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## Event-related potential (ERP) asymmetries to emotional stimuli in a visual half-field paradigm

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### Abstract

To investigate the hypothesis of a right hemispheric superiority in negative emotional processing, event-related potentials (ERPs) were recorded from 17 sites (Fz, Cz, Pz, F3/4, F7/8, C3/4, T7/8, P3/4, P7/8, O1/2) in a visual half-field paradigm. While maintaining fixation, right-handed women viewed pictures of patients with dermatological diseases before (negative) and after (neutral) cosmetic surgery. A principal components analysis with Varimax rotation performed on ERPs revealed factors identified as N1, N2, early P3, late P3, and slow wave. Repeated measures analyses of variance performed on factor scores revealed a significant effect of emotional content for all factors except for N1. However, asymmetries in emotional processing were restricted to N2 and early P3, with maximal effects over the right parietal region. N2-P3 amplitude was augmented for negative and reduced for neutral stimuli over right hemisphere regions. Visual field presentation interacted with these asymmetries in enhancing amplitudes contralaterally for early but ipsilaterally for late ERP components. Overall, findings for N2 and P3 support theories of an asymmetry in emotional processing.

**Descriptors:** Event-related potentials (ERPs), Laterality, Emotion, Visual half-field paradigm, N2-P3 amplitude, Principal components analysis (PCA)

Considerable evidence suggests functional hemispheric specialization in the regulation of affect. This evidence arises from studies of neurologic, psychiatric, and healthy populations using different techniques and paradigms and reflects a broad range of self-report, behavioral, and physiological indicators of emotional processes (e.g., reviewed by Davidson, 1984, 1995; Etcoff, 1989; Gainotti, 1989; Heller, 1993; Leventhal & Tomarken, 1986; Liotti & Tucker, 1995; Silberman & Weingartner, 1986; Tucker, 1981). A right hemispheric superiority for the perception of emotional stimuli has generally been supported, particularly for stimuli of negative valence (Etcoff, 1989; Silberman & Weingartner, 1986). Although the relationship between specific patterns of cortical and subcortical activity and specific emotional states is as yet unclear, both hemispheres appear to contribute

to the experience of affect (see Davidson, 1995; Gainotti, Caltagirone, & Zoccolotti, 1993; Leventhal & Tomarken, 1986; Liotti & Tucker, 1995).

A number of studies have examined the relationship between affective processes and hemispheric asymmetries for tonic measures of central nervous system (CNS) activity (e.g., electroencephalogram alpha power, as reviewed by Davidson & Tomarken, 1989). Fewer studies have recorded phasic measures, such as event-related potentials (ERPs), of CNS concomitants of the perception, classification, or discrimination of emotionally charged stimuli. ERPs provide evidence regarding the sequential pattern of brain activation underlying task-related information processing. Early, primarily exogenous and attentional processes (Hillyard & Picton, 1987; Näätänen & Picton, 1987) may be dissociated from later, primarily endogenous ERP components (Donchin, 1979; Picton, 1992; Ruchkin & Sutton, 1983). Although some researchers have investigated ERPs produced during the perception of emotionally relevant stimuli (e.g., Johnston, Miller, & Burleson, 1986; Johnston & Wang, 1991; Lang, Nelson, & Collins, 1990; Naumann, Bartussek, Diedrich, & Laufer, 1992), few studies have explicitly explored the lateralization of emotional perception (e.g., Carretié & Iglesias, 1995; De Pascalis, Morelli, & Montirosso, 1990; Laurian, Bader, Lanares, & Oros, 1991; Papanicolaou, Levin, Eisenberg, & Moore, 1983; Roschmann & Wittling, 1992; Vanderploeg, Brown, & Marsh, 1987). Those ERP studies that did investigate ERP asymmetries during the perception of emotionally

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relevant stimuli differed widely in methodology, including the experimental design, task, stimuli, modality, number and location of recording sites, ERP components evaluated, and statistical analysis.

An indirect approach would be to record ERPs to probe stimuli while participants are engaged in another task because the ERP is expected to be attenuated with greater involvement of a particular brain region. This technique has the advantage that ERPs are recorded to identical stimuli during the conditions that are contrasted. Using this method with a linguistic or left hemispheric task, asymmetries in P3 peak amplitude occurred only for neutral stimuli, whereas no indication of a left hemispheric advantage was found during positive and negative word processing (De Pascalis et al., 1990). Similar results were obtained by Papanicolaou et al. (1983), who found a double dissociation in the attenuation of ERP probes between hemispheres when a phonetic or a prosodic processing of speech signals was required.

A more direct approach would be to use faces with different emotional expressions (Ekman & Friesen, 1976) as stimuli of affective value and therefore as the time-locked event (Carretié & Iglesias, 1995; Laurian et al., 1991). Based on results from topographic mappings of P3 amplitude (336-350 ms) derived from 16 sites, Laurian et al. (1991) concluded that emotional expressions are processed mostly by right centroparietal regions, although their results may have been confounded by motor potentials because participants had to respond with their right hand to targets, that is, the emotional faces. A similar methodology was described by Roschmann and Wittling (1992) using photographs of normal and dermatologically deformed human faces. Disregarding ERP components with a latency of <300 ms and referring only to t-test probability mappings derived from 30 electrode sites, Roschmann and Wittling reported a greater negativity to negative affective stimuli at about 540 ms over right frontal areas and at about 700 ms over right temporooccipital regions. However, Carretié and Iglesias (1995) failed to report differential hemispheric asymmetries in processing neutral and happy facial expressions for different ERP components covering the latency range of 150-900 ms, but in their study lateral sites were restricted to T7/8.

Vanderploeg et al. (1987) averaged ERPs recorded from two midline (Fz, Pz) and four lateral (F7/8, P7/8) sites in response to drawings of faces. ERPs were grouped by the self-reported emotional value attributed to the faces, in which the value was partly generated by pairing faces with auditory presentations of positive, neutral, and negative words in the conditioning phase of the experiment. After a principal components analysis (PCA) of the ERP waveforms, two factors identified as P3 and slow wave revealed hemispheric differences for the emotional connotations, that is, a greater P3 amplitude for neutral compared with emotional faces over the left hemisphere, and a greater slow wave amplitude for emotional than for neutral faces over the right hemisphere. Vanderploeg et al. discussed the P3 effects in terms of a categorical decision accomplished by the left hemisphere and the right lateralized slow wave as continued processing involving facial recognition for positive/negative distinctions. In addition, addressing a major problem of the paradigm, they explained the absence of a right hemisphere advantage for facial processing (e.g., Bruyer, 1986) by the required verbal judgment of the emotional connotation. In other words, they related the observed and the absent asymmetrical effects to cognitive rather than to emotional processes.

