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# Reward processing in gain versus loss context: An ERP study

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**Abstract**

Previous research has shown that consummatory ERP components are sensitive to contextual valence. The present study investigated the contextual valence effect across anticipatory and consummatory phases by requiring participants to play a simple gambling task during a gain context and a loss context. During the anticipatory phase, the cue-P3 was more positive in the gain context compared to the loss context, whereas the stimulus-preceding negativity (SPN) was comparable across the two contexts. With respect to the consummatory phase, the feedback-related negativity (FRN) in response to the zero-value outcome was more negative in the gain versus loss context, whereas the feedback P3 (fb-P3) in response to the zero-value outcome was insensitive to contextual valence. These findings suggest that contextual valence effect occurs at a relative early stage of both the reward anticipation and consumption. Moreover, across the gain and loss contexts, the SPN was selectively correlated with the FRN, whereas the cue-P3 was selectively associated with the fb-P3, pointing to a close association between the anticipatory and consummatory phases in reward dynamics.

**KEYWORDS**

contextual valence, feedback-related negativity, P3, stimulus-preceding negativity

## 1 | INTRODUCTION

An outstanding issue in reward literature is that reward is not a single process but rather can be decomposed into different phases (Berridge & Robinson, 1998, 2003), including the motivation to chase a reward (i.e., reward anticipation or "wanting") and the hedonic pleasure experienced during its ensuing consumption (i.e., reward consumption or "liking"). The two components are typically related, but seminal research using animal models indicates that they can also be dissociated (Berridge & Robinson, 2003). The independence of reward anticipation and consumption has raised great interest and constituted a potential mechanism underlying various reward-related neuropsychiatric disorders such as depression (Sherdell, Waugh, & Gotlib, 2012), schizophrenia (Gard, Kring, Gard, Horan, & Green, 2007), and addiction (Finlayson, King, & Blundell, 2007).

One approach to dissociating the reward anticipation and consumption is to assess the neural influences of the reward parameters on the anticipatory phase and the consummatory phase, respectively. One of such reward parameters is contextual valence, which has a great influence on people's risk preference in economic decision making (Kahneman & Tversky, 1979). Specifically, an individual tends to be risk averse when he/she has something to gain (gain context), but risk seeking when he/she has something to lose (loss

  

context). In the present study, we were interested in electrocortical correlates of contextual valence across the anticipatory and consummatory phases during reward processing.

With its millisecond-level resolution, the ERP technique provides an ideal means of probing the neural dynamics of reward processing. Several ERP components are associated with the different phases of reward processing. Previous research shows that reward anticipation can be further decomposed into, among others, a cue-evaluation stage during which a cue is presented and provides the information of the possible outcomes on the current trial, and a feedback-anticipation stage that allows participants to anticipate the outcome (Broyd et al., 2012; Novak & Foti, 2015; Pornpattananangkul & Nusslock, 2015). The most relevant ERP component during the cue-evaluation stage is the cue-P3, a positive-going deflection peaking 300–500 ms following cue presentation (Broyd et al., 2012; Goldstein et al., 2006). The cue-P3 is associated with brain activation in the ventral striatum during reward anticipation (Pfabigan et al., 2014) and is thought to reflect the allocation of attentional resources to potential outcomes (Polich, 2007). The stimulus-preceding negativity (SPN) is a candidate ERP component associated with feedback anticipation. The SPN appears as a negative-going potential peaking immediately prior to the presentation of outcome over frontal and parietal locations (Brunia, 1988; Damen & Brunia, 1987). Initially, the SPN was isolated from the contingent negative variation (CNV), a component including subcomponents reflecting anticipatory attention and motor preparation (Walter, Cooper, Aldridge, McCallum, & Winter, 1964), and was thought to index the anticipatory component. More recent research suggests that the SPN constitutes an index for reward anticipation (Brunia, Hackley, van Boxtel, Kotani, & Ohgami, 2011; Hackley, Valle-Inclán, Masaki, & Hebert, 2014), and the anterior insula is the main neural origin of the SPN (Bocker, Brunia, & van den Berg-Lenssen, 1994; Brunia, de Jong, van den Berg-Lenssen, & Paans, 2000; Kotani et al., 2009). Two ERP components are associated with reward consumption, that is, the feedback-related negativity (FRN) and the feedback P3 (fb-P3). The FRN peaks 250–350 ms at frontocentral sites after feedback delivery. Early research has suggested that the FRN indexes a reward prediction error signal when an outcome is worse than expected (Walsh & Anderson, 2012). More recent research has emphasized that the variation in the FRN amplitude is driven by a positive deflection elicited by reward feedback that is superimposed on a negative deflection elicited by punishment or nonreward feedback (Proudfit, 2015). The fb-P3 is a positive, parietal deflection around 350–600 ms postfeedback onset (Sutton, Tueting, Hammer, & Hakerem, 1978; Yeung & Sanfey, 2004) and is considered as an indicator of motivational significance during reward consumption (San Martín, Manes, Hurtado, Isla, & Ibañez, 2010).

Previous studies have demonstrated that the consummatory ERP components are strongly modulated by contextual valence (Holroyd, Larsen, & Cohen, 2004; Huang & Yu, 2014; Kreussel et al., 2012; Kujawa, Smith, Luhmann, & Hajcak, 2013; Pfabigan et al., 2015; Sambrook, Roser, & Goslin, 2012; Zheng, Li, Wang, Wu, & Liu, 2015). In a now classic study, Holroyd et al. (2004) showed that the FRN amplitude was dependent on contextual valence insofar as the same objective zero-value outcome elicited a larger FRN in the gain versus loss context. As zero-value outcome is the worst possible outcome in the gain context but the best possible outcome in the loss context, the authors proposed that reward and punishment are presented in relative terms. However, in a following study, Kujawa et al. (2013) failed to find a FRN difference for zero-value outcome between gain and loss contexts, indicating that reward and punishment may be represented as opposites on a unidimensional continuum whereby zero-value outcome has a concrete, absolute meaning that is the same in both contexts. In contrast, the fb-P3 is more consistent across experiments with its amplitude being amplified in the gain compared to loss context (Kujawa et al., 2013; Pfabigan et al., 2015; Zheng et al., 2015).

Although the above ERP studies suggest a possible dissociation of how outcomes are processed between contexts with different valences, the question remains as to whether contextual valence also exerts influence on anticipatory ERP components. Whereas some previous studies found comparable cue-P3 for both gain and loss cues (Broyd et al., 2012; Goldstein et al., 2006; Novak & Foti, 2015), others observed an increased cue-P3 for gain versus loss cue (Pfabigan et al., 2014; Santesso et al., 2012). Using the time estimation task, a previous study found that the typical right hemisphere dominance of SPN disappeared selectively in gain but not loss contexts (Ohgami et al., 2006). Additionally, our recent research using a gambling task observed that the SPN was modulated by magnitude in gain but not loss contexts (Zheng et al., 2015).

