Received: 6 March 2018 | Revised: 29 August 2018 | Accepted: 18 October 2018

DOI: 10.1111/psyp.13304

ORIGINAL ARTICLE

WILEY

# Differential modulations of reward expectation on implicit facial emotion processing: ERP evidence

**Lulu Wu**[1,2] | **Hermann J. Müller**[3] | **Xiaolin Zhou**[4,5] | **Ping Wei**[1,6]

[1]Beijing Key Laboratory of Learning and Cognition and School of Psychology, Capital Normal University, Beijing, China

[2]State Key Laboratory of Cognitive Neuroscience and Learning and IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, China

[3]General & Experimental Psychology, Department of Psychology, LMU München, Munich, Germany

[4]School of Psychological and Cognitive Sciences, Peking University, Beijing, China

[5]Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, China

[6]Beijing Advanced Innovation Center for Imaging Technology, Capital Normal University, Beijing, China

**Correspondence**
Dr. Ping Wei, School of Psychology, Capital Normal University, Beijing 100048, China.
Email: aweiping@gmail.com or
Dr. Xiaolin Zhou, xz104@pku.edu.cn

**Funding information**
National Natural Science Foundation of China (31470979), Beijing Advanced Innovation Center for Imaging Technology (BAICIT-2016018), Support Project of High-Level Teachers in Beijing Municipal Universities in the Period of 13th Five-Year Plan, German Research Foundation grant (MU773/14–1) (to H.J.M.)

**Abstract**

Implicit emotional processing refers to the preferential processing of emotional content even if it is task irrelevant. Given that motivation enhances executive control by biasing attentional resources toward target stimuli, here we investigated the effects of reward expectation on implicit facial emotional processing in two experiments using ERPs. A precue signaling additional monetary reward for fast and accurate response for the upcoming trial (incentive condition; relative to a cue indicating no such additional reward, i.e., nonincentive condition) was followed by the presentation of a happy, angry, or neutral face. Participants had to determine the gender of the face in Experiment 1 and decide whether a number superimposed on the face was even or odd in Experiment 2. In both experiments, incentive cues elicited larger P3 and contingent negative variation responses, and the targets following incentive cues elicited more positive-going ERPs (200–700 ms), compared with the nonincentive condition. Importantly, the N2 responses (200–280 ms) to the target exhibited differential patterns of Reward × Emotion interaction: relative to the nonincentive condition, the N2 amplitude differences between emotional (i.e., happy and/or angry) and neutral faces increased in the incentive condition in Experiment 1, but diminished in Experiment 2. These results indicate that reward expectation can differentially modulate implicit processing of facial expressions, with increased sensitivity to emotions when the processing of whole faces is required, but with reduced sensitivity when the processing of faces is distractive. This study enriches the evidence for interactions between reward-related executive control and implicit emotional processing.

**KEYWORDS**
emotional face, ERP, negative bias, reward expectation

## 1 | INTRODUCTION

It is well documented that human cognitive processing is affected by both motivation and emotion (see Pessoa, 2009, for a review). A growing body of literature has indicated that motivation driven via reward expectation enhances executive control by facilitating the concentration of limited attentional resources on target stimuli in emotionally neutral contexts (e.g., Baines, Ruz, Rao, Denison, & Nobre, 2011; Padmala & Pessoa, 2011). In monetary incentive delay paradigms (Knutson & Cooper, 2005; Knutson, Westdorp, Kaiser, & Hommer, 2000), reward expectation is typically signaled by a prior cue that indicates the monetary reward condition (incentive vs. nonincentive) for the upcoming trial: participants are informed that they could gain additional monetary reward for fast and accurate response in the incentive condition, whereas no reward is offered in the nonincentive condition. Findings from these studies suggest that reward expectation facilitates the allocation of attention to target stimuli and inhibits attention to distractors, leading to improved behavioral performance (see Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Krebs & Woldorff, 2017, for reviews). At the same time, owing to the biological significance of emotional content, attention is usually biased toward emotional stimuli (Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004; Smith, Weinberg, Moran, & Hajcak, 2013) in both explicit and implicit emotional processing. In the explicit condition, emotional content is task relevant, "target" information, with participants being asked to directly discriminate the emotionality of the target stimuli; in the implicit condition, emotional content is task irrelevant, with participants being asked to classify emotional stimuli along a nonemotional dimension (e.g., to discriminate the gender of emotional faces; Wronka & Walentowska, 2011) or to perform tasks with emotional stimuli as distractors (e.g., Pessoa, Padmala, & Morland, 2005). Studies have demonstrated prioritized processing of emotional content irrespective of task relevance (Frühholz, Jellinghaus, & Herrmann, 2011; Rellecke, Sommer, & Schacht, 2012).

As background to the aforementioned effects of reward expectation and emotional processing on attention and executive control, recently several studies have attempted to directly examine the relationship between reward expectation and explicit and/or implicit emotional processing (Kaltwasser, Ries, Sommer, Knight, & Willems, 2013; Padmala & Pessoa, 2014; Padmala, Sirbu, & Pessoa, 2017; Wei & Kang, 2014; Wei, Wang, & Ji, 2016). When participants were instructed to discriminate the emotional valence of emotional stimuli (i.e., explicit emotional processing) following incentive or nonincentive cues, behavioral and electrophysiological evidence revealed that reward expectation in the incentive (vs. the nonincentive) condition amplifies emotional effects—that is, the preferential processing of negative and positive emotional stimuli versus neutral stimuli (Kang, Zhou, & Wei, 2015; Wei & Kang, 2014; Wei et al., 2016; Wei, Kang, Ding, & Guo, 2014).

While this suggests that reward incentives modulate emotional processing in such tasks, other studies examining whether and how reward expectation modulates implicit (task-irrelevant) emotional processing have produced inconsistent and inconclusive findings. For example, Kaltwasser and colleagues (2013) asked participants to judge the concreteness of emotionally positive, negative, or neutral target words that were presented after an incentive or a nonincentive cue. They found that the emotion-related and reward-related effects were independent from each other. In contrast, using a similar design but asking participants to judge the color of negative and neutral words, Wei et al. (2016, experiment 2) observed reduced differential amplitudes between negative and neutral words in the P3a time window (300–380 ms poststimulus onset) in the incentive, as compared to the nonincentive, condition, thus demonstrating an interactive effect between incentive motivation and implicit emotional processing. In a recent neuroimaging study, Padmala et al. (2017) instructed participants to identify the orientation of peripheral bars while ignoring a centrally presented negative or neutral picture. They observed significant interactions in the anterior insula and dorsal anterior cingulate cortex: compared with the nonincentive condition, reward expectation in the incentive condition reduced the brain responses to negative (vs. neutral) distractors.

