice opportunity (5.94 *vs* 5.44, $P = 0.037$, $d = 0.79$) but not when they had a no-choice opportunity (5.25 *vs* 5.75, $P = 0.111$, $d = -0.59$). Moreover, participants paid more attention to the choice than no-choice condition, $F(1, 31) = 4.73$, $P = 0.037$, $\eta p^2 = 0.13$. With respect to regularity, participants tended to determine a pattern to the 'correct' responses in the gain *vs* loss context, $F(1, 31) = 3.99$,

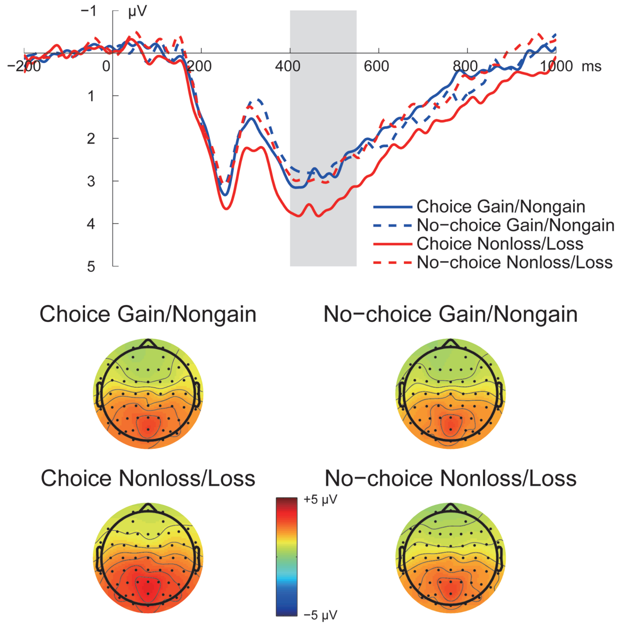

Fig. 3. Grand-averaged ERP waveforms over parietal areas (P1, Pz, P2) and topographic distribution maps of the cue-P3 (400–550 ms) during the cue-evaluation stage of the anticipatory phase.

$P = 0.055$, $\eta p^2 = 0.11$, and in the choice *vs* no-choice condition, $F(1, 31) = 3.55$, $P = 0.069$, $\eta p^2 = 0.10$. No other significant effects were observed ($P = 0.164$–0.999).

EEG data

Anticipatory phase. Anticipatory ERP components included the cue-P3 during the cue-evaluation stage and the SPN during the feedback-anticipation stage. Whereas the cue-P3 was manifested as a positivity maximal over parietal areas (P1, Pz, P2) relative to cue onset (Figure 3), the SPN was evident as a relative negativity over frontal areas (F7, Fz, F8) with a right hemisphere dominance prior to feedback onset (Figure 4).

A context (gain *vs* loss) × choice (choice *vs* no-choice) ANOVA for cue-P3 amplitudes yielded a significant main effect of choice, $F(1, 31) = 6.27$, $P = 0.018$, $\eta p^2 = 0.17$, with an enhanced cue-P3 in the choice *vs* no-choice condition. This choice effect was qualified by a marginally significant interaction between context and choice, $F(1, 31) = 3.47$, $P = 0.072$, $\eta p^2 = 0.10$. *Post hoc* comparisons revealed that cue-P3 amplitudes were greater for the choice than no-choice condition in the loss context (3.58 *vs* 2.82 μV, $P = 0.007$, $d = 1.03$) but not in the gain context (2.80 *vs* 2.67 μV, $P = 0.585$, $d = 0.20$). Furthermore, this interaction became significant, $F(1, 31) = 4.18$, $P = 0.049$, $\eta p^2 = 0.12$, when being analyzed at Pz where the cue-P3 was at its maximum. Given that the cue-P3 data mirrored the rating data of interest, it is possible that the cue-P3 findings were associated with participants' interest. This speculation is supported by a series of *post hoc* correlation analyses between cue-P3 amplitudes and rating scores of interest. Specifically, greater cue-P3 amplitudes were associated with greater interest scores, which appeared only for the choice cue in the loss context ($r = 0.36$, $P = 0.043$) but not for other cues ($P = 0.503$–0.622), although the correlation coefficient in the choice-cue/loss context was not significantly greater than that in other conditions ($z = 1.86$–1.34, $P = 0.063$–0.182).

