

Brain potentials reveal the timing of face identity and expression judgments

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Abstract

Event-related brain potentials (ERPs) were recorded from multiple scalp locations from young human subjects while they performed two different face processing tasks. The first task entailed the presentation of pairs of faces in which the second face was either a different view of the first face or a different view of a different face. The subjects had to decide whether or not the two faces depicted the same person. In the second task, pairs of faces (frontal views) were presented with the task of judging whether the expression of the second face matched that of the first face. Incongruous faces in the view (identity) matching task gave rise to a negativity peaking at about 350 ms with a frontocentral maximum. This effect was similar to the N400 obtained in linguistic tasks. ERP effects in the expression matching task were much later and had a different distribution. This pattern of results corresponds well with neuropsychological and neuroimaging data suggesting specialized neuronal populations subserving identity and expression analysis but adds a temporal dimension to previous investigations. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Event-related potential; Face processing; Humans; Identity; Expression

1. Introduction

Neuropsychologists have described a condition, prosopagnosia, which is characterized by a selective loss of the ability to identify faces (Bodamer, 1948; Meadows, 1974; Damasio et al., 1982). Recent developments have suggested that face processing can be further subdivided as in addition to such patients that lack the ability to identify faces patients have been described that have difficulties to judge expressions and emotions of faces (Kurucz and Feldmar, 1979; Bowers and Heilman, 1984; Bowers et al., 1985; Tranel et al., 1988; Oster et al., 1989; Etcoff and Magee, 1992; Humphreys et al., 1993; Young et al., 1993, 1995, 1996; Adolphs et

al., 1994, 1996; Campbell et al., 1996). Humphreys et al. (1993) pointed out that the ability to process expressions might be further specialized for static and moving faces. When electrical stimulation was used diagnostically in epileptic subjects undergoing presurgical evaluation the areas disrupting the processing of facial affect and facial identity did not overlap (Fried et al., 1982). De Renzi et al. (1989) presented data indicating that the extraction of age information from faces might be impaired as well. Moreover, it has been stressed that the ability to lip-read speech is separate from the expression analysis and might be impaired selectively as well (e.g. Campbell et al., 1986, 1996).

These patient data correspond nicely with results obtained by invasive electrophysiological recordings from monkeys that found cells selective for facial expression to be located in the superior temporal sulcus

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while cells selective for identity tend to be located in the inferior temporal gyrus (Hasselmo et al., 1989; Perrett et al., 1985, 1992; Desimone, 1991; Heywood and Cowey, 1992). Taken together the data from patients and non-human primates support models that assume at least a partial modularity of the human face processing system such as the one marshaled by Bruce and Young (1986) and by Tovee and Cohen-Tovee (1993).

It is therefore a challenge to psychophysiologicals to capture this proposed modularity, the timing and localization of processing routines by means of psychophysiological techniques. In fact, both functional magnetic resonance imaging (fMRI, Puce et al., 1995) and stimulation positron emission tomography (PET, Sergent et al., 1992; Grady et al., 1994) have been employed to investigate face processing. But so far, the emphasis of these studies was on the differences in the activation to faces and non-faces with more intricate questions of face processing left aside. While such techniques have an excellent spatial resolution their temporal resolution is quite low.

The temporal resolution of electrophysiological measures, such as the event-related potential or event-related magnetic fields (e.g. Lu et al., 1991) on the other hand is much higher and they are ideally suited to investigate the timing of the different operations in face processing.

In the current communication the ERP technique was used to assess the timing and distribution of effects related to the processing of facial identity and facial expression. There have been a number of studies that have addressed these questions. For example, Potter and Parker (1989) and Barrett et al. (1988) looked at ERPs to the second face of a pair when it did or did not match the first face in identity. Potter and Parker (1989) described a reduction of a negativity for the stimuli that matched the identity of the first face. This component was likened to the N400 component seen for word stimuli (see, Kutas and Hillyard, 1980; Kutas and Van Petten, 1994; Ganis et al., 1996) in similar paradigms. Barrett et al. (1988) did a similar study employing familiar and unfamiliar faces as stimuli. These authors as well described a negativity to the second face of a pair when it did not match the preceding stimulus. This effect, again interpreted as an N400-like component, was found to be more pronounced for familiar faces. In a second study, Barrett and Rugg (1989) presented pairs of famous faces that had to be matched for occupation (e.g. actors, sport's figures). For non-matching pairs a negativity in the sense of an N400 was found. The studies by Barrett and Rugg (1989), Barrett et al. (1988) and Potter and Parker (1989) used a very low number of electrodes which makes the comparison with the N400 from other domains difficult. Smith and Halgren (1987) re-

