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The effect of fearful expressions on recognition memory for faces: Behavioral and electrophysiological data

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ABSTRACT

Facial expressions affect memory for face identity. We tested how fearful expressions modulate recognition memory for faces. In two studies, participants completed a continuous recognition task with fearful and neutral faces while their electroencephalogram was recorded. Each face stimulus was presented twice and participants were instructed to indicate whether it was presented for the first ('new') or second time ('old'). The false alarm rate was higher for fearful than neutral faces, which is opposite to the emotion enhancement effect on memory but in line with the liberal response bias for emotional information. There was no evidence of emotional modulation of the N400 old/new effect, which suggests that the sense of familiarity was not affected by fearful facial expressions. The LPC old/new effect, however, was modulated by facial expression, as it was absent for fearful faces because of a greater positivity in response to new fearful than new neutral faces. This LPC old/new effect finding may reflect that the emotional salience of fearful new faces is mistaken for a sense of recollection, resulting in an increased false alarm rate. In short, people seem more likely to (mistakenly) think that they have encountered a person before when the person looks scared compared to non-emotional, which has relevance for daily life and forensic situations such as police lineups.

1. Introduction

Facial expressions affect memory for the owner of the face. Fearful facial expressions are highly salient. For example, fearful faces emerge from suppression into awareness more quickly than happy or neutral faces (Yang et al., 2007). Fearful faces signal the presence of danger in the environment and therefore increase vigilance to facilitate learning (Springer et al., 2007; Whalen, 2007). It is currently unknown whether fearful faces are more often correctly or falsely recognized than neutral faces, and what the electrophysiological signature of that effect is. This question has relevance for everyday life, as well as for forensic situations such as police lineups.

It is well-established that emotional information (and negative information in particular) is better remembered than neutral information, which is the so-called emotion enhancement effect on memory (Hamann, 2001; Phelps, 2004). The dual process model of recognition memory distinguishes between familiarity and recollection, where familiarity is the mere sense of having seen a stimulus previously without being able to recall any details of the circumstances and recollection is the explicit memory of the circumstances in which the stimulus was previously encountered (Yonelinas, 2002). It has been shown that emotion boosts recollection more than familiarity (Ochsner, 2000). The emotion enhancement effect has been observed in recognition tests for faces (Keightley et al., 2011). In recognition tests, participants indicate whether a stimulus is presented for the first time ('new') or whether it has been presented before ('old'), and emotional stimuli are more likely to be correctly recognized as old (i.e., a hit). In several previous studies on recognition memory for fearful faces, old/new discrimination was better for fearful than positive/happy and/or neutral faces (Fischer et al., 2007; Righi et al., 2012; Rohr et al., 2017; Sergerie et al., 2006; Wang, 2013).

Although old/new discrimination is often better for emotional stimuli (and negative stimuli in particular) than neutral stimuli, emotional stimuli are sometimes also more likely to be perceived as old regardless of their true old/new status, which is the so-called liberal response bias (Ochsner, 2000; Windmann and Kutas, 2001). It has been suggested that this liberal response bias for emotional stimuli occurs because the salience of emotional stimuli in a recognition task is misinterpreted as a sense of having seen the stimulus before, resulting in an increased hit rate for old stimuli but also in an increased false alarm rate for new

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stimuli (McNeely et al., 2004). This increased false alarm rate may cancel out the increased hit rate for emotional information, thereby eliminating (or even reversing) the emotion enhancement effect on memory (Johansson et al., 2004; Langeslag and Van Strien, 2008; Maratos et al., 2000).

Event-related potentials (ERPs) are especially suitable to study recognition memory for fearful faces, because there are two components of the ERP old/new effect that correspond with the two processes of the dual process model of recognition and that can be modulated by emotion. The ERP old/new effect entails a more positive ERP waveform for old than for new stimuli (Rugg and Allan, 2000) and the two components are the N400 and the Late Positive Complex (LPC) old/new effects. The N400 old/new effect is a negative waveform in the 300–500 ms time window after stimulus onset that is less negative (i.e., more positive) for old than new stimuli (Rugg and Allan, 2000). This N400 old/new effect is thought to reflect the automatic sense of familiarity when a stimulus is old (Curran and Clearly, 2003; Van Strien et al., 2005; Weymar et al., 2009). In a previous study, emotion did not modulate the N400 old/new effect for faces (Johansson et al., 2004). In another previous study with a study-test paradigm in which faces were presented with fearful, happy, or neutral expressions during study and with neutral expressions during test, the N400 old/new effect was greater for faces that were fearful compared to happy or neutral during study (Righi et al., 2012). It is important to note thought that presenting only neutral faces during retrieval introduces the confound that the neutral faces are identical during encoding and retrieval, whereas the emotional faces presented during encoding are presented with neutral expressions during retrieval. That is, any differences in ERP old/new effects between emotional and neutral faces could be the result of expressions being the same versus different during encoding and retrieval. It is therefore important to test whether the N400 old/new effect is affected by fearful facial expression while keeping facial expression constant between encoding and retrieval.

The Late Positive Complex (LPC) old/new effect is a sustained positive waveform peaking between 500 and 800 ms after stimulus onset that is more positive for old than new stimuli (Rugg and Allan, 2000). This LPC old/new effect is thought to reflect the recollection process (Curran and Clearly, 2003; Van Strien et al., 2005; Weymar et al., 2009). In line with the notion that emotion boosts recollection more than familiarity (Ochsner, 2000), the emotional modulation of the LPC old/new effect is more consistently observed across studies (Dietrich et al., 2001; Inaba et al., 2005; Langeslag and Van Strien, 2008; Pérez-Mata et al., 2012; Weymar et al., 2009) than the emotional modulation of the N400 old/new effect. For example, the LPC old/new effect was larger for negative than positive and neutral faces (Johansson et al., 2004). It should be noted though that the LPC old/new effect in some studies was reduced or even inversed for emotional compared to neutral words or pictures because the ERP was more positive for new emotional compared to new neutral stimuli (Langeslag and Van Strien, 2008; Maratos et al., 2000; Van Strien et al., 2009). This effect has been linked to the more liberal response bias for emotional than neutral stimuli, as the ERP positivity may reflect the salience that could be mistaken for a sense that the stimulus is old, resulting in an increased false alarm rate (Windmann and Kutas, 2001). To our knowledge, it has not been examined yet whether fearful expressions modulate the LPC old/new effect.