A limitation of previous ERP studies is that most have focused on contextual valence during either the consummatory phase (Holroyd et al., 2004; Kreussel et al., 2012; Kujawa et al., 2013; Pfabigan et al., 2015) or the anticipatory phase (Ohgami et al., 2006). Few, if any, studies that tested the contextual valence effect for both anticipatory and consummatory ERPs within the same experiment produced rather heterogeneous results. Using a monetary incentive delay task during which participants made a speeded response to a visual target presented after an incentive cue to obtain a gain or avoid a loss, one recent study demonstrated that contextual valence influenced the consummatory phase, but not the anticipatory phase (Novak & Foti, 2015). Specifically, both the cue-P3 and CNV were insensitive to contextual valence during the anticipatory phase. With regard to the

consummatory phase, the FRN tracked the outcome valence in the gain but not the loss context, whereas the fb-P3 was enhanced for loss versus nonloss outcomes, but comparable for gain versus nongain outcomes. Unfortunately, the findings of both the FRN and fb-P3 were confounded with asymmetric condition ratios because of the much higher successful rates (~70%). Moreover, the CNV results were ambiguous because the participants were simultaneously preparing for three events: the target, the response, and the feedback. In our previous study (Zheng et al., 2015), individuals made a choice between two options under either a gain context, during which a monetary bonus tended to be accumulated steadily, or a loss context, during which a monetary bonus tended to be dissipated gradually. This study observed a consistent contextual valence effect during both anticipatory and consummatory periods. An increased SPN was elicited by high- versus low-magnitude choices in the gain but not the loss context. Similarly, both the FRN and fb-P3 displayed an enhanced effect of outcome valence following high- versus low-magnitude choices in the gain instead of the loss context. However, this study also confounded asymmetric condition ratios with the ERP results due to less frequent choices of the high-magnitude options in the gain context, and did not report the cue-P3 results. Because of these confounds and limitations, it remains unclear whether contextual valence exerts influence on both reward anticipation and consumption commonly or selectively.

The main objective of the present study was to investigate the contextual valence effect across anticipatory and consummatory phases in a single experiment. To this end, we devised a simple gambling task in which participants experienced a gain context where monetary reward was delivered or omitted, and a loss context where monetary loss was delivered or omitted. This task enabled us to address the theoretical issue of whether reward and punishment are encoded commonly or independently (X. Liu, Hairston, Schrier, & Fan, 2011). If reward and punishment are processed in an integrated way, then the reward-related ERP components should be insensitive to contextual valence. In contrast, if reward and punishment are represented in a dissociated way, then these ERP components should be modulated by contextual valence.

Based on previous research, we predicted that the consummatory ERP components (i.e., the FRN and fb-P3) would be accentuated in the gain but not the loss context (Kreussel et al., 2012; Kujawa et al., 2013; Zheng et al., 2015). With respect to the anticipatory ERP components, we predicted that the cue-P3 would be larger (Pfabigan et al., 2014; Santesso et al., 2012) or comparable (Broyd et al., 2012; Goldstein et al., 2006; Novak & Foti, 2015) in the gain compared to loss context. The SPN would be insensitive to the contextual valence effect, since previous research found a null effect on this component when directly comparing the SPN between the two contexts (Ohgami et al., 2006; Zheng et al., 2015). Additionally, we explored the relationship between reward anticipation (i.e., the cue-P3 and SPN) and consumption (i.e., the FRN and fb-P3) during both the gain and loss contexts, which could provide additional information to contextual valence effect in reward dynamics.

## 2 | METHOD

### 2.1 | Participants

Thirty-seven right-handed undergraduate students participated in the experiment. One was excluded from final analysis due to an inadequate number of artifact-free trials (less than 50% of trials) available for the ERP analysis, leaving 36 (19 females; age: $M = 21.53$, range = 18–26) for the final sample. All participants had normal or corrected-to-normal visual acuity and reported no history of psychological or neurological disorder. Each signed a written informed consent and received a base payment of 30 yuan (roughly equal to $4.50) for participation, plus a bonus of 30 yuan. The study was approved by the Dalian Medical University Institutional Review Board.

### 2.2 | Procedure

Participants performed a simple gambling task (Figure 1), which was adopted from previous studies and modified for the current experiment (Proudfit, 2015). The task consisted of a gain context and a loss context. During both contexts, each trial began with a cue that explicitly stated the magnitude of outcome (9 or 99) at stake for 1,000 ms. A fixation then appeared for 500 ms and was replaced by two doors shown side by side. This pair of doors indicated a 50% chance of success and a 50% chance of failure and remained on the screen until the participants picked one by pressing the corresponding button with either their left or right index finger. Following their response, a fixation was presented for 2,500 ms, and thereafter a green number appeared for 1,000 ms to indicate the outcome on that trial (gain or nongain for gain context, loss or nonloss for loss context). Each trial ended with an intertrial interval varying from 1,200 to 1,500 ms. We used symmetric absolute values to equate the objective magnitude for gains (9 or 99) and losses (9 or 99), though the subjective magnitude for gains and losses may be different (Tversky & Kahneman, 1992).

In the gain context, participants were told that on each trial one of the two doors contained a gain indicated by the cue and the other was empty. In the loss context, participants were told that on each trial one of the two doors contained a loss indicated by the cue and the other was empty. Each

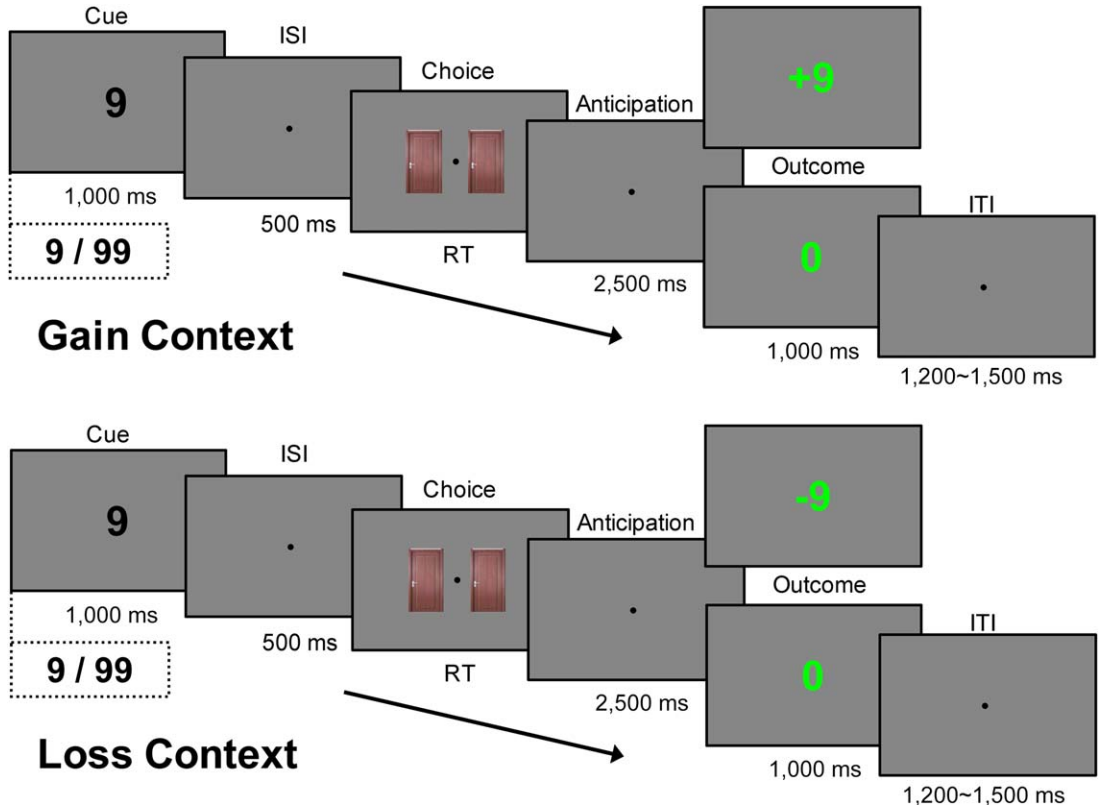


**FIGURE 1** Schematic representation of the gambling task. ISI = interstimulus interval; ITI = intertrial interval; RT = reaction time

