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Rapid emotional face processing in the human right and left brain hemispheres: an ERP study

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IMAGING work has begun to elucidate the spatial organization of emotions; the temporal organization, however, remains unclear. Adaptive behavior relies on rapid monitoring of potentially salient cues (typically with high emotional value) in the environment. To clarify the timing and speed of emotional processing in the two human brain hemispheres, event-related potentials (ERPs) were recorded during hemifield presentation of face images. ERPs were separately computed for disliked and liked faces, as individually assessed by post-recording affective ratings. After stimulation of either hemisphere, personal affective judgements of face images significantly modulated ERP responses at early stages, 80–116 ms after right hemisphere and 104–160 ms after left hemisphere stimulation. This is the first electrophysiological evidence for valence-dependent, automatic, i.e. pre-attentive emotional processing in humans. *NeuroReport* 10:2691–2698 © 1999 Lippincott Williams & Wilkins.

Key words: Brain hemispheres; Brain mapping; Emotion; Evoked Potentials; Face processing; Laterality; Microstates

Introduction

Discovering emotionally salient (e.g. threat-related) cues in the environment plays a fundamental role in evolutionary adaptation. To have survival value, monitoring of potentially salient cues with emotional valence (pleasant *vs* unpleasant) should be rapid and appropriate [1]. Human behavioral studies [2–4] demonstrated that emotional perception and judgement can take place outside the realm of consciousness, i.e. pre-attentively, without effort and automatically.

Neuroimaging studies recently demonstrated the involvement of the amygdala, pulvinar nucleus, anterior insula and anterior cingulate when threat-relevant cues (e.g. angry or fearful faces) are encountered [5]. Particularly, amygdalar activation was reported when subjects had no conscious awareness about the stimuli [6], suggesting that amygdalar monitoring for aversive information may be automatic and non-conscious.

Whereas the spatial organization of human emotions is increasingly understood, the temporal organization is unclear. Because imaging studies have poor temporal resolution, complementary methods are needed to prove that emotional stimuli are indeed processed quickly. For this purpose, scalp recordings of brain electrical activity (e.g. event-related potentials, ERPs) may be used because they offer non-invasive access to human brain activity with a time resolution of milliseconds.

When reviewing the psychological and electrophysiological literature on emotions, a discrepancy emerges. While behavioral studies have demonstrated that emotions are extracted pre-attentively and influence subsequent perception [2–4,7,8], electrophysiological studies have found no correlates for these processes [9–12].

The present study was designed to clarify the timing and speed of emotional processing, i.e., the time course of putatively valence-dependent brain electric activity. In search of preattentive processing, three aspects were emphasized. First, the paradigm consisted of spontaneous and unconstrained observation of emotionally loaded face images. Second, because pre-attentive processing supposedly serves to filter information [8] and this process is modulated by personal attitude [7], emotional categories were not decided *a priori* but were constructed for each subject by means of his/her personal evaluative judgment (like *vs* dislike). Third, because there is evidence that certain regions of the two human brain

hemispheres may be differentially involved in emotional processing [5], we directly investigated the relative contribution of the two hemispheres to emotional processing using hemifield stimulus presentation.

Materials and Methods

Subjects: Eighteen healthy, right-handed subjects (eight female; mean age 29.6, range 22–45 years) with normal or corrected-to-normal vision gave informed written consent for participating to the study, which was approved by the Hospital's Ethics Committee.