The research question was how fearful facial expressions affect recognition memory behaviorally and electrophysiologically. We used a 2 (Emotion) × 2 (Old/new) factorial design that balances facial expression between new and old stimuli to avoid confounding of ERP old/new effects by facial expression. One of two patterns was expected. The first pattern was that of enhanced old/new discrimination for fearful compared to neutral stimuli and an enhanced LPC (and perhaps N400) old/new effect for fearful compared to neutral faces. The other pattern was that of a more liberal response bias for fearful compared to neutral faces and a reduced LPC old/new effect for fearful compared to neutral faces because of an enhanced positivity for fearful new compared to neutral new faces.

2. Methods - study 1

2.1. Participants

Twenty-one university students participated for course credit.[1] One female participant was excluded because behavioral data were not recorded and one male participant was excluded because of excessive EEG artifacts, so nineteen participants (mean age = 20.8 yrs, age range = 19–27 yrs, 8 men) yielded usable data. The study was approved by the Psychology Research Ethics committee of the Erasmus Institute of Psychology. All participants gave written informed consent.

2.2. Stimuli

The stimuli were 30 pictures of neutral (15 male, 15 female) faces from the Psychological Image Collection at Stirling (PICS, http://pics.psych.stir.ac.uk/) and the AR Face Database (Martinez and Benavente, 1998); and 30 pictures of fearful (15 male, 15 female) faces from the NimStim Set of Facial Expressions (Tottenham et al., 2009).[2] Multiple databases were used to obtain the desired numbers and types of stimuli. There were 30 neutral (15 male, 15 female) and 30 fearful (15 male, 15 female) faces. Each picture portrayed a unique individual in a frontal pose. Face stimuli were edited to have a white background, if they did not have a white background already. Pictures were resized to 200 × 250 (w × h) pixels and converted to grayscale. See Fig. 1 for example stimuli. The face stimuli were presented in the center of a 20-in. PC monitor with a resolution of 1024 × 768 pixels, on a black background.

2.3. Procedure

After the EEG cap was attached, participants were seated in a sound attenuated, dimly-lit chamber at a distance of approximately 120 cm in front of the monitor. They completed a continuous recognition task in which each face stimulus was shown twice, in pseudo-random order. Participants were instructed to indicate whether each face was presented for the first ('new') or second time ('old') by pressing response buttons with the left and right index fingers. Response mapping was counterbalanced between participants. Participants were instructed to respond as accurately and fast as possible. Before the main task, the participants completed 18 practice trials (9 new and 9 old) with neutral faces that were not used in the main task.

Each trial consisted of (1) a fixation cross in the center of the computer screen with a variable duration of 450 to 600 ms to reduce time-locked EEG phase or expectancy effects, (2) a face stimulus for 300 ms, (3) another fixation cross for 1200 ms, and (4) a blank screen for 1500 ms, see Fig. 2. Participants had 2000 ms from the start of the face stimulus to respond. The total number of experimental trials was 120 (i.e., 2 (fearful/neutral) × 2 (old/new) × 30). The number of intervening trials between the first and second presentation of a certain face stimulus ranged from 3 to 10, with the proportion of new faces (0.5) being the same in the first and the second half of the main task. After completion of the continuous recognition task, the electrode cap was removed and participants were thanked.

[1] Sample sizes for Study 1 and 2 were based on previous ERP studies with emotional face stimuli, which had 14 and 16 participants per study (Johansson et al., 2004) and 18 participants (Righi et al., 2012). Unfortunately, there currently is no convenient way to perform a power analysis with more than one within-subject variable in G*Power (G*Power Feedback, personal communication, January 9, 2018).

[2] The stimuli are available upon request for replication purposes.

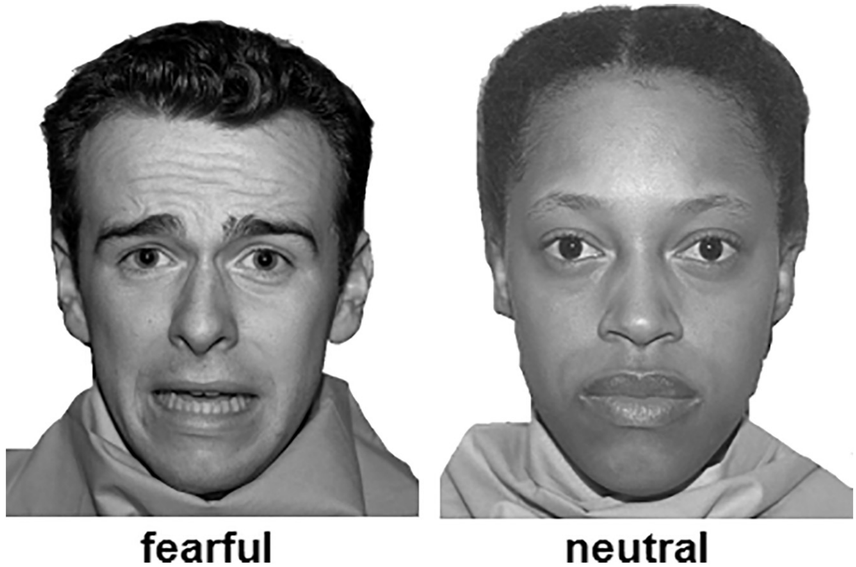

Fig. 1. Examples of fearful and neutral faces. In Study 1, the fearful and neutral faces were of different individuals. In Study 2, face identity was matched between fearful and neutral faces, with the mapping between face identity and facial expression counterbalanced between participants.