context consisted of 160 trials divided into four blocks (40 trials each), and a rest break was given between blocks. Six practice trials were provided before entering into each context. Half of the participants performed the gain context first, followed by the loss context, and the remainder completed the experiment in the reverse order. Prior to the experiment, the participants were told that they would complete the gain and loss contexts and were encouraged to use any strategy they wanted (ensuring gains and avoiding losses) to maximize their total points. The higher the number of points they earned, the more bonus money they would receive. However, the exchange rate was not provided until the end of the experiment. Unbeknownst to the participants, the outcome of each trial was predetermined and pseudorandom such that the participants succeeded (i.e., gain or nonloss) and failed (i.e., nongain or loss) on exactly 50% on each type of trial.

## 2.3 | Recording and analysis

The EEG was recorded at 30 scalp locations using Ag/AgCI electrodes according to the International 10/20 system (FP1, FP2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T3, C3, Cz, C4, T4, TP7, CP3, CPz, CP4, TP8, T5, P3, Pz, P4, T6, O1, Oz, O2). The EEG signals were recorded using a right mastoid reference electrode and rereferenced offline to the mean of the activity at the left and right mastoids. Eye movements and blinks were monitored via horizontal electrooculogram (EOG) placed at the external canthi of each eye and vertical EOG placed above and below the left eye. The EEG and EOG were amplified using a Neuroscan NuAmps amplifier with a low-pass filter at 100 Hz in DC acquisition mode. The signals were digitalized at a rate of 500 samples per second via an analog-to-digital converter. Electrode impedance was kept under 5 KΩ throughout the experiment.

The EEG data were analyzed using MATLAB 2014a (MathWorks, US) and EEGLAB toolbox (Delorme & Makeig, 2004). For the cue-P3 analysis, the raw EEG was filtered with a band-pass of 0.1 and 20 Hz (roll-off 6 dB/octave) and then was epoched from −3,000 to 1,500 ms relative to cue onset, with the activity from −200 to 0 ms serving as the baseline; for the SPN analysis, the raw EEG was filtered with a band-pass of 0.01 and 20 Hz and then was epoched from −4,000 to 1,000 ms relative to feedback onset, with the activity from −2,400 to −2,200 ms serving as the baseline (Masaki, Yamazaki, & Hackley, 2010); for the fb-P3 analysis, the raw EEG was filtered with a 0.1–20 Hz band-pass (roll-off 6 dB/octave) and then was epoched from −3,000 to 1,500 ms relative to feedback onset, with the activity from −200 to 0 ms serving as the baseline; for the FRN analysis, the raw EEG was filtered with a 2–20 Hz band-pass (roll-off 6 dB/octave) to minimize the influence of fb-P3 (San Martin, 2012) and then was epoched from

−3,000 to 1,500 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 (e.g., spikes, drifts, and nonbiological signals) and then were subjected to an infomax independent component analysis (runica; Delorme & Makeig, 2004; Jung et al., 2001). Individual components were inspected and blink components were removed. To remove additional artifacts, we utilized a semi-automated procedure (Foti, Weinberg, Dien, & Hajcak, 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 (Parvaz et al., 2015).

ERP components were scored as the mean voltage of different time windows at representative electrodes: the cue-P3 from 350 to 550 ms postcue onset at Pz; the SPN from −200 to 0 ms before feedback onset at laterofrontal electrodes (F7/8 and FT7/8); the FRN from 220 to 320 ms postfeedback onset at FCz; the fb-P3 from 320 to 420 ms postfeedback onset at Pz. All ERP data were analyzed with repeated measures analyses of variance (ANOVAs). The

