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The processing of anticipated and unanticipated fearful faces: An ERP study

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HIGHLIGHTS

- P2, N300, and P3 differ between unanticipated neutral and fearful faces.
- N1, N170, N300, and P3 differ between anticipated neutral and fearful faces.
- Early stage differs between unanticipated and anticipated emotional faces.
- SPN-like component differs between unpredictable and predictable trials.

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ABSTRACT

This study examined the processing of fearful and neutral expressions, which could either be anticipated or not from a prime word (i.e., 'fear' or 'neutral') with or without predictive value. In total, data from 17 participants (i.e., reaction times; ERP waveforms) were analyzed. ERP data showed that the expression effect (fearful vs. neutral faces) was different between predictable and unpredictable trials in early components (N1, N170 and P2) after face onset. However, the expression effect was essentially the same between predictable and unpredictable trials in late components (N300 and P3) after face onset. These results revealed that emotion processing of anticipated vs. non-anticipated stimuli differs mainly in the early stage of neural activity after face onset.

1. Introduction

Emotional stimuli frequently appear in our life. The ability to perceive the emotion present in a stimulus enables an individual to identify both safe and dangerous situations, which may direct an individual's decision to either approach or evade the stimulus [12]. A fearful face represents a special kind of emotional stimulus because it may signal a threatening situation [20].

Many studies have examined the time course of neural activity underlying the processing of fearful faces using event-related potentials (ERP) [4,14]. These studies identified several ERP components showing differential neural activity across fearful and neutral faces in two time periods: early processing (e.g., N1 and P2) and late processing (e.g., P3). More specifically, they found that: the N1 component is associated with early perceptual processing [18]; the P1 component captures early visual processing [1]; the P2 component reacts on attention engagement in individuals' attempts to detect emotional stimuli [7]; the N300 component signals the need for cognitive control whenever an individual reacts to an emotional stimulus [5]; and the P3 component is activated during the elaborate processing of emotion in higher-level cognitive stages [6]. Some studies also found P3 to be affected by subjective probability, leading to increased P3 amplitudes for stimuli with a relatively low probability of occurrence [6]. Apart from these components, some studies showed that, compared to neutral faces, larger N170 amplitudes were induced by faces showing negative emotions [2]. However, other studies did not confirm this finding [7].

To further explore potential factors influencing the time course of emotional face processing, previous studies examined the influence of attention, such as the influence of spatial attention [11] and the extent to which attentional resources are available [14]. However, the potential effect of *anticipation* on emotional face was not examined. To anticipate future events is important for an individual in changing his/her psychological state and/or planning an appropriate behavioral response, especially in a life-threatening situation [15]. Therefore, our ERP study was designed to study the time

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course of neural activity related to the processing of anticipated vs. unanticipated fearful faces.

Several ERP studies have dealt with the time course of anticipation [17,8]. These studies examined the processing of an anticipated (target) emotional picture preceded by a prime stimulus, and found that SPN (stimulus-preceding negativity, a negative slow wave) appeared between the prime and target stimulus in the frontal region. SPN signals anticipatory stimulus processing. In the present study, we studied stimulus processing before and after onset of an emotional face, enabling us to find out how anticipation influences face processing. To induce anticipated faces, we used a similar experimental procedure as used in previous fMRI studies [15]; to create a condition in which the expression of the face shown was either anticipated or unanticipated we relied on a prime stimulus with predictive or non-predictive value.

We used relatively short stimulus onset asynchrony (SOA) to evoke a priming effect [9]. Because the SOA in our study was shorter than in former studies [17,8] we did not expect to observe a slow wave (i.e., SPN) between the prime and target stimulus. However, we did expect to identify a SPN-like [pre-face negative] component which would signal anticipatory stimulus processing. The identification of this component would also increase our confidence in the effectiveness of our experimental manipulations (invoking stimulus anticipation). Because former research showed that stimulus anticipation does not only facilitate stimulus perception but also relates to motor preparation [22], we also examined the correlation between RTs and SPN-like component amplitudes.

Analogous to other studies examining neural activity underlying the processing of emotional faces [4,14,18,1,7,5,6,2], the following ERP components were studied *after* face onset: N1, P1, P2, N170, N300, and the P3 component. These components capture processing of emotional stimuli from an early stage (i.e., N1, P1, P2, and N170) to a late stage (i.e., N300 and P3) [14,7].