It is difficult to disentangle an effect of emotion per se from other confounding influences not related to emotional processes, for example, task-related processes or physical stimulus properties, which may

contribute to laterality effects. This issue concerns the well-known right hemispheric advantage in analyzing visuospatial stimuli in general and faces in particular (e.g., Bryden, 1982), and different hemispheric processing strategies or operational characteristics (Semmes, 1968; Sergent & Bindra, 1981; Tucker, 1989), which might be induced by the specific procedure applied (Erdmann & Kayser, 1990). Regarding the common characteristics of ERP studies, stimulus exposure is usually combined with performance requiring primarily cognitive operations, which blends emotional processes with cognitive factors. Most of the previously cited ERP studies have explored responses to sets of stimuli differing in emotional content within the context of standard ERP paradigms, including target detection (e.g., Lang et al., 1990), stimulus discrimination (e.g., Carretié & Iglesias, 1995), or stimulus ratings (e.g., Vanderploeg et al., 1987). Moreover, because behavioral performance is a common characteristic of ERP studies, a specific problem arises from the use of manual responses and related motor potentials and motor artifacts, particularly for those studies focusing on laterality effects (e.g., as in Laurian et al., 1991). Although this approach assures attention to the stimuli, it also engages the individual in multiple cognitive operations that are unrelated to the perception of the affective aspects of the stimuli. Although completely dissociating affective and cognitive processing might be impossible, it is possible to reframe the task so that one processing aspect is enhanced at the expense of another. Loosening the experimental constraints on the way individuals process the stimuli gives them more flexibility in their response to the emotional content. In the present approach, no discriminative or motor response was required.

The cited studies examining ERP asymmetries during the perception of affect-related stimuli did not aim to stimulate each hemisphere directly by means of stimulus lateralization, which is surprising. For instance, the visual half-field paradigm has been extensively and successfully applied in cerebral lateralization studies in general (e.g., Beaumont, 1982). Because of the direct contralateral pathways from the left and right visual fields to the right and left hemispheres, respectively, stimulus presentations in each visual field may be more effective than central presentations to obtain task-dependent ERP asymmetries (Rugg, 1983). To our knowledge, ERPs to lateralized emotional and neutral control stimuli have not been reported, although studies measuring ERPs to varied visual stimuli have investigated the effects of lateralized presentations in a different context (e.g., Kok & Rooyackers, 1986; Rugg & Beaumont, 1978; Schweinberger & Sommer, 1991; Schweinberger, Sommer, & Stiller, 1994; Sobotka, Pizlo, & Budohoska, 1984).

The goal of the present study was to contribute to the understanding of emotional lateralization by introducing a new and unique approach to ERP research that combined several different experimental manipulations. First, the impact of cognitive processing and motor-related artifacts was decreased by requiring no overt responses; second, asymmetries arising from exogenous stimulus processing were controlled by lateralizing stimulus input, directly stimulating each hemisphere; third, blending of visual-spatial and affective stimulus characteristics was reduced by using emotionally charged and neutral control stimuli highly similar in physical characteristics; and fourth, a multiple electrode array with 17 scalp placements was used to study the topographic distribution of ERPs related to the processing of emotionally relevant stimuli. By controlling for potentially confounding factors, we hoped to test the possibility that ERP measures may provide a direct electrophysiological correlate of regional brain activity associated with emotional processing. Our goal was to separate

hemispheric asymmetries in emotional processing related to early sensory/attentional processes (e.g., as reflected by N1) from those asymmetries related to later stages of information processing (e.g., as reflected by P3) and to explore further the postulated relationship of P3 to emotional significance (Johnston et al., 1986; Johnston & Wang, 1991). We hypothesized that, in the absence of an imposed task, negative stimuli would evoke a late positivity resembling a classic P3 when compared with neutral stimuli. This positivity was expected to be greater over the right hemisphere, particularly over parietal scalp placements. In contrast, asymmetries in early ERP components were not expected to reflect differences in emotional content.

## Method

### Participants

Twenty-three healthy women (age = 19-26 years, *Mdn* = 22 years) were recruited among undergraduates at the University of Bergen, Norway. All participants were right handed as indicated by the Edinburgh Handedness Inventory (Oldfield, 1971). Following the suggestions of Bryden (1977), a handedness score was calculated to vary from 10 (extremely right handed) to 50 (extremely left handed). Mean values revealed the sample to be strongly right handed (*M* = 18.4, *SD* = 3.3). Participants with a handedness score above 30 were not included in the study. All participants had normal or corrected-to-normal vision. Before the session, participants were given a baseline questionnaire to verify that, at the time of testing, they were not taking any medication, alcohol, caffeine, nicotine, and they were not distressed by mental (e.g., academic tests) or physical (e.g., exercise) demands. Participants were paid 75 NOK (approximately US \$12).

### Stimuli

The stimuli consisted of 32 pictures of patients with dermatological diseases, one-half displaying disordered facial areas before or immediately after surgical treatment (negative) and the other half showing the same facial areas a few years after the operation (neutral), that is, healthy skin or a healed scar. Hence, pictures after the healing served as direct "neutral" controls that differed only in the emotionally relevant feature and were identical in all other aspects, for example, their general physical characteristics. The 16 negative/neutral stimulus pairs were part of a somewhat larger stimulus set and had been evaluated in previous studies (Kayser, 1995). Ratings for pleasantness on a 7-point Likert scale ranging from -3 (unpleasant) to +3 (pleasant) from 45 participants had revealed clearly negative ratings for the negative stimuli (*M* = -1.6, *SD* = 0.4) and neutral ratings for the neutral stimuli (*M* = 0.0, *SD* = 0.4). In these experiments (Kayser, 1995), negative stimuli also elicited more and larger electrodermal responses than did neutral stimuli, which can be considered as evidence for the more arousing affective value of the negative stimuli (e.g., Boucsein, 1992). Thus, self-report ratings and skin conductance data were consistent with a valid manipulation regarding the valence construct.

### Procedure

Stimuli were exposed laterally for 250 ms as scanned images (resolution 640 × 480 pixels, 16 colors, full-screen display) on two PC monitors that were located side by side behind a window outside a sound-attenuated chamber. A red light-emitting diode (LED) in the middle of the two monitors served as fixation. Participants were seated in a comfortable relaxation chair in the chamber at an eye distance of

230 cm to the surface of the screens. Stimulus presentation subtended visual angles of 6.7° horizontally, ranging from 1.5° to 8.2° from fixation in each visual field, and 5° vertically, centered along the fixation horizon. Rapid and predictable stimulus onsets and offsets were coordinated by Micro Experimental Laboratory (MEL) software (Psychology Software Tools, 1990), setting up a new graphic page in the background to allow stimulus presentation within one screen-refresh cycle on the two monitors. Exposure times and trigger delays of both displays were verified by direct measurement with a photoresistor attached to the surface of the screen. Although no differences between displays were observed, monitors were switched between visual fields for half of the participants to control for any possible differences in stimulus exposure related to the setup.

Participants were instructed and trained to maintain fixation and to attend to the stimulus exposures. At the beginning of each session, six unrelated pictures (e.g., a landscape) were laterally exposed for 250 ms to verify that the participant was following the instructions. If horizontal eye movements occurred during stimulus exposure, the participant was re-instructed and the training trials were repeated. During debriefing at the end of the session, all participants indicated that they were aware of the content of both stimulus sets, for example, that they saw pictures of normal and disfigured faces. No manual response was required.

Each stimulus was exposed to each visual field (64 trials) in a block-randomized fashion, distributed over two blocks of 32 trials. However, the important conditions were equally distributed, that is, within four consecutive trials with each combination of emotional content (negative/neutral) and visual field (left/right) occurring once. Because the affective feature of a particular stimulus was not necessarily in the center of the picture, stimuli were mirrored for half of the participants (for a related issue, see Bryson, McLaren, Wadden, & MacLean, 1991). Each matched pair of participants was exposed to a different stimulus sequence. Stimuli were presented with variable intertrial intervals (ITIs) of 15-21 s (*M* = 18 s).<sup>1</sup> Each trial was initiated by the LED, followed after 3 s by the onset of the lateralized stimulus.

