

Event related potentials and the perception of intensity in facial expressions

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Abstract

It is well known from everyday experience, that facial expressions of emotions can very much vary in intensity, e.g. ranging from mild anger to rage, or from uneasiness and mild fear to angst and panic. However, the effect of different intensities of facial expressions of emotion on event related potentials has yet not been studied. We therefore investigated 16 healthy participants with a gender decision task to male and female faces displaying angry, disgusted and fearful facial expressions varying in intensity (50%, 100%, 150%). Analysis of ERP data showed a significant increase in amplitude of the N170 by intensity, but not by type of emotion. The intensity induced negative variation was most pronounced between 200 and 600 ms at electrodes P9 and P10. For this time segment, there was a clear linear relationship between intensity and degree of negative deflection. A dipole source localisation of the intensity effect using the difference waveform (150% minus 50% intensity) revealed two symmetrically positioned generators within the inferior temporo-occipital lobe. An emotion specific effect for disgust was further found at temporal electrode sites (FT7 and FT8) at around 350–400 ms. Results are summarised in a two-phase model of emotion recognition, suggesting the existence of an initial monitoring process which codes saliency of incoming facial information. In a second step, the specific emotional content of faces is decoded in emotion specific recognition systems.

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1. Introduction

The human face is an important source of social signals. It reveals the individual's identity and expresses, if not controlled intentionally, the inner feelings of our counterparts. The importance of facially transmitted signals in guiding interpersonal behaviour is reflected in the complex functional architecture of psychological processes, which is based on a widely distributed neural network, specifically dedicated to decode these information.

One of the most influential models of face processing (Bruce & Young, 1986) suggests an initial structural encoding process, which is followed by separable pathways for processing identity and facial expressions of emotions. Whilst, within this model, identity processing is highly elaborated and fractionated into distinct sub-processes, emotion recognition is represented only as a single and undifferentiated process.

Neuropsychological research in the past decade, however, has added substantially to the understanding of the psychological sub-processes as well as the neural substrates underlying facial emotion recognition.

Deficits in recognising fearful facial expressions after damage to the amygdala have first been described by Adolphs, Tranel, Damasio, and Damasio (1994). These initial findings have since been replicated by numerous neuropsychological studies investigating people with lesions or functional deficits to the amygdala (Broks et al., 1998; Calder et al., 1996; Meletti et al., 2003; Sato et al., 2002; Sprengelmeyer et al., 1999). Functional imaging studies could further show, that recognition of fearful faces is based on a spatially distributed neural network, involving superior colliculi, thalamic relay nuclei, striate and extrastriate regions, as well as the amygdala (e.g. Breiter et al., 1996; Fischer et al., 2003; Morris et al., 1996). Within this network, a fast sub-cortical processing route targeting the amygdala and a slow thalamo-cortical processing route is proposed. The fast processing route forms part of an evolutionary old system which is able to respond rapidly, automatically, and without conscious awareness to signals of threat and danger (LeDoux, 1996).

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Evidence for the fast route in humans comes from both single case (De Gelder, Vroomen, Pourtois, & Weiskrantz, 1999) and functional imaging studies (Morris et al., 1998; Morris, De Gelder, Weiskrantz, & Dolan, 2001).

A different pattern of results comes from studies looking at recognition of facial expressions of emotion in people with pre-clinical as well as clinical Huntington's disease (Gray, Young, Barker, Curtis, & Gibson, 1997; Hennenlotter et al., 2004; Sprengelmeyer et al., 1996; Sprengelmeyer, Schroeder, Young & Epplen, 2006; Sprengelmeyer et al., 1997b; Wang, Hoosain, Yang, Meng, & Wang, 2003). Participants with this disorder were particularly impaired in recognising facial expressions of disgust. Other disorders such as Parkinson's disease (Sprengelmeyer et al., 2003), Tourette's syndrome, Obsessive Compulsive disorder (Sprengelmeyer et al., 1997a), and Wilson's disease (Wang et al., 2003) were also associated with deficits in facial disgust recognition. Furthermore, functional imaging studies (Hennenlotter et al., 2004; Phillips et al., 1997; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998) reported the involvement of the basal ganglia and insula in recognising facial expressions of disgust. But in contrast to fear, there is no evidence for a fast processing route for disgust.