Of note, although the valence of the emotional stimuli was task irrelevant in all the studies mentioned above, the emotional stimuli were targets in some of these but distractors in others. We surmise that this discrepancy in task set may be responsible for the lack of a reliable conclusion regarding the interaction between reward expectation and implicit emotional processing. Moreover, compared with emotional words and pictures that were used in the aforementioned studies, facial emotions are believed to be evolutionarily more important to everyday interactions. It is widely acknowledged that facial emotions can be processed outside awareness and trigger preattentive capture of attention (Frühholz et al., 2011; Rellecke et al., 2012). Given this, it would be of particular interest to investigate the neurocognitive mechanisms underlying the modulatory role of reward expectation with regard to the processing of task-irrelevant facial emotions.

To examine these questions using maximally comparable designs and stimuli, in the current study we presented participants with the same set of face stimuli with happy, angry, or neutral expressions following incentive or nonincentive cues (adopted from Wei & Kang, 2014), and asked them to either judge the gender of the presented face (Experiment 1) or the even-/oddness of an Arabic numeral superimposed on the center of the face (Experiment 2). In Experiment 1, with faces as the to-be-processed targets, identifying the gender of the presented face may require participants to extract global structural information and specific details of the face to accomplish the task. Previous electrophysiological studies have shown that the processing of facial emotions in the gender discrimination task is associated with essentially a similar (albeit attenuated) pattern of brain responses to that seen in the explicit facial emotion categorization task (Rellecke et al., 2012; Wronka & Walentowska, 2011), with higher amplitudes for emotional relative to neutral expressions from around 100 ms poststimulus onest. By contrast, identifying a numeral superimposed on a face as even or odd, as required in Experiment 2, does not necessitate processing of the emotional face; accordingly, the face serves as an irrelevant background distractor in this task. Given that the incentive motivation finetunes executive control so as to prioritize the processing of targets and inhibit that of distractors (for reviews, see Botvinick & Braver, 2015; Chelazzi et al., 2013; Krebs & Woldorff, 2017), we expected increased attention to the facial emotional information in the incentive (vs. the nonincentive) condition in Experiment 1, but reduced attention to the exact same information in Experiment 2.

Importantly, we adopted the ERP technique, which offers excellent temporal resolution and provides a suitable tool for investigating the neural dynamics of the interactions between reward expectation and implicit emotional processing. For the period of cue presentation, previous studies (Schevernels, Krebs, Santens, Woldorff, & Boehler, 2014; van den Berg, Krebs, Lorist, & Woldorff, 2014) revealed that, compared with nonincentive cues, incentive cues elicited larger P3 (300–600 ms; frontoparietal) amplitudes, reflecting more elaborative processing of the incentive information. Moreover, the contingent negative variation (CNV; 800–1,600 ms; frontoparietal) was found to exhibit enhanced negativity for incentive (vs. nonincentive) cues, indicating superior preparation for the processing of the subsequent target (Schevernels et al., 2014; van den Berg et al., 2014). Thus, in accordance with these studies, we expected that, relative to the nonincentive cues, the incentive cues would elicit increased P3 and CNV amplitudes.

For facial targets, the anterior N2 component (or N300) was of particular interest. The N2 (200–300 ms; frontoparietal) is known to be generated in anterior cingulate cortex (ACC), reflecting conflict detection (van Veen & Carter, 2002), reward-related executive control (Kang, Chang, Wang, Wei, & Zhou, 2018; Pessoa, 2009; Zhan et al., 2016), and nonconscious executive control in emotional processing (Carretié et al., 2004; Zhang & Lu, 2012). Previous studies have observed modulations of reward-related executive control on emotional processing in the N2 time range or in ACC. For example, in Wei et al. (2014) in which participants were asked to explicitly discriminate the emotionality of facial targets, reward expectation was found to enhance sensitivity to emotional faces in terms of the N2 component, with increased N2 amplitude differences between emotional and neutral faces in the incentive (vs. the nonincentive) condition. The recent fMRI study of Padmala et al. (2017) demonstrated that the potential reward reduces the aversive impact of negative distractors in dorsal ACC, with a diminished activation difference between negative and neutral pictures in the incentive (vs. the nonincentive) condition. Motivation has been proposed to optimize the allocation of attentional resources available to executive control by engaging ACC (Pessoa, 2009). On these grounds, for the current ERP study, we hypothesized that the N2 would reveal differential modulations of reward-related executive control on processing the task-irrelevant emotional facial expressions between Experiments 1 and 2: specifically, we expected the N2 amplitude difference between emotional and neutral faces to be increased by reward expectation when the emotional faces were target stimuli in Experiment 1, whereas the N2 amplitude difference was expected to be reduced when the emotional faces were distractor stimuli in Experiment 2.

Albeit of secondary interest, we also examined a number of other typical ERP components related to the processing of faces to examine whether these components would reveal persistent effects of implicit emotional processing, reward processing, and/or a Reward × Emotion interaction. Both the N170 (130–200 ms; temporo-occipital) and the vertex positive potential (VPP; 130–200 ms; frontoparietal) have been linked to precategorical structural encoding of faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Joyce & Rossion, 2005; Rossion & Jacques, 2012). However, there is evidence that, while the N170 is insensitive to implicit emotional processing (Eimer & Holmes, 2002; Eimer, Holmes, & McGlone, 2003; but see Williams, Palmer, Liddell, Song, & Gordon, 2006; see Eimer & Holmes, 2007; Rellecke, Sommer, & Schacht, 2013, for reviews), the VPP exhibits an enhanced positivity for emotional (vs. neutral) faces during implicit emotional tasks, indicative of the rapid extraction of emotional information (Williams et al., 2006; Smith et al., 2013; see Eimer & Holmes, 2007, for a review). Moreover, facial targets following incentive (vs. nonincentive) cues elicited more positive-going N170 and VPP amplitudes, reflecting facilitated early structural encoding of facial targets driven by reward (Marini, Marzi, & Viggiano, 2011; Wei et al., 2014).

Moreover, the early posterior negativity (EPN; 240–340 ms; temporo-occipital) is known to reflect enhanced sensory encoding of emotional faces (Schacht & Sommer, 2009a; Schupp et al., 2004). There is no consensus, though, as to whether the EPN reflects automatic attentional orientation toward emotional stimuli (Kissler, Herbert, Winkler, & Junghöfer, 2009; Schacht & Sommer, 2009b) or whether it is sensitive to emotional content only when sufficient attention is allocated to the stimuli (Bayer, Sommer, & Schacht, 2012; Frühholz et al., 2011). In our recent study (Wei et al., 2016, experiment 1), the EPN exhibited a larger difference between negative and neutral words in the incentive (vs. the nonincentive) condition in an explicit emotional (word) categorization task, demonstrating an interaction between reward expectation and emotion at an early processing stage. However, to our knowledge, there are no studies in the literature that reported a modulatory effect of reward on the EPN in implicit emotional tasks.

Furthermore, the late positive complex potential (LPC; 400–700 ms; frontoparietal) is known to reflect elaborative categorization of emotional stimuli (Calvo & Beltrán, 2013; Rellecke et al., 2012), which is sensitive to voluntary attentional modulation. Prior studies proposed that the LPC differentiates emotional expressions from neutral ones in terms of an enlarged positivity (Frühholz et al., 2011; Smith et al., 2013). It is interesting to examine whether reward expectation interacts with this differential effect in an implicit task.