ported a study in which subjects had to decide for each of a series of faces whether it belonged to a previously memorized target-set. Non-matching faces gave rise to an N400-like negativity that was maximal over parieto-occipital scalp regions.

As far as the processing of facial expression is concerned, there is only very limited data available. The only study addressing the comparison of facial expressions is the one by Potter and Parker (1989). Subjects had to decide whether the second face of a pair matched the first one in terms of expression. The ERPs showed a later difference in the 490–540 ms time range that was seen only for a right parietal site. Laurian et al. (1991) presented their subjects with a series of faces (displaying a negative emotion, a positive emotion, or a neutral expression) and found that the target P300 was lateralized toward the right when the emotional connotation was defining the target but symmetrical when subjects had to respond to a facial feature.

In the present communication we present two experiments, one addressing identity matching and one addressing expression matching, and will show that both operations give rise to ERP responses differing greatly in timing and distribution.

2. Methods

2.1. Subjects

Two groups of subjects were drawn from the student population of Hannover Medical School, Germany. Group I ($n = 27$, 11 women, age range 20–28, mean 24.7 years) participated in the view matching task, while group II ($n = 27$, 14 women, age range 22–27, mean 25.1 years) participated in the expression matching task. All subjects were right-handed, healthy, and had normal or corrected to normal vision. Subjects were naive with respect to the specific questions investigated. Several additional subjects were rejected from further analysis because of an excessive rate of artifacts (more than 30% rejected trials, see below).

2.2. View matching task

A total of 160 pairs of stimuli were drawn from a base of about 1000 different black and white photos of human faces that were taken specifically for this study. A pair consisted of a frontal and a profile view of a person's face. The expression of the faces was neutral. Half of the people depicted were women, and the set contained 50% young and 50% old faces. The photos were scanned into a computer and the resulting images were edited to a height of 10 cm and a width of 7 cm on a 19-inch video-monitor. The stimuli were arranged to yield the following pairs:

	First stimulus	Second stimulus	Identity
40 pairs	frontal view	profile view	same face
40 pairs	profile view	frontal view	same face
40 pairs	frontal view	profile view	different face
40 pairs	profile view	frontal view	different face

The pairs were presented in a pseudorandom fashion with each face appearing on the video-screen for 600 ms and the stimulus-onset asynchrony between the first and the second face being 1000 ms. The interval between the pairs was varied randomly between 2500 and 3500 ms. The task of the subject was to decide as quickly as possible whether the second stimulus of a pair depicted the same or a different person by pressing one of two buttons held in the left and right hand. The button/hand assignment was counterbalanced across subjects.

2.3. Expression matching task

The stimuli were taken from the same base as for the identity matching task, however, none of the stimuli from the identity task was used in the expression task. Three different expressions were used: smiling, angry, and surprised. Several other expressions were considered but were found to be hard to enact by the persons photographed and difficult to identify unequivocally by several pilot subjects. Three prototypical faces displaying the three expressions were chosen to serve as the first stimulus of the pairs. The following pairs were constructed:

	First stimulus	Second stimulus	Expression
30 pairs	angry	angry	same
30 pairs	angry	smiling or surprised	different
30 pairs	smiling	smiling	same
30 pairs	smiling	angry or surprised	different
30 pairs	surprised	surprised	same
30 pairs	surprised	smiling or angry	different

While the stimuli at the first position always were one of the three faces with the prototypical expressions and thus were repeated, the stimuli at the second position were not repeated. The task of the subjects was to decide as quickly as possible whether the expression of the second stimulus matched the expression of the first stimulus by pressing one of two buttons held in the left and right hand. The button/hand assignment was coun-

terbalanced across subjects. The timing of the stimuli was identical to the identity matching experiment.