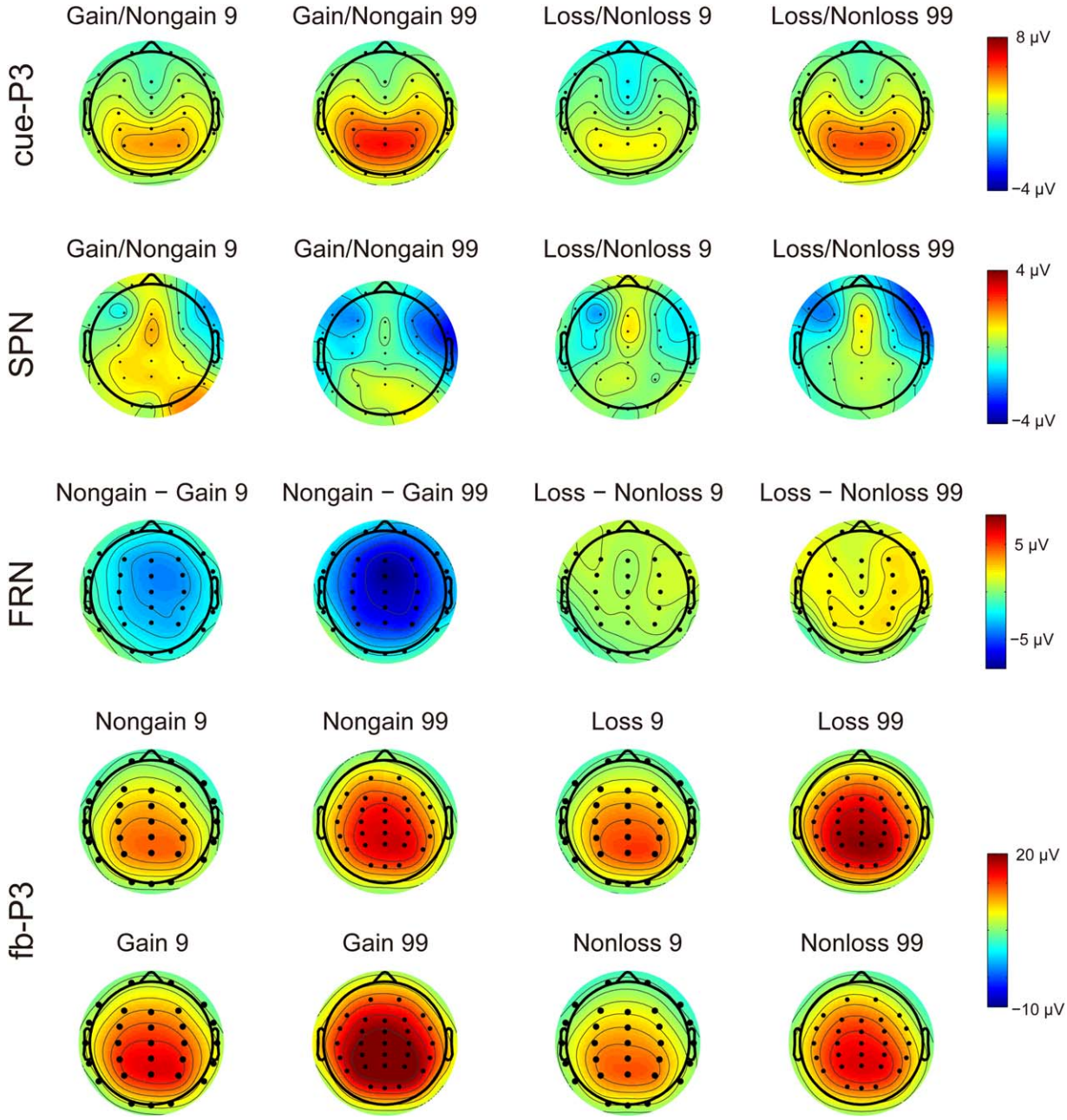


**FIGURE 2** Topographical distribution maps for the cue-P3 (350–550 ms), SPN (−200–0 ms), FRN (220–320 ms), and fb-P3 (320–420 ms)

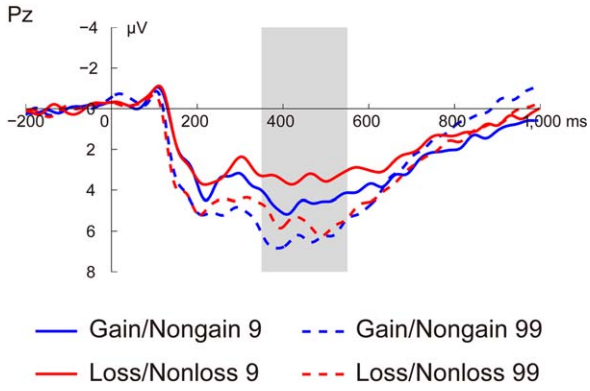


**FIGURE 3** Grand-averaged ERP waveforms during the cue-evaluation stage of the anticipatory phase, where the shaded area depict the time window during which the cue-P3 was scored

cue-P3 was analyzed with a Context (gain vs. loss) × Magnitude (small vs. large) ANOVA. The SPN was analyzed with a Context × Magnitude × Hemisphere (left vs. right) × Site (F7/8 vs. FT7/8) ANOVA. The FRN and fb-P3 were analyzed with a Context × Magnitude × Valence (unfavorable vs. favorable) ANOVA. Moreover, a Context × Magnitude was applied to the FRN and fb-P3 in response to the zero-value outcomes (i.e., nongain 9, nongain 99, nonloss 9, and nonloss 99) that possessed identical visual characteristics (Y. Liu, Nelson, Bernat, & Gehring, 2014). Greenhouse-Geisser epsilon correction was applied when factors had more than two levels (Jennings & Wood, 1976) and Bonferroni correction was used for post hoc comparisons. Furthermore, Pearson's correlation was applied to evaluate the relationship between anticipatory ERPs (i.e., the cue-P3 and SPN) and consummatory ERPs (i.e., the FRN and fb-P3) in each context, which was collapsed across small and large trials.

## 3 | RESULTS

### 3.1 | Behavioral data

On average, the decision-making time was 1,357 ± 119 ms. A Context × Magnitude ANOVA conducted on the decision-making time yielded no significant effects ($ps > .1$), indicating that the decision-making time was similar between the gain and loss contexts and between small and large magnitude choices.

### 3.2 | Electrophysiological data

#### 3.2.1 | Anticipatory phase

ERPs in response to reward anticipation consisted of the cue-P3 and SPN. Cues elicited a P3 component with maximal activity at Pz (Figure 2, 3). The SPN was evident as a relative negativity after the choice and reached its maximum before feedback onset (Figure 4). The topographic map indicated that the SPN was more pronounced at latero-frontal electrode sites (Figure 2). The amplitude data of the

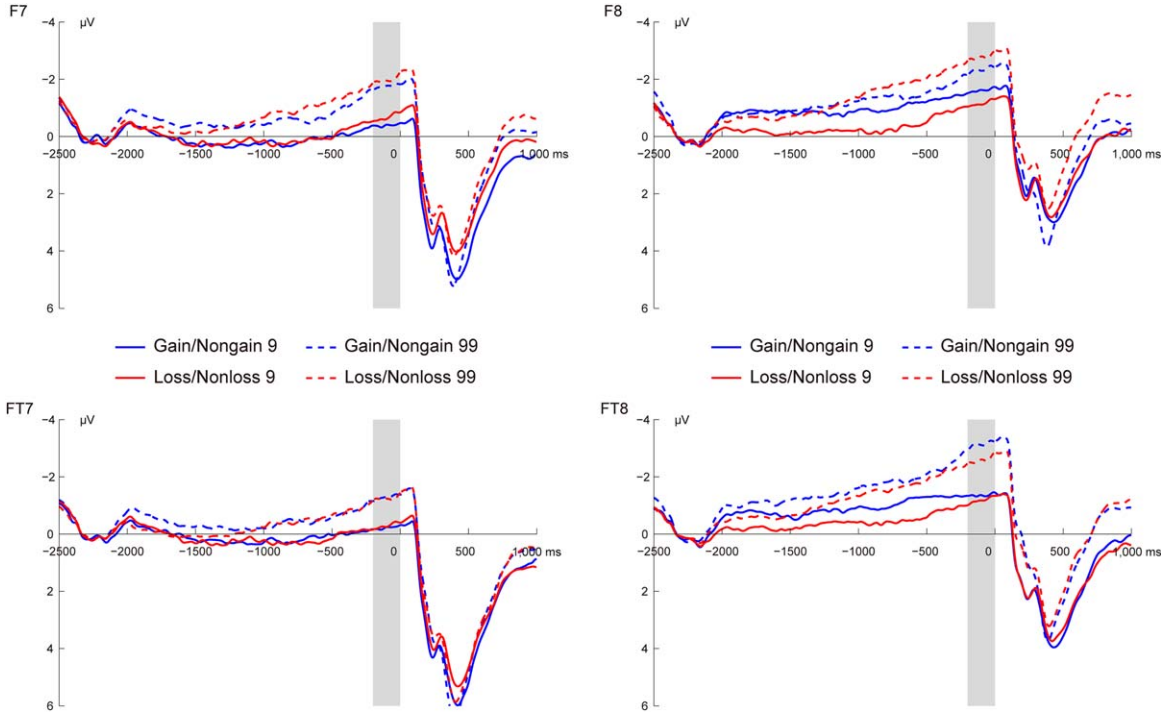


**FIGURE 4** Grand-averaged ERP waveforms during the feedback-anticipation stage of the anticipatory phase, where the shaded areas depict the time windows during which the SPN was scored