According to the dual mechanisms of control (DMC) theory [3], proactive control functions as an early selection mechanism based on predictive cues, and reactive control functions as a late correction mechanism involving higher-order cognitive processing based on stimulus inputs. Therefore, we expected that, in the early stage which is dominated by proactive control, expression processing in predictable versus unpredictable trials would differ because a predictive cue was present only in predictable trials. However, in the late stage which is dominated by reactive control, we expected expression processing in predictable versus unpredictable trails to be identical because input-based (i.e. face) processing is the same in both types of trials. Consequently, we assumed that the expression processing would differ between predictable and unpredictable trials in early components (e.g. N1 and P1) after face onset, but would not in late components (N300 and P3) after face onset.

2. Methods

2.1. Subjects

Eighteen students (12 females and 6 males) participated in the study. All students were from Beijing Normal University. Data from one female student was not analyzed due to excessive eye and head movements during brain wave recording. Therefore, data from 17 participants with a mean age of 23.71 years (SD = 2.76) were included in the analyses.

All 17 participants were suitable for the experiment because their scores on the Chinese version of State-Trait Anxiety Inventory (STAI) [24] and Beck Depression Inventory (BDI) [26] were all in the normal range. They were all right-handed and had normal or corrected-to-normal vision. They were informed about the experimental procedure, and they signed an informed consent form before taking part in the experiment.

2.2. Stimuli

The stimuli were presented in the center of the computer screen against a black background. The size of: (a) a face was 13.5×11.2 cm; (b) an individual Chinese character was 1.5×1.0 cm; and (c) an exclamation mark (i.e., "!") was 1.6×0.4 cm.

All emotional faces in the experiment were taken from the Chinese Facial Affective Picture System database [25]. In total 60 pictures were selected: 15 fearful male and 15 fearful female faces (valence: $M = 2.62$ [9-point scale], SD = .32; arousal: $M = 6.71$ [9-point scale], SD = .99) and 15 neutral male and 15 neutral female faces (valence: $M = 4.68$, SD = .32; arousal: $M = 4.22$, SD = .28). Fearful and neutral faces were significantly different in terms of valence ($F(1,58) = 596.49$, $p < .001$) and arousal ($F(1,58) = 172.06$, $p < .001$).

2.3. Procedure

After completing the prescreening questionnaire, the participant was seated in a comfortable chair facing a computer screen at a distance of 70 cm. During the experiment stimuli were presented in the center of the computer screen. Each trial started with a 100 ms presentation of a small white cross, after which the cross disappeared and the black screen remained empty for 500 ms. Next, the prime (i.e., the word "fear" or "neutral") was depicted for 150 ms. Following the prime, an empty black screen appeared again for 200 ms. Then a face was shown for 200 ms. Half of the participants were instructed to press the "1"-key with the left thumb if a fearful face was shown, or the "3"-key with the right thumb if a neutral face was shown, whereas the other half of the participants were instructed to use a reversed key arrangement. If the response was incorrect or invalid, an exclamation mark was displayed for 200 ms; otherwise the empty black screen remained for another 200 ms. Following the exclamation mark or the black screen, a green screen was presented with a random duration of 2100–2300 ms allowing the participant to relax for a while.

In *unpredictable* trials, the chance of a consistent prime-face sequence was 50%. As a consequence, participants were not in a position to anticipate the expression (fear/neutral) of the next face to appear. In contrast, in *predictable* trials, participants were able to anticipate the type of face to appear next because the chance of an inconsistent prime-face sequence was 75%. An *inconsistent* prime-face sequence was imposed in the majority of cases because a *consistent* prime-face sequence might have resulted in a substantial decrease in participants' reaction times (RTs) due to spreading activation of the information contained in the prime [10]. To avoid this unwanted effect, we decided to work with an inconsistent prime-face sequence.

The experiment consisted of 6 warm-up trials and a total of 480 formal trials, divided over two blocks. Each block represented a different condition: unpredictable or predictable trials. Each participant completed both blocks, but the sequence in which they were offered was random.

2.4. ERP data recording and analysis

The electroencephalogram (EEG) data were recorded using a NeuroScan system with 64 scalp sites with tin electrodes mounted in an elastic cap. All electrodes were referred to the left mastoid. The horizontal electrooculogram (EOG) was recorded with electrodes placed on the left and the right orbital rim, while the vertical EOG was recorded with electrodes placed above and below the left eye. During data collection, impedances of electrodes were below 5 kΩ and measured signals fell within a bandwidth of 0.05–100 Hz. Both the EEG and EOG data were digitized continuously at a sampling rate of 500 Hz/channel.