2.4. Recording technique

EEG was recorded from all 19 scalp electrodes of the international 10/20 system (Jasper, 1958) using tin electrodes mounted in an electrode cap (Electro-Cap) with reference electrodes placed at the mastoid processes. Additional electrodes were affixed at the right external canthus and at the right lower orbital ridge to monitor eye-movements for later off-line rejection. The bisignals were amplified with a bandpass from 0.01 to 100 Hz, digitized at 250 points per second and stored on magnetic disk. After artifact rejection by an automated procedure using individualized amplitude criteria on the EOG and frontal channels ERPs were averaged for 1024 epochs with a 100 ms prestimulus interval. Subjects with more than 30% of the trials rejected were not included in the further analysis.

The waveforms to the second stimuli were quantified by mean-amplitude measures in successive 100 ms time windows beginning 100 ms poststimulus and ending 800 ms poststimulus relative to a pre-stimulus baseline. These measures were subjected to repeated measures analyses of variance. Since ERP effects are differentially distributed over the scalp, separate analyses were done for the midline (ml; Fz, Cz, Pz), parasagittal (ps; Fp1/2, F3/4, C3/4, P3/4, O1/2), and temporal (te; F7/8, T3/4, T5/6) electrodes with the latter two sets split into an electrode-site and a hemisphere factor. The Greenhouse-Geisser correction for inhomogeneity of covariance was applied whenever applicable. Reported *P*-values are corrected.

3. Results

3.1. View matching task

Reaction times to second faces that showed the same person as the sample stimulus were significantly faster than decisions about different faces (915 ms, S.D. 139 ms vs. 1027 ms, S.D. 162 ms; $F(1,26) = 45.1$, $P < 0.001$). The level of performance was very high (96.7% correct same decisions, 97.1% correct different decisions, $F(1,26) = 0.91$, n.s.).

The grand average waveforms to the second stimulus of a pair are depicted in Fig. 1. The ERPs are characterized by an initial negative deflection at 100 ms with a maximum at frontal and central sites followed by a positivity at around 180 ms. At central, parietal and occipital sites a pronounced positivity was seen lasting of the entire recording epoch. Starting at about 150 ms the ERPs to the stimuli depicting different faces were

