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Event-related brain potential correlates of emotional face processing

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Abstract

Results from recent event-related brain potential (ERP) studies investigating brain processes involved in the detection and analysis of emotional facial expression are reviewed. In all experiments, emotional faces were found to trigger an increased ERP positivity relative to neutral faces. The onset of this emotional expression effect was remarkably early, ranging from 120 to 180 ms post-stimulus in different experiments where faces were either presented at fixation or laterally, and with or without non-face distractor stimuli. While broadly distributed positive deflections beyond 250 ms post-stimulus have been found in previous studies for non-face stimuli, the early frontocentrally distributed phase of this emotional positivity is most likely face-specific. Similar emotional expression effects were found for six basic emotions, suggesting that these effects are not primarily generated within neural structures specialised for the automatic detection of specific emotions. Expression effects were eliminated when attention was directed away from the location of peripherally presented emotional faces, indicating that they are not linked to pre-attentive emotional processing. When foveal faces were unattended, expression effects were attenuated, but not completely eliminated. It is suggested that these ERP correlates of emotional face processing reflect activity within a neocortical system where representations of emotional content are generated in a task-dependent fashion for the adaptive intentional control of behaviour. Given the early onset of the emotion-specific effects reviewed here, it is likely that this system is activated in parallel with the ongoing evaluation of emotional content in the amygdala and related subcortical brain circuits.

Keywords: Face processing; Emotion; Emotional facial expression; Event-related brain potentials; Cognitive affective neuroscience

1. Introduction

The investigation of emotional states, their neural correlates, and their role for the regulation of cognition and action is now one of the most active research areas in cognitive neuroscience (see Adolphs, 2003; Dolan, 2002, for reviews). On the most general level, emotional states are evolutionary adaptations that are critically involved in the regulation of basic survival mechanisms, and in the control of behaviour in complex environments (Damasio, 1999). A number of complementary methods, such as single cell recordings, functional brain imaging, or neuropsychological investigations of focal brain damage have been used to identify brain structures that are involved in the perception and analysis of emotionally significant information, mediate bodily emotional responses, and control social cognition and behaviour.

Many recent studies have investigated the neural network underlying emotional processing by measuring brain responses to emotionally salient stimuli. Differences in brain responses to stimuli that vary in their emotional content have been interpreted as evidence for functional specialisation among neural processes responsible for the processing of emotional information. Such studies have revealed a complex interconnected network of brain structures responsible for the analysis of emotional events. This network includes higher order sensory cortices, where perceptual representations of emotionally relevant stimuli are formed, and the amygdala, orbitofrontal cortex, and ventral striatum, where such sensory representations appear to be classified in terms of their emotional significance. It also includes paralimbic and higher cortical areas such as somatosensory cortex, anterior cingulate, and medial prefrontal cortex, where conscious representations of emotional states are generated, which can be used in the strategic control of behaviour in complex social situations, and in the planning of future goals and actions (see Adolphs, 2003, for more details).

Emotional facial expressions are particularly salient stimuli for conveying important nonverbal communications to other species members, and, in humans, are immediate indicators of affective dispositions in other people. Because of this paramount

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emotional significance of facial expression, numerous recent functional imaging, lesion, and single-cell recording studies have used emotional faces to identify neural substrates of emotional processing. These studies have found that brain areas generally involved in the processing of emotional information (see above) are also activated during the processing of facial emotion. The initial perceptual analysis of faces takes place in inferior occipital cortex ('occipital face area'; see Rossion et al., 2003) and in the middle fusiform gyrus for structural properties of faces which determine face identity (Hoffman & Haxby, 2000; for reviews, see Haxby, Hoffman, & Gobbini, 2000; Gobbini & Haxby, 2006, this issue). The superior temporal sulcus is involved in the processing of dynamic aspects of faces, such as facial expression, eye and mouth movements (Allison, Puce, & McCarthy, 2000; see also Puce, Epling, Thompson, & Carrick, 2006, this issue). A rapid evaluation of the emotional and motivational significance of facial expression appears to be mediated by the amygdala and orbitofrontal cortex, while structures such as the anterior cingulate, prefrontal cortex and somatosensory areas are linked to the conscious representation of emotional facial expression for the strategic control of thought and action, as well as to the production of concomitant feeling states (see Adolphs, 2003, for more details).

