An ERP study on the time course of emotional face processing

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Received 25 November 2001; accepted 10 January 2002

Using event-related brain potentials (ERPs), we investigated the time course of facial expression processing in human subjects watching photographs of fearful and neutral faces. Upright fearful faces elicited a frontocentral positivity within 120 ms after stimulus presentation, which was followed by a broadly distributed sustained positivity beyond 250 ms post-stimulus. Emotional expression effects were delayed and attenuated when faces were inverted. In contrast, the face-specific N170 component was completely unaffected by facial expression. We conclude that emotional expression analysis and the structural encoding of faces are parallel processes. Early emotional ERP modulations may reflect the rapid activation of prefrontal areas involved in the analysis of facial expression. *NeuroReport* 13:1–5 © 2002 Lippincott Williams & Wilkins.

Key words: Emotion; Emotional expressions; Event related potentials; Face processing

INTRODUCTION

Emotions represent important evolutionary adaptations that produce specific bodily responses, aimed at preparing the organism for survival-related behaviour [1]. In primates, the identification of emotions is also important for the regulation of social behaviour. Facial expressions provide the most important cues to emotional states in other individuals. Single cell, neuroimaging, and lesion studies have shown that orbitofrontal cortex and the amygdala play a prominent role in the processing of facial emotional expressions [2], and that other prefrontal areas, the right anterior cingulate, right inferior parietal cortex, ventromedial occipitotemporal cortex, inferotemporal cortex, and the hippocampus are also involved in the analysis of faces and facial expressions [3–5]. However, little is known about the time course of these processes. Given the biological and social significance of emotions, information about emotional states derived from faces should be processed rapidly to be available for the online regulation of behaviour. Event-related potentials are well suited to examine the timing of processes involved in face perception and facial expression analysis. An early face-specific ERP component (N170) has been linked to the pre-categorical structural encoding of faces [6–8]. It is not yet known whether this component is affected by facial expression. ERP modulations sensitive to the emotional significance of stimuli are usually observed at longer latencies. A positive slow wave elicited at about 300 ms after stimulus onset in response to pictures with emotional content [9,10] has been interpreted as reflecting sustained selective attention directed to motivationally relevant input [9].

The purpose of this study was to examine the temporal characteristics of facial expression processing. ERPs were recorded while subjects watched photographs of single faces or houses on a computer screen. Faces were taken from a standard set of pictures of facial affect [11], with facial expression either neutral or fearful (100% intensity). Fearful expressions were chosen because they are salient emotional stimuli, as demonstrated by modulations of cortical regions via the amygdala during fear perception [12,13]. Half of all fearful and neutral faces were presented upright, while the other half was presented upside-down. Because face inversion disrupts the recognition of emotional expression [14,15] ERP modulations produced by the detection and processing of facial expression should be attenuated and/or delayed for inverted relative to upright faces.

MATERIALS AND METHODS

Subjects: Eighteen paid volunteers (12 female), aged 18–34 years (mean 24.4 years) participated in the experiment, which was conducted with the understanding and consent of each participant, and was approved by the Psychology ethics committee.

Stimuli and procedure: Subjects sat in a dimly lit sound attenuated cabin, and a computer screen was placed at a viewing distance of 70 cm. Stimuli were pictures of faces of 10 different individuals and 10 different houses. Faces were either fearful or neutral, and were presented either upright or upside-down, resulting in a total of 40 different face stimuli. Houses were always presented upright. Stimuli

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were presented at the centre of a computer screen, covering a visual angle of $5.5 \times 7.5°$. The experiment consisted of four experimental blocks (115 trials each). In 100 trials, single upright fearful faces, upright neutral faces, inverted fearful faces, inverted neutral faces, and houses were presented in random order, with equal probability, and without immediate stimulus repetitions. In the remaining 15 trials, the stimulus presented on the previous trial was repeated. Subjects had to respond with a right-hand button press to these immediate stimulus repetitions, and to refrain from responding on all other trials. Stimuli were presented for 300 ms, and were separated by an internal interval of 1 s.