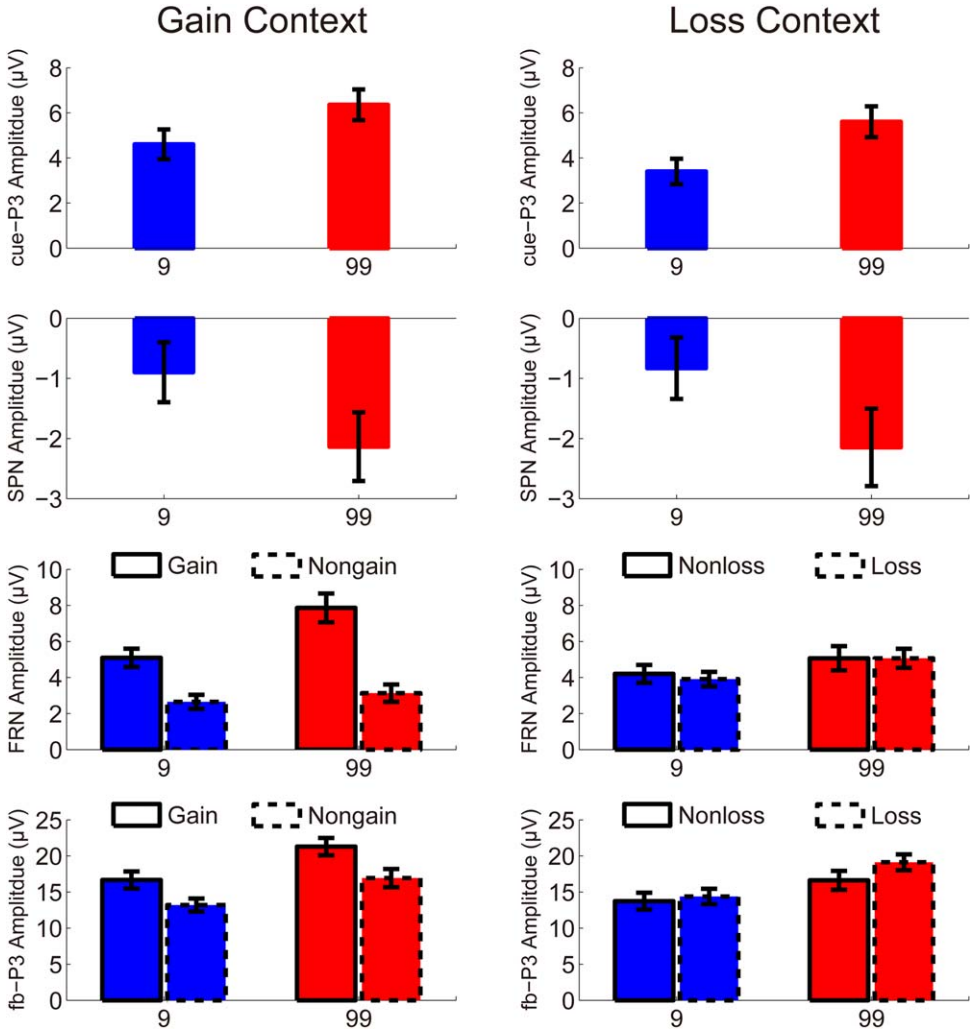


**FIGURE 5** Mean amplitude data for the cue-P3, SPN, FRN, and fb-P3 in the gain and loss contexts. Error bars represent standard errors of the means

cue-P3 and SPN for the gain and loss contexts are depicted in Figure 5.

The two-way cue-P3 ANOVA model yielded a significant main effect of context, $F(1, 35) = 7.00$, $p = .012$, $\eta_p^2 = .17$, with a larger cue-P3 during the gain context than during the loss context. Moreover, large cues compared with small cues elicited a greater cue-P3, as reflected by a significant main effect of magnitude, $F(1, 35) = 39.29$, $p < .00001$, $\eta_p^2 = .53$.

The four-way SPN ANOVA model yielded a main effect of magnitude, $F(1, 35) = 8.66$, $p = .006$, $\eta_p^2 = .20$, indicating that the SPN amplitude was greater for large cues than for small cues. This magnitude effect was comparable between the gain context and the loss context, as revealed by a nonsignificant Context × Magnitude interaction, $F < 1$. Moreover, the main effect of hemisphere was marginally significant, $F(1, 35) = 3.80$, $p = .059$, $\eta_p^2 = .10$, and the interaction of Context × Valence failed to reach significance, $F < 1$.

### 3.2.2 | Consummatory phase

ERPs in response to reward delivery consisted of the FRN and fb-P3. Figure 2 presents the topographic maps for the FRN (220–320 ms) and fb-P3 (320–420 ms). Figure 6 displays the grand-averaged ERP waveforms elicited by unfavorable and favorable outcomes at FCz and Pz, as well as the difference waveforms (unfavorable minus favorable outcomes) at FCz. Figure 5 plots the amplitude data of the FRN and fb-P3 for the gain and loss contexts.

The three-way FRN ANOVA model yielded significant main effects of valence, $F(1, 35) = 27.50$, $p < .00001$, $\eta_p^2 = .44$, and magnitude, $F(1, 35) = 19.66$, $p < .0001$, $\eta_p^2 = .36$. There was a three-way interaction among context, valence, and magnitude, $F(1, 35) = 19.35$, $p < .0001$, $\eta_p^2 = .36$, along with two-way interactions of Context × Valence, $F(1, 35) = 84.10$, $p < .000001$, $\eta_p^2 = .71$, Context × Magnitude, $F(1, 35) = 6.16$, $p = .018$, $\eta_p^2 = .15$, and Valence × Magnitude, $F(1, 35) = 9.45$, $p = .004$, $\eta_p^2 = .21$.