In summary, recent neuroscientific investigations of emotional processing have uncovered components of a complex network for the detection and analysis of emotionally significant information. Since most of these recent studies have used fMRI measures, which are based on relatively slow hemodynamic brain responses to emotional stimuli, information about the time course of emotional processing has been relatively scarce. The availability of detailed temporal information is necessary to obtain a more comprehensive picture of the functional properties of the emotional brain. Thus, fMRI measures need to be complemented with methods that provide insights into temporal parameters of emotional processing, such as event-related brain potential (ERP) or magnetoencephalographic (MEG) measures.

This paper reviews a series of recent studies in our lab that have used ERP measures to investigate the processes involved in the detection and analysis of emotional facial expression. In Section 2, we will introduce ERP correlates of emotional face processing by discussing differential ERP responses to fearful versus neutral faces. Section 3 will review ERP modulations triggered by other basic emotional expressions. In Section 4, we will present ERP results that support the hypothesis that the structural encoding of faces and the detection of their emotional expression represent parallel and independent processes. Section 5 will discuss the impact of selective attention on ERP responses elicited by emotional facial expression, and Section 6 will briefly review recent findings concerning the impact of the spatial frequency content on such emotional expression effects. Overall, the studies reviewed in this paper will demonstrate that ERPs represent a useful tool to study the time course and the functional properties of emotional face processing stages, such as their automaticity, specificity, and sensitivity to attentional states. Perhaps most importantly, our studies have shown that although selective brain responses to emotional faces, as measured with ERPs, are triggered at very short latencies, they are strongly dependent on attention. This suggests that they are not directly linked to the initial automatic detection of emotional content mediated by the amygdala and related structures, but rather to subsequent, cognitively penetrable stages of emotional processing.

2. ERP correlates of emotional face processing: fearful faces

The basic question addressed in our initial study (Eimer & Holmes, 2002) was when and how the difference between emotional and neutral facial expressions would be reflected in ERP waveforms. We recorded ERPs while participants viewed photographs of single fearful faces, neutral faces, or houses, which were presented at the centre of a computer screen. As in all other studies reported below, fearful and neutral faces were taken from a standard set of pictures of facial affect (Ekman & Friesen, 1976). Participants' task was to detect infrequent immediate repetitions of identical stimuli across successive trials. Half of all fearful and neutral faces were presented in their standard upright orientation, while the other half was presented upside-down. Because face inversion disrupts not only face identification, but also to some degree the recognition of emotional facial expression (de Gelder, Teunisse, & Benson, 1997; Searcy & Bartlett, 1996), we expected ERP modulations indicative of the detection and processing of facial expression to be attenuated and possibly also delayed in response to inverted relative to upright faces.

Fig. 1 shows ERPs triggered in response to fearful faces and neutral faces, for faces presented in their usual upright orientation (top panel), and for inverted faces (bottom panel). An enhanced positivity was present for ERPs to fearful relative to neutral faces, and this difference started remarkably early. For upright faces, significant differences between fearful and neutral faces started 120 ms after stimulus onset (Fig. 1, top panel). When faces were presented upside-down (Fig. 1, bottom), the onset of this enhanced positivity for fearful as compared to neutral faces was delayed. The time course and scalp topography of these emotional expression effects is further illustrated in Fig. 2, which shows ERP scalp distribution maps for mean difference amplitudes, obtained by subtracting ERP waveforms in response to neutral faces from ERPs triggered by fearful faces within six successive post-stimulus latency windows. In these maps, enhanced positivities for fearful relative to neutral faces are shown in red colours, while blue colours indicate that amplitude differences were small or absent. Emotional positivities for upright fearful faces (Fig. 2, top panel) consisted of an early frontocentrally distributed effect (triggered between 110 and 200 ms after stimulus onset), and a more broadly distributed effect that started at about 250 ms post-stimulus, and remained present throughout the 1000 ms analysis interval. Emotional expression effects triggered by upside-down faces were substantially delayed and also attenuated (Fig. 2, bottom panel). They only emerged beyond 150 ms post-stimulus, and disappeared beyond 700 ms.

These ERP results suggest that emotional facial expression is analysed rapidly and can affect cortical processing at very short