Stimuli and task procedure: Stimuli were 32 black/white photographs of psychiatric patients' faces (Szondi portraits), suited to elicit affective judgments [13]. After electrode placement, subjects were seated in a comfortable chair in a sound-, light- and electrically shielded recording room. ERPs were recorded during a pseudo-random hemifield presentation paradigm. Subjects were naive about the specific goal of the study, not informed about the emotional content of the stimuli, and were instructed to passively observe single face images presented randomly either left or right of a central fixation cross. No overt task was given to minimize possible cognitive and sensorimotor interference. Each trial started with the presentation of a fixation cross in the middle of the screen; after 500 ms, a face image was presented for 100 ms either left (left visual field/right hemisphere (LVF/RH) presentation) or right (right visual field/left hemisphere (RVF/LH) presentation) of the fixation cross (inter-trial interval 2000 ms). The digitized, size-, brightness-, and contrast-adjusted face images were presented on light gray background on a computer screen 85 cm in front of the subject (stimulus eccentricity 1.5–3.9° of visual angle). Each run consisted of a pseudo-random presentation of the 32 face images; half of the stimuli were presented to the LVF/RH, the other half to the RVF/LH, with the constraint that no more than three stimuli in the same hemifield were presented consecutively. There were 14 runs, with a total of 448 trials presented.

Emotional rating of the face images: After ERP recording, subjects evaluated each face image (printed on individual hard copies) for its affective appeal using a vertical 10 cm scale, whose ends were randomly (but constant for a given face) labeled disliked face (=0) and liked face (=10). Order of ratings was randomized over subjects.

Data acquisition and analysis: ERPs were recorded from 27 leads (Fpz as reference, Fp1/2, Fz, F3/4, F7/8, FC1/2, Cz, C3/4, T7/8, CP1/2, Pz, P3/4, P7/8, PO3/4, Oz and O1/O2) of the 10/10 system (filter 0.3–70 Hz; sampling 256 Hz; electrode impedances $< 5\,K\Omega$), and eye movements from outer left canthus *vs* Fpz. After off-line artifact rejection, four ERP map series covering 1024 ms after stimulus onset were separately averaged for the LVF/RH and RVF/LH presentation using the 10 most disliked (mean across subjects 1.70; range 0.35–3.61) and liked faces (mean 7.68; range 6.40–9.07). The ERPs were recomputed off-line to average reference (digital 1.5–30 Hz temporal band pass). A grand mean ERP map series was computed across all subjects for each stimulus presentation separately (collapsing disliked and liked conditions).

ERPs were analyzed with space-oriented field analysis [14]. Based on the rationale that changes of the configuration of the brain electric field must have been caused by activation of at least partially different neuronal populations [15], this analysis allows conclusions about the neural organization underlying brain processes. Notably, changes of the configuration of the brain electric field occur stepwise and discontinuously [14,16]: epochs of quasi-stable field configurations (so-called microstates) are concatenated by rapid transitions. Accordingly, microstates describe brief periods of quasi-stable spatial configurations of the active neural generators. Thus, ERP component identification aims to find start and end times of specific field configurations, assumedly indexing specific brain functions.

At each time frame, field configuration was assessed by the locations of the positive and negative centroids (i.e. the location of the point of gravity of the positive and negative map areas [16]; Fig. 1). To determine time windows for ERP analyses, we employed a data-driven segmentation procedure extensively described elsewhere [14,16]. Using the entire available information from the scalp, this iterative parsing procedure identifies ERP components as periods in time characterized by stable map configuration (microstates). This was achieved using the locations of the negative and positive centroids of the grand mean ERP map series for RVF/LH and LVF/RH presentation separately. Only results concerning the first 250 ms after stimulus onset are reported.

In each identified microstate and for each hemifield presentation, differences between ERPs elicited by disliked and liked faces were assessed using multivariate analysis of variance (MANOVA) with emotion (disliked *vs* liked faces) and centroids (positive *vs* negative centroid) as repeated measures, and the locations along the left–right brain axis, and those along the anterior–posterior brain axis as