A context (gain *vs* loss) × choice (choice *vs* no-choice) × site (F7 *vs* Fz *vs* F8) ANOVA for SPN amplitudes yielded a significant main effect of site, $F(2, 62) = 8.10$, $P = 0.001$, $\eta p^2 = 0.21$. *Post hoc* comparisons, revealed that the SPN was more negative-going at F8 relative to Fz, with no differences between F8 and F7 as well as between F7 and Fz. There was a significant main effect of choice, $F(1, 31) = 7.82$, $P = 0.009$, $\eta p^2 = 0.20$, with an increased SPN in the choice condition compared to the no-choice condition, which was qualified by a significant interaction between context and choice, $F(1, 31) = 5.97$, $P = 0.020$, $\eta p^2 = 0.16$. *Post hoc* analyses revealed that the choice effect was present during the gain context (0.21 *vs* 1.67 μV, $P = 0.002$, $d = -1.25$) but not the loss context (0.67 *vs* 0.97 μV, $P = 0.425$, $d = -0.29$). Moreover, there was a marginally significant three-way interaction among context, choice and site, $F(2, 62) = 2.70$, $P = 0.090$, $\eta p^2 = 0.08$. No other significant effect was observed ($P = 0.844$–0.911).[1]

Consummatory phase. Consummatory ERP components consisted of the RewP and the fb-P3. The RewP was manifested as a relative positivity over frontocentral areas (FC1, FCz, FC2) post feedback onset (Figure 5). Following the RewP, the fb-P3 was shown as a positivity with a parietal distribution (P1, Pz, P2) post feedback onset (Figure 6).

A context (gain *vs* loss) × choice (choice *vs* no-choice) × outcome (positive: gain/nonloss *vs* negative: nongain/loss) ANOVA for RewP amplitudes yielded a significant main effect of outcome, $F(1, 31) = 34.99$, $P < 0.001$, $\eta p^2 = 0.53$, which was qualified by a significant interaction between context and outcome, $F(1, 31) = 48.70$, $P < 0.001$, $\eta p^2 = 0.61$. This interaction was because the outcome-valence effect was reversed across contexts. Specifically, the RewP was increased for positive (gain) compared to negative (nongain) outcomes in the gain context (6.76 *vs* 3.73 μV, $P < 0.001$, $d = 2.91$) but decreased for positive (nonloss) compared to negative (loss) outcomes in the loss context (4.86 *vs* 5.83 μV, $P = 0.002$, $d = -1.19$).

There was a significant main effect of choice, $F(1, 31) = 39.83$, $P < 0.001$, $\eta p^2 = 0.56$, with a larger RewP in the choice than the no-choice condition. Critically, there was a significant three-way interaction of context × choice × outcome, $F(1, 31) = 4.37$, $P = 0.045$, $\eta p^2 = 0.12$. As shown in Figure 5, this interaction appears to be because the outcome-valence effect in the gain context was clearly amplified in the choice compared to the no-choice condition. In contrast, the outcome-valence effect in the loss context was comparable across the choice and no-choice conditions. To confirm these observations, we created a difference wave (positive minus negative