EEG activity of trials reflecting correct responses were overlapped and averaged to form grand average ERP waveforms for each experimental condition. The grand average ERP waveforms were time-locked to the onset of the prime and the average epoch was 1500 ms, including a 100 ms pre-prime stimulus baseline. As explained in the Introduction, seven components were analyzed in detail. One component was registered after the prime but before the face appeared: the SPN-like component (260–360 ms after prime onset). The other six components were registered after face onset: N1 (410–510 ms after prime onset or 60–160 ms after face onset), P1 (450–520 ms after prime onset or 100–170 ms after face onset), P2 (510–570 ms after prime onset or 160–220 ms after face onset), N300 (570–700 ms after prime onset or 220–350 ms after face onset), P3 (760–830 ms after prime onset or 410–480 ms after face onset), and N170 (500–600 ms after prime onset or 150–250 ms after face onset). The time window of each component across all conditions in a particular region was specified such that is centered around its peak. The mean amplitude of each component was depicted in that specific time window.

Grand average ERP waveforms were obtained for the following 28 electrode positions: AF3, FP1, FPZ, FP2, AF4, F5, F3, FZ, F4, F6, FC5, FC3, FCZ, FC4, FC6, CZ, CPZ, P7, PZ, P8, PO7, PO3, POZ, PO4, PO8, O1, OZ, and O2. In accordance with previous studies [14,2], we analyzed the following components in specific brain regions: SPN-like component, N1, and P2 in the prefrontal (AF3, FP1, FP2, and AF4), the frontal (F5, F3, F4, and F6), and the frontal-central region (FC5, FC3, FC4, and FC6); P1 in the parietal–occipital (PO3 and PO4) and the occipital region (O1 and O2); N170 in the left occipital–temporal (P7 and PO7) and the right occipital–temporal region (P8 and PO8); and, finally, N300 and P3 in the frontal midline (FPZ, FZ, and FCZ), the central-parietal (CZ, CPZ, and PZ), and the occipital midline region (POZ and OZ). The amplitude of neural activity within each region was determined by averaging amplitudes recorded in all electrodes situated in that region.

RT data were analyzed using repeated measures ANOVA comprising the following factors: expression (two levels: fearful face; neutral face), predictability (two levels: predictable; unpredictable), and priming (two levels: consistent; inconsistent). In the ANOVA analysis of ERP data another factor brain region (2 or 3 levels depending on the ERP component) was included, but the factor priming was omitted. In this study, we only analyzed ERP data from *inconsistent* trials because only in these trials the prime-target relationship was inverse regardless of whether the face was predictable or not. As such, the predictive value of the prime stimulus was the main point of difference across both conditions, ensuring that the observed differences in processing predictable vs. unpredictable faces were attributable to the predictive nature of the prime stimulus.

All degrees of freedom as calculated in the ANOVAs were Greenhouse–Geisser corrected to account for (diagnosed) violations of the sphericity assumption. We used *F*-tests in a 'simple effects analyses', and only reported significant results.

3. Results

3.1. Behavioral data

Because ANOVA analyses revealed no significant effects on accuracy rates, we only show RT results. As shown in Fig. 1, in unpredictable trials, the interaction effect between expression and priming was highly significant ($F(1,16) = 11.04$, $p = .005$). More specifically, when processing fearful faces (but not when processing neutral faces), the RTs in consistent trials and inconsistent trials were significantly different ($F(1,16) = 18.71$, $p = .001$). In predictable trials, the interaction effect between expression and priming was also significant ($F(1,16) = 8.17$, $p = .012$) but the pattern of means was different. RTs in consistent trials and inconsistent trials were significantly different when processing neutral faces ($F(1,16) = 8.97$, $p = .009$), but not when processing fearful faces.

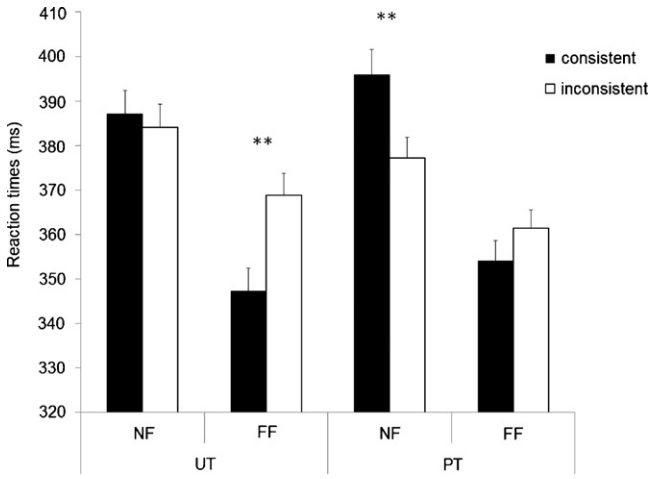

Fig. 1. Average RTs in various experimental conditions (Expression: NF, neutral faces; FF, fearful faces. Predictability: PT, predictable trials; UT, unpredictable trials). $^{**}p < .01$.