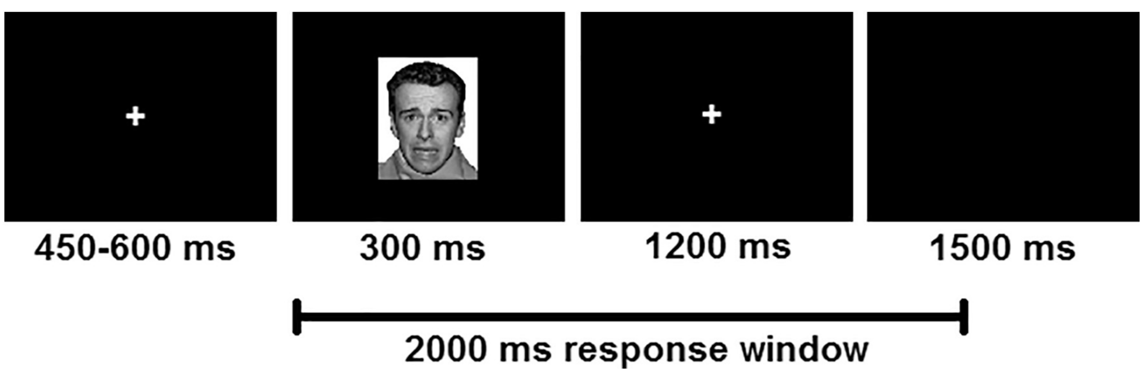

Fig. 2. Trial overview. Images are not to scale.

2.4. EEG recording and preprocessing

EEG activity was recorded with a BioSemi Active-Two system from 32 pin type active Ag/AgCl electrodes mounted in an elastic cap. Active electrodes were also attached to the left and right mastoids. Electrooculogram (EOG) activity was recorded from active electrodes placed above and beneath the left eye, and from electrodes at the outer canthus of each eye. An additional active electrode (CMS - common mode sense) and a passive electrode (DRL - driven right leg) were used to comprise a feedback loop for amplifier reference. The EEG and EOG signals were digitized with a 512 Hz sampling rate, a low pass filter of 134 Hz, and 24-bit A/D conversion. Response latencies were recorded online along with the EEG data.

Offline, an averaged mastoids reference was applied. The data were filtered using a 0.1–20 Hz band pass filter (phase shift-free Butterworth filters; 24 dB/octave slope) and a 50 Hz notch filter. Data were segmented in epochs from 100 ms before stimulus onset until 1000 ms after stimulus onset. Ocular artifact correction was applied according to the Gratton and Coles algorithm (Gratton et al., 1983) and the 100 ms pre-stimulus period was used for baseline correction. Artifact rejection was performed at individual electrodes with the criterion minimum and maximum baseline-to-peak −100 to +100 μV. Average ERPs were computed for each participant for the following conditions: fearful new, neutral new, fearful old, and neutral old. Only trials with a correct response were included in these averages. At the electrodes used in the analyses (see below), the average number of accepted trials per electrode per condition ranged from 22.7 to 26.8 out of 30.

2.5. Statistical analyses

Hit rates (H, i.e. proportion old responses to old stimuli) and false alarm rates (FA, i.e. proportion old responses to new stimuli) were computed using the correction recommended by Snodgrass and Corwin (1988). Performance on the continuous recognition test was represented by the discrimination index $Pr = H - FA$, and by the response bias index $Br = FA/(1 - Pr)$ (Snodgrass and Corwin, 1988). A Pr of 1 indicates perfect performance, while a Pr of 0 indicates chance performance. A Br smaller than 0.5 indicates a conservative response bias, whereas a Br greater than 0.5 indicates a liberal response bias. H, FA, Pr, and Br were analyzed using repeated measures analyses of variance (rmANOVA) with the factor Emotion (fearful, neutral) as within-subject factor. Reaction times (RTs) for correct responses were analyzed using a rmANOVA with Emotion and Old/New (new, old) as within-subject factors.

Consistent with a previous study (Mograss et al., 2006) and with previous findings that the N400 and LPC old/new effects are typically maximal at midline electrodes (Van Strien et al., 2005), the ERP was scored at midline electrodes (Fz, Cz, Pz). Consistent with previous studies, the N400 was quantified by mean amplitude measures in the 350–450 ms time window (Langeslag et al., 2015; Van Strien et al., 2007, 2011), and the LPC by mean amplitude measures in the 500–800 ms time window (Langeslag et al., 2015; Van Strien et al., 2005). The N400 and LPC mean amplitude measures were subjected to rmANOVAs with Emotion, Old/New, and Electrode (Fz, Cz, Pz) as within-subjects factors. Only effects involving the factors Emotion and/or Old/New will be reported.

When applicable, the degrees of freedom were corrected using the Greenhouse-Geisser correction. The F values, uncorrected degrees of freedom, the ε values, corrected probability values, and effect sizes (η_p^2) are reported. A significance level of 5% (two-sided) was selected. Follow-up paired t-tests were conducted according to Fisher's least significance difference (LSD) procedure, which controls type I error rate by conducting follow-up paired t-tests for significant main and interaction effects only.

To test the association between the ERP old/new effects and task performance, Pearson correlation coefficients were computed between the N400 and LPC old/new effects (old-new, collapsed across Fz, Cz, and Pz) on the one hand, and the hit rate, false alarm rate, discrimination index Pr, and response bias Br on the other hand, separately for fearful and neutral faces.