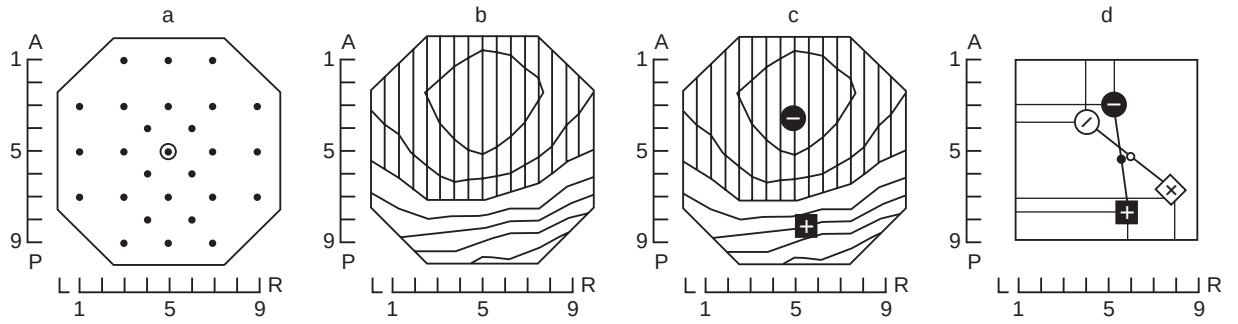

FIG. 1. Spatial feature extraction and statistical analysis of momentary scalp field maps. (**a**) Schematic of the electrode array (head see from above, left ear left). Numbers refer to the electrode positions of the international 10-10 system as rows (vertical, from anterior (A = 1) to posterior (P = 9), Cz = 5] and columns (horizontal, from left (L = 1) to right (R = 9), Cz = 5). The circle shows the position of Cz. (**b**) Example of a potential distribution map at a momentary time point. The ERP is measured at the electrode positions as in (a) and linearly interpolated (isopotential contour lines in steps of 1.0 μV). Positive area in white, negative area vertically hatched *vs* average reference. (**c**) At each time point, the ERP field topography can be reduced to the locations of the positive (square) and negative (circle) centroids. (**d**) The spatial configuration of a momentary map is numerically expressed by four coordinate values, which can be tested for differences between conditions (black *vs* white symbols). The locations of the point of gravity of the absolute map voltages [13] (the mean position between the positive and negative centroids; small circles) were tested for main effects of emotion.

dependent variables. V values are reported (Pillai's criterion).

For significant multivariate effects, univariate ANOVAs were conducted for each dependent variable (Bonferroni-corrected $p < 0.025$). Paired *t*-tests were used in *post-hoc* analyses (two-tailed *p*). Note that a main effect of emotion means that the averaged location between the positive and negative centroid is located differently for disliked and liked faces. This mean location is the point of gravity of the absolute voltages on the head surface and is a conservative estimate of the mean location of all momentarily active, intracerebral, electric sources, projected orthogonally onto the head surface [13].

Two additional approaches assessed the robustness of results. In the first, we used binomial statistics to test whether the number of subjects showing the differences as in the MANOVA analyses differed from chance; binomial probabilities for B(18,0.5) are reported. In the second, a split-half replication procedure assessed whether the relevant differences were found for each microstate in two randomly selected subject sub-groups (both $n = 9$). Confirmatory statistic used paired *t*-tests (two-tailed *p*).

Results

Within the first 250 ms after stimulus onset, three microstates were identified with comparable latencies for LVF/RH and RVF/LH presentation (Fig. 2). The first two microstates (P100 and N100) displayed lateralized potential distributions with largest potential values over the posterior regions of the contralateral hemisphere, as typically found in paradigms using hemifield presentation [9,14,17]. After LVF/RH presentation (Table 1A), the MANOVA analysis for the first microstate (80–116 ms)