3.2. ERP data

As to amplitudes *after prime onset* (see Fig. 2A and B), the SPN-like component showed a significant interaction effect between predictability and region, $F(2,32) = 5.26$, $p = .019$, $\eta_p^2 = .25$, and a marginally significant interaction effect between predictability, expression, and region, $F(2,32) = 3.51$, $p = .054$, $\eta_p^2 = .18$. Simple effect analyses revealed that the difference between predictable and unpredictable trials was significant in the prefrontal region ($p = .013$), and marginally significant in the frontal region ($p = .057$). In particular, in predictable trials, the anticipation of fearful faces induced larger amplitudes than the anticipation of neutral faces in the prefrontal region ($p = .017$). However, no significant differences were found in unpredictable trials. The correlation between SPN-like component amplitude *differences* in predictable vs. unpredictable trials and RT *differences* in predictable vs. unpredictable trials was positive and significant, $r = .54$, $p = .031$.

After face onset (see Fig. 2C and D), the N1 component showed a significant interaction effect between predictability and region, $F(2,32) = 6.97$, $p = .009$, $\eta_p^2 = .30$. Across predictable and unpredictable trials N1 amplitudes were significantly different in the prefrontal region ($p = .039$), but not in the other two regions (i.e., frontal and frontal–central region). Furthermore, a significant interaction effect between predictability and expression was found, $F(1,16) = 10.27$, $p = .006$, $\eta_p^2 = .39$. Specifically, larger amplitudes were registered for fearful faces than for neutral faces but only in predictable trials ($p = .016$). No significant main or interaction effects were found in the P1 component. However, the P2 component showed a significant interaction effect between predictability and expression, $F(1,16) = 6.23$, $p = .024$, $\eta_p^2 = .28$, and between predictability and region, $F(2,32) = 4.63$, $p = .035$, $\eta_p^2 = .22$. In comparison to neutral faces, fearful faces induced larger amplitudes in unpredictable trials ($p = .002$), but not in predictable trials. The N300 component revealed a significant main effect of expression, $F(1,16) = 18.93$, $p < .001$, $\eta_p^2 = .54$. More specifically, fearful faces induced smaller N300 amplitudes than neutral faces. Furthermore, fearful faces induced larger P3 amplitudes than neutral faces, $F(1,16) = 38.05$, $p < .001$, $\eta_p^2 = .70$. For the N170 component, the interaction effect between predictability and expression was marginally significant, $F(1,16) = 3.92$, $p = .065$,