3. Results - study 1

3.1. Behavioral data

Overall accuracy was 82%. See the left panel of Fig. 3 for the hit rate, false alarm rate, discrimination index Pr, and response bias Br. For hit rate, there was a main effect of Emotion, $F(1,18) = 13.3$, $p = .002$, $\eta_p^2 = 0.42$, which indicated that the hit rate was higher for fearful than neutral faces. For false alarm rate, there was also a main effect of Emotion, $F(1,18) = 36.3$, $p < .001$, $\eta_p^2 = 0.67$, which indicated that the false alarm rate was higher for fearful than neutral faces as well. As a result, the discrimination index Pr was numerically lower for fearful than neutral faces, although the main effect of Emotion was not significant, $F(1,18) = 1.4$, $p = .251$, $\eta_p^2 = 0.07$. There was a main effect of Emotion for the response bias Br, however, $F(1,18) = 59.5$, $p < .001$, $\eta_p^2 = 0.77$, which indicated that the response bias was more liberal for fearful than neutral faces. This means that participants had a greater tendency to respond 'old' to fearful than to neutral faces regardless of their true old/new status.

See the left panel of Fig. 4 for the RTs for correct responses to fearful and neutral new and old faces. There was a significant Emotion ∗ Old/New interaction, $F(1,18) = 27.6$, $p < .001$, $\eta_p^2 = 0.61$. Follow-up tests showed that responses were slower to fearful new than neutral new faces, $p = .001$, but faster to fearful old than neutral old faces, $p = .003$.

3.2. Event-related potentials

See Fig. 5 for the ERP waveforms in the four conditions (top left panel) and the scalp topographies of the differences between conditions (bottom left panel). See Table 1 for an overview of the significance of the effects. In the 350–450 ms time window, there was a main effect of Emotion, $F(1,18) = 21.4$, $p < .001$, $\eta_p^2 = 0.54$, indicating that the ERP was more positive in response to fearful than neutral faces. There was a main effect of Old/New as well, $F(1,18) = 8.0$, $p = .011$, $\eta_p^2 = 0.31$, indicating that the ERP was more positive in response to old than new faces, which is the N400 old/new effect. None of the other effects involving the factors Emotion and/or Old/New (including interactions involving the factor Electrode) reached significance, all Fs < 3.3, all ps $> .052$. So, although the scalp topographies, see Fig. 5, suggest that the emotion effect had a centroparietal maximum and the N400 old/new effect had a frontocentral maximum, the effects were not significantly different between electrodes Fz, Cz, and Pz.

In the 500–800 ms time window, there was a main effect of Emotion, $F(1,18) = 5.5$, $p = .031$, $\eta_p^2 = 0.23$, which was modulated by an Emotion ∗ Old/New interaction, $F(1,18) = 7.3$, $p = .015$, $\eta_p^2 = 0.29$. Follow-up tests showed that there was an LPC old/new effect for neutral faces, with the ERP being more positive in response to neutral old than neutral new faces, $p = .006$, but not for fearful faces, $p = .643$. The follow-up tests also showed that the ERP was more positive in response to fearful new than neutral new faces, $p = .006$, but not for old faces, $p = .440$. None of the other effects involving the factors Emotion and/or Old/New (including interactions involving the factor Electrode) reached significance, all Fs < 4.4, all ps $> .050$. So, although the scalp topographies, see Fig. 5, suggest that the emotion effect and the LPC old/new effect had frontocentral maxima, the effects were not significantly different between electrodes Fz, Cz, and Pz.

3.3. Correlations

See the four left columns of Table 2 for the correlations between the ERP old/new effects and task performance. None of these correlations were significant.

4. Interim summary

To summarize, participants showed higher hit and false alarm rates, and hence a more liberal response bias, for fearful than neutral faces. In addition, correct responses were slower to fearful new than neutral new faces, but faster to fearful old than neutral old faces. The ERP in the 350–450 time window, was more positive for fearful than neutral faces and more positive for old than new faces, with no interaction between the two. The ERP in the 500–800 ms time window, in contrast, showed the LPC old/new effect for neutral faces, but not for fearful faces. This absence of an old/new effect for fearful faces was due to a greater positivity for fearful new than neutral new faces.

We conducted a second study to replicate these findings using an improved study design. Most importantly, we matched face identity between the fearful and neutral faces, which means that fearful and neutral faces of the same individuals were used (although the mapping between face identity and facial expression was counterbalanced between participants). We also replaced the faces from possibly dated face databases (i.e., PICS (http://pics.psych.stir.ac.uk) and AR Face

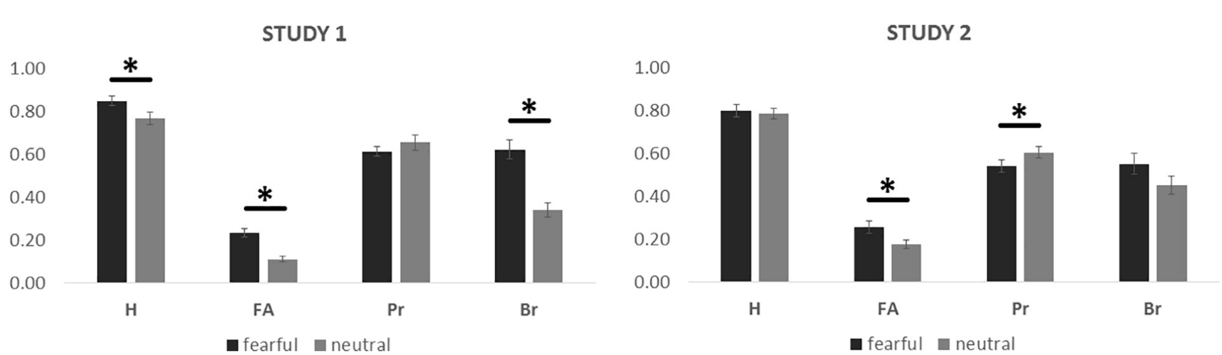

Fig. 3. Hit rate (H), false alarm rate (FA), discrimination index (Pr), and response bias (Br) for fearful and neutral faces in both studies, *$p < .05$.