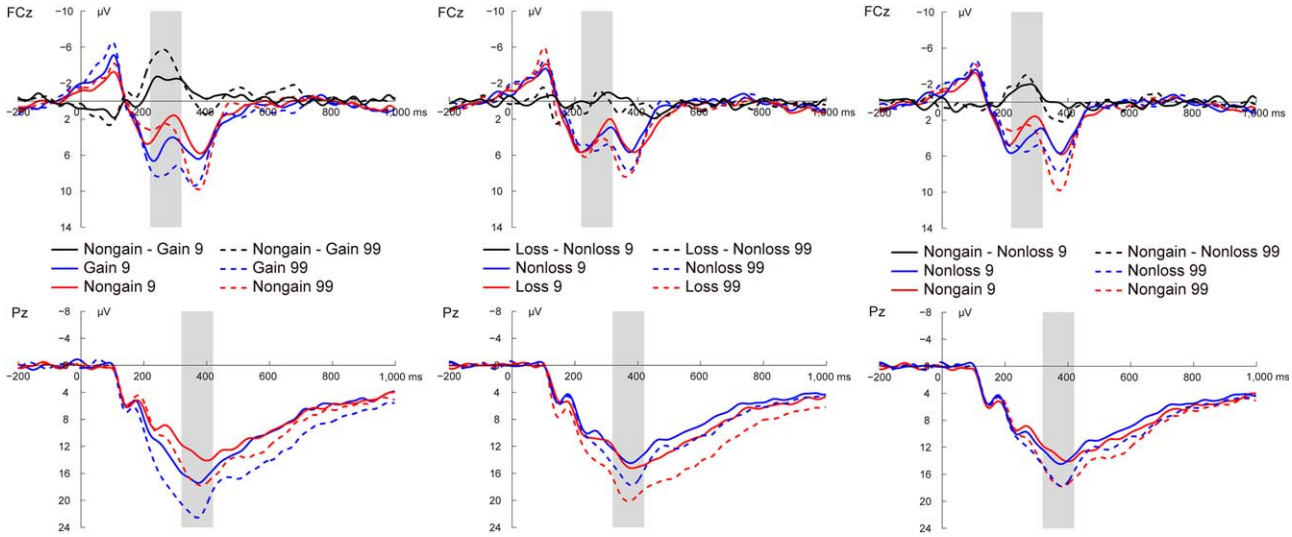


**FIGURE 6** Grand-averaged ERP waveforms during the consummatory phase, where shaded areas depict the time windows during which the FRN (top) and fb-P3 (bottom) were scored. The left and middle columns depict the ERPs elicited by all eight types of outcomes, whereas the right column depicts the ERPs elicited by zero-value outcomes

To decompose the three-way interaction, a separate Valence × Magnitude ANOVA was performed for the gain and loss contexts. In the loss context, there was a main effect of magnitude, $F(1, 35) = 13.58$, $p = .001$, $\eta_p^2 = .28$. Importantly, the interaction of Valence × Magnitude was not significant, $F(1, 35) = 0.43$, $p = .515$, $\eta_p^2 = .01$, indicating that the three-way interaction was not caused by the FRN variation in the loss context. In the gain context, there were main effects of valence, $F(1, 35) = 65.76$, $p < .000001$, $\eta_p^2 = .65$, and magnitude, $F(1, 35) = 19.53$, $p < .0001$, $\eta_p^2 = .36$. Critically, there was a pronounced two-way interaction between valence and magnitude, $F(1, 35) = 28.31$, $p < .00001$, $\eta_p^2 = .45$. This interaction was caused by the more positive FRN in response to large gains as revealed by the fact that the difference between small and large magnitude was significant following gain outcomes ($p < .00001$), but not following nongain outcomes ($p = .187$).

The three-way fb-P3 ANOVA model yielded a significant main effect of magnitude, $F(1, 35) = 83.36$, $p < .000001$, $\eta_p^2 = .70$, with more positive fb-P3 responses to outcomes with large magnitude than to outcomes with small magnitude. There was a significant main effect of valence, $F(1, 35) = 8.41$, $p = .006$, $\eta_p^2 = .19$, which was strongly qualified by a significant two-way Valence × Context interaction, $F(1, 35) = 61.20$, $p < .0001$, $\eta_p^2 = .64$. Post hoc comparison revealed that, in the gain context, favorable (gain) outcomes elicited an enhanced fb-P3 compared to unfavorable (nongain) outcomes ($p < .0001$). In contrast, in the loss context, favorable (nonloss) outcomes elicited a reduced fb-P3 compared to unfavorable (loss) outcomes ($p = .004$). This interaction was further modulated by magnitude, $F(1, 35) = 7.24$, $p = .011$, $\eta_p^2 = .17$. The valence effect in the gain context was significant for both small and large outcomes ($ps < .0001$). However, the valence effect in the loss context was significant for large outcomes ($p = .001$) but not for small outcomes ($p = .255$).

The FRN to zero-value outcome was more negative during the gain versus loss context, $F(1, 35) = 13.22$, $p = .001$, $\eta_p^2 = .27$, and for small versus large magnitude trials, $F(1, 35) = 5.01$, $p < .05$, $\eta_p^2 = .13$. Although the fb-P3 to zero-value outcome was enhanced following large relative to small magnitude trials, $F(1, 35) = 35.73$, $p < .00001$, $\eta_p^2 = .51$, it was similar across the gain and loss contexts, $F < 1$.

### 3.2.3 | Relationships between anticipatory ERPs and consummatory ERPs

Table 1 shows the correlations between the anticipatory and consummatory ERPs. Note that negative correlation coefficients between a negative component (i.e., the SPN or FRN) and a positive component (i.e., the cue-P3 and fb-P3) always mean a direct association (large ERP response) and vice versa.

The anticipatory ERPs (i.e., the cue-P3 and SPN) were significantly correlated with the consummatory ERPs (i.e., the FRN and fb-P3) across the gain and loss contexts. Because the FRN and fb-P3 are highly correlated and thus possibly overlap, we performed partial correlational analyses to control for the potential influence of the fb-P3 on the FRN, and vice versa. The correlations between the cue-P3 and FRN were no longer significant after controlling for the potential modulation of the fb-P3, but the correlations

**TABLE 1** Correlations between anticipatory (the cue-P3 and SPN) and consummatory (the FRN and fb-P3) ERPs (collapsed across small and large trials)

| | Favorable FRN | | Unfavorable FRN | | Favorable fb-P3 | | Unfavorable fb-P3 | |
|---|---|---|---|---|---|---|---|---|
| | Original | Adjusted | Original | Adjusted | Original | Adjusted | Original | Adjusted |
| **Gain context** | | | | | | | | |
| Cue-P3 | .34* | −.05 | .03 | −.12 | .64** | .57** | .66** | .67** |
| SPN | −.60** | −.53** | −.44** | −.41* | −.34* | −.10 | −.24 | −.18 |
| **Loss context** | | | | | | | | |
| Cue-P3 | .14 | −.21 | .25 | .12 | .56** | .57** | .59** | .56** |
| SPN | −.65** | −.57** | −.55** | −.52** | −.38* | −.06 | −.23 | −.11 |

*Note*. Adjusted value is the partial correlation between an anticipatory ERP component and one consummatory ERP component (e.g., favorable FRN) while controlling for the other consummatory ERP component (e.g., favorable fb-P3). The negative correlation coefficients between a negative component (i.e., the FRN or SPN) and a positive component (i.e., the cue-P3 or fb-P3) always indicate a direct association (larger ERP response) and vice versa.
[a]*$p < .05$. **$p < .01$.

between the cue-P3 and fb-P3 were still significant after controlling for the potential modulation of the FRN (Figure 7). In contrast, the correlations between the SPN and the FRN after controlling for the potential modulation of the fb-P3 were still significant (Figure 7), but the correlations between the SPN and fb-P3 were no longer significant after controlling for the potential modulation of the FRN. In short, the correlational analyses suggested that the cue-P3 was