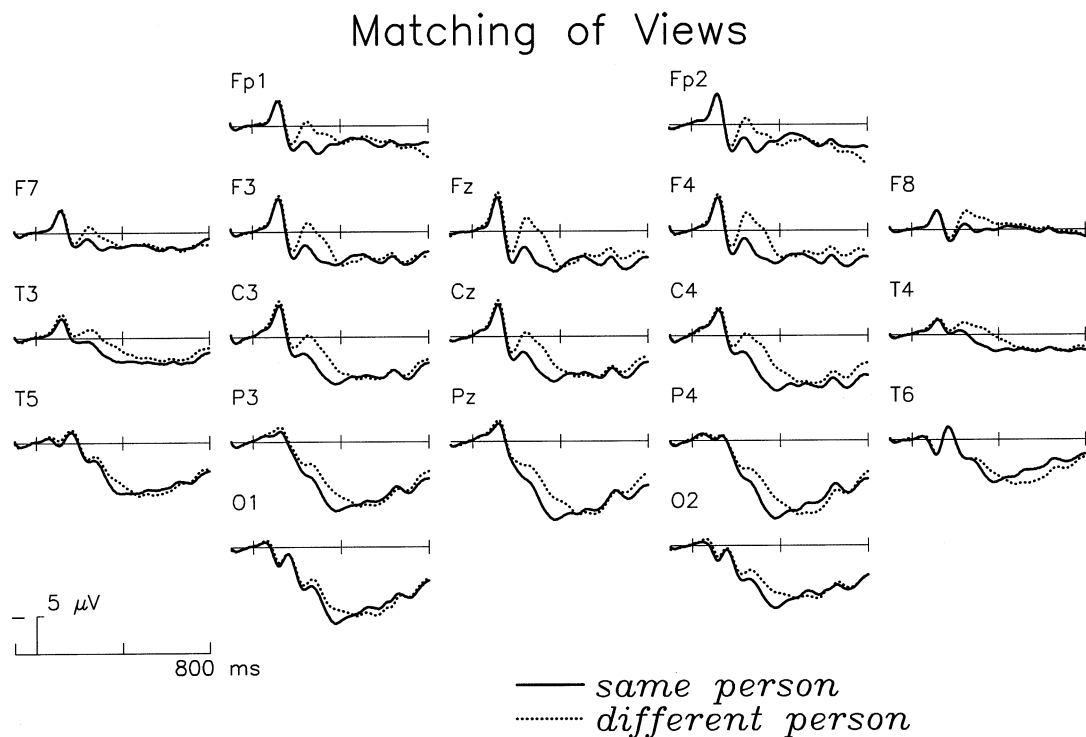


Fig. 1. Grand average potentials from the view matching task ($n = 27$). While ERPs to different person stimuli are characterized by a negativity peaking at about 280 ms, this wave is absent from the ERPs to the same person stimuli.

associated with a more negative waveform, that took the form of a monophasic negative component. From 400 ms onwards the ERPs to the same and different faces were again very similar.

The statistical comparisons for the three different electrode sets are shown in Table 1. These show that a main effect of identity match can be found in the 100–200 ms time window. Beyond the 300–400 ms window no main effects of identity are obtained. The late positivity seen for non-matching faces for the posterior parasagittal and temporal sites gave rise to identity \times site interaction effects in later time windows (for temporal sites the more pronounced effect at T6 gave rise to a identity \times site \times hemisphere interaction in the 400–500 ms, 500–600 ms and 700–800 ms intervals). The timing of the identity ERP effect will be examined in more detail in the Sections 3.2 and 3.3 (comparison of identity and expression matching).

3.2. Expression matching task

Decisions about the expression of faces were generally slower than the identity decisions. Faces that depicted the same expression were answered slightly faster than faces depicting a different expression than the sample stimulus (1211 ms, S.D. 197 ms vs 1253 ms, S.D. 201 ms, $F(1,26) = 4.81$, $P < 0.04$). The level of performance was again quite high (89.5% correct decisions for same stimuli, 88.9% correct for different stim-

uli, $F(1,26) = 1.12$, n.s.). The grand average difference waves for the expression task are shown in Fig. 2. ERPs to stimuli having a congruent and an incongruent expression with regard to the sample stimuli were virtually superimposable during the first 350 ms post-stimulus. From then on the ERPs to the congruent stimuli took a more positive course. This congruity effect was largest at central and parietal scalp sites and was slightly bigger over the right.

Statistically, reliable differences were found between the two stimulus classes in the time-windows 400–500 ms to 600–700 ms (Table 2). The differential distribution of the effect in the anterior/posterior direction gave rise to a Expression \times Site interaction in these time-windows.

3.3. Comparison of tasks

To assess the electrophysiological effects related to the differential processing of the stimuli in the two tasks, difference waves (different person – same person; incongruent minus congruent) were computed for the two tasks (Fig. 3). This figure illustrates that the electrophysiological concomitants of view matching and expression matching are radically different with respect to both, distribution and timing. While the negativity in the view matching task showed a frontocentral maximum, the negativity in the expression matching task was largest over centroparietal scalp regions. To assess

Table 1
Statistical results for the identity matching study

Time (ms)	Midline sites		Parasagittal sites			Temporal sites		
	Identity	I × site	Identity	I × site	I × hemis.	Identity	I × site	I × hemis.
100–200	10.33 (0.0035)	–	8.19 (0.009)	–	–	5.62 (0.03)	–	4.79 (0.04)
200–300	42.20 (0.0001)	12.92 (0.0001)	40.15 (0.0001)	10.81 (0.0001)	–	27.39 (0.0001)	19.37 (0.0001)	–
300–400	31.74 (0.0001)	–	30.32 (0.0001)	6.38 (0.003)	7.01 (0.015)	22.18 (0.0001)	5.96 (0.02)	–
400–500	–	–	–	–	–	–	6.93 (0.015)	–
500–600	–	–	–	4.30 (0.02)	–	–	23.90 (0.0001)	–
600–700	–	–	–	–	–	–	9.50 (0.0004)	–
700–800	9.46 (0.005)	–	–	6.34 (0.003)	–	–	–	–

Degrees of freedom: Identity 1,26; I(density) × site, midline, temporal: 2,52, I(density) × site, parasagittal: 4,104, Hemis. 1,26.

the distribution of the view matching and expression matching effects statistically, mean amplitude measurements in a 100-ms time-window centered around the peak of the two components were taken on the difference waves and the resulting data-sets were rescaled according to the suggestions of McCarthy and Wood (1985). The statistical comparison (with topography as within subject factors and task as between subject factor) revealed a significant task by topography interaction ($P < 0.001$), thus indicating that different neural generators subserve identity (view) and expression matching.