1 To prove that the SPN effects were not secondary to a shift in baseline, we reanalyzed the SPN data using an earlier baseline (−3200 to −3000 ms relative to feedback onset). A context × choice × site ANOVA yielded a significant main effect of choice, $F(1, 31) = 9.12$, $P = 0.005$, $\eta p^2 = 0.23$, which was qualified by a significant interaction between context and choice, $F(1, 31) = 8.47$, $P = 0.007$, $\eta p^2 = 0.22$. *Post hoc* comparisons revealed that the SPN was significantly enhanced in the choice relative to the no-choice condition in the gain context (−1.00 *vs* 1.04 μV, $P < 0.001$, $d = -1.53$) but not in the loss context (0.22 *vs* 0.55 μV, $P = 0.527$, $d = -0.23$). However, the three-way interaction among context, choice and site, which was marginally significant for the SPN using the baseline from −1900 to −1700 ms, was no longer significant, $F(2, 62) = 1.32$, $P = 0.275$, $\eta p^2 = 0.04$. No other effects achieved significance ($P = 0.380$–0.872). In sum, these results, together with those obtained using the baseline from −1900 to −1700 ms, suggest that our SPN finding of the interaction between context and choice is robust.

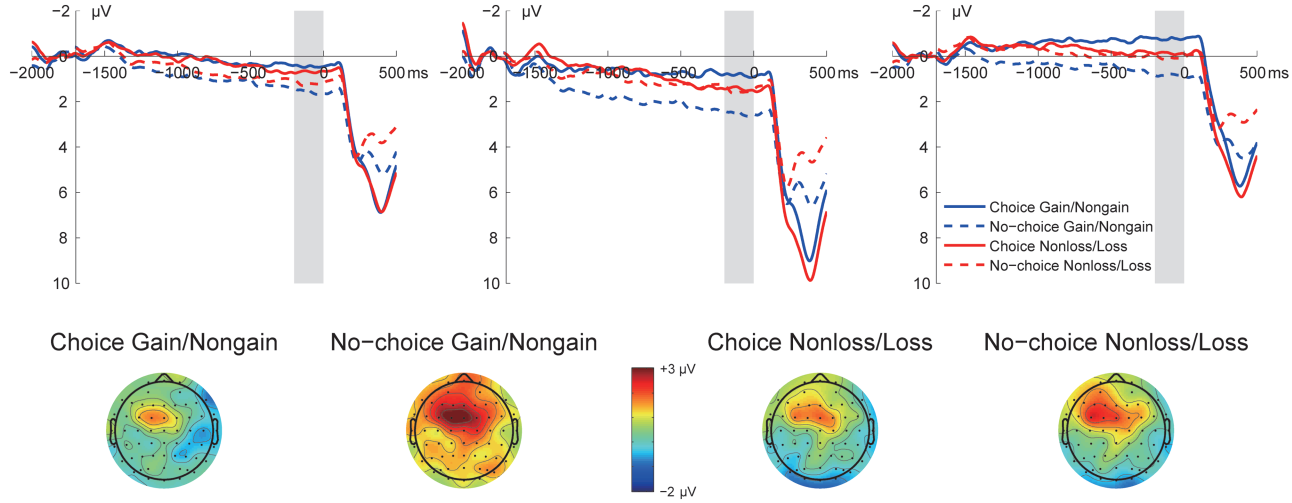

Fig. 4. Grand-averaged ERP waveforms over frontal areas (left: F7, middle: Fz, right: F8) and topographic distribution maps for the SPN (−200 to 0 ms) during the feedback-anticipation stage of the anticipatory phase.