While the association between amygdala and insular-striatal regions and recognition of fear and disgust is supported by numerous studies, there is only one study linking the nucleus accumbens with recognition of facial expressions of anger (Calder, Keane, Lawrence, & Manes, 2004).

However, neuropsychological and functional imaging studies are not able to tell anything about the time course of face processing. To investigate these aspects in detail, various ERP studies have been conducted so far. The most prominent deflection of face related potentials is the N170, first described by Bentin, Allison, Puce, Perez, and McCarthy (1996) and Bötzel, Schulze and Stodieck (1995). Although questioned in the past (Rossion, Curran & Gauthier, 2002; see Bentin & Carmel, 2002 for response), the N170 is now thought to represent the face specific structural encoding process as hypothesised by the Bruce and Young model.

Other studies looked particularly at the ERP modulation associated with processing of facial expressions of emotions. Eimer and Holmes (2002) reported a positive fronto-central ERP component within 200 ms after stimulus onset when comparing neutral with fearful facial expressions. Batty and Taylor (2003) investigated the effect of happy, surprised, fearful, sad, disgusted and angry compared to neutral facial expressions on ERPs and found an overall emotion effect on the N170 and emotion specific modulation of ERPs in the 220–450 ms time window at fronto-central sites. An emotion specific N230 at posterior sites to happy, fearful, sad, angry, and surprised compared to neutral faces was reported by Balconi and Pozzoli (2003).

Interpretation of these data is straightforward as long as this is done in a static framework of 'basic emotions'. If done so, the results clearly indicate emotion specific processing of facial expressions as early as 200 ms after stimulus onset.

Facial expressions, however, differ not only in respect to the kind of emotion, but also in respect to saliency, that is,

how intense a particular emotion is displayed. Given, that ERP responses reflect both kinds of information, the question arises, where and when is this information processed? Existing ERP literature cannot answer this question beyond pure speculation, since intensity in facial expressions has never been controlled for, reported ERP effects therefore could either indicate emotion specific processing, or processing of intensity, or a mixture of both.

To address this neglected issue, the present study aims to investigate the effect of different intensities of emotional facial expressions on ERPs. In addition, by using the neuropsychologically well-researched basic emotions fear, disgust, and anger, the study also aims to look for ERP components associated with cognitive processing within emotion specific face recognition systems.

2. Methods

2.1. Participants

Sixteen healthy participants (6 female, 10 male) free of neurologic and psychiatric disorders gave written informed consent to take part in the study. The mean age of the participants was 27.7 years (S.D. 6.7). All subjects had normal or corrected-to-normal vision and received payment for their participation (£10). Participants were randomly chosen from a healthy population, resulting in more male than female participants. Since we were investigating general aspects of emotion processing and not concerned about and interested in any gender differences, all participants were included in the analysis without balancing for gender.

2.2. Stimuli and apparatus

The stimuli were presented on a CRT Monitor controlled by a personal computer. Responses were recorded using two buttons mounted horizontally 10 cm apart on a response panel in front of the participant. Left and right key press responses were made with the index fingers of the left and right hand, respectively. The stimuli were computer-manipulated photographs of three different facial expressions (anger, disgust, and fear) varying in intensity (50%, 100%, 150%). These expressions were posed by each of eight models (four females, four males). All stimuli used were taken from the FEEST (for more and detailed information, see Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002). Viewing distance was held constant at 1 m (Fig. 1).

2.3. Procedure and design

The experiment started with a practice block (36 trials) followed by 10 experimental blocks (with 72 trials in each block). Participants were asked to respond to the gender of the face stimulus presented on the screen. Half of the participants pressed the left key for female and the right key for male faces, the other half received the reverse mapping. A trial started with the presentation of a fixation cross for 500 ms, followed by the face stimulus, which was presented until a response was made. 1500 ms after a response was registered the next trial started. Face stimuli were presented individually and in random order.