In summary, the present study was predicated on the assumption that task set determines how deeply emotional content is processed (Frühholz et al., 2011; Rellecke et al., 2012; Wei et al., 2016; see Eimer & Holmes, 2007, for a review). Accordingly, we expected that emotional (vs. neutral) facial expressions would engender stronger brain responses, in a large number of the aforementioned ERP components, when the faces were targets (as in Experiment 1), rather than distractors (as in Experiment 2), even though the emotionality of the faces was irrelevant in both cases. Moreover, considering the effects of incentive motivation on executive control, reward expectation would facilitate the biasing of attention toward the target stimuli in two experiments (i.e., the faces in Experiment 1 and the numbers in Experiment 2). Accordingly, we expected that the face-specific components (e.g., N170 and VPP) would reveal stronger responses in incentive (vs. nonincentive) conditions in Experiment 1, but not in Experiment 2. Furthermore, previous studies showed that target stimuli in the incentive (vs. the nonincentive) condition elicited more positive-going N2, EPN, and LPC amplitudes, indicating enhanced allocation of attention to rewarded stimuli (Potts, 2011; Schevernels et al., 2014; van den Berg et al., 2014; Wei et al., 2016). We hence expected that incentive (vs. nonincentive) trials would elicit more positive-going ERP responses for the N2, EPN, and LPC components in both experiments, whereas the differential extent of reward modulation on these components between the two experiments was also of interest to examine.

## 2 | METHOD

### 2.1 | Participants

Two groups of 24 undergraduate and graduate students participated in Experiments 1 and 2, respectively. We discarded data from three participants in Experiment 1, and from four participants in Experiment 2, who exhibited excessive eyeblinks or muscle artifacts. The data of one additional participant in Experiment 1 were discarded owing to a technical problem with the recording of behavioral performance. In Experiment 1, the remaining participants were 11 female and 9 male, and they aged between 20 and 24 years; in Experiment 2, there were 13 female and 7 male participants, aged between 19 and 26 years. Participants in both experiments were exclusively right-handed, had normal or corrected-to-normal vision, and had no known cognitive or neurological disorder. The study was approved by the Ethics Committee of the School of Psychology at Capital Normal University, and all participants gave informed consent (in writing) prior to the experiments, in accordance with the Declaration of Helsinki.

### 2.2 | Design and materials

We used a $2 \times 3$ within-participant factorial design for both experiments. The first factor was the trial condition type of reward expectation (incentive vs. nonincentive), and the second factor was the emotional expression of the face (happy, angry, or neutral). The stimuli consisted of 90 pictures from the Chinese Facial Affective Picture System, whose valence and arousal levels had been rated on a 9-point Likert scale (Wang & Luo, 2005). There were 30 happy faces, 30 angry faces, and 30 neutral faces, with 15 male and 15 female faces in each category. Specifically, happy and angry stimuli were matched according to arousal level [mean ($M$) ± standard deviation ($SD$): happy = $6.2 \pm 0.75$; angry = $6.0 \pm 1.10$], and the three categories of facial pictures differed significantly from one another in their normative valence rating (happy = $6.6 \pm 0.47$; angry = $2.9 \pm 0.39$; neutral = $4.6 \pm 0.21$, $p < 0.001$). On the display screen, each picture occupied a visual angle of 4.93° (horizontally) × 5.99° (vertically), viewed at a distance of 65 cm.

### 2.3 | Procedure

Our experimental procedures were adopted from Wei and Kang (2014). Presentation of the stimuli and recording of reaction times (RTs) and error rates was controlled using Presentation software (https://nbs.neurobs.com/). Participants were seated in a dimly lit and sound-attenuated room. At the start of each trial (Figure 1), a white fixation cross (size: 0.4° × 0.4° of visual angle) appeared at the center of a black screen for 500 ms, followed by a visual cue (size: 2.3° × 2.3°) displayed for 1,000 ms. For half the participants, an asterisk symbol (*) indicated an incentive condition and a hash symbol (#) a nonincentive condition, and vice versa for the other half. The incentive cue indicated the chance of obtaining additional monetary reward if the response was both correct and faster than the baseline reaction time, which was acquired in the practice session (for details, see the description of the practice session below); the nonincentive cue indicated no additional monetary reward. After a variable cue-target interval (CTI) of 600–1,000 ms, the target stimulus (size: 4.93° × 5.99°) was presented at the center of the screen for 300 ms. The purpose of using variable CTIs was to prevent participants from forming time-based expectations about target onset.

In Experiment 1, participants were instructed to judge the gender of the face as quickly and accurately as possible by pressing the left button of the computer mouse for a male face and the right button for a female face. In Experiment 2, an Arabic numeral (randomly selected from between 1 and 9; size: 0.6° × 0.7°) was superimposed over the nose of the face. Participants were instructed to respond to the numeral as quickly and accurately as possible by pressing the left

**FIGURE 1** Example of the trial sequence in Experiments 1 and 2. Participants were asked to classify the gender of the face in Experiment 1 and to determine whether a number superimposed on the face was even or odd in Experiment 2

button of the computer mouse for an odd number and the right button for an even number. Note that the assignment of the response buttons was counterbalanced across participants in each experiment. Upon termination of the target stimulus, the fixation cross reappeared for 1,400–1,800 ms, followed by the presentation of response feedback for 500 ms. In the nonincentive condition, a filled gray circle indicated a correct response and an empty gray circle an incorrect response. In the incentive condition, participants were presented with a picture of a 1 Chinese yuan coin following responses that were correct and faster than the baseline RT, a filled gray circle following responses that were correct but slower than the baseline RT, and an empty gray circle for incorrect responses. Finally, the fixation cross was again presented for the length of the intertrial interval (1,100–1,600 ms). Each experiment consisted of six types of experimental trials (i.e., nonincentive happy, nonincentive angry, nonincentive neutral, incentive happy, incentive angry, incentive neutral), which were presented in a pseudorandomized order within each block, with the restriction that no more than three trials from the same condition were presented consecutively. Each block consisted of 36 trials (with each condition having six trials). In total, each experiment consisted of 10 blocks, with each experimental condition having 60 trials.

Participants underwent 24 practice trials before each experiment. During practice, participants were informed that the cue signs as such were irrelevant and so should be ignored (this applied only to the practice trials); they should just respond as quickly and accurately as possible to the respective target stimulus. Participants received only “correct response” and “incorrect response” feedback (i.e., no coin feedback) while practicing the task: filled and empty gray circles indicating correct and incorrect responses, respectively. The average (correct) RT achieved by each participant during the practice phase was then introduced as that participant’s baseline RT in the main experiment.