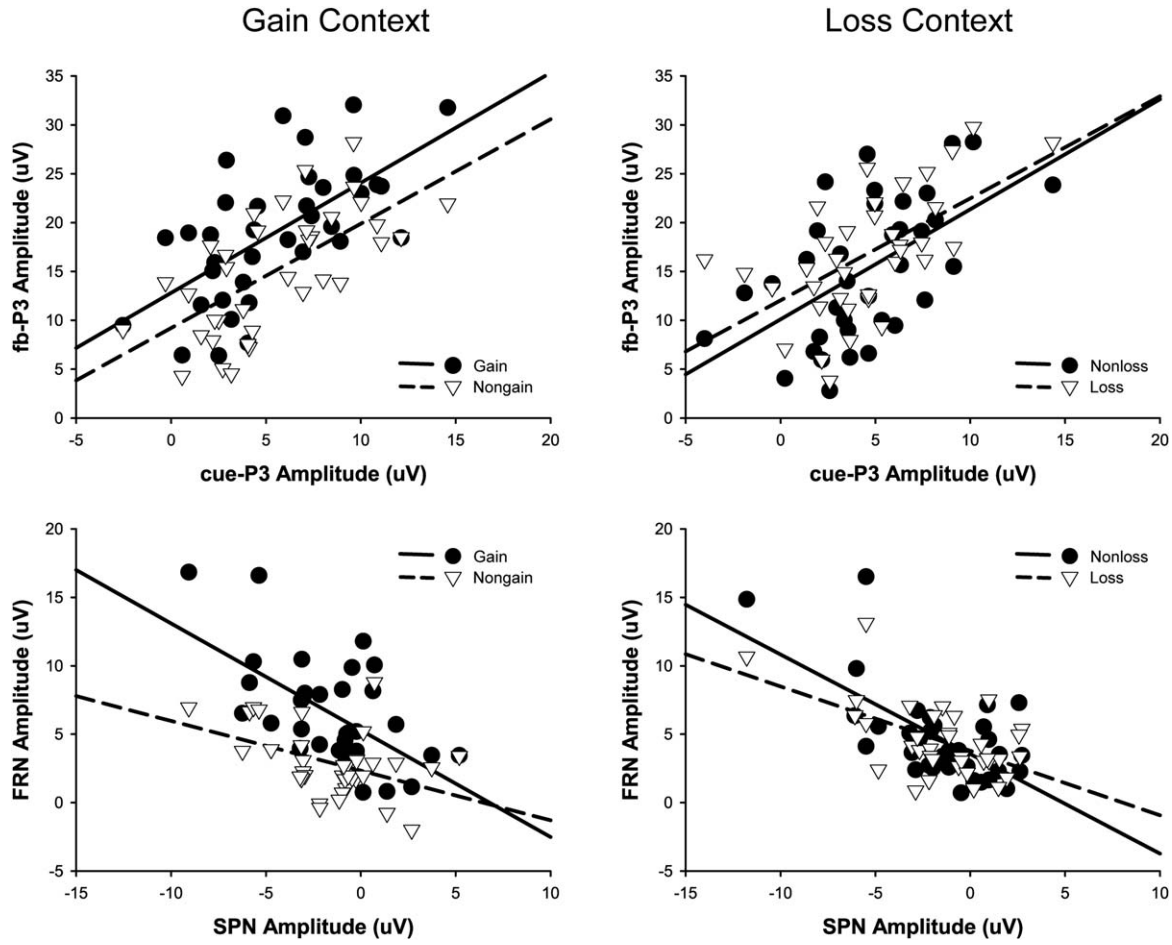


**FIGURE 7** Scatter plots of the correlations between the cue-P3 and fb-P3 (top) and the SPN and FRN (bottom) in the gain and loss contexts, which were collapsed across small and large trials

selectively correlated with the fb-P3, whereas the SPN was selectively correlated with the FRN.[1]

## 4 | DISCUSSION

In the present study, we investigated the contextual valence effect on both the anticipatory and consummatory phases by making participants perform the same gambling task during a gain context in which they tried to maximize their winnings and during a loss context in which they tried to minimize their losses. Two main findings were obtained. First, contextual valence affected the early stages (as indexed by the cue-P3 and FRN), but not the late stages (as indexed by the SPN and fb-P3), of the anticipatory phase and the consummatory phase of reward processing. Second, for both the gain and loss contexts, the SPN was selectively associated with the FRN, whereas the cue-P3 was selectively correlated with the fb-P3.

During the anticipatory phase, large relative to small magnitude choices increased the cue-P3 across the gain and loss contexts. Similarly, the SPN was enhanced for large versus small magnitude choices, which is in line with previous studies (Mattox, Valle-Inclan, & Hackley, 2006; Poli, Sarlo, Bortoletto, Buodo, & Palomba, 2007; Zheng et al., 2015; Zheng & Liu, 2015; but see Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006). The magnitude effects observed for both the cue-P3 and SPN suggest a common component of motivational salience across the cue-evaluation stage and the feedback-anticipation stage. Interestingly, only the cue-P3 rather than the SPN was modulated by contextual valence. Specifically, the cue-P3 was enhanced in the gain context compared to the loss context, whereas the SPN was comparable across the two contexts, suggesting a dissociation between the cue-evaluation stage and the feedback-anticipation stage. The enhanced cue-P3 in the gain versus loss context is in line with previous research (Pfabigan et al., 2014; Santesso et al., 2012) and possibly reflects the asymmetry of perceived task relevance in the gain and loss contexts. While these results clearly indicate that mechanisms underlying the cue-P3 are involved in encoding contextual valence, the SPN was comparable in the gain and loss contexts. The presence of magnitude effect and the absence of the contextual valence effect on the SPN point to a general motivational mechanism responsible for salient stimuli during feedback anticipation.

With respect to the consummatory phase, we compared the FRN and fb-P3 in response to zero-value outcomes with identical visual characteristics and similar outcome frequencies, which were uncontrolled in most previous studies. Similar to the anticipatory processing, contextual valence affected the early stage (as indexed by the FRN), but not the late stage (as indexed by the fb-P3), of the consummatory processing. The FRN in response to the zero-value outcome was larger in the gain context than in the loss context, reflecting the context dependence of the FRN (Holroyd et al., 2004). In contrast to the FRN, the fb-P3 was enhanced for large compared to small magnitude outcomes but was comparable across the gain and loss contexts, indicating that motivational salience, rather than contextual valence, is encoded during the late stage of outcome processing (Pfabigan et al., 2015; Yeung & Sanfey, 2004).

Although other feedback stimuli with varying visual characteristics were not the focus of the present study, our results relate in interesting ways to previous findings. We found that the FRN amplitude was more negative for unfavorable versus favorable outcomes in the gain context but comparable across unfavorable versus favorable outcomes in the loss context. The absence of outcome valence effect in the loss context is at variance with the Holroyd et al. (2004) study. This discrepancy may be attributed to the subtle methodological differences between the two studies. In the Holroyd et al. study, participants who performed the gain context were unaware of the loss context that would be presented, and vice versa. In contrast, the participants in our study were told explicitly prior to the experiment that they would complete both the gain and loss contexts. The block design used by Holroyd et al. might reflect more of a global rather than a local context, which might be diluted by the global-instructed knowledge in our experiment. Specifically, the global-instructed knowledge might cause both the loss and nonloss outcomes to be regarded as bad outcomes and, thus, attenuate the amplitude differences between them, since the FRN reflects the binary evaluation of good versus bad outcomes (Kujawa et al., 2013). On the other hand, recent evidence highlights that the FRN is driven by a positive deflection elicited by reward feedback that is superimposed on a negative deflection elicited by punishment or nonreward feedback (Proudfit, 2015). In this regard, it is unsurprising that there were no FRN amplitude differences between loss and nonloss outcomes. Actually, we found a Valence × Magnitude interaction in the gain context, which was caused by the amplitude differences between small and large gains.