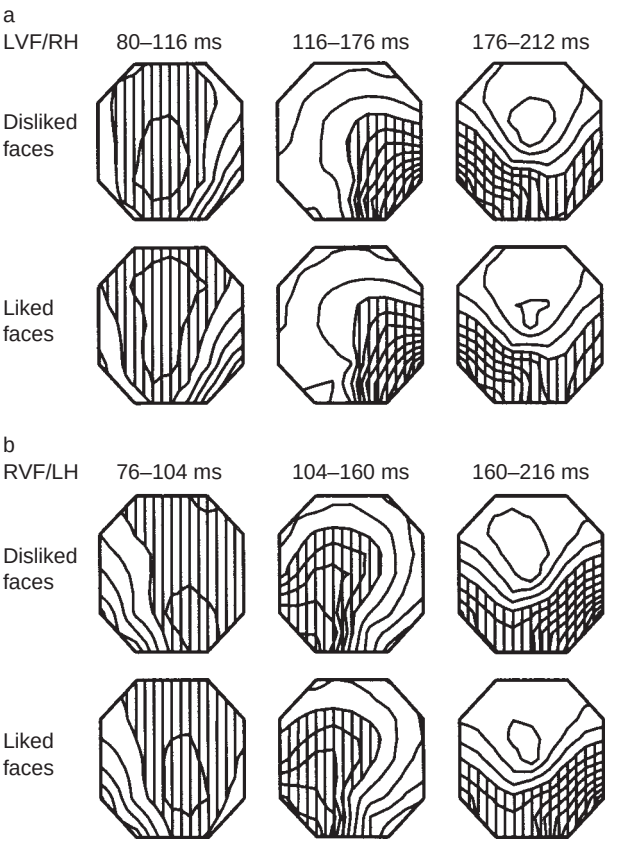

FIG. 2. Mean potential distribution maps for each microstate averaged across subjects ($n = 18$) for (**a**) LVF/RH and (**b**) RVF/LH presentation, each for disliked and liked faces. Map explanations as in Fig. 1.

revealed a significant emotion × centroid interaction ($p < 0.012$). Bonferroni-corrected univariate tests showed that the differences were along the anterior–posterior brain axis ($p < 0.005$): liked faces (Fig. 3c) were associated with a more posterior positive centroid ($p < 0.005$; observed in 13 of the 18 subjects, $p(13/18) < 0.05$) and with a more anterior

Table 1. Valence-modulated ERP responses as a function of stimulated hemisphere

		Disliked faces		Liked faces			
		Cp	Cn	Cp	Cn	MANOVA V[a]	Univariate F[b]
A. LVF/RH							
1st microstate (80–116 ms)	L-R	6.09 (1.11)	4.61 (0.56)	6.04 (0.85)	4.69 (0.49)	E: 0.55	–
	A-P	5.89 (1.16)	5.92 (1.11)	6.40 (1.05)	5.31 (1.28)	E × C: 5.87*	E × C: L-R: 0.26; A-P: 10.97**
2nd microstate (116–176 ms)	L-R	4.30 (0.50)	6.30 (0.53)	4.26 (0.51)	6.34 (0.65)	E: 0.53	–
	A-P	5.30 (1.24)	6.45 (1.06)	5.42 (1.33)	6.43 (0.96)	E × C: 0.65	–
3rd microstate (176–212 ms)	L-R	5.39 (0.56)	4.51 (0.73)	5.35 (0.61)	4.60 (0.76)	E: 0.54	–
	A-P	4.47 (0.94)	6.90 (0.82)	4.51 (1.05)	6.85 (0.93)	E × C: 0.25	–
B. RVF/LH							
1st microstate (76–104 ms)	L-R	3.38 (0.52)	5.85 (0.60)	3.70 (0.87)	5.72 (0.53)	E: 0.88	–
	A-P	6.16 (1.10)	5.35 (1.25)	6.14 (1.16)	5.55 (1.36)	E × C: 1.16	–
2nd microstate (104–160 ms)	L-R	5.75 (0.63)	4.11 (0.55)	5.93 (0.69)	4.00 (0.59)	E: 5.32*	E: L-R: 0.82; A-P, 6.93*
	A-P	5.79 (1.20)	5.91 (1.13)	6.05 (1.38)	5.82 (1.24)	E × C: 4.79*	E × C: L-R, 7.36*; A-P: 3.33
3rd microstate (160–216 ms)	L-R	4.59 (0.50)	5.79 (0.65)	4.59 (0.51)	5.65 (0.65)	E: 3.55	–
	A-P	4.53 (0.91)	7.05 (0.67)	4.56 (0.82)	6.99 (0.72)	E × C: 0.81	–