After the practice session, participants were informed of the meaning of the cue signs and of the coin feedback introduced in the experiment proper. Participants were asked to attend to the cue signs and respond as quickly and accurately as possible to the target stimuli. Participants were paid 55 Chinese yuan for completion of the experiment, with an extra payment of 15 Chinese yuan dependent on their task performance in the incentive trials. Specifically, participants were told that they could gain the extra reward of 15 Chinese yuan if they managed to earn the coin feedback on more than 75% of the total number of incentive trials.

## 2.4 | ERP recordings and analyses

ERP recordings were obtained from 62 scalp sites using Ag/AgCI electrodes embedded in an elastic cap at locations from the extended International 10–20 system (NeuroScan; Compumedics, EI Paso, TX). These electrodes were referenced to the right mastoid during recording and rereferenced to the average of the right and left mastoid potentials offline. Two additional channels were used for recording the horizontal and vertical electrooculogram (EOG). Impedance was reduced below 5 KΩ, and EEG signals were filtered with a band-pass of 0.05–40 Hz and sampled at a rate of 500 Hz. The averaging epochs for cue processing and target processing were 1,600 ms and 1,000 ms, respectively, with an additional 100 ms recorded prior to stimulus onset. Error trials were excluded from the analyses. Also, trials with a voltage, relative to the 100-ms baseline, exceeding ±75 μV at any electrode were excluded from the analysis, as were trials with artifacts in the EOG channels.

We averaged the remaining trials for each condition (i.e., the nonincentive happy, nonincentive angry, nonincentive neutral, incentive happy, incentive angry, and incentive neutral conditions, respectively, with at least 50 valid trials for each participant). Based on the visual inspection of the effects and findings of previous ERP studies on reward and emotional processing (Kaltwasser et al., 2013; Luo, Feng, He, Wang, & Luo, 2010; van den Berg et al., 2014; Williams

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to be faster to happy faces ($M = 474$ ms) than to neutral faces ($M = 485$ ms; $p = 0.005$); RTs to angry faces were intermediate but did not differ significantly from the other two conditions ($M = 481$ ms). The interaction was not significant, $F(2, 38) < 1$.

Experiment 2 revealed only a main effect for reward, $F(1, 19) = 57.84$, $p < 0.001$, $\eta^2_p = 0.75$, with faster RTs in the incentive condition (538 ms) than in the nonincentive condition (604 ms). There were no significant effects involving target emotional content (interaction Reward × Emotion, $Fs(2, 38) < 1$).

The same ANOVAs were used to analyze error rates in both experiments. Experiment 1 revealed a main effect for emotionality, $F(2, 38) = 11.38$, $p < 0.001$, $\eta^2_p = 0.38$. Bonferroni-corrected pairwise comparisons showed that participants made fewer errors in the happy face condition (4.0%) than in the angry face (6.5%; $p = 0.007$) and neutral face conditions (7.5%; $p = 0.001$). No other effects or interactions reached significance. The results of Experiment 2 revealed no significant effects or interactions.

We performed cross-experiment ANOVAs on the behavioral data, with experiment as a between-participants factor. For RTs, the results revealed a main effect of experiment, $F(1, 38) = 23.56$, $p < 0.001$, $\eta^2_p = 0.38$, with overall faster RTs in Experiment 1 than in Experiment 2 (480 vs. 571 ms), and a main effect of reward, $F(1, 38) = 97.61$, $p < 0.001$, $\eta^2_p = 0.72$, with overall faster RTs in the incentive condition than in the nonincentive condition (501 vs. 550 ms). Moreover, reward significantly interacted with experiment, $F(1, 38) = 11.31$, $p = 0.002$, $\eta^2_p = 0.23$, with a larger difference in RTs between the incentive and nonincentive conditions in Experiment 2 than in Experiment 1 (66 vs. 32 ms). No other effects or interactions reached significance.

For the error rates, the cross-experiment ANOVA yielded a main effect of experiment, $F(1, 38) = 6.44$, $p = 0.015$, $\eta^2_p = 0.15$, with fewer errors in Experiment 2 than in Experiment 1 (3.8% vs. 6.0%) and a main effect of emotionality, $F(2, 76) = 7.30$, $p = 0.001$, $\eta^2_p = 0.16$. Bonferroni-corrected pairwise comparisons revealed error rates to be fewer with happy faces (3.9%) than with both angry faces (5.1%; $p = 0.032$) and neutral faces