2.4. Electrophysiological recordings

Using a BIOSEMI Active-Two amplifier system electroencephalographic (EEG) activity was continuously recorded from 70 Ag/AgCl electrodes including electrodes for recording of horizontal and vertical eye movements. Two additional electrodes (common mode sense (CMS) active electrode and driven right leg (DRL) passive electrode) were used as reference and ground electrodes, respectively; cf. www.biosemi.com/faq/cms&drl.htm). EEG and EOG recordings were sampled at 256 Hz. Off-line, the continuous EEG record

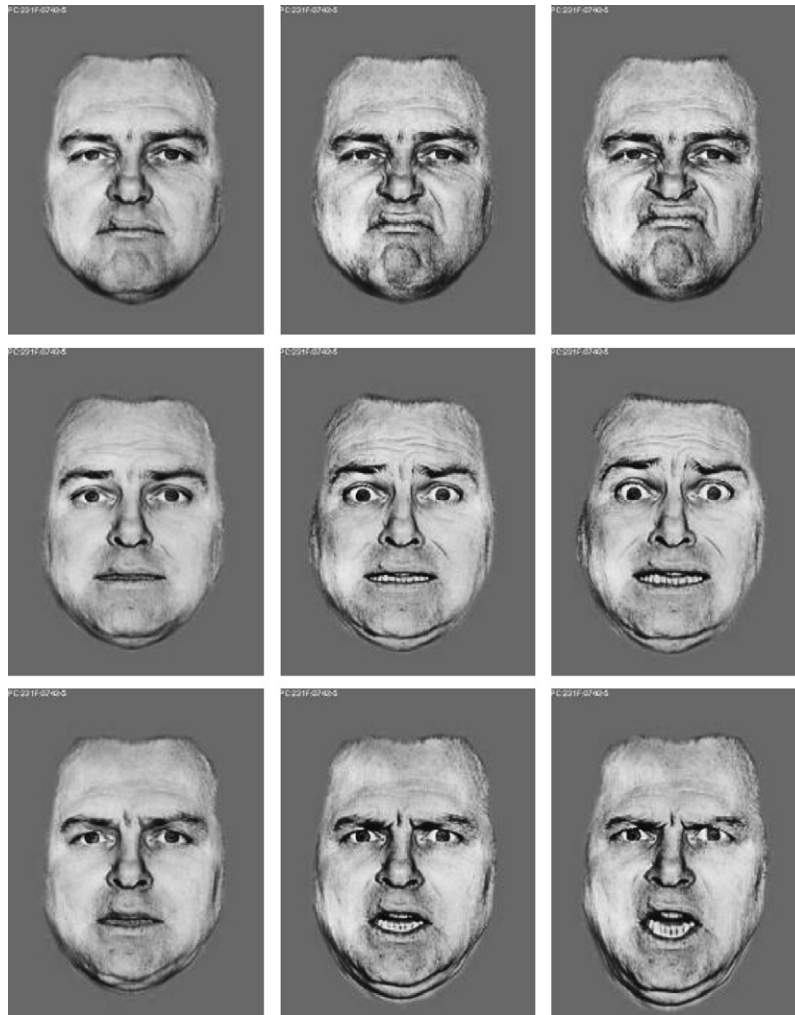


Fig. 1. Examples of stimuli used in the experiment. Top row: disgust; middle row: fear; and bottom row: anger. First column: 50% intensity; second column: 100% intensity; third column: 150% intensity.

was separated into epochs of 1000 ms duration, synchronized with the stimulus onset, containing 200 ms pre-stimulus activity. Trials containing blinks and eye movements were corrected using a dipole approach (BESA 2000) and trials containing any EEG artefacts or incorrect responses were not considered for analysis. Epochs were baseline corrected using a 200 ms pre-stimulus baseline, filtered (band-pass 0.01–10 Hz, 6 dB/oct), averaged time-locked to the presentation onset of the face stimulus, and re-referenced to average reference.

3. Results

3.1. Behavioural data

Only trials with a correct response and with RT between 200 and 2000 ms were included in analyses of RT and error rate. Statistical analyses were performed by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA) including the within-subject variables expression (anger, disgust, fear), and intensity (50%, 100%, and 150%).