Mean locations (and s.d.; $n = 18$) of spatial descriptors characterizing the ERP field topography associated with disliked and liked faces for the LVF/RH (**A**) and RVF/LH (**B**) presentation. Locations of the positive (Cp) and negative (Cn) centroids are reported in electrode positions along the left–right (L-R) and the anterior–posterior (A-P) brain axis as in Fig. 1a. In cases of significant MANOVA results, univariate analysis results along each of the two brain axes are reported. E = main effect of emotion (disliked; liked), E × C = interaction between emotion and centroid (Cp; Cn).

[a]V(2,16); * $p < 0.05$.

[b]F(1,17); * $p < 0.025$ (Bonferroni-corrected), ** $p < 0.005$.

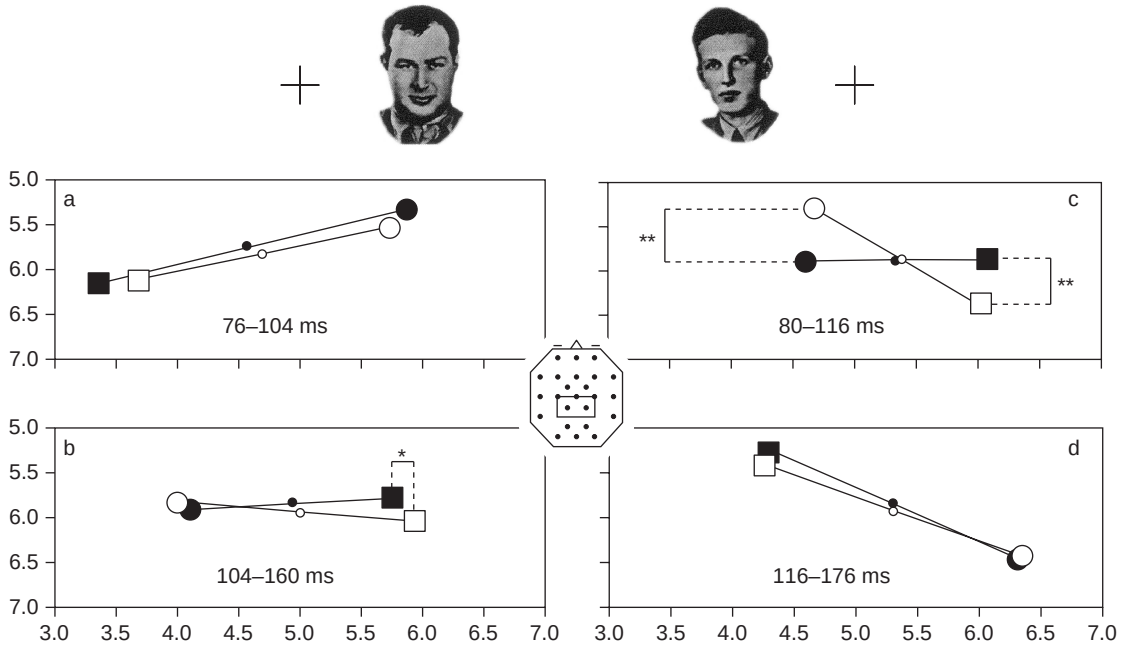

FIG. 3. Locations of the positive (squares) and negative (circles) centroid for the first two microstates after (**a**,**b**) RVF/LH and (**c**,**d**) LVF/RH presentation are displayed for ERP elicited by disliked (dark symbols) and liked (open symbols) faces ($n = 18$). The frames show an area extending from electrode position 3.0 to 7.0 along the left–right axis (horizontal) and from 5.0 to 7.0 along the anterior–posterior axis (vertical) as in Fig. 1a. * $p < 0.025$, ** $p < 0.005$

negative centroid ($p < 0.005$; observed in 16 of the 18 subjects, $p(16/18) < 0.001$) than were disliked faces. The split-half replication procedure showed that the posteriorization (group 1: $p < 0.05$; group 2: $p = 0.072$) and the anteriorization (group 1: $p < 0.05$; group 2: $p < 0.008$) was present in both sub-groups. The second (116–176 ms) and third (176–212 ms) microstates displayed no significant effects.