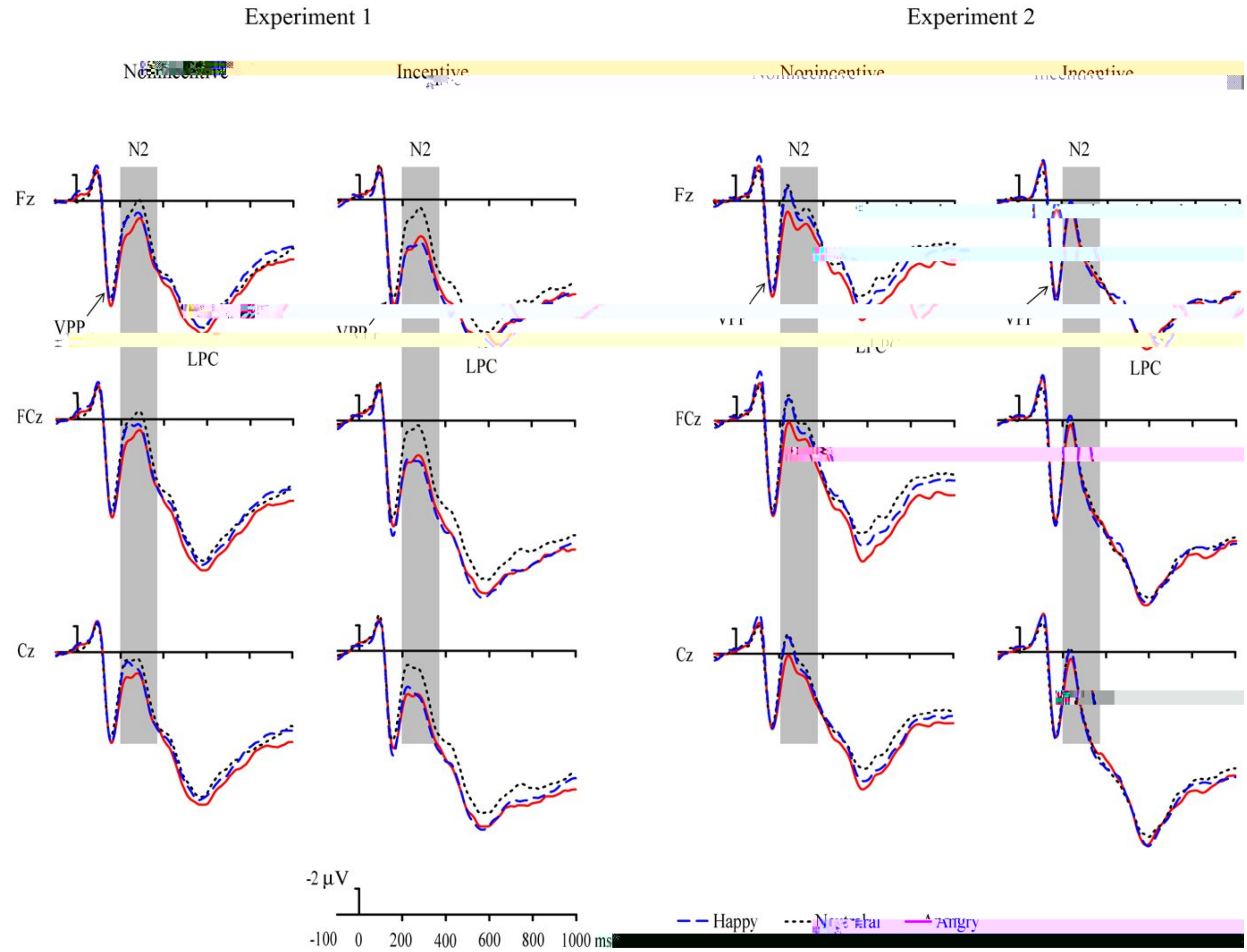


**FIGURE 3** Grand-averaged waveforms at representative electrodes showing the VPP, N2, and LPC potentials produced in response to the presentation of the target stimulus in Experiments 1 and 2. Critically, the N2 responses (200–280 ms) exhibited differential patterns of Reward × Emotion interaction between the two experiments. Positive voltage is plotted downward. For all waveforms, neutral conditions are plotted in dotted lines, happy conditions in dashed lines, and angry conditions in solid lines

more positive-going ERP responses compared to the neutral faces (VPP: 6.36 vs. 5.48 μV, $p = 0.008$, and 6.28 vs. 5.48 μV, $p = 0.001$; N2: 2.98 vs. 1.93 μV, $p = 0.001$, and 3.54 vs. 1.93 μV, $p < 0.001$; and LPC: 10.02 vs. 9.38 μV, $p = 0.049$, and 10.29 vs. 9.38 μV, $p = 0.001$).

We performed separate ANOVAs for the N2 components for the incentive and nonincentive conditions because the Reward × Emotion interaction was significant, $F(2, 38) = 8.96$, $p = 0.001$, $\eta^2_p = 0.32$. Results revealed significant main effects of emotionality in the nonincentive condition, $F(2, 38) = 9.24$, $p = 0.001$, $\eta^2_p = 0.33$, with a more positive-going N2 for angry faces (2.97 μV) than for happy and neutral faces (2.08 μV, 1.73 μV; $p = 0.008$, $p = 0.002$, respectively). The main effects of emotionality were also significant in the incentive condition, $F(2, 38) = 36.76$, $p < 0.001$, $\eta^2_p = 0.70$, and exhibited a pattern different from the nonincentive condition, with more positive-going N2 for angry (4.11 μV) and happy faces (3.89 μV) than for neutral faces (2.13 μV; *p*s <0.001). Bonferroni-corrected pairwise comparisons showed that the amplitude difference between ERPs for angry faces and neutral faces in the incentive condition (1.98 μV) appeared to be greater than the difference in the nonincentive condition (1.24 μV), $t(19) = 2.06$, $p = 0.053$; the amplitude difference between ERPs for happy faces and neutral faces in the incentive condition (1.76 μV) were also greater than the differences in the nonincentive condition (0.35 μV), $t(19) = 4.78$, $p < 0.001$.

### 3.2.2 | Experiment 2

The lower panel of Figure 2 depicts ERP responses time-locked to cue onset from the selected exemplar electrode in Experiment 2. Consistent with the results in Experiment 1, the incentive cues elicited larger P3 responses (3.72 vs. 2.38 μV), $F(1, 19) = 12.83$, $p = 0.002$, $\eta^2_p = 0.40$, and larger CNV (−1.81 vs. −0.79 μV), $F(1, 19) = 7.02$, $p = 0.016$, $\eta^2_p = 0.27$, relative to the nonincentive cues.

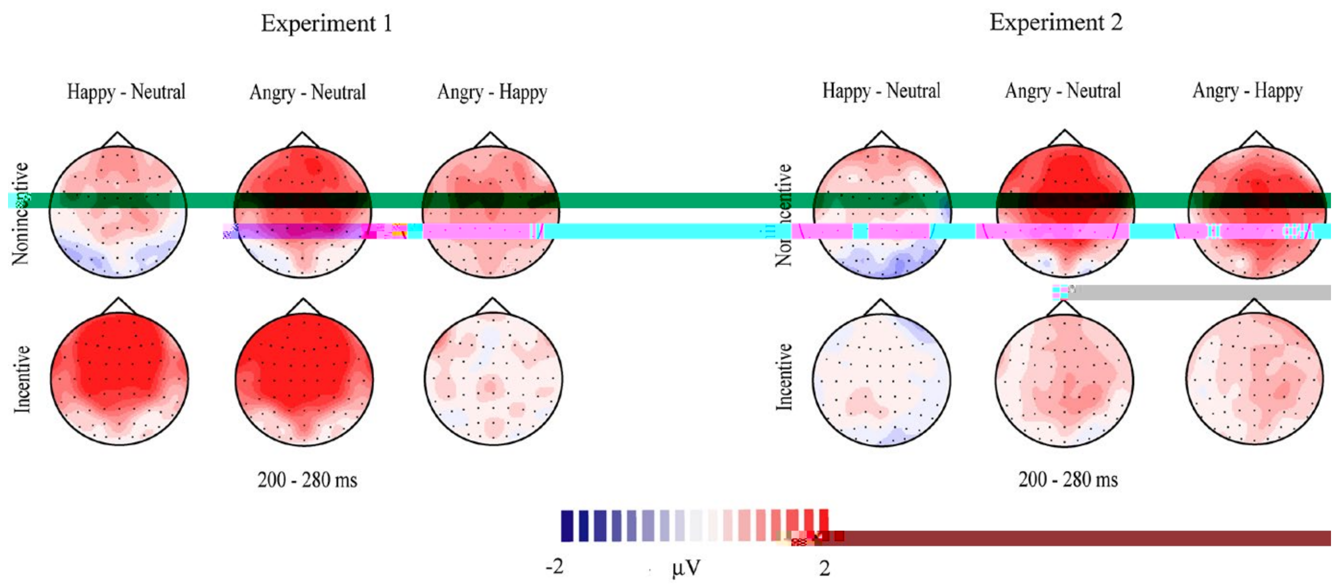


**FIGURE 4** The topographies of the N2 potential in Experiments 1 and 2. Relative to the nonincentive condition, the N2 amplitude differences between emotional (i.e., happy and/or angry) and neutral faces increased in the incentive condition in Experiment 1, but diminished in Experiment 2

Figure 3 (right) depicts ERP responses time-locked to target onset for frontocentral electrodes showing VPP and N2 components, and Figure 4 (right) depicts the topography of the N2 potential. Figure 5 (lower) depicts ERP responses time-locked to target onset for selected exemplar electrodes showing N170 and EPN components. Compared to nonincentive trials, incentive trials elicited more positive-going ERP responses for the N2, EPN, and LPC components. Moreover, angry faces elicited more positive-going N2 responses compared to happy and neutral faces. Furthermore, for the N2 component, the differences between the ERP responses for angry faces and neutral faces in the incentive condition were smaller than the differences in the nonincentive condition. The significant results of the ANOVAs on the mean amplitudes of the N170, VPP, N2, EPN, and LPC components in Experiment 2 are reported in Table 2 (lower).