### ERP Recording

Electroencephalograms (EEGs) were recorded from 17 standard derivations (10-20 system: Fz, Cz, Pz, F3/4, F7/8, C3/4, T7/8, P3/4, P7/8, O1/2) referenced to linked ears (A1 and A2), with a Fpz ground and impedances maintained at 5 kΩ or less. EEG gain was 5,000, with a 0.01-100-Hz band pass (-6 dB/octave). Data were sampled for 1,100 ms at 200 Hz (100-ms prestimulus baseline) and low pass filtered off-line at 20 Hz (-24 dB/octave). Horizontal electrooculograms (EOGs) were recorded differentially from the outer canthi of each eye, and vertical EOGs were recorded from Fp2 with a linked ear reference. Horizontal eye movements were calibrated by asking the participants to alter their gaze between the LED and a white dot shown in the center of each monitor.

### Data Reduction and Analysis

Trials contaminated by artifacts were eliminated when EEG and horizontal EOG data exceeded +100 μV following vertical EOG reduction (linear regression; Semlitsch, Anderer, Schuster, & Presslich,

<sup>1</sup>The long and variable interstimulus intervals were necessary because phasic skin conductance responses were recorded at the same time. Because this autonomic measure is subject to habituation, only a comparably small number of trials (16 per condition) were presented. The results for electrodermal activity will be reported elsewhere.

1986). Trials in which horizontal eye movements exceeded  $2^\circ$  from fixation during stimulus exposure also were rejected. For comparability, the matched stimulus presentations of a rejected trial also were excluded (i.e., all four trials of a particular negative/neutral stimulus pair), resulting in a mean of 13.0 trials ( $SD = 2.7$ ,  $Mdn = 14$ ) per condition and participant. Average ERP waveforms were computed from these valid trials.

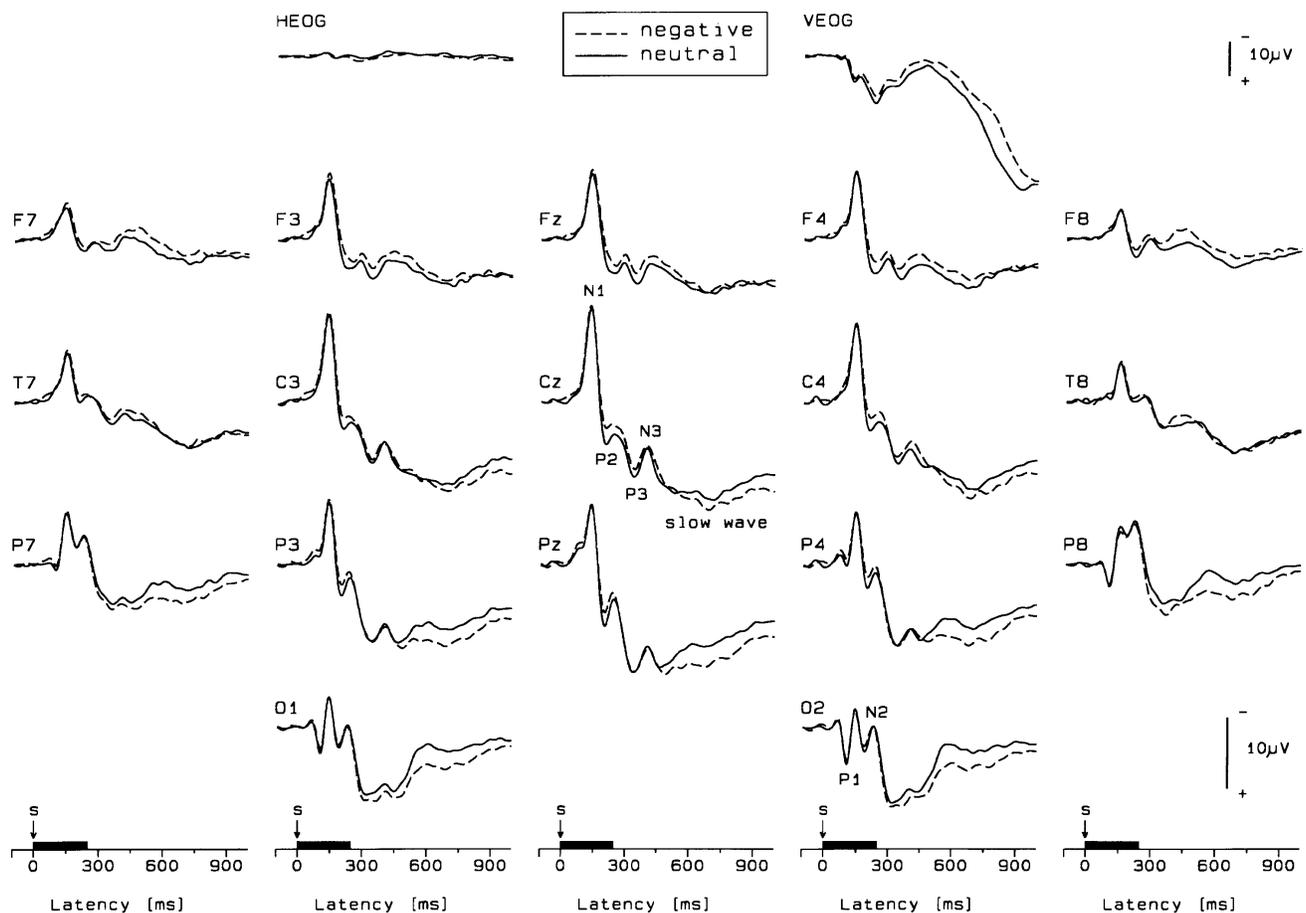
To determine the sources of variance in the ERP waveforms (Donchin, Kutas, & McCarthy, 1977), the averaged ERP waveforms were submitted to a PCA derived from the covariance matrix, followed by a Varimax rotation. The factor analysis was computed on an IBM/CMS mainframe computer using BMDP statistical software (BMDP4M; Dixon, 1985). Columns of the data matrix represented time (sample points), and rows consisted of participants (23), conditions (4), and lateral electrode sites (14). The number of orthogonal factors extracted by the PCA was limited by a criterion of eigenvalues greater than 1.0. PCA factor scores were submitted to repeated measures ANOVAs with emotional content (negative/neutral), visual field (left/right), hemisphere (left/right), and site (7 symmetrical pairs of electrodes), excluding midline electrodes, as within-subjects variables. Greenhouse-Geisser epsilon ( $\epsilon$ ) correction was used to evaluate F ratios for within-subjects effects involving more than 2 degrees of freedom (Jennings, 1987; Vasey & Thayer, 1987). Significant topographic

effects involving emotional content and hemisphere were also evaluated after scaling the amplitudes for each condition by the vector amplitude measured across electrodes (hemisphere and site) in each participant (McCarthy & Wood, 1985).