After RVF/LH presentation (Table 1b) there were no effects for the first microstate (76–104 ms). For the second microstate (104–160 ms), however, the MANOVA analysis showed a significant main effect of emotion ($p < 0.017$) as well as a significant emotion × centroid interaction ($p < 0.023$). Univariate tests for the main effect of emotion (Fig. 3b) demonstrated that the differences were along the anterior–posterior brain axis ($p < 0.017$), the point of gravity of the absolute voltages being more posterior for liked (5.93 ± 0.74) than for disliked (5.85 ± 0.66) faces (observed in 15 subjects; $p(15,18) < 0.005$). This posteriorization was only present in one of the randomly selected sub-groups (group 1: $p < 0.016$; group 2: $p > 0.2$). Univariate tests for the emotion × centroid interaction showed that the differences were along the left–right brain axis ($p < 0.014$). *Post-hoc* tests (Fig. 3b) revealed that liked faces were associated with more right located positive centroids ($p < 0.025$; observed in 14 subjects $p(14/18) < 0.02$), and (non-significantly) more left located negative centroids ($p = 0.1$) than were disliked faces. The split-half replication procedure showed that the right-shift (group 1: $p < 0.049$; group 2: $p = 0.11$) was present in both sub-groups. The third microstate (160–216 ms) did not reveal significant effects.

To assess the specificity of the results, two control analyses were performed. First, to exclude the possibility that such early valence-dependent ERP modulations may be linked to different physical characteristics of the stimuli, MANOVA analyses were repeated with ERPs re-computed only for those faces with normally distributed ratings (across subjects) around the midpoint of the rating scale (25 of 32 faces). Despite lower signal-to-noise ratio, the results were confirmed (LVF/RH: emotion × centroid for 80–116 ms: $V(2,16) = 3.15$, $p < 0.072$; RVF/LH: emotion × centroid for 104–160 ms: $V(2,16) = 3.53$, $p < 0.053$). Second, because repeated stimulus exposure may modulate preference judgments (mere exposure effect [2]), ERPs were separately re-computed for two experimental blocks (first and last seven runs), and entered in 2 (emotion) × 2 (centroid) × 2 (block) MANOVA analyses. The emotion × centroid interactions were, again, confirmed (LVF/RH: $V(2,16) = 4.25$, $p < 0.033$; RVF/LH: $V(2,16) = 3.98$, $p < 0.039$), while no significant main effect of block or interactions including block and emotion emerged.

To allow comparisons with conventional ERP waveform studies, average amplitudes were computed (*vs* technical zero baseline) between 80 and 116 ms for LVF/RH and between 104 and 160 ms

for RVF/LH presentation, and entered into ANOVAs which were performed separately for midline (Fpz, Fz, Cz, Pz, Oz), anterior (Fp1/2, F3/4, F7/8, FC1/2), central (C3/4, T3/4) and posterior (CP1/2, P3/4, P7/8, PO1/2, O1/2) electrodes, with emotion, electrode and hemisphere (when applicable) as factors. For LVF/RH, only a main effect of emotion at posterior electrodes ($p < 0.037$) emerged; liked rather than disliked faces generally evoked larger P100 amplitudes, but this effect was statistically supported only at P4 ($p < 0.002$; Fig. 4a) and P8 ($p < 0.08$; Fig. 4b). Larger P100 amplitudes for liked faces at P4 and P8 reflect the posteriorization of the positive centroid in our space-oriented analysis.