Mean reaction times and error rates are shown in Table 1. A two-way ANOVA including the factors emotion and intensity did not reveal any significant effects, neither in reaction time ($F_s < 1.9$, $p_s > 0.17$), nor in error rates ($F_s < 2.6$, $p_s > 0.06$).

3.2. Event-related brain potentials

ERP activity was quantified by mean amplitude measures in subsequent time segments: 90–110 ms (P1), 160–180 ms (N170), 200–250 ms, 250–300 ms, 300–350 ms, 350–400 ms, and 400–600 ms. The two early time intervals are chosen around the peaks of the P1 and the N170 component. We decided for 20 ms intervals (instead of the larger intervals for later latencies) because of the shorter duration (higher frequency) of these early components. All signals were averaged separately for experimental conditions and aligned to a 200 ms baseline

Table 1

Mean correct reaction time and error rate for the different intensities (50%, 100%, and 150%) and face expressions (anger, disgust, fear)

	Reaction time (ms)			Errorrate(%)		
	Anger	Disgust	Fear	Anger	Disgust	Fear
50%	475	469	475	3.4	2.0	1.8
100%	478	473	481	3.0	2.0	3.2
150%	484	476	477	2.7	3.0	3.5

Table 2

F-values and significance levels for the ANOVA of the ERP time segments including the factors electrode site (*S*), emotion (*E*), and intensity (*I*)

	d.f.	<i>F</i>						
		P1	N170	200–250 ms	250–300 ms	300–350 ms	350–400 ms	400–600 ms
<i>S</i>	63, 945	10.3***	42.0***	6.3***	8.4***	13.4***	23.6***	39.8***
<i>E</i> × <i>S</i>	126, 1890	1.2	1.2	0.9	1.2	1.1	1.5*	1.1
<i>I</i> × <i>S</i>	126, 1890	1.1	3.1***	3.9***	4.9***	3.3***	2.4**	2.8***
<i>E</i> × <i>I</i> × <i>S</i>	252, 3780	1.0	0.9	0.9	1.0	1.0	1.1	0.9

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

starting 200 ms before stimulus onset. Statistical analyses were performed on ERP data by means of Huynh-Feldt corrected repeated measures analyses of variance (ANOVA) for each time segment including the factors expression, intensity, and electrode site (64 locations). Note that because the average reference sets the mean activity across all electrodes to zero, any condition effect is only meaningful in interaction with electrode site. Therefore, any condition effect reported here, will be in interaction with electrode site.

The results of this analysis are shown in Table 2. A clear effect of intensity was found in the N170 and all subsequent analysis intervals. Post hoc analyses revealed that this effect was largest over parietal-occipital scalp regions. Fig. 2 depicts the average waveforms for the three intensities on P9 and P10 electrodes (top panel). In order to better visualise the intensity effect, two difference waves (100% minus 50%, and 150% minus 50%) were calculated and are shown in Fig. 2 (bottom panel). Fig. 3 (top) shows the distribution of this intensity effect across scalp locations. A spatio-temporal dipole source model using the difference wave (150% minus 50%) was determined in an analysis interval of 200–300 ms relative to stimulus onset using brain electrical source analysis (BESA) software.

An initial principal component analysis (PCA) of the activity revealed that a single principal component could account for over 97% of the variance in this time interval. Therefore, one pair of single equivalent dipoles, symmetrical in location was fitted using a four-shell spherical head model. Talairach coordinates of these dipoles were $x = 46.3$; $y = -63.6$; $z = -6.7$, and $x = -46.3$; $y = -63.6$; $z = -6.7$, respectively, which located these dipoles in Brodmann area 19/37. The results are shown in Fig. 3 (bottom).

As shown in Table 2, there was a significant effect of emotion in the time segment 350–400 ms. *Post hoc* analyses (Bonferroni corrected pairwise comparisons (*t*-tests)) revealed this effect to be maximal over temporal electrode sites (FT7 and FT8, respectively), due to a larger negativity for disgust as compared to anger and fear (see Fig. 4).