ER-P recording and data analysis: Recordings were made from Ag-AgCl electrodes and linked-earlobe reference at Fpz, F7, F3, Fz, F4, F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, T5, P3, Pz, P4, T6, and Oz (according to the 10–20 system), and from OL and OR (located halfway between O1 and T5, and O2 and T6, respectively). Horizontal EOG (HEOG) was recorded bipolarly from the outer canthi of both eyes. Electrode impedance was kept $<5\,\text{k}\Omega$. Amplifier bandpass was 0.1–40 Hz. EEG and EOG were sampled with a digitisation rate of 200 Hz. ERP analyses were conducted relative to a 100 ms pre-stimulus baseline, and were restricted to non-repetition trials. Trials with eyeblinks, lateral eye movements, or overt responses were excluded. The onset of emotional expression effects was determined by comparing ERPs elicited by fearful and neutral faces with paired *t*-tests conducted successively for each sampling point in the 300 ms time interval following stimulus onset (separately for upright and inverted faces; see Table 1). ERP mean amplitudes were analysed separately for upright and inverted faces by repeated measures ANOVAs within six successive post-stimulus time intervals (110–150 ms; 155–200 ms; 205–250 ms; 255–450 ms; 455–700 ms; 705–1000 ms) for the factors stimulus orientation (upright *vs* inverted), emotional expression (fearful *vs* neutral), electrode site, and recording hemisphere (left *vs* right). N170 components elicited by faces *vs* houses, and by fearful *vs* neutral faces were compared by analysing ERP mean amplitudes and peak latencies at T5 and T6 between 160 and 200 ms post-stimulus.

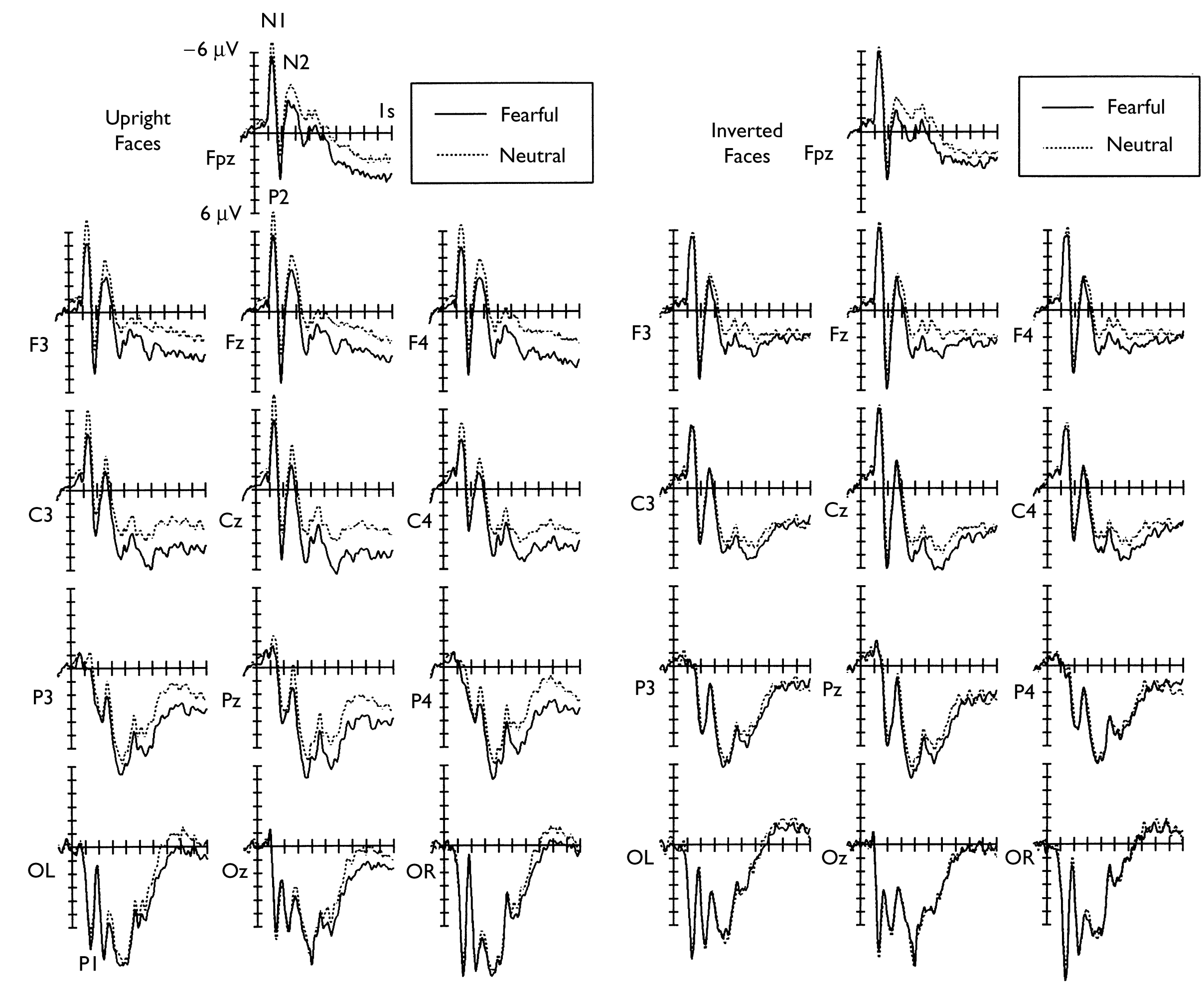

Fig. 1. Grand-averaged ERP waveforms in response to fearful faces (solid lines) and neutral faces (dashed lines), displayed separately for upright faces (left) and inverted faces (right).