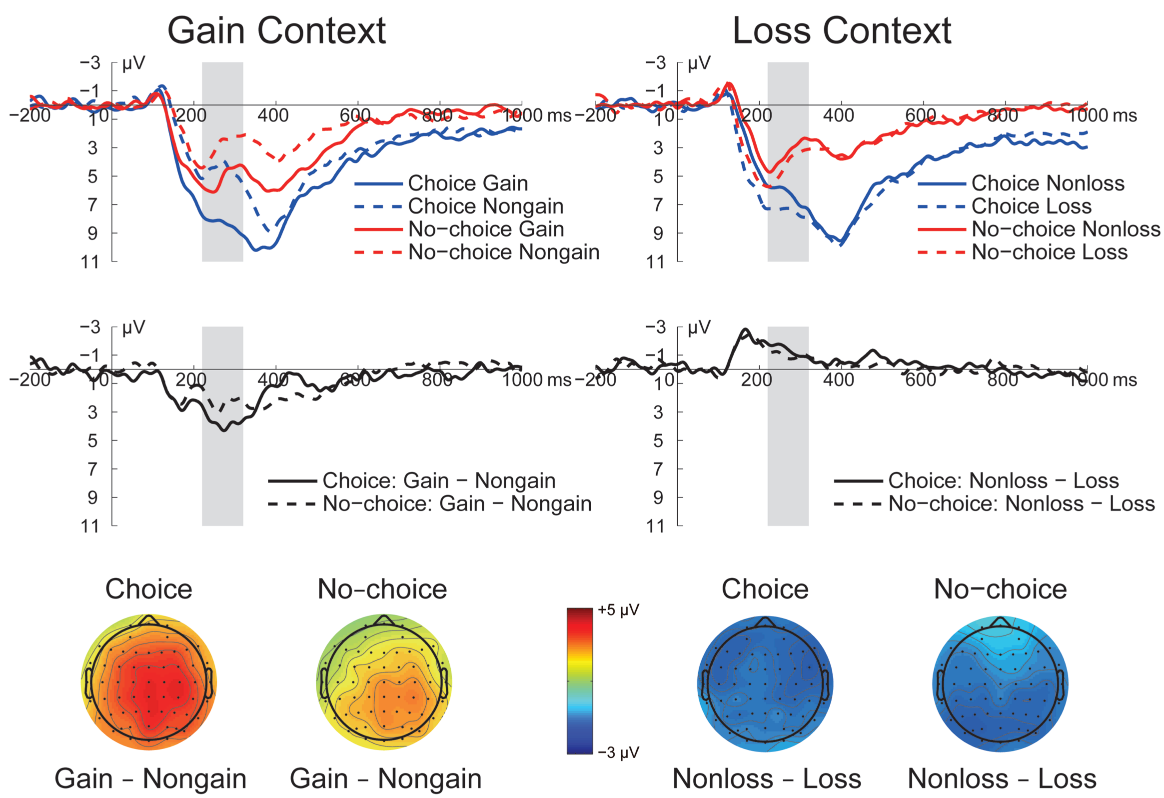

Fig. 5. Grand-averaged ERP waveforms as well as the difference waveforms (positive minus negative feedback) over frontocentral areas (FC1, FCz, FC2) and topographic distribution maps for the ΔRewP (220–320 ms) during the consummatory phase.

outcomes, i.e. the ΔRewP) separately for the choice and no-choice conditions in the gain and loss contexts and then performed a choice × context ANOVA on the ΔRewP. The results revealed a significant main effect of context, $F(1, 31) = 48.70$, $P < 0.001$, $\eta p^2 = 0.61$, which was qualified by a significant interaction between choice and context, $F(1, 31) = 4.37$, $P = 0.045$, $\eta p^2 = 0.12$. *Post hoc* analyses revealed that the ΔRewP was enhanced for the choice compared to the no-choice condition in the gain context (3.75 *vs* 2.32 μV, $P = 0.020$, $d = 0.88$) but not in the loss context (−1.13 *vs* −0.81 μV, $P = 0.528$, $d = -0.23$).