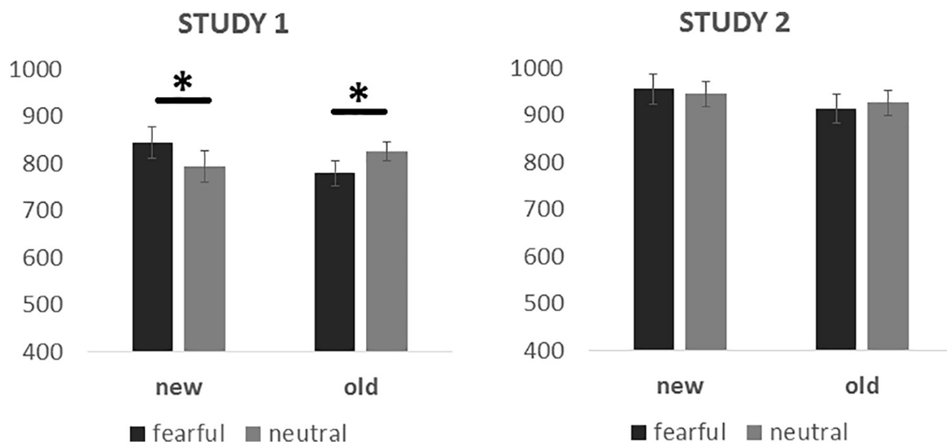

Fig. 4. Reaction times for correct responses for new and old fearful and neutral faces in both studies, *$p < .05$.

Database (Martinez and Benavente, 1998)) with faces from a more recent and versatile database (i.e., Radboud Faces Database (Langner et al., 2010)). Finally, we used a gender-balanced sample and collected valence and arousal ratings for the faces.

5. Methods - study 2

The methods of Study 2 were the same as the methods of Study 1, with the exception of the following.

5.1. Participants

There were 24 participants (mean age = 20.5 yrs, age range = 18–24 yrs, 12 men) who had not participated in Study 1. No participants were excluded.

5.2. Stimuli

The stimuli were 128 pictures of faces from two faces databases: the NimStim Set of Facial Expressions (Tottenham et al., 2009) and the Radboud Faces Database (Langner et al., 2010)[2]. There were 64 individuals (32 male, 32 female), each with a fearful and a neutral facial expression. Each individual was shown with one facial expression only to each participant, as the mapping between face identity and facial expression was counterbalanced between participants. The pictures of the Radboud Faces Database were cropped (by removing pixels at the borders) to match the cut out of the pictures of the Nimstim database. Pictures were resized to 250 × 325 pixels.

5.3. Procedure

Before the main task, the participants completed 4 practice trials (2 new and 2 old) with neutral faces that were not used in the main task. The total number of experimental trials in the continuous recognition task was 128 (i.e., 2 (fearful/neutral) × 2 (old/new) × 32). After removal of the EEG cap, participants rated the valence and arousal elicited by the 64 faces that they encountered in the continuous recognition task with a computerized version of the Self-Assessment Manikin (Bradley and Lang, 1994). Specifically, participants were instructed to rate how unpleasant or pleasant and how calming or arousing each face made them feel on a 1–9 scale, where 1 = highly unpleasant/calm and 9 = highly pleasant/arousing.

5.4. EEG recording and preprocessing

At the electrodes used in the analyses, the average number of accepted trials per electrode per condition ranged from 23.9 to 26.5 out of 32.

5.5. Statistical analyses

The valence and arousal ratings were analyzed using rmANOVAs with Emotion as a within-subjects factor. To test if the absence of an LPC old/new effect for fearful faces because of a greater positivity for fearful new than neutral new faces replicated, planned *t*-tests were conducted to test the emotion effects for new and old faces in the 500–800 ms time window.

6. Results - study 2

6.1. Ratings

For valence ratings, there was a main effect of Emotion, $F(1,23) = 21.5$, $p < .001$, $\eta_p^2 = 0.48$, indicating that participants felt more unpleasant when viewing fearful ($M = 3.6$, $SD = 1.1$) than neutral faces ($M = 4.9$, $SD = 0.6$). For arousal ratings, there was a main effect of Emotion as well, $F(1,23) = 36.5$, $p < .001$, $\eta_p^2 = 0.61$, indicating that participants felt more aroused when viewing fearful ($M = 4.5$, $SD = 1.5$) than neutral faces ($M = 2.5$, $SD = 1.2$).

6.2. Behavioral data

Overall accuracy was 79%. See the right panel of Fig. 3 for the hit rate, false alarm rate, discrimination index Pr, and response bias Br. For hit rate, the main effect of Emotion was not significant, $F(1,23) < 1$, *ns*. For false alarm rate, however, there was a main effect of Emotion, $F(1,23) = 8.4$, $p = .008$, $\eta_p^2 = 0.27$, which indicated that the false alarm rate was higher for fearful than neutral faces. As a result, the discrimination index Pr was lower for fearful than neutral faces as indicated by a significant main effect of Emotion, $F(1,23) = 6.9$, $p = .015$, $\eta_p^2 = 0.23$. Also as a result, the response bias Br tended to be more liberal for fearful than neutral faces as indicated by the near-significant main effect of Emotion, $F(1,23) = 3.7$, $p = .067$, $\eta_p^2 = 0.14$. So if anything, participants had a greater tendency to respond 'old' to fearful than to neutral faces regardless of their true old/new status.

See the right panel of Fig. 4 for the RTs for correct responses to fearful and neutral new and old faces. Although the pattern of results was the same as in Study 1, none of the main and interaction effects were significant, all Fs < 2.2, all ps $> .15$, all η_p^2s < 0.085.