For the N2 main effect of emotionality, further Bonferroni-corrected pairwise comparisons showed that angry faces elicited more positive-going ERP responses compared to the happy and neutral faces (3.02 vs. 1.88 μV, $p = 0.001$, and 3.02 vs. 2.04 μV, $p < 0.001$). Because the N2 component exhibited a significant interaction between reward and emotionality, $F(2, 38) = 4.53$, $p = 0.017$, $\eta^2_p = 0.19$, we performed further, simple effects analyses to explore this interaction. These tests showed that the main effect of emotionality was significant in the nonincentive condition, $F(2, 38) = 20.21$, $p < 0.001$, $\eta^2_p = 0.52$, with a more positive-going N2 for angry faces (2.90 μV) than for happy and neutral faces (1.44 μV, 1.22 μV; *ps* <0.001); but this effect was not significant in the incentive condition, $F(2, 38) = 2.41$, $p > 0.1$.

### 3.2.3 | Overall analysis of Experiments 1 and 2

We performed cross-experiment ANOVAs on the cue-elicited P3 and CNV components as well. The interactions between reward and the between-participants factor experiment were not significant, $Fs(1, 38) < 1$. This indicates that participants in the two experiments were similarly motivated by the incentive cue, thus effectively ruling out the possibility that the differential patterns of Reward × Emotion interaction between the two experiments resulted from distinctive processing of the incentive cues.

For the target-elicited responses, cross-experiment ANOVAs were performed on the N170, VPP, EPN, N2, and LPC responses, respectively. For the N170, a significant Reward × Experiment interaction was observed, $F(1, 38) = 7.99$, $p = 0.007$, $\eta^2_p = 0.17$, with a larger amplitude difference between the incentive and nonincentive conditions in Experiment 1 than in Experiment 2 (0.35 vs. −0.36 μV), statistically confirming the differential patterns of reward effects between the two experiments. No other effects reached significance.

For the VPP responses, there was a significant main effect of emotionality, $F(2, 76) = 7.48$, $p = 0.001$, $\eta^2_p = 0.16$, with more positive-going amplitudes for happy (6.21 μV) and angry faces (6.18 μV) than for neutral faces (5.71 μV), $p = 0.014$ and $p = 0.001$, respectively. Importantly, reward significantly interacted with experiment, $F(1, 38) = 10.50$, $p = 0.002$, $\eta^2_p = 0.22$, with a larger amplitude difference between the incentive and nonincentive conditions in Experiment 1 than in Experiment 2 (0.71 vs. −0.18 μV),

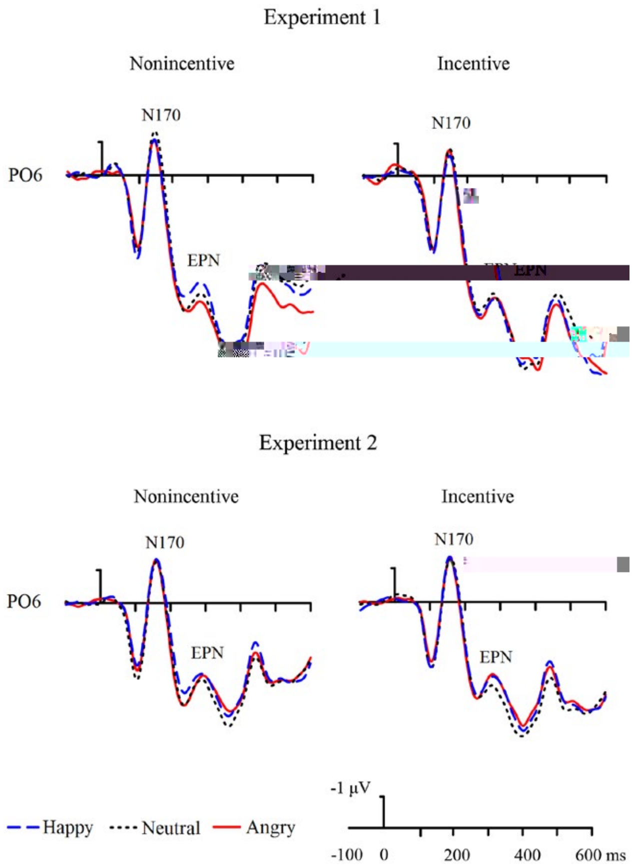


**FIGURE 5** Grand-averaged waveforms at the PO6 electrode showing the N170 and EPN components in response to the target stimuli in Experiment 1 (upper) and Experiment 2 (lower). Compared with the nonincentive trials, incentive trials elicited more positive-going N170 in Experiment 1 but not in Experiement 2, and incentive trials elicited more positive-going EPN in both experiments. Positive voltage is plotted downward

confirming the differential patterns of reward effects between the two experiments. Furthermore, emotionality significantly interacted with experiment, $F(2, 76) = 4.21$, $p = 0.018$, $\eta^2_p = 0.10$, with a larger amplitude difference between happy and neutral faces in Experiment 1 than in Experiment 2 (0.88 vs. 0.11 µV), and with a larger difference between angry and neutral faces in Experiment 1 than in Experiment 2 (0.60 vs. 0.13 µV), confirming the differential patterns of emotional effects between the two experiments. No other effects reached significance.

For the N2 responses, the cross-experimental ANOVA revealed a main effect of reward, $F(2, 38) = 19.83$, $p < 0.001$, $\eta^2_p = 0.34$, with more positive-going amplitudes for the incentive conditions than for the nonincentive conditions. Moreover, there was a significant main effect of emotionality, $F(2, 76) = 40.20$, $p < 0.001$, $\eta^2_p = 0.51$, with more positive-going amplitudes for angry faces (3.28 µV) than for happy (2.51 µV) and neutral faces (1.91 µV; *p*s <0.001), and more positive-going amplitudes for happy faces than for neutral faces ($p = 0.002$). Furthermore, emotionality significantly interacted with experiment, $F(2, 76) = 4.29$, $p = 0.017$, $\eta^2_p = 0.10$, with a greater difference in amplitudes between the happy and neutral faces in Experiment 1 than in Experiment 2 (1.1 vs. 0.2 µV). Importantly, the interaction between reward and emotionality also interacted with experiment, $F(2, 76) = 7.26$, $p = 0.001$, $\eta^2_p = 0.16$, statistically confirming the differential patterns of Reward × Emotion interaction between the two experiments.