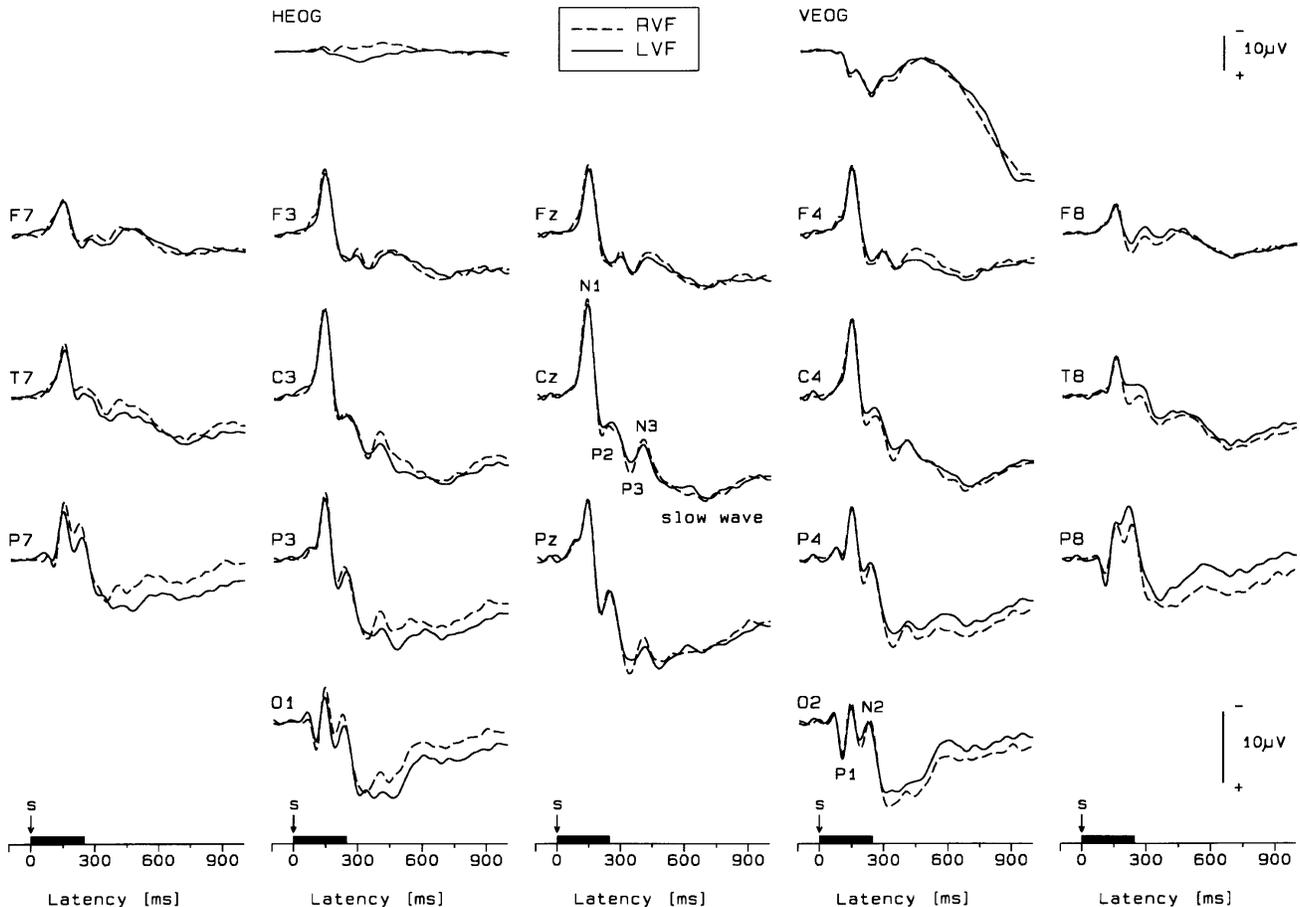
## Results

### ERP Component Structure

Grand-average ERP waveforms, averaged across emotional content (negative/neutral) and visual field (left, right), are shown for all leads in Figures 1 and 2, respectively. Across all conditions, distinctive ERP components were identified as P1 (latency 100 ms), N1 (130 ms), P2 (190 ms), N2 (225 ms), P3 (320 ms), a negative peak labeled N3 (400 ms), and slow wave ( $>450$  ms). As can be seen from Figures 1 and 2, N1 was present at all electrode sites but most prominent centrally. P3 and slow wave were broadly distributed but P3 showed a maximum over posterior regions, whereas slow wave was maximal at central sites and had not yet returned to baseline by the end of the recording epoch. N2 was most distinctive at lateral-posterior sites, especially over the right hemisphere. P1 was restricted to posterior sites. Because the present study focused on hemispheric asymmetries, data from the midline electrode sites will not be considered further.



**Figure 1.** Grand average event-related potentials (ERPs) from neutral (solid line) and negative (dashed line) stimuli (averaged across visual field) for each electrode recording site ( $N = 23$ ). ERP components are indicated at Cz and O2. Note the different scalings for electrooculogram (EOG) channels showing VEOG averages before artifact removal.



**Figure 2.** Grand average event-related potentials (ERPs) from left (solid line) and right (dashed line) visual field exposures (averaged across emotional content) for each electrode recording site ( $N = 23$ ). ERP components are indicated at Cz and O2. Note the different scalings for electrooculogram (EOG) channels showing VEOG averages before artifact removal.

### PCA Factors and ERP Components

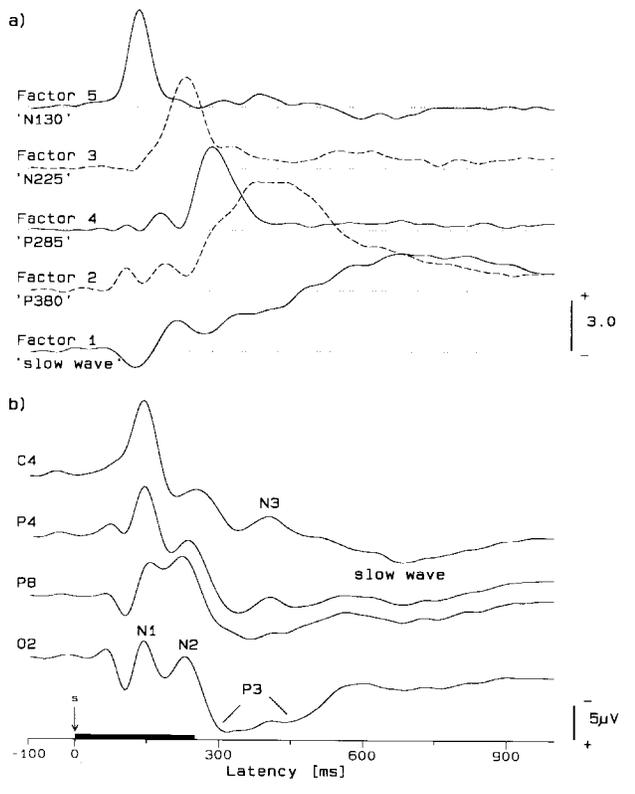
The first five principal components extracted by the PCA accounted for 82% of the ERP variance. Figure 3 represents a plot of the factor loadings at each time point, together with selected grand average ERP waveforms over the right hemisphere. Figure 4 depicts the topographical distribution of the corresponding factor scores. Hence, the degree of association of each factor with the temporal locus and the scalp region of activity can be inferred from Figures 3 and 4, respectively.