6.3. Event-related potentials

See Fig. 5 for the ERP waveforms in the four conditions (top right panel) and the scalp topographies of the differences between conditions

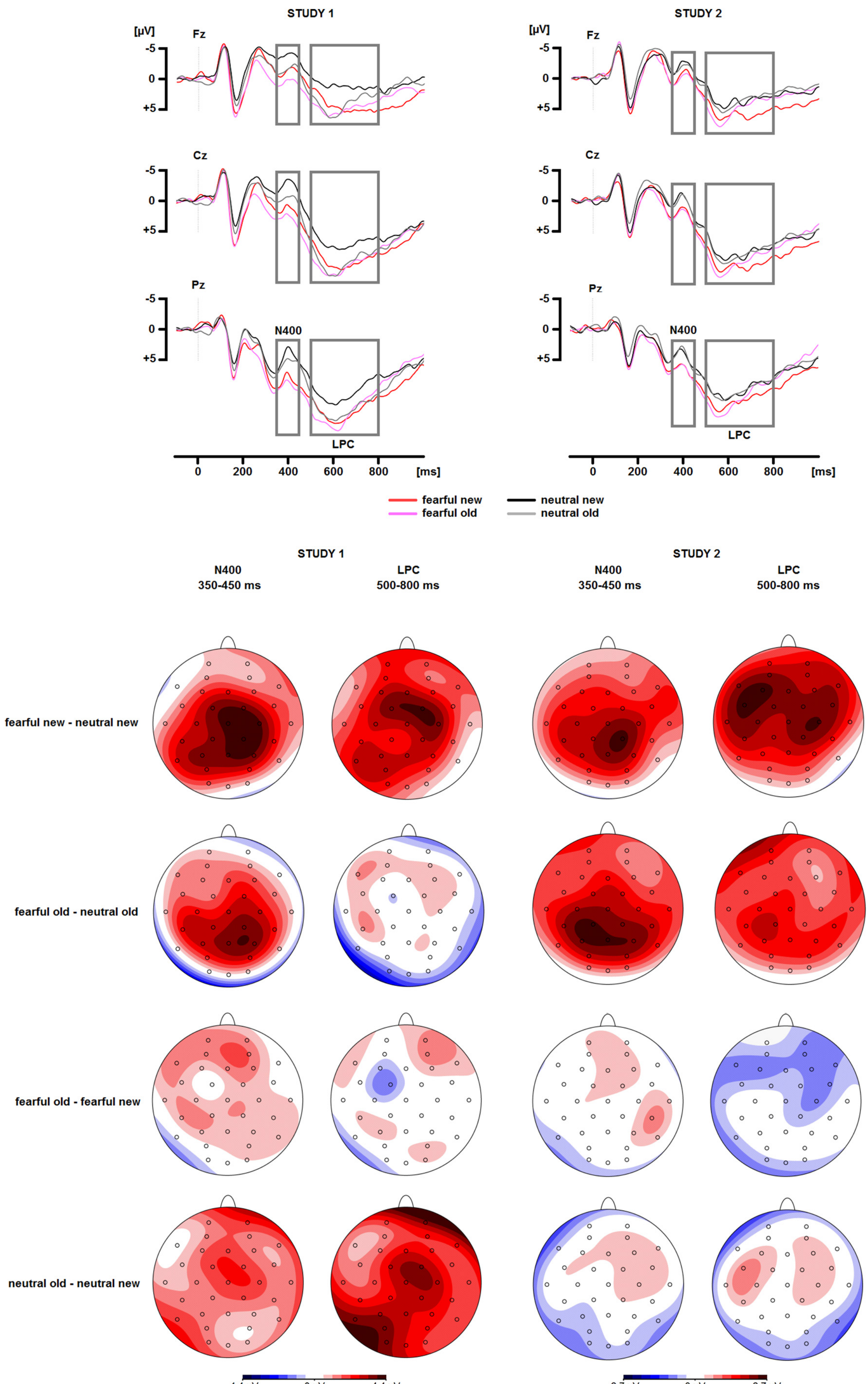

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Fig. 5. Top panel Event-related potentials at midline electrodes in response to fearful new, fearful old, neutral new, and neutral old faces (correct responses only) in both studies. The grey boxes indicate the time windows analyzed. Positive plotted downwards. Bottom panel Scalp topographies of the differences between conditions in both studies.

Table 1
Overview of significance of rmANOVA effects on the ERP in both studies.

	Study 1		Study 2	
	350–450 ms	500–800 ms	350–450 ms	500–800 ms
Main effect of Emotion	*	*	*	*
Main effect of Old/New	*			
Emotion * Old/New interaction		*		

Note.
* $p < .05$, see Result section for details. None of the interactions involving the factor Electrode were significant.

(bottom right panel). See Table 1 for an overview of the significance of the effects. In the 350–450 ms time window, there was a main effect of Emotion, $F(1,23) = 8.6$, $p = .007$, $\eta_p^2 = 0.27$, indicating that the ERP was more positive in response to fearful than neutral faces. None of the other effects involving the factors Emotion and/or Old/New (including interactions involving the factor Electrode) were significant, all $Fs < 1.4$, all $ps > .26$. So, although the scalp topographies, see Fig. 5, suggest that the emotion effect had a centroparietal maximum, this effect was not significantly different between electrodes Fz, Cz, and Pz.

In the 500–800 ms time window, there was a main effect of Emotion, $F(1,23) = 4.9$, $p = .036$, $\eta_p^2 = 0.18$, indicating that the ERP was more positive in response to fearful than neutral faces. None of the other effects involving the factors Emotion and/or Old/New (including interactions involving the factor Electrode) were significant, all $Fs < 1$, *ns*, indicating that there was no LPC old/new effect. In addition, although the scalp topographies, see Fig. 5, suggest that the emotion effect had a frontocentral maximum, this effect was not significantly different between electrodes Fz, Cz, and Pz. The planned comparisons replicated the finding from Study 1 that the reason for the absent LPC old/new effect was that the ERP was more positive in response to fearful new than neutral new faces, $p = .033$, but not for old faces, $p = .144$.