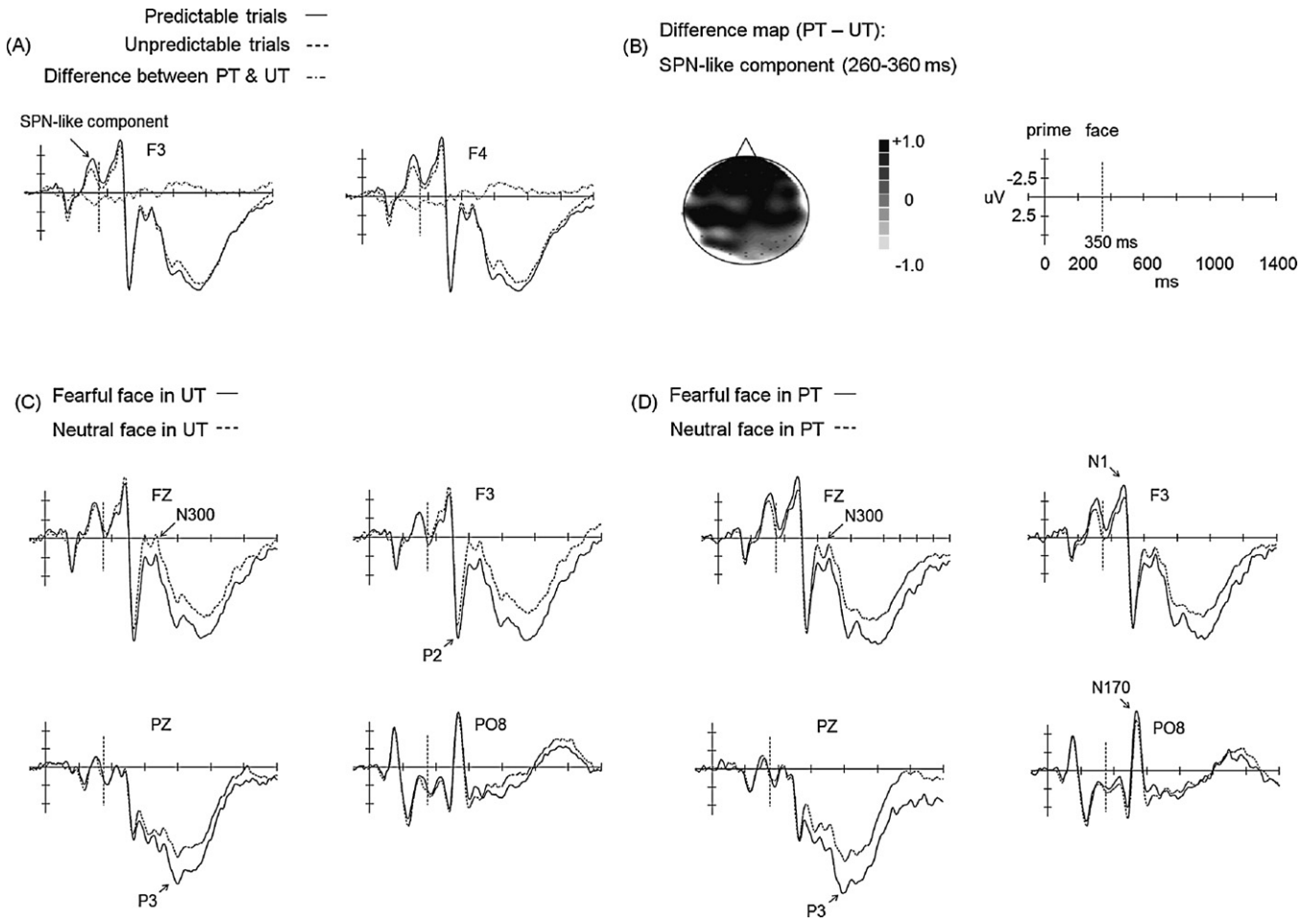

Fig. 2. (A) Grand average ERPs recorded in unpredictable trials (UT), predictable trials (PT), and difference between them on F3 and F4 sites; (B) the topographic map of ERP differences between PT and UT for the SPN-like component; and grand average ERPs recorded during processing of fearful and neutral faces on FZ, F3, PZ, and PO8 sites in UT (C) and PT (D).

$\eta_p^2 = .20$, and the interaction effect between expression and region was significant, $F(2,32) = 9.54$, $p = .007$, $\eta_p^2 = .37$. When compared to neutral faces, fearful faces induced larger amplitudes in the right occipital–temporal region in predictable trials ($p = .043$), but not in unpredictable trials.

4. Discussion

This experimental study was unique in that it systematically compared the time course of processing anticipated vs. unanticipated emotion depicted in faces.

RT data on fearful faces showed that, in unpredictable trials, fearful faces are processed significantly faster in consistent trials than in inconsistent trials. In predictable trials, the same difference, albeit non-significant, was found across consistent and inconsistent trials. These results indicate that processing fearful faces is influenced by anticipation. However, the effect in predictable trials was not strong enough to result in faster RTs in inconsistent trials than in consistent trials. As negative information is more critical for survival, people tend to react automatically to threatening cues, that is negative information gets more attention [21]. The presence of this negative bias may explain why even opposed to anticipation, judgments of fearful faces following a "fear" cue were found *not* to be slower than judgments of fearful faces following a "neutral" cue. As far as *neutral faces* are concerned, we found that differences in RTs across consistent and inconsistent trials displayed a pattern which was opposite to the pattern observed for fearful faces in both predictable and unpredictable trials. Significantly shorter RTs in inconsistent than in consistent trials in predictable trials may indicate that the effect of anticipation on processing neutral faces is stronger as opposed to fearful faces. However, the cue word may also have contributed to this pattern in RTs. Specifically, the "fear" cue, which expresses negative valence, could have led to faster RTs than the "neutral" cue.