4. Discussion

The aim of this study was twofold; first, we were very much interested in how psychophysically controlled variations of intensity of facial expressions of emotions might impact on ERPs. The second aim of the study was to look for ERP

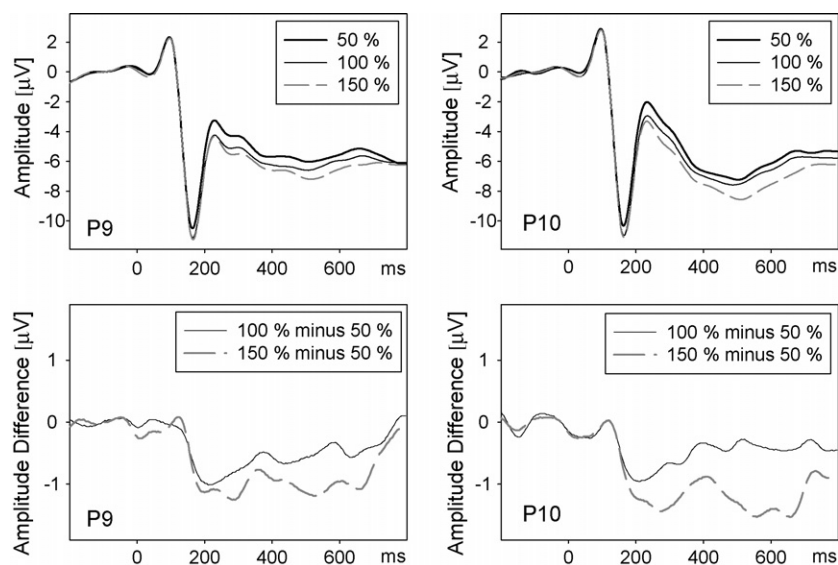


Fig. 2. Top panel: grand mean event-related potentials at electrode sites P9 and P10 superimposed for the three intensities (50%, 100%, and 150%) of expressed emotion. Bottom panel: ERP difference waveforms showing the effects of intensity on electrode sites P9 and P10. The difference waves for the intensities (100% minus 50%) and (150% minus 50%) are superimposed.