The cross-experimental ANOVA on the EPN only revealed a main effect of reward, $F(1, 38) = 9.75$, $p = 0.003$, $\eta^2_p = 0.20$, with more positive-going amplitudes for the incentive condition than for the nonincentive condition (4.21 vs. 3.65 µV). No other effects reached significance.

Finally, for the LPC responses, the cross-experimental ANOVA revealed a main effect of reward, $F(1, 38) = 26.21$, $p < 0.001$, $\eta^2_p = 0.41$, with more positive-going amplitudes for the incentive condition than for the nonincentive condition (11.16 vs. 9.01 µV) and a main effect of emotionality, $F(2, 76) = 5.30$, $p = 0.007$, $\eta^2_p = 0.12$, with more positive-going amplitudes for angry faces (10.29 µV) than for neutral faces (9.79 µV, Bonferroni-corrected $p = 0.004$). Moreover, emotionality significantly interacted with experiment, $F(2, 76) = 3.34$, $p = 0.041$, $\eta^2_p = 0.08$, with a larger amplitude difference between happy and neutral faces in Experiment 1 than in Experiment 2 (0.63 vs. 0.13 µV) and a larger difference between angry and neutral faces in Experiment 1 than in Experiment 2 (0.90 vs. 0.09 µV), statistically confirming the differential patterns of emotional effects between the two experiments. No other effects reached significance.

## 4 | DISCUSSION

We investigated whether reward expectation modulates implicit facial emotion processing in two electrophysiological experiments, one in which the face stimuli (though not their emotional expressions) were target stimuli (Experiment 1), and one in which they were distractors (Experiment 2). For the cue period, both experiments revealed larger P3 and CNV responses to the incentive cue than to the nonincentive cue; and for the target period, both experiments revealed more positive-going ERPs and improved behavioral performance on incentive (vs. nonincentive) trials, consistent with previous studies that manipulated reward expectation (Baines et al., 2011; Padmala & Pessoa, 2011; Schevernels et al., 2014; Small et al., 2005; van den Berg et al., 2014; Wei et al., 2014; Wei et al., 2016). Importantly, the N2 component (200–280 ms posttarget onset) exhibited differential patterns between the two experiments, depending on the task set.

The N2 was the crucial component regarding reward-based modulations of the processing of emotional facial

**TABLE 2** Results of the ANOVAs of the mean amplitudes of the N170, VPP, N2, EPN, and LPC components, separately for Experiments 1 and 2

| | | | N170 (140–200 ms) | VPP (140–200 ms) | N2 (200–280 ms) | EPN (240–320 ms) | LPC (500–700 ms) |
|---|---|---|---|---|---|---|---|
| Experiment 1 | Reward | *F* | 5.47 | 8.66 | 17.59 | 7.22 | 26.82 |
| | | *p* | 0.03 | 0.008 | <0.001 | 0.015 | <0.001 |
| | | $\eta^2_p$ | 0.22 | 0.31 | 0.48 | 0.28 | 0.59 |
| | Emotion | *F* | | 11.79 | 27.76 | | 8.32 |
| | | *p* | | <0.001 | <0.001 | | 0.001 |
| | | $\eta^2_p$ | | 0.38 | 0.59 | | 0.30 |
| | Reward × Emotion | *F* | | | 8.96 | | |
| | | *p* | | | 0.001 | | |
| | | $\eta^2_p$ | | | 0.32 | | |
| | Reward × Electrode | *F* | | | 3.58 | | |
| | | *p* | | | <0.001 | | |
| | | $\eta^2_p$ | | | 0.16 | | |
| | Emotion × Electrode | *F* | | | 8.64 | | |
| | | *p* | | | <0.001 | | |
| | | $\eta^2_p$ | | | 0.31 | | |
| | Reward × Emotion × Electrode | *F* | | | 1.99 | | |
| | | *p* | | | 0.002 | | |
| | | $\eta^2_p$ | | | 0.10 | | |
| Experiment 2 | Reward | *F* | | | 6.14 | 4.38 | 29.27 |
| | | *p* | | | 0.023 | 0.05 | <0.001 |
| | | $\eta^2_p$ | | | 0.24 | 0.19 | 0.61 |
| | Emotion | *F* | | | 16.50 | | |
| | | *p* | | | <0.001 | | |
| | | $\eta^2_p$ | | | 0.47 | | |
| | Reward × Emotion | *F* | | | 4.53 | | |
| | | *p* | | | 0.017 | | |
| | | $\eta^2_p$ | | | 0.19 | | |
| | Reward × Electrode | *F* | | | | | |
| | | *p* | | | | | |
| | | $\eta^2_p$ | | | | | |
| | Emotion × Electrode | *F* | | | 2.20 | | |
| | | *p* | | | <0.001 | | |
| | | $\eta^2_p$ | | | 0.10 | | |
| | Reward × Emotion × Electrode | *F* | | | | | |
| | | *p* | | | | | |
| | | $\eta^2_p$ | | | | | |

*Note*. For all components: reward, $df = (1, 19)$; emotion and Reward × Emotion, $df = (2, 38)$. For the N170 and EPN components: Reward × Electrode, $df = (1, 19)$; Emotion × Electrode and Reward × Emotion × Electrode, $df = (2, 38)$. For the VPP, N2, and LPC components: Reward × Electrode, $df = (14, 266)$; Emotion × Electrode and Reward × Emotion × Electrode, $df = (28, 532)$.

information: reward expectation enhanced sensitivity to emotional information in Experiment 1 but reduced sensitivity in Experiment 2. In the nonincentive conditions of both experiments, N2 amplitudes were less negative-going for angry faces than for happy and neutral faces, consistent with previous reports of reduced N2 negativities for emotional versus neutral faces (Calvo & Beltrán, 2013; Williams et al., 2006; Zhang & Lu, 2012) or emotional versus neutral pictures (Carretié et al., 2004; Olofsson & Polich, 2007). Of note, the less negative N2s have been interpreted as reflecting facilitated processing of emotionally salient stimuli (Zhang & Lu, 2012; see Eimer & Holmes, 2007, for a review). In the present study, angry faces may have had the highest priority in attracting attention relative to happy and neutral faces, owing to the biological salience of threatening information—thus replicating the intrinsic negativity superiority effect (Rellecke et al., 2012). This effect manifested (in the nonincentive condition) regardless of whether the faces were targets or distractors, illustrating that angry faces may capture attention rather automatically.