PCA factors largely correspond to the identified ERP components. Consequently, the first five factors will be described according to their peak latencies. Factor 5 (3.8% explained variance) peaked at 130 ms and almost entirely overlapped N1 (see Figure 3). Factor 5 amplitude was most negative at C3, which is consistent with the central maximum of N1 (see Figure 4). For these reasons, Factor 5 was labeled 'N130'. Analogously, Factor 3 (5.8% explained variance) peaked at 225 ms and had a topography similar to N2 (see Figures 3 and 4). Factor 3 amplitude was most negative at posterior-lateral sites, especially over the right parietal region. Factor 3 was identified as 'N225'. Factor 4 (4.5% explained variance) amplitude was greatest at 285 ms, corresponding to the early phase of the P3 component (see Figure 3). In accordance with this interpretation, factor scores of Factor 4 were positive over posterior regions, maximal at the right occipital site (see

Figure 4). Factor 4 was labeled 'P285'. Factor 2 (27.0% explained variance) extended over a relatively long time period of 270-600 ms, peaking at approximately 380 ms (see Figure 3). Factor 2 amplitude was most positive at posterior regions and most negative at anterior regions (see Figure 4). Factor 2 appeared to be linked to the late phase of the P3 component and was named 'P380', although its loading interval also includes the N3 component peaking at 400 ms. The topography of 'P380' indicates a posterior positivity coincident with an anterior negativity. Factor 1 revealed high loadings over a long time period (see Figure 3), which explained 41.0% of the variance. Because of the high loadings in the late range of the sample interval, especially beyond 450 ms, and the broad distribution with a central maximum (see Figure 4), Factor 1 was labeled 'slow wave'.<sup>2</sup>

The relevance of the factors extracted by the PCA is apparent from the temporal and topographic distinctiveness of factors 'N130', 'N225', and 'P285'. These factors accurately reflect the negative and positive ERP components labeled N1, N2, and early P3 that were identified in the ERP waveforms. 'N130' was distributed frontocentrally, whereas

<sup>2</sup>The ERP components P1 and P2 were clearly represented in two other factors, that is, Factor 8 (1.4% explained variance, 'P100') and Factor 7 (3.4% explained variance, 'P170'). However, because the amount of additional experimental variance explained by these two factors was low, further analyses of these factors are not reported.



**Figure 3.** Varimax rotated factor loadings plotted over time for five orthogonal factors extracted by principal components analysis (PCA) (a), and selected grand mean event-related potential (ERP) waveforms from the right hemisphere (b). Loadings represent the degree of association of each time point with each factor. Factor labels (in single quotes) were chosen to reflect both the time course of the factor loadings (a) and the polarity of the associated ERP components (b).

'N225' showed a modality-specific distribution for this visual task and was larger over preoccipital areas (Hillyard & Picton, 1987). 'P285' amplitude was broadly distributed but maximal over posterior regions, comparable to the widespread distribution of P3 in conventional ERP tasks (Johnson, 1993; Picton, 1992). The identification of underlying

ERP components corresponding to factors 'P380' and 'slow wave' must be somewhat more tenuous, due to their long time duration and less simple morphology.

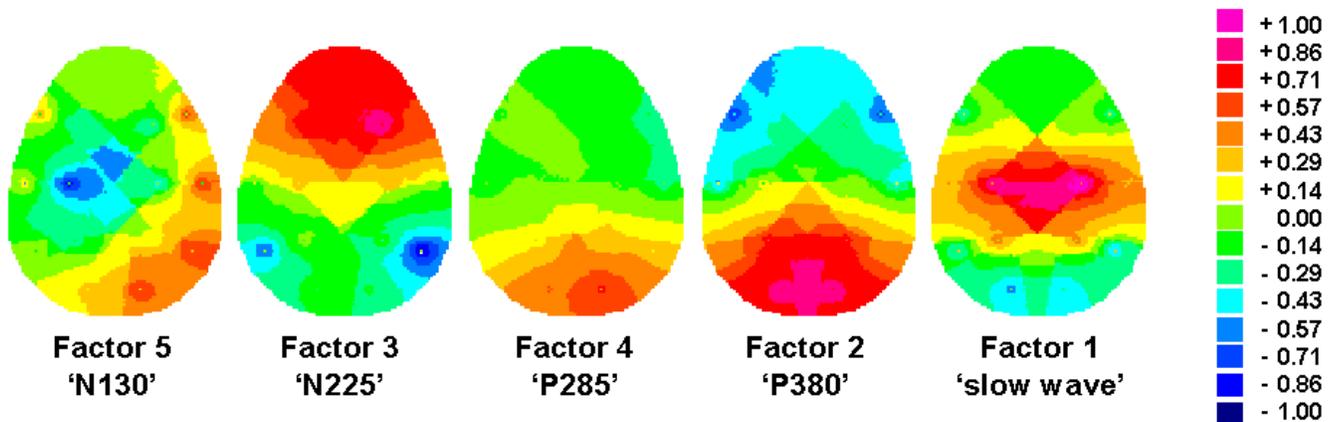
Factors 'P285' and 'P380' showed considerable overlap in temporal and regional activity. Although both factors appear to contribute to P3, factor loadings and factors scores were distinct. The posterior positivity inverted frontally only for factor 'P380'. To clarify the specific impact of both factors with respect to P3, the original ERP waveforms were compared with ERP waveforms re-referenced to Cz. Because both the 'slow wave' and 'N130' factors were highly associated with central activity, re-referencing effectively removed both N1 and slow wave from the ERP waveforms, but all other components were enhanced. The two positive peaks observed in the original waveforms (see Figure 3) were now clearly distinguishable, peaking at 285 and 380 ms, respectively. As factor 'P285' picked up only the variance of the earlier positive peak, factor 'P380' gathered variance primarily for the later positive peak.

Factor 'P380' loaded between 320 and 520 ms after stimulus onset and thereby included N3 peaking at 400 ms. The topography of 'P380' indicated a posterior positivity coincident with an anterior negativity. Although a frontal inversion (comparable to that often seen for P3) may account for the observed topography, factor 'P380' also might be linked to a distinct, frontal negativity (see Figure 1). Because recent reviews have suggested that multiple P3 generators varying with stimulus and task conditions appear to influence P3 topography (Johnson, 1993; Molnar, 1994; Picton, 1992), different but linked P3 generators might be responsible for the observed 'P380' topography.

The temporal and topographic distribution of 'slow wave' are compatible with positive slow wave (Ruchkin & Sutton, 1983). However, because 'slow wave' was the first factor extracted and accounts for over 40% of the variance, this factor may incorporate additional activity related to the grand mean waveform.

**Findings for PCA Factor Scores**

Results of the repeated measures ANOVAs performed on the factor scores are summarized in Table 1. The site main effect for all factors and several complex interactions including site were highly significant, indicative of a distinctive topography of each factor (see Figure 4).



**Figure 4.** Topographic mappings of principal components analysis (PCA) factor amplitudes. Maps were calculated from the factor scores for 14 lateral electrodes averaged across conditions. Scores represent the degree of association of each region with each factor. The sign of the factor scores reflects the polarity of the underlying event-related potential (ERP) component (positive scores are associated with positive ERP components and vice versa).

**Table 1.** Summary of *F* Ratios (and  $\epsilon$  Corrections) From ANOVAs Performed on PCA Factor Scores

Variable	<i>df</i>	Factor									
		'N130'		'N225'		'P285'		'P380'		'slow wave'	
SITE	6, 132	13.95 ***	(0.3202)	17.50 ***	(0.3681)	6.25 **	(0.3245)	30.59 ***	(0.3878)	33.78 ***	(0.4396)
EMOT	1, 22			4.50 *		4.54 *		5.84 *		5.23 *	
HEMI	1, 22	26.79 ***									
SITE × EMOT	6, 132	2.80	(0.4268)	2.54	(0.4745)			3.45 *	(0.3068)	9.57 ***	(0.4229)
SITE × HEMI	6, 132	8.86 ***	(0.5645)	5.35 **	(0.4652)	4.18 *	(0.4559)				
VF × HEMI	1, 22			4.17				15.49 **		27.23 ***	
EMOT × HEMI	1, 22			3.74							
SITE × VF × HEMI	6, 132			4.04 *	(0.3593)	5.91 **	(0.5506)	2.72	(0.4557)	23.34 ***	(0.4445)
SITE × VF × EMOT × HEMI	6, 132			2.57	(0.4728)						

Note. SITE = electrode site; EMOT = emotional content; HEMI = hemisphere; VF = visual field. Only *F* ratios with  $p < .10$  are reported. Effect sizes (partial eta squared) for significant effects ( $p < .05$ ) range from  $\eta^2 = .16$  to  $\eta^2 = .61$ .