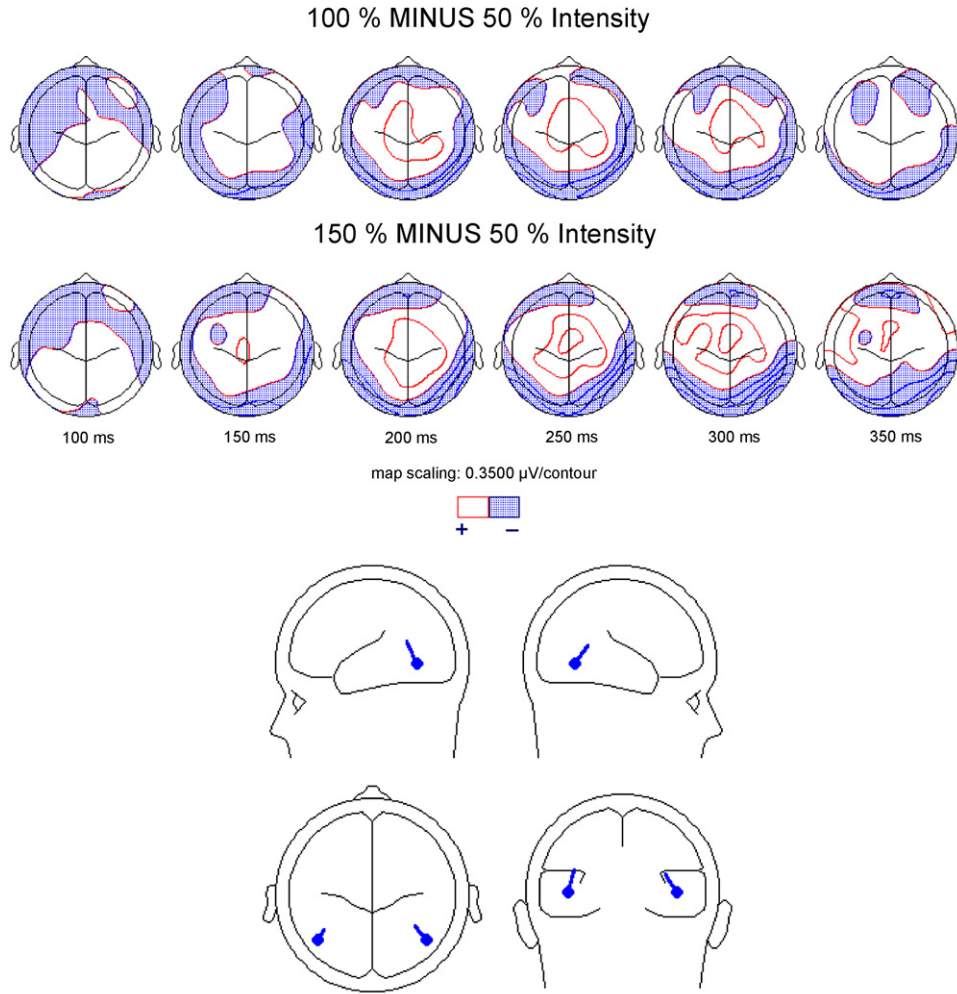


Fig. 3. Top panel: voltage maps (110° projection, spherical spline interpolation) showing the topographical distribution of the intensity effects across the scalp at different time points relative to the stimulus onset. Bottom panel: dipole source localisation results of the intensity effect using the difference waveform (150% minus 50% intensity).

components associated with activation of emotion specific face recognition systems.

To address these questions, we investigated healthy subjects with a gender decision task to male and female faces taken from an established and validated battery (Young et al., 2002). These faces differed in respect to emotions (anger, fear, and disgust) as well as to the degree of intensity, to which these emotions were

displayed (50%, 100%, 150%). We decided for anger, fear, and disgust, because facial expression recognition of these emotions were most intensely researched in the recent past, and because there are hypotheses about the neuroanatomical substrates associated with these emotions.

Looking first at the behavioural data, there were no significant effects in respect to the rate of errors or the speed participants

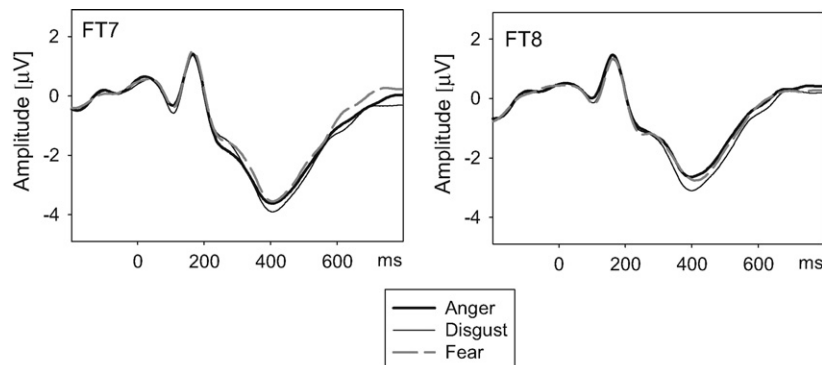


Fig. 4. Grand mean event-related potentials at electrode sites FT7 and FT8 for disgust, anger and fear.

responded to the stimuli. It should be noted, that significant effects were not expected, since participants had to concentrate on the gender of the people presented on the screen and not on their emotional facial expression or intensity of facial expressions.

We now turn to the ERP data. Although there is a large body of evidence from neuropsychological single case and group studies as well as functional imaging studies, indicating separable emotion specific face recognition systems, there is not very much supporting evidence for these systems from our study. The only indication for the existence of one of these systems (the disgust recognition system) is a significant ERP activation differentiating disgust from fear and anger, which we found in the time window between 350 and 400 ms over temporal electrode sites. This finding is in accordance with neuropsychological and functional imaging studies, which highlight the insula cortex and the basal ganglia as the neuroanatomic site implicated in disgust recognition. There was no ERP component being associated with information processing within a proposed fear or anger recognition system. One reason for this rather sparse evidence could be that emotion recognition systems are predominantly associated with deep cerebral structures, which are particularly difficult to investigate with electrophysiological methods.