A context (gain *vs* loss) × choice (choice *vs* no-choice) × outcome (positive: gain/nonloss *vs* negative: nongain/loss) ANOVA for fb-P3 amplitudes yielded a significant main effect of choice, $F(1, 31) = 103.78$, $P < 0.001$, $\eta p^2 = 0.77$, with an enhanced fb-P3 in the choice condition compared to the no-choice condition. A larger fb-P3 was elicited when outcomes were positive than when they were negative, $F(1, 31) = 27.91$, $P < 0.001$, $\eta p^2 = 0.47$. However, this outcome-valence effect was significant in the gain context (9.12 *vs* 6.76 μV, $P < 0.001$, $d = 2.29$) but not in the loss context (7.08 *vs* 7.56 μV, $P = 0.129$, $d = -0.56$), as revealed

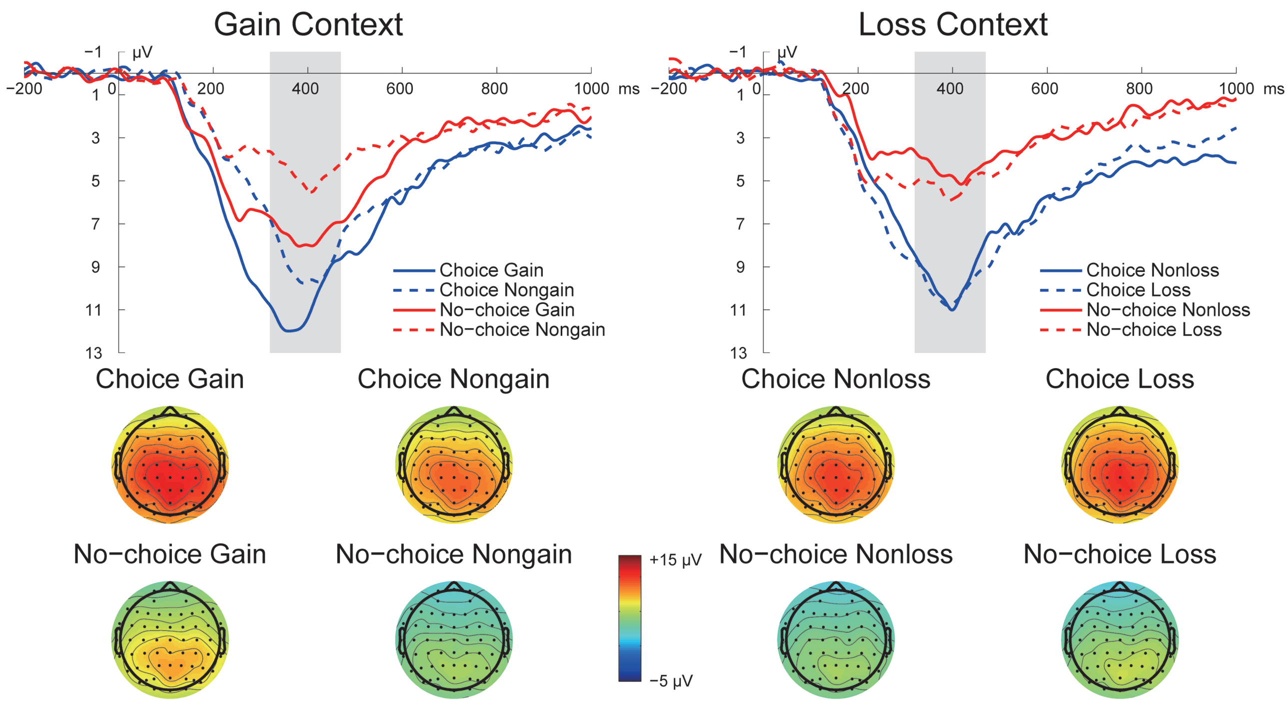

Fig. 6. Grand-averaged ERP waveforms over parietal areas (P1, Pz, P2) and topographic distribution maps for the fb-P3 (320–470 ms) during the consummatory phase.

by a significant interaction between context and outcome, $F(1, 31) = 24.01$, $P < 0.001$, $\eta p^2 = 0.44$. No other effects achieved significance ($P = 0.111$–0.381).