To further assess the timing differences of the two effects, mean amplitudes in successive 50 ms time-windows were taken on the difference waves and compared to baseline (for the midline electrodes). The resulting F -values were graphed against time (Fig. 4). Clearly, the electrophysiological effects of identity matching occur much earlier in time and are over by the time the effects of expression matching reach statistical significance.

4. Discussion

The present study aimed at the delineation of neurophysiological correlates of the processing of faces for identity and for expression as a step to provide electrophysiological data from humans to support cognitive models of face processing (Bruce and Young, 1986; Tovee and Cohen-Tovee, 1993). In fact, large differences in the ERP responses with regard to their unfolding in time and space were found for the two different face processing functions. These electrophysiological effects therefore appear to qualify as physiological counterparts of the proposed modularity of face processing. In the following discussion we will first consider the timing and distribution of the ERP effects and subsequently their relation to findings from human patients, non-human primates, neuroimaging studies and previous electrophysiological results.

4.1. Timing and distribution of ERP effects

The earliest differences in the identity (view) matching task were found at about 200 ms, whereas the earliest effects in the expression matching task were apparent only at 450 ms. This 250 ms timing difference suggests that the processing of expressions and the processing for identity required for the recognition of a person follow different time-courses and that the former process occurs considerably later in time. It is important to note that timing differences in cognitive functions such as the ones found in the present studies can only be assessed with electrophysiological methods and are not accessible with other neuroimaging technique. However, for a complete mapping of cognitive function in time and space it appears necessary to provide temporal data (Münte et al., 1995) in addition to the neuroanatomical data provided by PET and fMRI.

ERP responses to the view matching and expression matching were different not only in time but also in their scalp distribution. While the matching for identity was associated with a fronto-central effect, the matching for expressions was associated with a centroparietal ERP effect. Thus, the present data replicate and extend previous findings (obtained with fewer electrodes) on face identity matching (Barrett et al., 1988; Potter and Parker, 1989) and expression processing (Potter and Parker, 1989). The most conservative interpretation of such a pattern is that the two functions under study are performed by different neuronal populations. While one can not deduct that the ERP effects observed in the two tasks are necessarily generated by the neurons that fulfill the view and expression matching operations, it is safe to assume that as the two operations give rise to different ERP signatures downstream they also require different neuronal substrates.