\*  $p < .05$ . \*\*  $p < .01$ . \*\*\*  $p < .001$ .

Because of the degree of localization evidence of these effects, repeated measures ANOVAs with emotional content, visual field, and hemisphere were calculated separately for each PCA factor at symmetrical pairs of electrodes to evaluate the interaction effects directly. Results of these analyses are summarized in Table 2. To reduce the likelihood of Type I errors in the follow-up analyses applying a significance level of  $p < .05$ , effects were evaluated only if higher order interactions including site were observed or if effects were explicitly

hypothesized, that is, main effects of emotional content, hemisphere, and the interaction of Emotional Content × Hemisphere at parietal sites. More exploratory analyses were held to a more stringent significance level ( $p < .01$ ), although all effects were tabled.

*Factor N130.* A highly significant main effect of hemisphere and a highly significant Site × Hemisphere interaction was observed for factor 'N130'. Overall, 'N130' amplitude was more negative over the

**Table 2.** Summary of *F* Ratios From ANOVAs for Symmetric Pairs of Electrodes Performed on PCA Factor Scores

Factor	Electrode site						
	Medial				Lateral		
	F3/4	C3/4	P3/4	O1/2	F7/8	T7/8	P7/8
'N130'							
EMOT				3.02			
HEMI		24.96 ***	19.39 ***	8.75 **	6.41 *	35.44 ***	24.39 ***
VF × HEMI						7.78 *	
'N225'						3.42	
VF							
EMOT	3.65	4.98 *	6.51 *				
HEMI	7.97 *				4.24		3.65
VF × HEMI	7.94 *	5.02 *			15.55 **	17.81 ***	
EMOT × HEMI		6.47 *			5.33 *		
VF × EMOT × HEMI							6.50 *
'P285'							
EMOT				4.49 *		9.41 **	8.81 **
HEMI	5.10 *			3.30	5.30 *		
VF × HEMI	3.27		14.46 **	4.48 *			
EMOT × HEMI			5.97 *				5.12 *
'P380'							
EMOT	5.70 *	9.09 **			12.35 **	15.46 **	
VF × HEMI			9.93 **	30.19 ***	7.52 *	10.25 **	5.38 *
'slow wave'							
EMOT		7.44 *	9.57 **	11.54 **			9.48 **
VF × HEMI		9.06 **	51.14 ***	25.06 ***		6.47 *	83.68 ***

Note. EMOT = emotional content; HEMI = hemisphere; VF = visual field. *df* = 1, 22. Only *F* ratios with  $p < .10$  are reported. Effect sizes (partial eta squared) for significant effects ( $p < .05$ ) range from  $\eta^2 = .17$  to  $\eta^2 = .79$ .

\*  $p < .05$ . \*\*  $p < .01$ . \*\*\*  $p < .001$ .

left hemisphere, as the related ERP component N1 was enhanced over the left hemisphere. As indicated by the Site  $\times$  Hemisphere interaction and the hemisphere main effects of symmetrical pairs of electrodes (see Table 2), 'N130' amplitude was most negative at medial-central sites and less negative (compatible with a N1 reduction) at lateral and occipital right hemispheric sites (see Figure 4).

*Factor N225.* A significant main effect of emotional content was found for factor 'N225'. Mean factor scores were more negative for negative than for neutral stimuli. Maximal differences occurred at medial locations as indicated by the suggestive interaction of Site  $\times$  Emotional Content and the emotional content main effects for C3/4 and P3/4 (see Table 2). Differences for emotional content occurred at locations where N2 was inverted in polarity (see C3/4 and P3/4 in Figure 1) rather than where N2 was maximal in amplitude (see P8 in Figure 1). Hemisphere and Visual Field  $\times$  Hemisphere effects were found primarily at frontocentral locations, where N2 amplitude was small (see Table 2), accounting for the Site  $\times$  Hemisphere and Site  $\times$  Visual Field  $\times$  Hemisphere interactions.

For theoretical reasons, the interactions Emotional Content  $\times$  Hemisphere and Visual Field  $\times$  Emotional Content  $\times$  Hemisphere are of particular importance. Differences between negative and neutral stimuli in 'N225' amplitude were greater over the right hemisphere, as indicated by a simple main effect of emotional content at right hemisphere,  $F(1,22) = 6.56, p < .05$ , and this difference was noted particularly at C4 and F8 (see Table 2). Emotional content interacted with Visual Field  $\times$  Hemisphere only at lateral-parietal sites. To simplify this effect, note that the Visual Field  $\times$  Hemisphere interaction is statistically equivalent to a main effect of contra- versus ipsilateral visual fields. For negative stimuli, the hemispheric asymmetry at P7/8 was not affected by visual field, that is, N2 was greater at P8, but for neutral stimuli, N2 was relatively enhanced with exposures to the contralateral visual field.

*Factor 'P285'.* Mean 'P285' amplitude was larger for negative than for neutral stimuli, which resulted in a significant main effect for emotional content. In the separately calculated ANOVAs for symmetrical lead pairs, this effect was found only at occipital and lateral-posterior sites (see Table 2), and the effect was most pronounced at parietal sites of the right hemisphere (see P8 in Figure 1). Although no Site  $\times$  Emotional Content  $\times$  Hemisphere interaction was noted, the significant interaction of Emotional Content  $\times$  Hemisphere at P3/4 and

P7/8 and a simple main effect emotional content at right hemisphere,  $F(1,22) = 14.8, p < .01$ , support this observation.

*Factors 'P380' and 'slow wave'.* Analyses for factors P380 and 'slow wave' both revealed a significant main effect of emotional content and a significant Site  $\times$  Emotional Content interaction. Mean 'P380' amplitude was smaller for negative than for neutral stimuli, in particular at frontal and central but not at posterior sites (see Table 2), that is, differences for emotional content occurred at locations where late P3 inverted (see frontal leads in Figure 1). In contrast, mean 'slow wave' amplitude was greater for negative than for neutral stimuli, particularly at posterior and medial-central but not at anterior sites (see Table 2; Figure 1). Hence, the significant Site  $\times$  Emotional Content interaction for 'P380' and 'slow wave' derived from different topographies.

For both factors, Visual Field  $\times$  Hemisphere and Site  $\times$  Visual Field  $\times$  Hemisphere interactions (suggested for 'P380') were noted. As can be seen from Figure 2, mean amplitudes of late P3 and slow wave were relatively enhanced with stimulation of the ipsilateral visual field, particularly over posterior brain regions (see Table 2).