The more surprising were the ERP data in respect to the intensity, a particular emotion was displayed. Statistical analysis revealed a significant intensity of emotion effect in the face specific N170 component and in all subsequent time intervals, most prominent over parieto-occipital scalp regions (P9 and P10). That is, the more intense an emotion was expressed, the more negative was the deflection of the ERP (see Fig. 2). Since very early visual components such as the P1 were not influenced by intensity of expressed emotion, this effect cannot be explained by differences in low level stimulus attributes for the different intensity conditions. A dipole source analysis showed that this intensity effect was produced by two symmetrically positioned generators within the temporo-occipital region of the right and left hemisphere (see Fig. 3, bottom panel).

Although a number of ERP studies found, depending on reference system and electrode site, positive or negative variations to emotional facial expressions compared to neutral facial expressions, a close link between intensity of emotional facial expressions and the degree of negative deflection has not yet been reported.

It is early on to speculate about the function of this component, but we consider this worthwhile, because it may help to generate testable hypothesis and to guide future research.

The first question concerns the cognitive domain that the negative deflection is associated with. Given, that the dipole source analysis revealed a generator in secondary visual areas (Brodmann area 19/37), it is reasonable to assume, that the deflection is functionally linked to the visuo-perceptual system.

The second question is whether the negative slow wave indicates a form of basic categorization of randomly presented visual stimuli into three perceptual classes. Although not finally ruled out, this possibility seems unlikely, since the negative deflection was specifically linked to increments of intensity of emotional facial expressions (50%, 100%, 150%), and not to the kind of

expression (anger, fear, disgust) *per se*. We therefore think, that this ERP component could represent an early higher order rather than a low level perceptual process.

Specific aspects of this process will be discussed later in the framework of the Bruce and Young model; for the time being, we tentatively suggest, that this process might be involved in coding saliency of certain external stimuli.

The third question derives from this speculation and asks whether a process assumed to code saliency of external stimuli is involved in both object and face recognition, or in face recognition alone. Our data, which are entirely based on face processing, do not allow to answer this question. However, particularly interesting findings are reported by Schupp, Junghöfer, Weike, and Hamm (2003), who used positively and negatively valenced non-facial pictures from the International Affective Picture System—IAPS (Lang, Bradley, & Cuthbert, 1999), rated either as high-arousing or low-arousing. We would like to note, that arousal normally refers to a complex physiological response of the organism after perceptual processing has taken place. Since we were interested in early perceptual processing, we decided to use the term emotional saliency instead of arousal to describe the perceptual properties of the IAPS-stimuli. Schupp and co-workers could show, that emotionally high-salient pictures produced a stronger posterior negativity than emotionally low-salient pictures, irrespective of valence. This effect started around 200 ms and lasted for several hundred ms. The neuroanatomical site of this effect was further investigated by Sabatinelli, Bradley, Fitzsimmons, and Lang (2005) in an fMRI study using stimuli from the IAPS. The authors could show an increase in activation in the inferior temporo-occipital lobe to emotionally high-salient compared to emotionally low-salient pictures.

It is noteworthy, that time course as well as neuroanatomical location of the effect reported by Schupp and co-workers and Sabatinelli and co-workers is remarkably similar to the intensity effect reported in our paper. Future research will show, whether or not the negativity to emotionally high-salient scenes and the negativity to salient facial expressions of emotions reflect the same underlying neurocognitive process. If this holds true, we have to deal with a system, which (1) emits a physiological response evoked by seeing something emotionally salient, as well as (2) a physiological response evoked by seeing a different person's facial expression seeing something emotionally salient. This could point to the possible existence of a mirror neuron system for coding emotional saliency of visual stimuli. The existence of such a system would not come as a particular surprise: a similar mirror neuron system for processing disgust has been described already by Wicker et al. (2003).

Alternative explanations are also possible. It may well be, that, despite intriguing psychophysiological similarities, coding of emotional saliency in complex visual scenes, and coding saliency in facial expressions of emotions are based on separate processes. In this case, coding of saliency in faces would best be described as a process, in which the deviation of a given face from an average face is analysed. It would be interesting to investigate, whether the latter process is also involved in identity recognition.