For RVF/LH, a main effect of emotion ($p < 0.005$) emerged at central electrodes. This effect was modulated by significant emotion × electrode ($p < 0.022$) and emotion × electrode × hemisphere ($p < 0.049$) interactions. Follow-up tests demonstrated larger (i.e. more negative) N100 amplitude for liked than for disliked faces at T7 ($p < 0.003$; Fig. 4c). For anterior electrodes, a significant emotion × electrode interaction emerged, and follow-up analyses revealed that this was the case only for electrodes over the RH ($p < 0.009$). *Post hoc* tests showed significantly smaller amplitude at F7 for liked *vs* disliked faces ($p < 0.006$; Fig. 4d).

Discussion

In line with the view that detecting emotionally salient cues plays a fundamental role in evolutionary adaptation, personal judgment of face images (as assessed after ERP recording) consistently altered the brain electric field configuration at early stages of the information processing flow. After right hemisphere stimulation, the valence-dependent brain activity started at 80 ms (i.e. when the stimuli were still visible) and lasted until 116 ms. After left hemisphere stimulation, it started later (at 104 ms) and lasted until 160 ms. Since different configurations of the brain electric field must arise from differences in geometry of the momentarily active neuronal elements [15], we conclude that at least partially different neuronal populations were already active at 80 ms when disliked and liked face images were presented.

The onset of the first valence-modulated ERP microstate (80–100 ms) occurred at a similar time to the earliest latencies of increased firing rates of face-sensitive cells [18] as well as ERP latencies associated with identification of complex visual stimuli (100–150 ms [19–21]) and enhancement of sensory representations in the extrastriate cortex depending on the momentary relevance of the stimulus (70–140 ms [17]).

The early valence-dependent microstates were not caused by different physical characteristics of the stimuli, i.e. were not due to pre-attentive detection of specific local facial features (e.g. smiling mouth, brow angle [8]). The fact that 78% of our stimuli (25/32) had normally distributed ratings underscores the need to consider large inter-individual differences in emotional processes in future neuroscientific investigations of emotions. Our ERP differences were also not attributable to mere exposure effects [2] (because the differences were stable across experimental blocks), or to differential repetition priming effects between the two emotional conditions [19,20] (because all face images were presented equally).

Prior research employing recording of autonomic responses suggested that humans may be evolutionary tuned to react to face images in an automatic

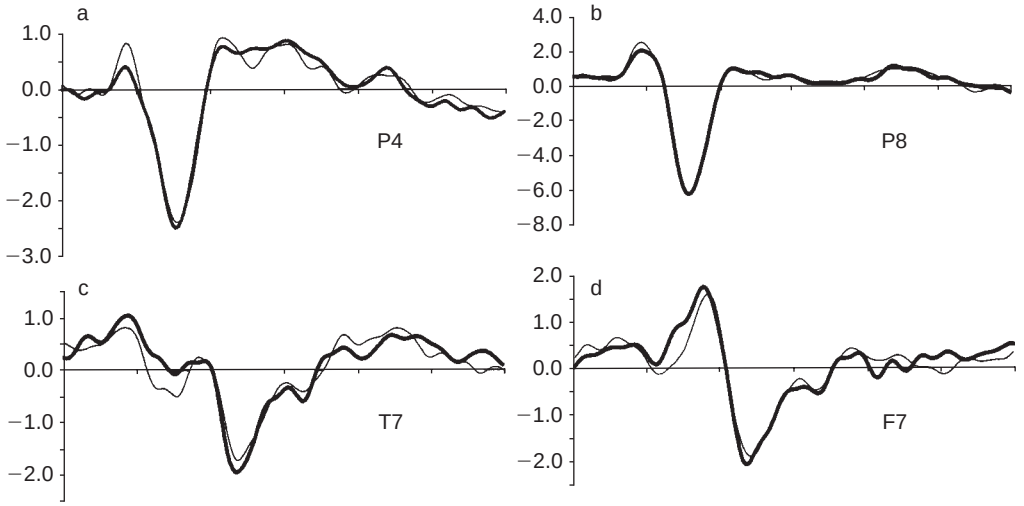

FIG. 4. Grand mean ERP ($n = 18$) waveforms evoked by liked (thin lines) and disliked (thick lines) faces at (**a**) P4 and (**b**) P8 after LVF/RH presentation, and at (**c**) T7 and (**d**) F7 after RVF/LH presentation. Horizontal: time in ms (from 0 to 600 ms post-stimulus); vertical: amplitude in μV.