6.4. Correlations

See the four right columns of Table 2 for the correlations between the ERP old/new effects and task performance. There was a negative correlation between the N400 old/new effect and the false alarm rate for fearful faces. There was also a positive correlation between the N400 old/new effect and the discrimination index Pr for fearful faces. These two correlations indicate that a greater N400 old/new effect for fearful faces was associated with fewer false alarms and better old/new discrimination for fearful faces. To explore whether these associations were mediated by valence or arousal ratings, Pearson correlation coefficients were computed between the N400 old/new effect (old-new, collapsed across Fz, Cz, and Pz) for fearful faces on the one hand, and the valence and arousal ratings for fearful faces on the other hand. These correlations were not significant, both $r(22)s > -.35$, both $ps > .095$, which means that the associations between the N400 old/new effect for fearful faces on the one hand and the false alarm rate and old/new discrimination for fearful faces on the other hand were not mediated by valence or arousal ratings.

In addition, there were negative correlations between the LPC old/new effect for fearful faces and the hit rate, false alarm rate, and response bias Br for fearful faces. These three correlations indicate that a greater LPC old/new effect for fearful faces (in the typical direction of a greater positivity for old than new stimuli) was associated with lower hit and false alarm rates, and a more conservative response bias, for fearful faces. Or in other words: a greater *inverse* LPC old/new effect for fearful faces (i.e., a greater positivity for new than old stimuli) was associated with higher hit and false alarm rates, and a more liberal the response bias, for fearful faces. To explore whether these associations were mediated by valence or arousal ratings, Pearson correlation coefficients were computed between the LPC old/new effect (old-new, collapsed across Fz, Cz, and Pz) for fearful faces on the one hand, and the valence and arousal ratings for fearful faces on the other hand. These correlations were not significant, both $r(22)s > -.17$, both $ps > .43$, which means that the associations between the LPC old/new effect for fearful faces on the one hand and the hit rate, false alarm rate, and response bias for fearful faces on the other hand were not mediated by valence or arousal ratings.

7. Discussion

The research question was how fearful facial expressions affect recognition memory. To this end, young adult participants in two studies viewed fearful and neutral faces in a continuous recognition paradigm while their electroencephalogram was recorded. Participants indicated by button presses whether each face was presented for the first ('new') or the second time ('old'). Valence and arousal ratings collected in Study 2 showed that the fearful faces were relatively low arousing (4.5

Table 2
Correlations between the N400 and LPC old/new effects (old-new, collapsed across Fz, Cz, Pz) on the one hand and task performance (H, FA, Pr, Br) on the other hand in both studies, separately for fearful and neutral faces.

	Study 1				Study 2			
	N400 old/new effect		LPC old/new effect		N400 old/new effect		LPC old/new effect	
	Fearful	Neutral	Fearful	Neutral	Fearful	Neutral	Fearful	Neutral
H	$r(17) = .31$ $p = .198$	$r(17) = .20$ $p = .411$	$r(17) = -.26$ $p = .279$	$r(17) = .18$ $p = .471$	$r(22) = -.18$ $p = .402$	$r(22) = .14$ $p = .512$	$r(22) = -.45$* $p = .027$	$r(22) = .18$ $p = .408$
FA	$r(17) = .19$ $p = .441$	$r(17) = .12$ $p = .613$	$r(17) = .07$ $p = .780$	$r(17) = .27$ $p = .262$	$r(22) = -.58$* $p = .003$	$r(22) = -.11$ $p = .622$	$r(22) = -.59$* $p = .002$	$r(22) = .03$ $p = .883$
Pr	$r(17) = .14$ $p = .561$	$r(17) = .13$ $p = .609$	$r(17) = -.31$ $p = .192$	$r(17) = .05$ $p = .837$	$r(22) = .43$* $p = .037$	$r(22) = .20$ $p = .352$	$r(22) = .18$ $p = .399$	$r(22) = .13$ $p = .543$
Br	$r(17) = .20$ $p = .413$	$r(17) = .24$ $p = .314$	$r(17) = -.09$ $p = .724$	$r(17) = .37$ $p = .118$	$r(22) = -.40$ $p = .051$	$r(22) = .00$ $p = .993$	$r(22) = -.51$* $p = .012$	$r(22) = .12$ $p = .590$

Note. H = hit rate, FA = false alarm rate, Pr = discrimination index, Br = response bias.
* $p < .05$ (uncorrected for multiple comparisons).

on a 1–9 scale), which is in line with the arousal ratings for angry faces in a previous study (Langeslag and Van Strien, 2018) and with the notion that emotional faces (and words) are less arousing than emotional pictures (Keil, 2006). Most importantly, participants still felt more unpleasant and aroused when viewing the fearful than the neutral faces, which is in line with the intended manipulation of facial expression.

The hit rate (i.e., proportion 'old' responses to old stimuli) was higher for fearful than neutral faces in both studies (significant in Study 1) and so was the false alarm rate (i.e., proportion 'old' responses to new stimuli) (significant in both studies). As a result, the discrimination index was lower for fearful than neutral faces in both studies (significant in Study 2) and the response bias was more liberal for fearful than neutral faces (significant in Study 1 and trend in Study 2). Despite the differences between the studies in whether effects reached significance or not, the emerging pattern is identical. That is, participants had a greater tendency to (incorrectly) respond 'old' to fearful than neutral faces, which resulted in worse old/new discrimination for fearful than neutral faces. This pattern is opposite to the emotion enhancement effect on memory (Hamann, 2001; Phelps, 2004), but in correspondence with the liberal response bias for emotional information (Ochsner, 2000; Windmann and Kutas, 2001). In line with previous findings (Righi et al., 2012) and with the liberal response bias for fearful faces, participants in both studies were also quicker to correctly decide that fearful compared to neutral faces were old, but slower to correctly decide that fearful compared to neutral faces were new (significant in Study 1). Although previous studies have observed enhanced recognition memory for fearful faces (Fischer et al., 2007; Righi et al., 2012; Rohr et al., 2017; Sergerie et al., 2006; Wang, 2013), a liberal response for fearful faces has been observed instead in prior research as well (Rohr et al., 2017). Interestingly, the latter study examined the role of spatial frequencies in recognition memory for emotional faces and found that low spatial frequencies drive the enhanced recognition memory for fearful faces, whereas high spatial frequencies drive the liberal response bias for fearful faces.