As expected, ERP results showed that amplitudes in the SPN-like component differed: (a) between predictable and unpredictable trials and (b) between fearful and neutral faces in predictable trials. Both results indicate that the SPN-like component may be involved in the processing of anticipated stimuli. Moreover, an additional correlation analysis showed a significant correlation between: (a) SPN-like component amplitude *differences* in predictable vs. unpredictable trials and (b) RT *differences* in predictable vs. unpredictable trials. As such, our study also provides evidence for a relationship between emotion anticipation and motor plan preparation. All in all, the similar function (i.e., involvement in processing of anticipated stimuli and relationship to motor preparation) of the SPN-like component as observed in our study and SPN suggests that we dealt with a component representing a short form of SPN [8]. Obviously, more studies are needed to strengthen this conclusion.

Our study results showed that emotion processing clearly differed between predictable and unpredictable trials in the early stage. Emotion processing started earlier in *predictable* trials (N1 and N170) than in *unpredictable* trials (P2), which indicates that

processing of expression was accelerated in predictive trials. The reason for accelerated processing may be found in increased anticipation-related processing in predictive trials, as shown by the larger amplitudes recorded for the SPN-like component. Consequently, the processing of expression was already identified in early components. Similar results were obtained by Van Hooff et al. [23]; they found that, when the emotional content of words is anticipated, threatening words induce larger amplitudes than neutral words in an early component (P1). In contrast to Van Hooff's study, we obtained our evidence from N1 and N170 (and thus not from P1). Failure to find evidence from P1 is not be that surprising because earlier research has shown that the P1 component was not always associated with processing fearful faces [13].

As opposed to the expression effect in P2 we observed in *unpredictable trials*, such effect was not observed in *predictable trials*. A possible reason for this may be an *inhibition* of the expression effect due to other ongoing processes, such as comparing the face expression with the meaning of the prime word. Because only in predictable trials a predictable relationship between face and prime word was imposed, making a comparison between face and prime word (to validate stimulus anticipation) was required *after* the initial stage of expression processing (i.e., expression effect in N1).

After P2, substantial differences in N300 and P3 amplitudes were found when processing fearful vs. neutral faces. However, N300 and P3 amplitudes did not differ between predictable and unpredictable trials. These findings regarding N300 and P3 suggest that cognitive control and elaborate processing of emotion are not modulated by subjective anticipation. However, some studies did conclude that subjective probability may impact P3 amplitudes [4,6]. Our differential finding related to P3 may be due to the fact that anticipatory processing already started in the early stage (e.g., N1 and P2). In a later stage, the distinction between fearful and neutral faces is more crucial than whether or not the stimulus is predictable. This may explain why both N300 and P3 amplitudes differed across fearful and neutral faces, but not across predictable and unpredictable trials.

In this study, we examined possible interactions between brain region, predictability, and expression. First, we found that the predictability effect in the SPN-like component appeared in the prefrontal and fontal region. The similarity of the distribution of the SPN-like component and SPN, which is also located frontally [8], provided additional evidence for the SPN-like component being merely conceived as a short form of the SPN component. Both the SPN-like component and SPN may be situated in the anterior cingulate cortex (ACC) which is involved cognitive control, including anticipation [16]. Second, in predictable trials we found a significant expression effect in N170 in the right occipital–temporal region. This expression effect may be due to the fact that N170 is more strongly embedded within the right hemisphere [19].

This study is not without limitations. First, we used words as prime stimuli (in combination with an inverse prime-target relationship to avoid spreading activation in predictable trials) mainly because words facilitate a fast discovery of prime-target relationships. However, by design, a larger proportion of inverse prime-target sequences was created in predictable as opposed to unpredictable trials. Even though our ERP analyses only dealt with data on inconsistent trials (in which proportional differences were less forthright), future studies may rely on symbols (e.g., arrows) rather than words as prime stimuli to remedy this problem. A second limitation concerns the short SOA between prime and face. In general, a short SOA helps invoking a priming effect [9]. We believe that those ERP components associated with face processing (i.e. N1, P1, N170, N300, and P3) are unlikely to be substantially influenced by the prime stimulus (the waveforms observed in our study did not differ from those obtained in similar studies not using a prime stimulus [7,11]). Even if the prime would have marginally affected our ERP data comparisons across the two types of faces studied, the comparison would not have been biased as the effect of the prime is basically invariant across trials with a different type of face shown. Future ERP studies should experiment with longer SOAs to be sure that emotional face processing is not affected by the prime.

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