Importantly, though, the negativity superiority effect was amplified in the incentive condition of Experiment 1, whereas it was diminished in Experiment 2. This pattern suggests that reward expectation enhances executive control over implicit emotional processing by biasing the allocation of limited processing capacity toward the respective target stimuli. As reviewed in the Introduction, performing a gender discrimination task on emotional faces (as in the current Experiment 1) elicits brain responses similar to performing an explicit emotional categorization task (Rellecke et al., 2012; Wronka & Walentowska, 2011). Moreover, the Reward × Emotion interaction obtained in the current gender task (Experiment 1) corresponds well with Wei et al. (2014): implementing a similar manipulation of reward expectation in an explicit facial emotional categorization task, they found enhanced N2 differences between emotional and neutral faces in the incentive (vs. the nonincentive) condition. Together, the results of the present Experiment 1 and of Wei et al. (2014) demonstrate that reward expectation enhances emotional facial processing in the gender task (in which the processing of the facial expressions is implicit, that is, not necessary for deciding on the response), as well as in the facial emotional categorization task (in which the facial expressions must be explicitly discerned to decide on the response).

In Experiment 2, by contrast, reward expectation reduced the negativity superiority effect of emotional distractors, in line with recent studies that examined the effect of reward expectation on negative distractors (Padmala & Pessoa, 2014; Padmala et al., 2017). Padmala et al. (2017) observed that, relative to the nonincentive condition, reward expectation diminished brain responses to negative distractors in the anterior insula and dorsal ACC, suggesting that reward expectation reduces attention to emotional distractors so as to ensure uncompromised target processing. Intriguingly, ACC, where the Reward × Emotion interaction was observed in Padmala et al. (2017), is thought to be the neural source of the N2 component (Carretié et al., 2004; van Veen & Carter, 2002; Zhang & Lu, 2012). Moreover, ACC receives neural input from brain structures such as the nucleus accumbens and the amygdala (which are crucial in processing reward and emotional information, respectively) and sends signals to prefrontal cortex (Padmala & Pessoa, 2011; Pessoa, 2009). In this way, in Experiment 2, incentive motivation signals may have been integrated to influence executive control processes in the prefrontal cortex, enhancing the allocation of attention to the target—the numeral (superimposed on the background face)—associated with stronger inhibition of the irrelevant emotional face.

The different task sets in the two experiments not only influenced the interaction between emotion and reward, but also the main effect of reward itself. As can be seen in Table 2 and from the cross-experiment analyses, although there were main effects of reward on the N2, EPN, and LPC components in both experiments, the N170 and VPP exhibited a reward effect in Experiment 1 but not in Experiment 2. Assuming that the N170 and VPP reflect early sensory and structural encoding of faces (Bentin et al., 1996; Joyce & Rossion, 2005; Rossion & Jacques, 2012), the distinctive patterns of reward effect may indicate that reward expectation enhanced attentional allocation toward facial targets in Experiment 1, whereas this attentional bias was no longer operative when the faces were made background objects (distractors) in Experiment 2. This again supports the notion that incentive motivation enhances executive control, biasing visual attention toward the task-relevant stimuli, especially at early processing stages.

Although we did not observe Reward × Emotion interaction in the N170, VPP, EPN, and LPC components, the emotional effects revealed in these components may augment our understanding of implicit facial emotion processing. The N170 did not reveal any emotion effects in either experiment, supporting the idea that N170 is insensitive to implicit facial emotion processing (Eimer & Holmes, 2002; Eimer et al., 2003; but see Calvo & Beltrán, 2013; Luo, Feng, He, Wang, & Luo, 2010; Williams et al., 2006; see Eimer & Holmes, 2007; Rellecke et al., 2013, for reviews). Moreover, when the faces were targets in Experiment 1, both the VPP and the LPC exhibited larger amplitudes for emotional than for neutral faces, but these two components showed no emotional modulation when the emotional stimuli were background distractors in Experiment 2. There is evidence that the VPP reflects rapid extraction of facial emotions at early stages (Smith et al., 2013; Williams et al., 2006; see Eimer & Holmes, 2007, for a review), and that the LPC reflects elaborate categorization of the emotional content at late stages of processing (Calvo & Beltrán, 2013; Rellecke et al., 2012). Thus, the present findings suggest that implicit facial emotion processing is sensitive to top-down attentional modulation at both early and late stages. Furthermore, the EPN did not reveal any emotional effects in either experiment, at variance with recent arguments that the EPN reflects automatic attentional orientation toward emotional information unaffected by the task relevance of the emotional content (Kissler et al., 2009; Schacht & Sommer, 2009b). Instead, the EPN may reflect enhanced sensory processing of emotion only when explicit attention is allocated to the emotional content (Bayer et al., 2012; Frühholz et al., 2011; Kaltwasser et al., 2013; Wei et al., 2016).

Finally, a comparison of Experiment 2 of Wei et al. (2016) and the current Experiment 1 is of interest: the emotional valence was task irrelevant and the emotional stimuli were the processing targets in both experiments, but reward expectation reduced emotional processing in the former experiment, while enhancing it in the latter. We propose that the category of the target emotional stimuli and the processing depth of the emotional stimuli may account for these inconsistent results. In Experiment 2 of Wei et al. (2016), participants were asked to judge the color of negative and neutral words following incentive or nonincentive cues. The results showed that reward expectation diminished sensitivity to the emotionality of words, with smaller P3a amplitude differences between negative and neutral words for incentive versus nonincentive trials. Emotional words represent emotionality at a semantic level, and identifying the color of the words does not require analysis of semantic meaning. In this situation, reward expectation would engender a bias of selective attention toward the task-critical target feature (i.e., the color of the word) and suppress processing of target emotionality (i.e., the emotional valence of the target words), which might be a potential source of response interference. Unlike words, emotional faces signal the emotional valence from facial structural features, and identifying facial gender requires perceptual analysis of the facial structure, as outlined in the Introduction. Thus, to maximize behavioral outcome in the gender discrimination task and gain the extra reward, participants would have mobilized more attentional resources to enhance perceptual analysis of the facial structural features in the incentive condition, as compared to the nonincentive condition (as indicated by the reward effects on the face-sensitive N170 and VPP in the current Experiment 1). Enhanced perceptual analysis of faces in turn facilitates the extraction of facial emotions (Gorno-Tempini et al., 2001; Wronka & Walentowska, 2014). In this way, reward expectation enhances the processing of facial emotions in the gender task, even though the facial emotions are task irrelevant.

To conclude, by asking participants to perform tasks in which emotional faces were targets or, respectively, distractors, the current findings suggest that reward expectation differentially modulates implicit emotional effects, with increased sensitivity to emotions when the processing of whole faces is required, but with reduced sensitivity when processing of the faces is distractive. The present study thus enriches the ERP evidence for interactions between reward-related executive control and implicit emotional processing.

## ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (31470979), the Beijing Advanced Innovation Center for Imaging Technology (BAICIT-2016018), and the Support Project of High-level Teachers in Beijing Municipal Universities in the Period of 13th Five-year Plan. Hermann Müller was supported by the German Research Foundation (DFG) grant MU773/14-1.

## ORCID

*Ping Wei* http://orcid.org/0000-0002-3781-3844

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**How to cite this article:** Wu L, Müller HJ, Zhou X, Wei P. Differential modulations of reward expectation on implicit facial emotion processing: ERP evidence. *Psychophysiology*. 2018;e13304. https://doi.org/10.1111/psyp.13304