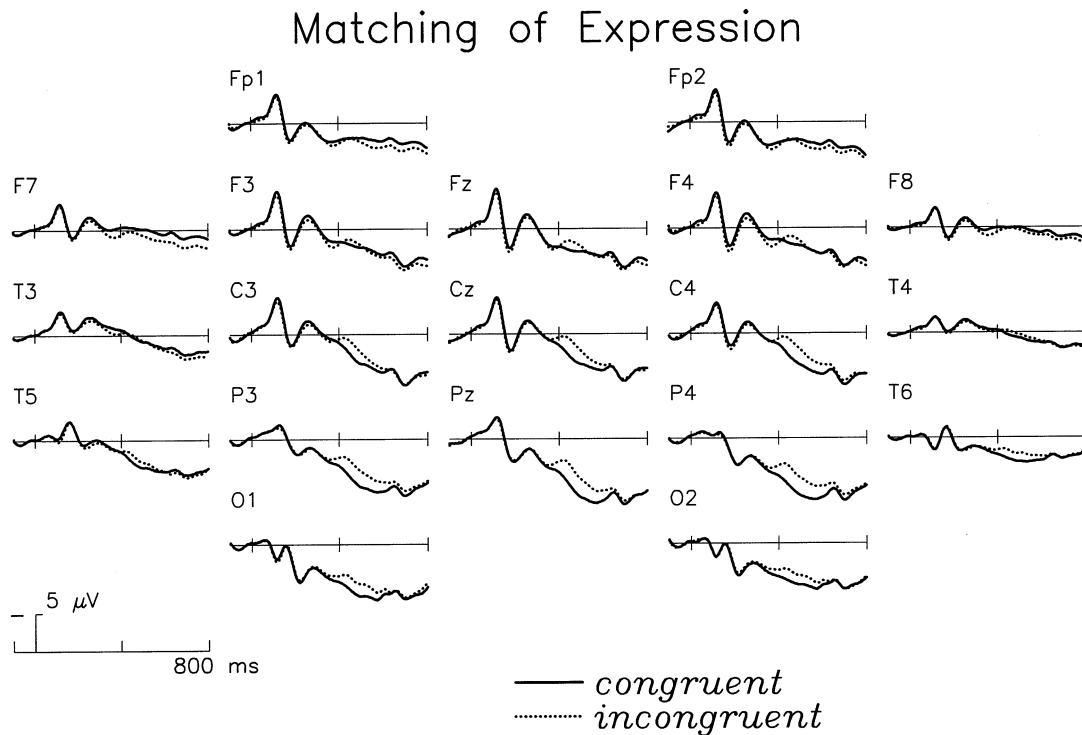


Fig. 2. Grand average potentials from the expression matching task ($n = 27$). In this task, ERPs to the congruent stimuli diverge from the incongruent stimuli at about 350 ms. The difference between the stimulus classes is most pronounced at central and parietal scalp sites.

4.2. Relationship to previous electrophysiological results

We have pointed out already that the current data are similar to the ones obtained by Barrett et al. (1988) and Potter and Parker (1989). The identity matching tasks from these earlier experiments gave rise to a negativity for the non-matching faces with a peak latency of about 350 ms. Both, Barrett et al. (1988) and Potter and Parker (1989) have likened this effect to the N400 component that is readily obtained to word stimuli that do not match a context semantically (Kutas and Hillyard, 1980; for reviews Kutas and Van Petten, 1988, 1994; Osterhout and Holcomb, 1995). A similar conclusion was reached by Bobes et al. (1994). These researchers presented incomplete faces (missing an important feature) that were completed by an congruent or incongruent feature. Time-locked to the presentation of the incongruent feature a negativity was seen. In a second condition features were presented at the wrong position. These position mismatches gave rise to a late positivity. Again Bobes et al. (1994) viewed the negativity to the incongruent features in terms of a non-linguistic counterpart of the N400 component. While the similarities between the face negativity from the view matching and feature matching tasks and the N400 from linguistic tasks seem appealing, it has to be pointed out that both timing and distribution of the negativity in the present study differs from the classical N400. While the N400 in linguistic tasks has a maxi-

imum over central and parietal scalp regions with a slight preponderance over the right hemisphere, the negativity in the present task showed a more frontal maximum. Onset and peak latencies of the negativity in the present study were about 50 ms earlier than those usually seen for linguistic tasks. The differences between the N400 to words and the negativity to faces resembles the differences described for negativities for pictures and words (Ganis et al., 1996). In spite of the distributional differences found for the negativities to words and pictures, Ganis et al. (1996) argued that this not necessarily means that two different cognitive operations are involved. A similar argument was made by Rugg and Coles (1995) who pointed out that ERPs are sensitive to the content as well as to the identity of a cognitive operations and that topographical differences may arise when the same cognitive operation is applied to representations differing in their cortical location.

A popular account of the N400 component, which by analogy should also apply to the negativity seen in view matching tasks, is the contextual integration account (Smith and Halgren, 1987; Rugg, 1990; Brown and Hagoort, 1993; Holcomb, 1993; Rugg and Doyle, 1994). This account holds that a given stimulus is encoded into a representation that includes information of its context. When a word (or a face) is repeated this second occurrence can be integrated with less effort into its context, hence the attenuation of the N400 component. Unlike alternative, lexical interpretations