### Findings for N2-P3 Amplitude

Effects of primary interest, that is, asymmetries in emotional processing, were limited to factors 'N225' and 'P285'. Because these factors were hypothesized to jointly reflect endogenous ERP activity (analogous to N2-P3 peak-to-peak differences in classical oddball paradigms), factor score difference amplitudes between N2 and early P3 were calculated and submitted to an additional repeated measures ANOVA. This analysis revealed a significant Emotional Content  $\times$  Hemisphere interaction,  $F(1,22) = 4.28, p < .05$ , resulting from pronounced right hemispheric differences between negative and neutral stimuli, with N2-P3 amplitude being maximal for negative and minimal for neutral stimuli over right hemisphere regions. This analysis also revealed highly significant main effects for site,  $F(6,132) = 19.98, p < .001, \epsilon = 0.3561$ , and emotional content,  $F(1,22) = 9.77, p < .01$ , and a significant Site  $\times$  Hemisphere interaction,  $F(6,132) = 10.05, p < .05, \epsilon = 0.5911$ . To elucidate these effects further, separate repeated measures ANOVAs were again calculated for each symmetrical pair of electrodes (see Table 3). The relevant mean 'P285'/'N225' factor score difference topographies are illustrated in Figure 5.

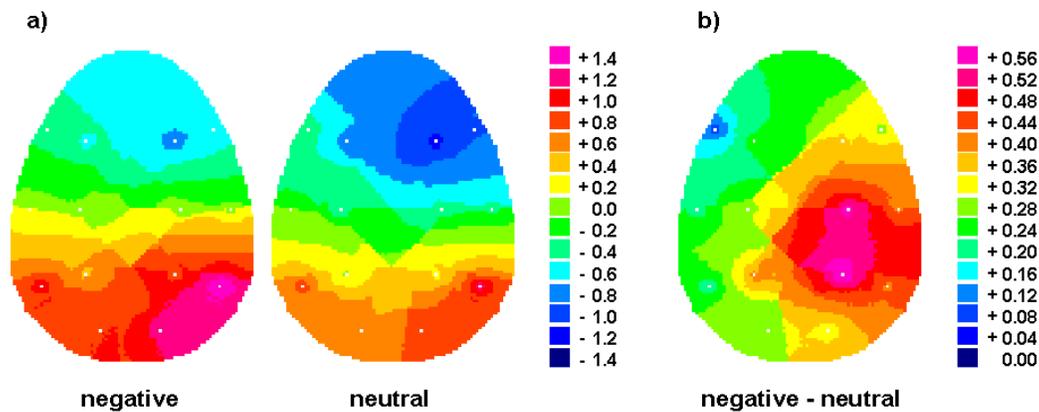
Overall, 'P285'/'N225' factor score differences were positive over posterior regions and negative over anterior regions; both extremes,

**Table 3.** Summary of *F* Ratios from ANOVAs for Symmetric Pairs of Electrodes Performed on PCA Factor Score Differences 'P285' - 'N225'

Variable	Electrode site						
	Medial				Lateral		
	F3/4	C3/4	P3/4	O1/2	F7/8	T7/8	P7/8
EMOT	3.05	5.40 *	9.96 **	5.71 *	5.73 *	11.16 **	6.36 *
HEMI	11.49 **		3.45	4.65 *	7.32 *		6.23 *
VF $\times$ HEMI			3.56			4.71 *	
EMOT $\times$ HEMI		4.05	4.52 *				3.13
VF $\times$ EMOT $\times$ HEMI							3.61

*Note.* EMOT = emotional content; HEMI = hemisphere; VF = visual field.  $df = 1, 22$ . Only *F* ratios with  $p < .10$  are reported. Effect sizes (partial eta squared) for significant effects ( $p < .05$ ) range from  $\eta^2 = .17$  to  $\eta^2 = .34$ .

\*  $p < .05$ . \*\*  $p < .01$ .



**Figure 5.** Topographies of N2-P3 amplitude (differences of principal components analysis [PCA] factor scores 'P285' - 'N225'). Maps were calculated for (a) negative and neutral stimuli (averaged across visual fields), and (b) the corresponding difference map for negative-minus-neutral stimuli.

high positive and high negative, were accentuated over the right hemisphere (see Figure 5a). For all electrode sites, factor score differences were relatively larger for negative than for neutral stimuli, as indicated by the significant main effect emotional content for each location (suggested for F3/4; see Table 3). Most important, the difference between negative and neutral stimuli, that is, the net effect of emotional content, was evident in N2-P3 amplitude over the entire right hemisphere but maximal over the medial-parietal region (see Figure 5b). Virtually no differences for emotional content were seen in this measure over the left lateral-frontal region.

#### Confirmatory Findings

Interpreting significant interactions in ERP studies involving electrode location can be ambiguous because they may result from differences in source strength from the same source or sources (McCarthy & Wood, 1985). Therefore, significant interactions involving emotional content and hemisphere also were evaluated after scaling the amplitudes for each condition by the vector amplitude measured across electrodes in each participant. For each factor, all interactions (except the Site  $\times$  Emotional Content interaction for factor P380 which became insignificant after *c* correction) were preserved or even strengthened. This finding was notably the case for the Emotional Content  $\times$  Hemisphere interaction,  $F(1,22) = 6.18$ ,  $p < .05$ , in the respective ANOVA using 'N225'/'P285' factor score difference amplitudes.

Given the use of hemifield exposures, shorter ERP latencies could be expected for contralateral rather than for ipsilateral brain regions, which could in turn have affected the results by producing contralateral versus ipsilateral differences in weights for given time points that were ignored by the generation of principal components derived from data derived from all conditions combined. This possibility was excluded after performing two additional PCAs separately for contralateral and ipsilateral data which revealed literally identical factors, that is, 'slow wave' (39.6% and 41.9% explained variance contralateral vs. ipsilateral data, respectively), 'P380' (25.9% and 27.9%), 'N225' (4.9% and 6.0%), 'P285' (6.2% and 3.5%), and 'N130' (4.2% and 3.5%), reversing only the order of factors 'N225' and 'P285'.

The applicability of PCA methodology in the analysis of ERPs is enhanced when the extracted factors can be shown to reflect and clarify

the conventionally defined component structure of the ERP. without distortion due to misallocated variance from overlapping components, outlying cases, or temporal "jitter" (Friedman, Vaughan, & Erlenmeyer-Kimling, 1981; Vaughan, Ritter, & Simson, 1983; see also Wood & McCarthy, 1984). Although these problems are inherent in any technique for component identification, for example, measurements of peak amplitude or peak latency, we confirmed and validated prominent PCA findings by taking mean amplitude values over respective time periods. ERP components of the average waveforms were defined as the mean voltage area within distinctive time windows as P1 (80-120 ms), N1 (130-180 ms), N2 (190-240 ms), P3 (250-400 ms), and slow wave (410-999 ms) and submitted to repeated measures ANOVAs. Results of the time window analyses are in accordance with the PCA results (for a summary, see Kayser et al., 1995). However, the strength and advantage of PCA factor scores over time window definitions of ERP components is evident in our data by the ability of the scores to disentangle overlapping ERP components, that is, N2, early P3, and late P3.

#### Discussion

##### ERP Components Associated With Emotional Processing

In the present study, the influence of emotional content was evident in N2, early P3, late P3, and slow wave. Negative stimuli produced a greater amplitude positivity than did neutral stimuli for early P3 and for slow wave at locations in which the component's amplitude was largest (lateral-posterior for early P3, medial-central for slow wave). Our results provide evidence for a topographical differentiation of the emotionally responsive late positive components and thereby replicate and extend the findings of Johnston and colleagues (Johnston et al., 1986; Johnston & Wang, 1991), who also used PCA to summarize ERP waveforms.