Discussion

To our knowledge, this is the first study to investigate the interface between choice and contextual valence across anticipatory (as indexed by the cue-P3 and SPN) and consummatory (as indexed by the RewP and fb-P3) phases during incentive processing. In the current study, contextual valence was manipulated as expected value (i.e. positive in the gain context and negative in the loss context), and perceived control was exercised through voluntary choice. As expected, participants reported a higher level of perceived control in and paid more attention to the choice than no-choice condition, although the two conditions were exactly the same except for a choice opportunity available in the former. Importantly, we found that the choice effect was modulated by contextual valence during both the anticipatory and consummatory phases of incentive processing.

During the anticipatory phase, a larger cue-P3 was elicited by the choice than the no-choice condition. However, this choice effect was observed in the loss context but not in the gain context. This result is in contrast to our hypothesis but in line with the well-known phenomenon of loss aversion, that is, 'losses loom larger than gains' (Kahneman and Tversky, 1979). Interestingly, previous electrophysiological studies of incentive processing provided little, if any, evidence for this robust behavioral phenomenon. Our cue-P3 findings mirrored the rating data of interest such that participants in the current experiment were more interested in the loss context than the gain context when they had a choice opportunity. Indeed, *post hoc* correlation analyses suggested that the cue-P3 findings may have been driven by participants' interest such that greater cue-P3 amplitudes were associated with greater interest scores, which appeared only for the choice cue in the loss context but not for other cues. However, it should be noted that the correlation analyses were exploratory in nature. Given that the correlation coefficients were not significantly different between conditions and the interaction on the cue-P3 achieved significance only at the Pz electrode, the cue-P3 findings should be interpreted cautiously, and more research is needed before any robust conclusions can be drawn.

Following the cue-P3, a more negative SPN was elicited over F8 than Fz, which is in line with previous research demonstrating a right hemisphere preponderance of this component (Kotani *et al.*, 2009). Consistent with recent studies (Masaki *et al.*, 2010; Meng and Ma, 2015; Muhlberger *et al.*, 2017; Chen *et al.*, 2018; Yi *et al.*, 2018), the SPN was enhanced for the choice condition compared to the no-choice condition over both laterofrontal and frontocentral areas, supporting the crucial role of voluntary choice in anticipation of motivational outcomes. Critically, the choice effect was modulated by contextual valence such that it was present in the gain context but disappeared in the loss context. In our previous study, we found that the effect of choice on the SPN was present when the reward probability was high and medium but was diminished when it was low (Chen *et al.*, 2018). Together with this study, it is possible that the value of the choice was decreased during the anticipatory phase of incentive processing when a reward was improbable.

During the consummatory phase, an enhanced RewP was elicited by positive (gain) *vs* negative (nongain) feedback in the gain context. In contrast, this outcome-valence effect (i.e. the ΔRewP) was reversed in the loss context such that the RewP in response to negative (loss) feedback was increased compared with positive (nonloss) feedback. These results indicate that the RewP is sensitive to motivational salience (i.e. gain > nongain and loss > nonloss), rather than motivational valence (i.e. gain > nongain and nonloss > loss), of feedback stimuli, thus supporting the view that RewP variation reflects a salience prediction error (Talmi *et al.*, 2013; Garofalo *et al.*, 2014;

Soder and Potts, 2018) instead of a reward prediction error (Heydari and Holroyd, 2016; Mulligan and Hajcak, 2018). Importantly, the outcome-valence effect was modulated by a significant interaction between context and choice. Specifically, the outcome-valence effect in the gain context was elevated when choices were available compared to when they were unavailable. However, the outcome-valence effect in the loss context was comparable across the choice and no-choice conditions. These findings suggest that motivational salience, as indexed by the ΔRewP, is increased by choice in the context of potential gains but not in the context of potential losses.