Table 2
Statistical results for the expression matching study

Time (ms)	Midline sites		Parasagittal sites			Temporal sites		
	Expression	E × site	Expression	E × site	E × Hemis.	Expression	E × site	E × Hemis.
100–200	–	–	–	–	–	–	–	–
200–300	–	–	–	–	–	–	–	–
300–400	–	–	–	–	–	–	4.55 (0.05)	–
400–500	19.76 (0.0001)	7.83 (0.009)	11.88 (0.002)	7.31 (0.002)	–	–	9.06 (0.005)	–
500–600	–	13.37 (0.0009)	–	10.01 (0.0002)	–	–	9.77 (0.004)	4.71 (0.04)
600–700	–	5.45 (0.025)	–	3.38 (0.05)	–	–	–	–
700–800	–	–	–	–	–	–	–	–

Degrees of freedom: Expression 1,26; E(expression) × site, midline, temporal: 2,52, E(expression) × site, parasagittal: 4,104, Hemis. 1,26.

of the N400 (Holcomb and Neville, 1990; Van Petten et al., 1991) the contextual integration account has no difficulties to accommodate data obtained with non-linguistic stimuli such as faces and pictures. However, in a direct test of the predictions of the contextual integration account these were not borne out (Rugg et al., 1994).

This debate on the nature of the N400 notwithstanding, the present results as well as previous findings using view matching and feature matching tasks in faces suggest that cognitive operations similar to the ones required by the processing of words vis a vis a context are required when processing faces for identity.

Turning to the ERP effect for the expression matching task its radically different distribution suggests that it is distinct from the N400 component. Its centroparietal distribution and its timing make it likely that this effect is a member of the P300/LPC family of components. The P300/LPC is an ubiquitous electrophysiological response that can be recorded in a wide variety of paradigms (see Johnson, 1986 for the factors influencing P300 amplitude). Intracranial recordings (Baudena et al., 1995; Halgren et al., 1995a,b) obtained during presurgical evaluation of patients with intractable epilepsy suggest that the surface P300/LPC represents the composite activity of multiple intracerebral generators each probably with its own functional correlates. It is unclear at present, which of the factors known to influence P300/LPC is responsible for the effect seen in the expression matching task. One possibility is that subjects assign 'target' status to the stimuli matching the sample in expression. Target stimuli are known to be associated with larger P300/LPC amplitudes than non-target stimuli.

4.3. Relation to data from patients, non-human priming and neuroimaging

The different ERP effects obtained in the two tasks appear to be a correlate of the double dissociations of identity matching and expression matching observed in

patient populations (e.g. Bowers et al., 1985; De Renzi et al., 1989; Humphreys et al., 1993). Unfortunately, pinpointing the exact anatomical centers that subserve expression and identity analysis has been even more difficult than the localization of other neuropsychological functions. Adolphs et al. (1996) recently suggested that patients with lesions in the right inferior parietal cortex and the mesial anterior infracalcarine cortex are susceptible to disruptions in expression processing. Other data indicate that the amygdala is crucial for the processing of emotional (especially fear) expressions (Adolphs et al., 1994; Young et al., 1995, 1996). Identity matching on the other hand has been associated with occipitotemporal areas (Damasio et al., 1982) but also with anterior and mesial temporal areas (Tovee and Cohen-Tovee, 1993).

Data from monkeys suggests that there are specialized cells for the analysis of expression located primarily in the superior temporal sulcus and others that are specialized for the analysis of identity with a predominant location in the inferior temporal gyrus (Hasselmo et al., 1989; Heywood and Cowey, 1992). These data thus correspond roughly with the lesion data in humans. Brain imaging studies to date have provided only a limited picture of the neuroanatomical structures involved in face processing. Some studies have looked at the differences in activation between faces and scrambled faces and are thus not relevant for the present concerns (Allison et al., 1994). Sergent et al. (1992) found complex patterns of activation in a PET study of face identity matching (fusiform gyrus, anterior temporal regions, parahippocampal regions). A recent PET study by Morris et al. (1996) investigated emotional expressions and could show activations in the amygdala.