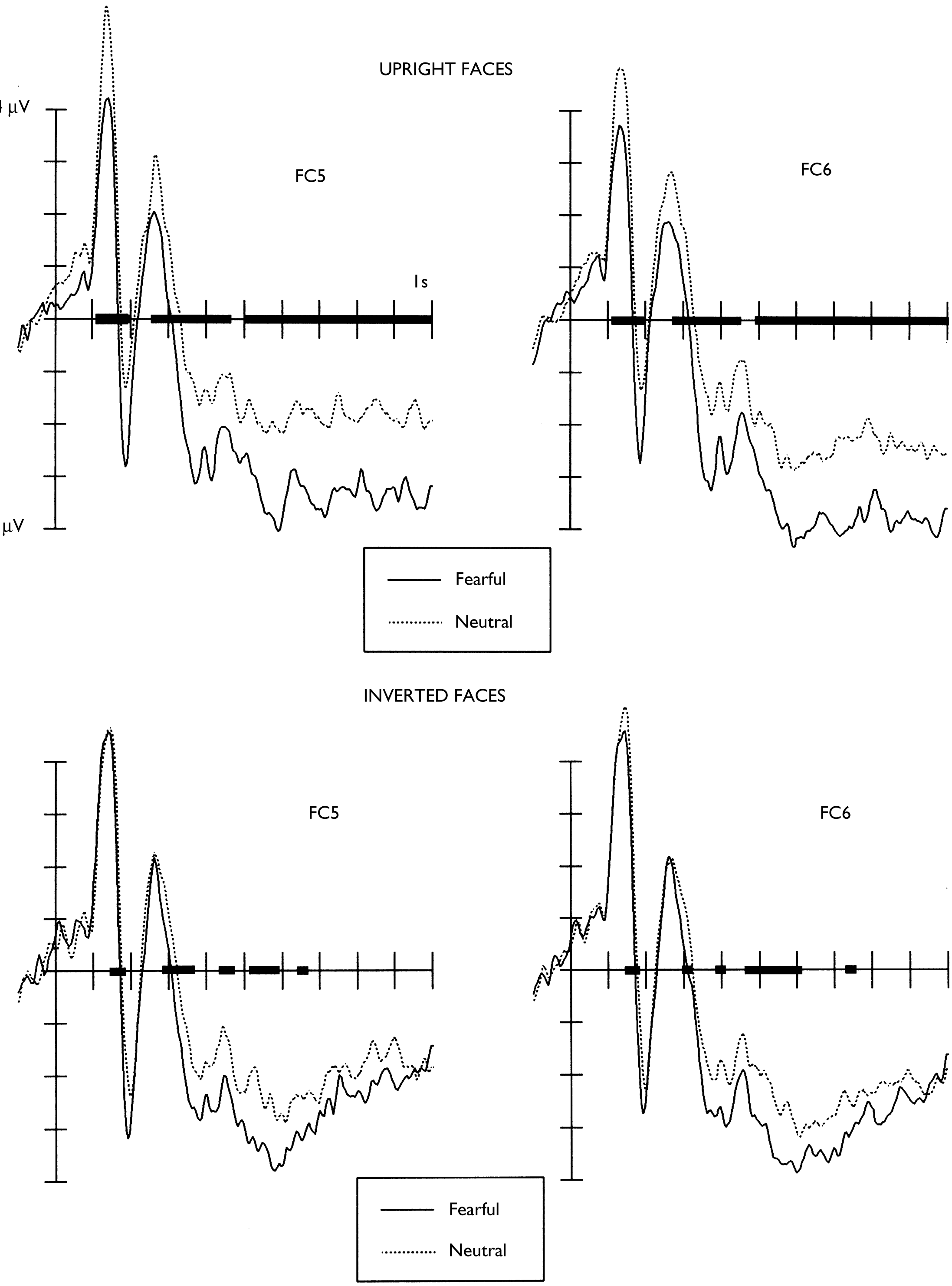

Fig. 2. Grand-averaged ERPs elicited by fearful faces (solid lines) and neutral faces (dashed lines) at FC5 (left hemisphere) and FC6 (right hemisphere), displayed separately for upright faces (top) and inverted faces (bottom). The line markers along the x-axes indicate the time intervals where ERPs differed significantly for ≥ 6 successive sampling points (as determined by two-tailed paired *t*-tests).