The fb-P3 is believed to reflect the allocation of attentional resources based on the motivational significance of stimulus evaluation (Sutton *et al*., 1978; Yeung and Sanfey, 2004; San Martin *et al*., 2010). In the gain context, positive (gain) feedback elicited a greater fb-P3 than negative (nongain) feedback, and this outcome-valence effect was present across the choice and no-choice conditions. In contrast, no outcome-valence effect between positive (nonloss) and negative (loss) feedback was observed in the loss context. The interaction between outcome valence and contextual valence is in accordance with previous studies (Kujawa *et al*., 2013; Pfabigan *et al*., 2015; Zheng *et al*., 2015; Zheng *et al*., 2017), suggesting that task relevance, that is, positive feedback as the natural target, might be enhanced in the gain relative to loss context. Moreover, the fb-P3 showed a robust choice effect, as revealed by larger amplitudes in the choice condition than in the no-choice condition. This choice effect was present across contexts, which is in contrast to the interplay observed for the SPN and RewP components. This finding suggests that context and choice are coded independently and additively during the late stage of the consummatory phase and that the fb-P3 is possibly less relevant to incentive processing.

Our findings of the interaction of context and choice on the SPN and ΔRewP (i.e. the outcome-valence effect) indicate that in the context of positive outcomes, choice might be inherently valuable. However, in the context of negative outcomes, specifically monetary losses, the value of the choice was diminished. The interplay between choice and contextual valence is broadly consistent with our previous studies that have demonstrated an effect of reward magnitude on both the SPN (Zheng *et al*., 2015) and ΔRewP (Zheng *et al*., 2015; Zheng *et al*., 2017) in the context of potential gains but not in the context of potential losses. The explanation for this interaction might be associated with participants' beliefs about positive and negative contexts. Evidence from research on attribution has demonstrated that most people tend to attribute success internally but failure externally (Rotter, 1966; Brewin and Brewin, 1984). In this study, participants accumulated money increasingly in the gain context due to the positive expected value (at an average rate of +5 points per trial), whereas they lost money gradually in the loss context because of the negative expected value (at an average rate of −5 points per trial). It is thus possible that participants made a more internal attribution in the context of potential gains when they had a choice opportunity, whereby a higher level of perceived control was experienced. In the face of potential losses, however, they might attribute outcomes to external sources regardless of whether they had a choice opportunity, which resulted in the absence of the choice effect on both the SPN and ΔRewP components.

On the other hand, the choice-by-context interaction of the SPN and ΔRewP might be accommodated within the framework of the reinforcement learning theory. Recent research has highlighted that the SPN and RewP constitute complementary indices of reinforcement learning: the prediction system indexed by the SPN and the prediction error system indexed by the RewP (Brunia *et al*., 2011). In the current experiment, participants attempted to learn the action–outcome contingency to earn money in the gain context and avoid losing money in the loss context. This action–outcome contingency was feasible when they could make choices by themselves but not when they accepted choices made by the computer passively, which may explain the choice effect observed for the SPN and RewP. Importantly, the absence of a choice effect on both the SPN and ΔRewP indicates that this action–outcome contingency played little role in the loss context. To go a step further, our findings suggest that positive reinforcement induced by the gain context has a stronger effect than negative reinforcement induced by the loss context during reinforcement learning. This explanation is in line with previous ERP research that has demonstrated that the variation of the RewP elicited by reward parameters (e.g. magnitude and probability) is more pronounced for gains than for losses (Cohen *et al*., 2007; Kreussel *et al*., 2012; Zheng *et al*., 2017).

To summarize, this study provides electrophysiological evidence that the choice effect is associated with multiple ERP components across the anticipatory and consummatory phases during incentive processing, which, however, is contingent upon the valence of the context. Specifically, choice effects on the SPN and ΔRewP were present only in the context of potential gains, whereas the cue-P3 choice effect occurred only in the context of potential losses. One issue that merits exploration in future investigations is to address the mechanism by which control-related disorders, such as depression (the feelings of helplessness), influence the choice effect across the anticipatory and consummatory phases of incentive processing.

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