At this stage of our investigation it seems premature to directly link the ERP effects observed in the two tasks with any of the structures implicated in identity and expression matching of faces. It is intriguing, though, that the negativity observed in the identity matching task would be compatible with generators in

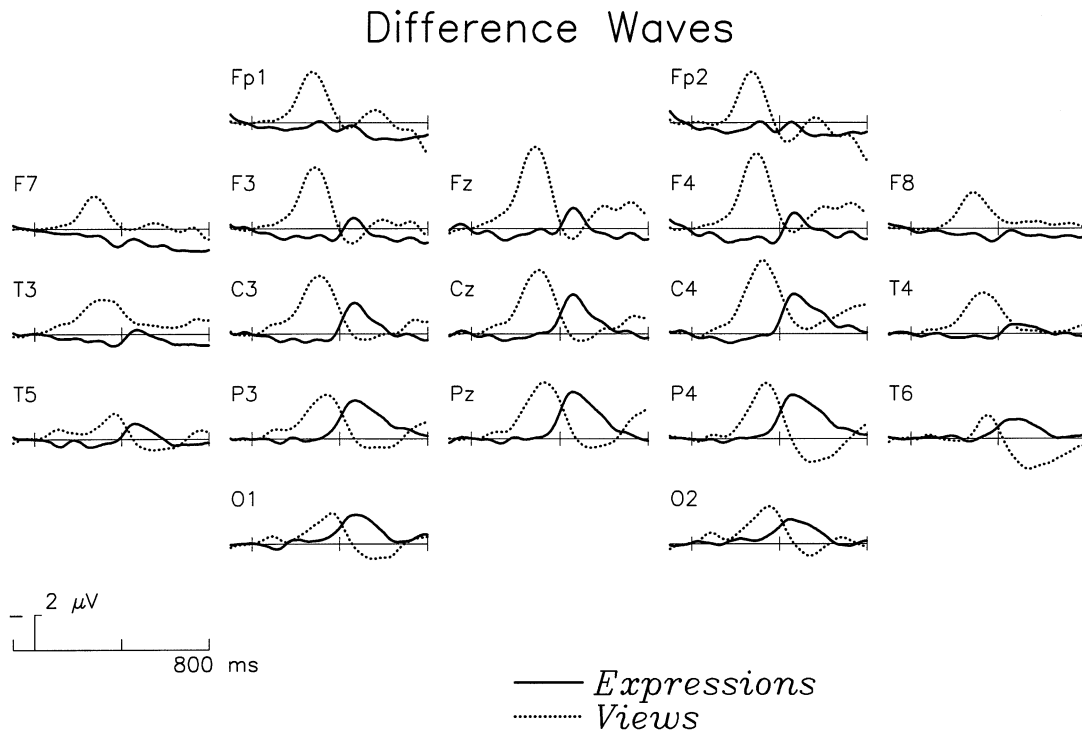


Fig. 3. Difference waves for the two tasks: The electrophysiological difference in the view matching task occurs much earlier than the difference in the expression matching task. Also, their distribution is different.

the medial temporal lobe, a notion supported both by intracranial recordings and intracranial source models (Münte, 1993).

To summarize, the current data provide electrophysiological evidence for a difference in timing and neuroanatomical organization of two different face processing functions. These results support current models of face processing (Bruce and Young, 1986) and

are in line with data obtained from human patients, monkeys and in brain imaging studies.

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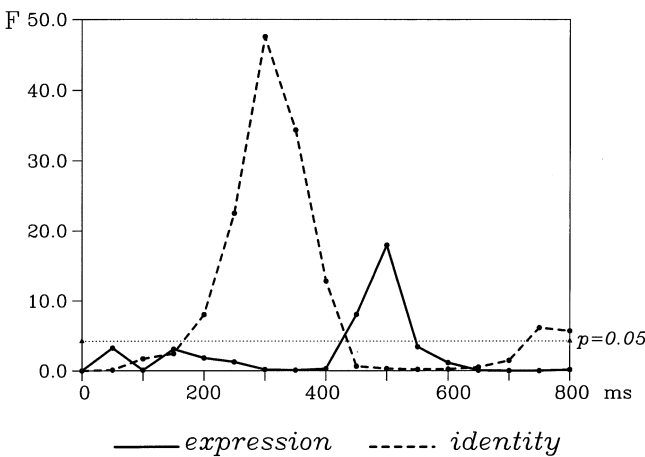


Fig. 4. Time course differences of the electrophysiological effects of view and expression matching are revealed by plotting the F-values from ANOVAs on successive mean amplitude measurements (time window width: 50 ms) against time. Measurements were taken on the midline channels.

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