RESULTS

Subjects detected 86% of immediate stimulus repetitions (mean response time: 607 ms). False alarms to non-repeated stimuli occurred on 1.2% of all trials. Figure 1 shows ERPs in response to fearful faces (solid lines) and neutral faces (dashed lines) for upright faces (left) and for inverted faces (right). ERPs to fearful faces were more positive than ERPs elicited by neutral fares. Figure 2 illustrates the time course of these emotional expression effects for upright and inverted faces at left and right frontocentral electrodes (FC5/6). For upright faces, reliable ERP differences between fearful and neutral faces started 115 ms after stimulus onset (Table 1), reflected by a significant emotional expression effect in the 110–150 ms latency interval at all frontocentral electrodes (all $F(1,17)>12.3$, all $p<0.01$). Frontocentral emotional expression × stimulus orientation interactions (all $F(1,17) > 4.9$, all $p<0.05$) indicated that emotional expression effects were absent for inverted faces in this latency range (Table 1). In the subsequent measurement window (155–200 ms), enhanced positivities for fearful faces were found at all frontocentral electrodes and at Pz for upright and for inverted faces (all $F(1,17)>10.5$, all $p<0.01$). Between 205 and 250 ms post-stimulus, these effects disappeared, but reappeared after 250 ms. For upright faces, emotional expression effects were reliable frontocentrally between 250 and 1000 ms, and were present at posterior electrodes between 455 and 1000 ms (all $F(1,17)>5.3$, all $p<0.05$). For inverted faces, enhanced positivities for fearful faces were elicited at frontal electrodes between 255 and 700 ms, and at central sites between 450 and 700 ms (all $F(1,17)>6.7$, all $p<0.01$). No hemispheric differences were observed for these emotional expression effects.

Figure 3 shows ERPs elicited at lateral posterior electrodes T5 and T6 in response to upright fearful faces, neutral faces, and houses (upper panel), and to inverted fearful and neutral faces (bottom panel). Faces elicited enhanced N170 components when compared to houses ($F(1,17)=39.5$, $p<0.001$), and this component was delayed for inverted relative to upright faces (183 ms *vs* 178 ms; effect of stimulus orientation on N 170 peak latencies: $F(1,17)=7.7$; $p<0.02$). Importantly, N170 amplitudes and latencies were entirely unaffected by the facial expression of either upright or inverted faces (all $F > 1$).