and pre-attentive way [3]. Behaviorally, modulations of perception and judgment by means of subliminal affective stimuli [2,7], pre-attentive extraction of facial expression [8], automatic orienting of attention toward undesirable trait terms [4] have been reported. Due to an inescapable attraction of attention [4], emotion-modulated processes were assumed to be initiated by a coarse, diffuse, preliminary, possibly nonconscious stimulus processing, operating along the evaluative dimension of the stimulus (bad *vs* good, disliked *vs* liked [7]). It has been speculated [3,7] that such preattentive encoding of emotional cues might parallel the subcortical (thalamic–amygdala) detector system demonstrated in animal fear conditioning [1]. Intriguingly, a recent study [22] demonstrated a subcortical pathway (retinocollicular–pulvivar–amygdalar) active during processing of fear-relevant stimuli outside the realm of consciousness, which was complementary to a more cortical one (retinogeniculostriate–extrastriate–fusiform) involved in conscious stimulus perception.

Although the widespread assumption that emotional stimuli are evaluated quickly and automatically, the present results are the first electrophysiological demonstration of neuronal correlates of this process in humans. Prior ERP studies [9–12] found emotion-modulated ERP components considerably later, typically between 250 and 600 ms (but see [23] for a very recent exception, not reporting, however, valence-dependent analyses). Surprisingly, most of these studies investigated emotional processing using rather cognitive (e.g. oddball) paradigms and/or restricted *a priori* their analyses to the P300 or slow wave components [10–12]. Recently, it has been demonstrated that task-modulated ERP components might interfere with, and thus conceal, emotion-modulated responses [12]. The present study differs from prior ERP studies in two main aspects: first, possible differential involvement of the two hemispheres in processing both positive and negative facial stimuli was considered; and more importantly, emotional categories were individually assessed. Having taken into account large inter-individual differences in emotions possibly enhanced the power of our analyses.

Because of both latency and scalp topography of the first valence-modulated microstates (P100), generating processes in the posterior cortex (possibly extrastriate visual cortex [17]) are likely. Imaging studies have consistently demonstrated the involvement of the primary and secondary visual cortex in emotional response [24], and hypothesized that this posterior activation may be caused by re-entrant processes from more anterior structures (e.g. amygdala) linked to attentional and motivational processes. Recent studies reported amygdala modulation of extrastriate regions [25] as well as the existence of a subcortical pathway for putatively fast visual responses [26] (superior colliculus–extrageniculate thalamus–amygdala) paralleling the one involved in auditory fear conditioning [1]. These studies are intriguing, and perhaps complementary to our brain electric signatures of emotional responses, but the possible mechanisms of sub-cortical modulations cannot be evaluated with ERP data alone.

Conclusion

The present results demonstrate that the human brain differentiates between pleasant and unpleasant stimuli earlier than previously thought and that both hemispheres are able to perform this differentiation. This differentiation started at an earlier processing step when stimuli were initially directed to the right than left hemisphere. These results extend neurophysiological findings in non-human primates that previously demonstrated differential neuronal firing responses for face expressions around 100 ms [27]. The present and other recent ERP results [19–21] clearly challenge the traditional distinction between exogenous (to which the P100 belongs) and endogenous ERP responses, the former considered ''manifestation of primitive sensory processes insensitive to psychological factors'' ([28]; p. 434–435), the latter considered characterized by ''the nature of the interaction between the subject and the event'' ([28]; p. 414), a definition that would apply also to our valence-dependent P100 responses.

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