The ERP in the 350–450 ms time window was less negative (or: more positive) in response to old than new faces in Study 1, which is the N400 old/new effect (Rugg and Allan, 2000). No N400 old/new effect was observed at the group level in Study 2. Individual differences did occur, suggesting that some participants in Study 2 showed an N400 old/new effect while others did not. Specifically, participants who had a greater N400 old/new effect for fearful faces made fewer false alarms for fearful faces and hence showed better old/new discrimination for fearful faces. It is unclear why these associations occurred for fearful faces and in Study 2 only. But the associations between the N400 old/new effect and lower false alarm rates and better old/new discrimination are in line with the notion that the N400 old/new effect reflects familiarity (Curran and Clearly, 2003; Van Strien et al., 2005; Weymar et al., 2009). The ERP in the 350–450 ms time window was also more positive in response to fearful than neutral faces in both studies. Important for the current research question is that we found no evidence of emotional modulation of the N400 old/new effect in either of the two studies, which is in accordance with several previous studies that used stimuli other than fearful faces (Johansson et al., 2004; Langeslag and Van Strien, 2008; Weymar et al., 2009) and with the notion that emotion does not affect familiarity (Ochsner, 2000). Even though the N400 old/new effect in a previous study was enhanced for faces that were presented with fearful compared to happy and neutral expressions during encoding and with a neutral expression during retrieval (Righi et al., 2012), the current findings suggest that familiarity as reflected by the N400 old/new effect is not influenced by fearful facial expressions when faces are presented with the same expression during encoding and retrieval and in a continuous recognition paradigm.

The ERP in the 500–800 ms time window was more positive in response to neutral old than neutral new faces in Study 1, which is the LPC old/new effect (Rugg and Allan, 2000) for neutral faces but not for fearful faces. Individual differences occurred in Study 2 (discussed below), suggesting that some participants in Study 2 showed an LPC old/new effect while others did not. The absence of an LPC old/new effect for fearful faces at the group level in both studies was due to a positivity for fearful new compared to neutral new faces. Even though the LPC old/new effect was larger for emotional than neutral words, pictures, faces (and negative words, pictures, and faces in particular) in multiple previous studies (Dietrich et al., 2001; Inaba et al., 2005; Johansson et al., 2004; Langeslag and Van Strien, 2008; Pérez-Mata et al., 2012; Weymar et al., 2009), several other previous studies have observed a reduced or even inversed LPC old/new effect for emotional compared to neutral words or pictures because of a positivity for new emotional compared to new neutral stimuli (Langeslag and Van Strien, 2008; Maratos et al., 2000; Van Strien et al., 2009). The current study now demonstrates a similar effect for fearful faces. The reduced ERP old/new effect for emotional stimuli because of a greater positivity for new emotional than new neutral stimuli has been linked to the liberal response bias for emotional stimuli (Windmann and Kutas, 2001). The individual differences observed in Study 2 are in line with this suggestion. Specifically, participants who had a greater *inverse* LPC old/new effect for fearful faces (i.e., a greater positivity for new than old fearful faces) made more hits and false alarms for fearful faces, and hence had a more liberal response bias for fearful faces. So it seems that the emotional salience of fearful new faces as reflected by an ERP positivity is mistaken for a feeling that the stimulus was old, resulting in an increased false alarm rate and liberal response bias for fearful faces. It should be noted that, since accuracy was around 80% in both studies, not enough trials were available to analyze ERP responses to false alarms. A previous study, however, showed an even larger ERP emotion effect for false alarms than correct rejections, thereby solidifying the link between the ERP positivity in response to emotional stimuli and the liberal response bias (Windmann and Kutas, 2001). Thus, in line with the notions that emotion boosts recollection more than familiarity (Ochsner, 2000) and that false memories can be accompanied by recollection (Brainerd and Reyna, 2002), the positivity for new emotional compared to new neutral stimuli in the time window of the LPC (rather than the N400) suggests that false memories of emotional stimuli, including fearful faces, are accompanied by a sense of recollection.

It has been suggested that inconsistent findings regarding the emotional modulation of ERP old/new effects are due to differences between studies in arousal level, stimulus type, retention interval duration, and memory paradigm (e.g., continuous vs. study-test recognition, and incidental vs. intentional encoding) (Dolcos et al., 2020; Weymar and Hamm, 2013). The current study involved relatively low arousing facial stimuli and a continuous recognition task that inherently has a short retention interval and intentional encoding. It would be interesting to test if the current findings replicate when using a study-test recognition paradigm, a longer retention interval, and/or incidental encoding.

This study has some limitations. First, facial identity was not balanced between fearful and neutral faces in Study 1. But because the pattern of results was similar in Study 2, in which facial identity was balanced between expressions, it is unlikely that facial identity confounded the findings of Study 1. Second, the sample sizes of both studies were relatively small. Importantly, we conducted two independent studies and based our main conclusions only on effects that occurred in both studies, which supports the replicability of those effects and hence reduces the chance that they are spurious. Third, it is unclear why no LPC old/new effect for neutral faces and no N400 old/new effects for fearful or neutral faces were observed in Study 2. The absence of those old/new effects, however, was not due to an increased positivity for new stimuli, while the absence of an LPC old/new effect for fearful faces in both studies was. So our conclusion remains the same. Fourth, the correlations between the ERP old/new effects and task performance occurred in Study 2 only and should be interpreted with caution until they are replicated in future studies.

To conclude, by keeping facial expression balanced between encoding and retrieval, we found support for the hypothesized pattern of a more liberal response bias for fearful than neutral faces and a related reduced LPC old/new effect because of an enhanced positivity for fearful new faces. The current findings suggests that people are more likely to (mistakenly) think that they have encountered a person before when the person looks scared compared to non-emotional. Besides relevance for everyday life, this also has implications for forensic situations such as police lineups.

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