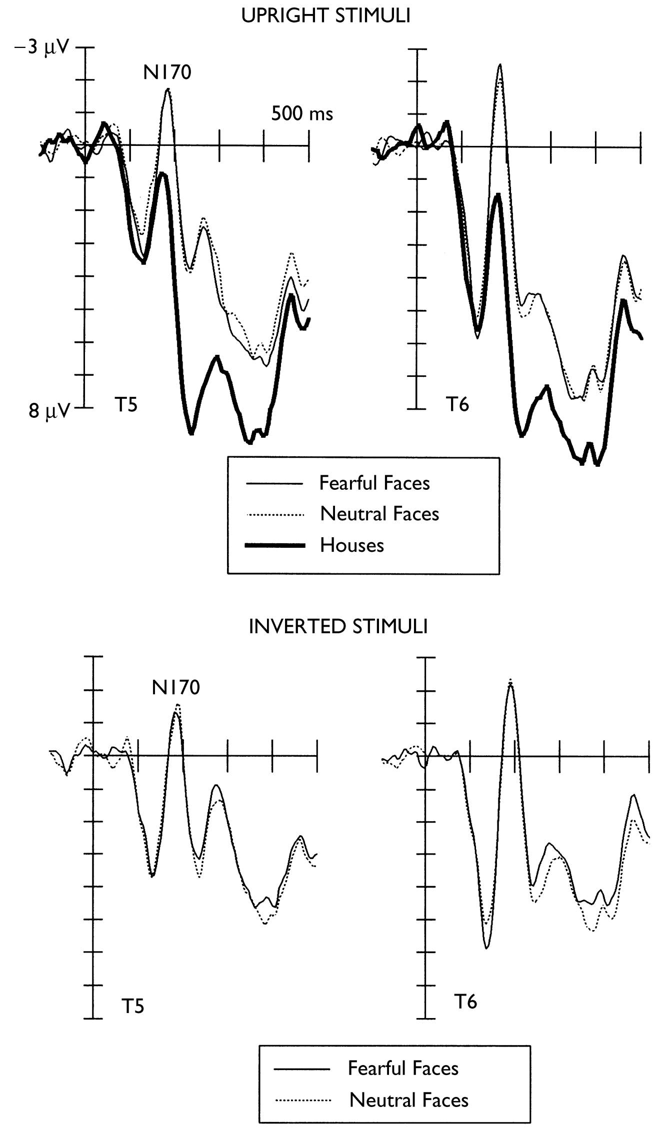

Fig. 3. Grand averaged ERPs elicited at lateral posterior electrodes T5 (left hemisphere) and T6 (right hemisphere). Upper panel: ERPs to upright fearful faces (thin solid lines), neutral faces (dashed lines), and houses (thick solid lines). Bottom panel: ERPs to inverted fearful faces (solid lines) and neutral faces (dashed lines).

DISCUSSION

The present ERP data demonstrate that the emotional facial expression is analysed rapidly and can affect cortical processing at very short latencies. A frontocentral positivity was elicited by upright fearful faces within the first 120 ms after stimulus presentation. This early emotional expression effect was smaller and delayed by about 40 ms for inverted faces, suggesting that face inversion results in a disruption

Table I. Onset of early emotional expression effects (in ms post-stimulus).

Frontal	Fpz	F7	F3	Fz	F4	F8	FC5	FC6	
Upright	115	115	115	110	110	115	110	115	
Inverted		160	155	155	165	150	155	155	155
Central	T7	C3	Cz	C4	T8	CP5	CP6		
Upright	125	110	115	120	145	115	135		
Inverted	–	155	155	160	–	–	–		
Posterior		T5	P3	Pz	P4	T6	OL	Oz	OR
Upright	–	260	255	255	–	270	–	–	
Inverted	–	–	–	–	–	–	–	–	

Latency values were determined on the basis of two-tailed paired *t*-tests comparing ERPs elicited by fearful and neutral faces for each sampling point in the 300 ms interval after stimulus onset. Effect onset was defined as the latency where ERPs started to differ significantly for at least six successive sampling points. Estimated onsets are displayed separately for upright and inverted faces. No latency value (–) indicates that no reliable early emotional expression effect was observed at a given electrode site.

and/or delay of the initial analysis of emotional facial expression. In previous ERP studies investigating emotional processing with non-face stimuli, positive potentials to emotionally significant stimuli were observed at latencies beyond 300 ms post-stimulus, presumably indicating sustained attention directed to emotionally relevant input [9]. This late positivity was also found in the present study. It was present throughout the 1000 ms analysis epoch with upright faces, but was attenuated and shorter-lived for inverted faces, suggesting that face inversion also disrupts the attentional processing of emotional faces. Such differences in early and late emotional expression effects between upright and inverted faces demonstrate that these effects are not simply caused by low-level visual feature differences between fearful and neutral faces, since these features are not affected by face inversion.

It has been argued that emotional faces have to be analysed to the level of facial identity before their emotional significance can be evaluated by specialised brain systems [2]. The present findings do not support this hypothesis. The early emotional expression effect observed in this study preceded previously reported ERP correlates of face recognition [16–18] by about 200 ms, suggesting that the detection of facial expression does not depend on face identification. This is in line with neuropsychological evidence demonstrating that the processing of facial expression and identity are at least partially independent [19,20]. The tract that the N170 component, which reflects the structural encoding of faces, was entirely unaffected by facial expression in the present experiment also indicates that structural encoding and the analysis of facial expression may operate independently, and in parallel.

Overall, results suggest that the detection and analysis of the emotional significance of faces consists of an initial rapid registration of facial expression (reflected by an early frontocentral positivity), which is followed by an extended attentive processing of emotional faces (reflected by later sustained emotional expression effects). The early emotional positivity might reflect the rapid activation of prefrontal areas involved in the detection of emotionally significant events. Converging evidence for this assumption comes from studies reporting early modulations of ERP waveforms in response to liked and disliked faces [21], and of early MEG responses during a facial emotion recognition task [22]. A recent single case patient study [23] found differential responses of single neurons in the right ventral prefrontal cortex to neutral and aversive scenes at latencies comparable to the onset of early emotional expression effects observed in the present study. An important question that has to be clarified in future research is whether the early emotional expression effects observed here are specifically elicited by fearful faces, or whether other types of emotional facial expressions similarly elicit rapid brain responses.

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Acknowledgements: This study was supported by Unilever Research. The authors thank Heijo van de Werf for technical assistance.