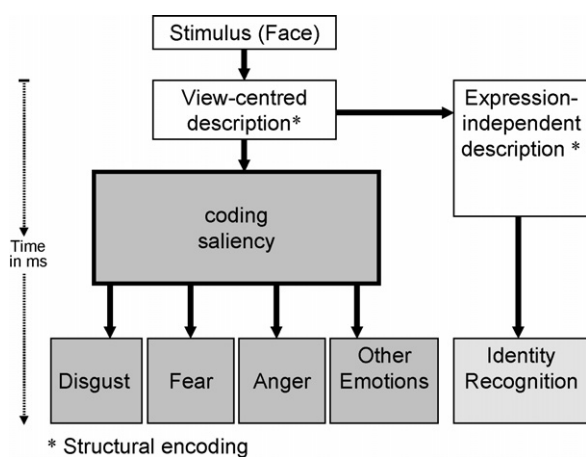


Fig. 5. Two-phase model of emotion recognition (see dark grey boxes). Phase 1 represents the initial monitoring process that codes saliency of incoming (structural encoded) facial information. In phase 2, the specific emotional content of faces is analysed in emotion specific recognition systems. The light grey box represents the very much simplified identity recognition system. White boxes represent the structural encoding stage, whose information is fed into the emotion and identity recognition systems.

For illustration, a face recognition model, incorporating the idea of Bruce and Young (1986) of separate processing streams for facial emotion and facial identity recognition is shown in Fig. 5. In this figure, processes involved in facial emotion recognition are summarised as a two-phase model of emotion recognition.

In the original Bruce and Young model, structural encoding entails two different sub-processes, the work-out of a ‘view centred description’, then followed by the ‘expression independent description’. According to this model, facial expression analysis is based on the ‘view centred description’, while identity recognition is based on the ‘expression independent description’. Since structural encoding is considered to be associated with the N170, the time course of our ERP data indicate, that the process responsible for the negative deflection to intensity of facial expressions of emotions seems to partly overlap and then follow the structural encoding stage. Our data further indicate, that the process which codes emotional saliency seems to precede information processing within the ‘slow route’ of emotion specific face recognition systems, starting (at least in respect to facial disgust) at around 300–350 ms (see also Krolak-Salmon et al., 2003). This does not preclude the possibility of information processing within the proposed ‘fast route’ of the fear recognition system (Krolak-Salmon, Hénaff, Vighetto, Bertrand, & Maguière, 2004). However, for the sake of simplicity, speculations about the interactions between both processing routes and possible gating effects of the ‘fast route’ on the ‘slow route’ are not included in Fig. 5.

How can the process which codes emotional saliency be described in cognitive terms? If we follow the logic outlined above, it is most likely, that the raw material this process is working on are view centred descriptions of a face. We therefore formulate the preliminary working hypothesis, that the process in question may represent a kind of template matching, in which a view centred description of a face is compared with a stored

description of a face in respect to its emotional saliency. Since the electrophysiological response to varying degrees of intensity of facial expressions lasts for the duration of the whole analysis epoch until 800 ms, it is likely, that the sustained negativity reflects continued perceptual monitoring. It could further be speculated, that the negative deflection mirrors cognitive resources devoted to attend and process situations preferentially, which are signalled by salient emotional facial expression. This assumption makes sense from an evolutionary point of view, in that emotionally intense facial expressions indicate potentially negative or positive situations, which might require an immediate response. The assumption, that coding emotional saliency represents an early visuo-cognitive monitoring process is supported by its neuroanatomical location in the posterior portion of the ventral pathway.

Taken together, we report for the first time an ERP component indicating an early cognitive process particularly responsive to increments in intensity of facial expressions of emotions, but not sensitive to the kind of emotions. We assume, that this process is functionally located between structural encoding and emotion specific facial expression recognition. Future research, whose direction is outlined in the second half of the discussion section, will determine the function of this process and its exact location within the face recognition system more precisely.

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