[1]Because the baseline (−200 to 0 ms) used for both FRN and fb-P3 lies at the measurement window of the SPN, any variance in SPN amplitude across conditions might influence ANOVA and correlation results for FRN and fb-P3. Although we applied high-pass filtration to reduce contamination by the SPN, it might be insufficient since the SPN offset occurs rather abruptly and would be less affected by high-pass filtration. To test the robustness of the ANOVA and correlation results, we reanalyzed the FRN and fb-P3 data using a posttrial baseline (1,000 to 1,300 ms postfeedback onset). This approach yielded comparable results for correlation and ANOVA except that the fb-P3 valence effect in the loss context disappeared (as revealed by a significant Valence × Context interaction, $F(1, 35) = 11.56$, $p = .002$, $\eta_p^2 = .25$).

As for the fb-P3, we found an outcome valence effect in the gain context (i.e., a larger fb-P3 for gain versus nongain trials). However, this outcome valence effect was reversed for large outcomes (when using the posttrial interval as baseline), or at least disappeared (when using the prestimulus interval as baseline) in the loss context. These findings appear to be caused by the magnitude differences between the favorable and unfavorable outcomes. However, this could not explain the fact that the outcome valence effect disappeared in the loss context at least for small outcomes. As the P3 is associated with motivational significance (Nieuwenhuis, Aston-Jones, & Cohen, 2005), the fb-P3 findings suggest that task relevance was enhanced in the gain versus loss context.

Taken together, our findings provide insight into the unresolved issue whether reward and punishment are encoded in an integrated way or in a dissociated way. For example, it is still controversial whether or not the FRN sensitivity to reward prediction error is modulated by valence (Alexander & Brown, 2011; Holroyd & Coles, 2002). Moreover, whether the reward prediction system, as indexed by the cue-P3 and SPN, is sensitive to valence is largely untouched. In the present study, we found that reward and punishment were processed in a dissociated way not only in the consummatory phase as indexed by the FRN but also in the anticipatory phase as indexed by the cue-P3. In this regard, our findings are consistent with abundant evidence pointing to a functional dissociation in brain areas for processing positive and negative reward information (X. Liu et al., 2007). For example, previous fMRI research has demonstrated that medial brain areas (e.g., medial orbitofrontal cortex and striatum) are more sensitive to gains whereas lateral brain areas (e.g., lateral orbitofrontal cortex and anterior insula) are more sensitive to losses (O'Doherty, Critchley, Deichmann, & Dolan, 2003; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). Importantly, our findings go beyond these fMRI studies to demonstrate that this dissociation occurs very early during different phases of incentive processing. Furthermore, for both the anticipatory and consummatory phases, our findings suggest that, once contextual valence has been processed during the early stages (the cue-P3 and FRN), it seemed no longer to be touched by the neural system during the late stages (the SPN and fb-P3).

The second finding has to do with the significant correlations between the anticipatory and consummatory ERPs in both the gain and loss contexts. Specifically, whereas the cue-P3 was selectively correlated with the fb-P3, the SPN was selectively associated with the FRN. These correlational findings provide valuable constraints toward the functional significances of reward-related ERP components. First, our finding of the SPN sensitivity to magnitude but not contextual valence raised the issue that SPN amplitude possibly varies with reward value simply because participants pay more attention to choices of larger monetary gambles, but not to reward per se. However, it may be impossible because the SPN was selectively associated with the FRN rather than the fb-P3. It is well known that the FRN encodes reward prediction error (Holroyd & Coles, 2002), whereas the fb-P3 is largely determined by attentional resources based on motivational significance (Nieuwenhuis et al., 2005). Therefore, the correlation between the SPN and the FRN indicates that the SPN constitutes a complementary component of reward prediction error system as indexed by the FRN, that is, the reward prediction system (Brunia et al., 2011). This explanation is in line with recent evidence that both the SPN and FRN are modulated by the dopaminergic system (Foti & Hajcak, 2012; Mattox et al., 2006) as well as by reinforcement learning (Moris, Luque, & Rodriguez-Fornells, 2013). On the other hand, there was no relationship between the SPN and the fb-P3, indicating that it is unlikely that the SPN reflects the attentional allocation as the fb-P3 does.

The relationship between the cue-P3 and the fb-P3 is also interesting. In the present study, we found that contextual valence modulated the P3 elicited in the anticipatory phase (i.e., the cue-P3) but not the P3 elicited in the consummatory phase (i.e., the fb-P3), suggesting that these two P3 components may reflect different facets of reward processing (Novak & Foti, 2015). However, we also obtained a significant correlation between the cue-P3 and fb-P3, indicating a common element between these two components. The correlational finding is inconsistent with a recent study reporting that the cue-P3 was not correlated with the fb-P3 (Novak & Foti, 2015). This discrepancy may reflect methodological differences between the current study and the previous one. First, the visual characteristics of the cue and feedback stimuli were totally different in their study but were more comparable in the present study. Second, as the authors indicated, the time window of the cue-P3 overlapped with the offset of the cue stimulus and thus might result in additional processing, whereas this was not the case for the present study. Taken together, the relationship between the cue-P3 and the fb-P3 seems to be complex, and future studies are needed to clarify this issue.

One limitation of this study is the manipulation of contextual valence on the SPN. As in previous research, the contextual valence in the current experiment was manipulated by varying the sign of the expected value in each context. Specifically, options in the gain context yielded either gain or nongain outcomes, whereas options in the loss context yielded either nonloss or loss outcomes. The probability of each outcome was 50%. Therefore, the expected values of options were positive in the gain context (+4.5 for the option 9 and +49.5 for the option 99), but negative in the loss context (−4.5 for the option 9 and −49.5 for the option

99). Although participants seemed to hold positive anticipation in the gain context, their anticipation might also be more positive in the loss context. Presumably, participants would choose the "correct" door and believed that they would be more likely to obtain a favorable outcome (a gain outcome in the gain context or a nonloss outcome in the loss context; Hajcak, Moser, Holroyd, & Simons, 2007). One way to address the valence effect on the SPN is to collect the participants' predictions before they anticipate the outcome of their choice.

In summary, this study demonstrates that a highly dynamic neural system of reward processing, as reflected by the anticipatory and consummatory phases, was modulated by contextual valence in the relatively early (the cue-P3 and FRN) instead of late (the SPN and fb-P3) stages in each phase. Across the two contexts, the anticipatory ERPs were related to the consummatory ERPs. These observations point to a close association between the anticipatory and consummatory phases in reward dynamics among healthy populations, and our research should be extended to clinical populations with reward deficits, such as depression, schizophrenia, as well as addiction.

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