Johnston et al. (1986) recorded ERPs from midline electrodes (Fz, Cz, Pz) using central exposures of comparable but less carefully controlled stimuli (babies, people, dermatological slides, nudes of both sexes). The waveforms illustrated in Johnston et al. (1986, see Fig. 2, p. 687) closely match the component structure described in the present study, allowing the identification of P1, N1, P2, N2, P3, N3, and slow

wave in their data. Johnston et al. reported three ERP factors, peaking at 300, 540, and 920 ms, which were responsive to emotional content. The factor peaking at 300 ms with a parietal maximum closely matches the timing of the negative peak we identified as N2 in their data. In the present study, N2 differences related to emotion were most evident at medial locations rather than over lateral-parietal regions, where the component was largest (i.e., over modality-specific preoccipital regions). The third factor in the study by Johnston et al. probably corresponds to the N2-P3 transition rather than to P3, particularly because three midline electrodes provide inadequate spatial sampling to distinguish between the two components.

In the present study, differences for emotional content were seen at anterior sites for factor P380, that is, where the polarity of the component was inverted. If we assume that factor P380 is associated with both a medial-frontal negativity and a lateral-posterior positivity, then we have to conclude that the observed emotion-related ERP differences are related to a medial-frontal negativity at 400 ms rather than to a late posterior P3. However, both lateral-posterior positivity and medial-frontal negativity are linked in the present data. Because such a linkage may result from the way the data was submitted to the PCA, that is, failing to observe a dissociation of different processes associated with each condition (Friedman et al., 1981), we performed two separate PCAs for negative and neutral stimuli. These analyses yielded very similar factor structures, thus confirming the linkage of lateral-posterior positivity and medial-frontal negativity for factor P380 across conditions (i.e., neither condition is exclusively linked to either of these patterns). A parsimonious interpretation is that late P3 is overlapped by a negative component at medial-frontal sites, peaking at 400 ms. This frontal negativity might be related to the processing contextually novel visual stimuli common to both conditions (i.e., pictures of isolated facial features), which is analogous to the N400 produced during the processing of linguistic material (Curran, Tucker, Kutas, & Posner, 1993; Kutas, Van Petten, & Besson, 1988).

Emotion-related differences in the later (primarily endogenous) ERP components were not due to differences in physical stimulus properties. If physical properties of the stimuli contributed to these emotion-related differences, we would also expect to see differences in early (primarily exogenous) ERP components (Hillyard & Picton, 1987; Näätänen & Picton, 1987). These early components were sensitive to stimulus lateralization but not to emotional content.

### ***ERP Hemispheric Asymmetries in Emotional Processing***

A differential hemispheric activation was evident for N2 (at frontal and central sites) and early P3 (at parietal sites), which is consistent with theories of asymmetrical emotional processing stressing the importance of right brain regions for processing emotional stimuli (e.g., Davidson, 1984; Silberman & Weingartner, 1986; Tucker, 1981). The difference between these two successive peaks, as measured by P285/N225 factor score differences, revealed a robust overall asymmetry for processing negative emotional content (i.e., this asymmetry was not restricted to a particular brain region), emphasizing that both components contribute to this effect. However in this measure, the disparity between negative and neutral stimuli, or the net effect of emotional content, was also maximal at right parietal sites (see Figure 5b).

Hemispheric asymmetries related to emotional processing are unlikely to have been a result of differences in hemispheric strategies associated with the implicit behavioral response or other inherent task requirements; nor were they a result of the physical characteristics of the stimuli. A manual or a verbal response was not required, and

negative and neutral stimuli were nearly identical. The long interstimulus intervals further reduce the likelihood that long latency response-related processes, such as the contingent negative variation (CNV), contribute to these differences. Although we observed a marked hemispheric asymmetry for N1, there were no indications of any differences in this asymmetry between negative and neutral stimuli. If the different features distinguishing both stimulus qualities were nonetheless decisive, we would expect to observe the opposite hemispheric asymmetry, that is, a left hemispheric advantage for processing stimuli containing distinctive features (Sergent, 1982; Sergent & Bindra, 1981), or local as opposed to global aspects of visual stimuli (cf. Hellige, 1995; Semmes, 1968). We would also expect a pronounced involvement of the left hemisphere, if the participants had inhereently used a verbal or analytical approach to view the stimuli (Kayser, 1995; Shearer & Tucker, 1981; Tucker & Newman, 1981). Therefore, cognitive processing is not a parsimonious explanation to account for the results.

Although stimulus probability was equated within the experimental paradigm, the two classes of stimuli may differ in their subjective probability, that is, common (high probability) neutral stimuli and unexpected (low probability) negative stimuli. Therefore, participants could be said to react to perceptual mismatches, and emotion-related effects (e.g., larger N2 and P3 amplitudes) should be interpreted in terms of conventional discriminative and automatic ERP processes (e.g., mismatch negativity; see Näätänen, 1992). In discussing a similar criticism of their method, Johnston et al. (1986) noted that their ERP findings paralleled self-report ratings of the stimuli. Furthermore, if subjective probability were responsible for their observed effects, the largest late components should have been elicited by their dermatological slides rather than, as they found, by pictures of the opposite sex.

Our results are not inconsistent with the previously cited ERP studies exploring hemispheric asymmetries during affect perception. Laurian et al. (1991) reported differential P3 amplitude asymmetries at parietal sites that correspond to our P3 amplitude time window. However, the findings of the present study restrict this differential hemispheric asymmetry to early P3. The failure of Carretié and Iglesias (1995) to report differential hemispheric asymmetries for early and late ERP components also matches our data because none of the emotional asymmetry effects reported in the present study were found at lateral-temporal sites, that is, T7/8, the only lateral electrode pair employed by Carretié and Iglesias (1995).

We did *not* find a visual field main effect, nor did we find interactions of visual field with site or emotional content for any of the five PCA factors. This lack of effect is surprising, insofar as a left visual-field (right hemisphere) advantage is often assumed in processing visual-spatial stimuli (e.g., Beaumont, 1982), but the lack of effect is not uncommon. Behavioral evidence of functional hemispheric asymmetries (e.g., such as a left hemisphere advantage in language processing) has been inconsistent for divided visual-field studies (e.g., Bryden, 1982, 1988). Although we did find clear visual-field effects, they were unrelated to emotional content. However, concluding that the observed asymmetries in emotional processing were unrelated to the divided stimulus presentations of visual half-field paradigm itself would be premature. A direct comparison of lateralized and central stimulus exposure in a single paradigm is required to rule out this possibility.

### ***Findings Related to General Stimulus Properties***

A hemispheric asymmetry was evident for exogenous ERP components

regardless of the hemifield stimulated. P1 amplitude was larger over the right hemisphere, and N1 amplitude was larger over the left hemisphere, an effect also reported for face stimuli (Barrett, Rugg, & Perrett, 1988). Along with these authors, we interpret these asymmetries as consistent with other neuropsychological evidence suggesting a right hemisphere superiority for various aspects of processing faces or face-like stimuli (e.g., Begleiter, Porjesz, & Wang, 1993; Bruyer, 1986; Ellis, 1983; Hertz, Porjesz, Begleiter, & Chorlian, 1994).

#### ***Hemispheric Asymmetries of Early ERP Components Associated With Lateralized Stimulus Input***

Early ERP components (P1, N1, N2) were enhanced contralateral to the stimulated hemifield in a manner consistent with the organization of the geniculostriate system and were in agreement with other ERP studies based on the visual half-field paradigm (e.g., Kok & Rooyackers, 1986; Mangun & Hillyard, 1988; Rugg & Beaumont, 1978; Schweinberger & Sommer, 1991; Sobotka et al., 1984). This contralateral pattern was prominent at posterior sites (O1/2, P7/8) for P1 but was distinct for N1 only at temporal-lateral sites (T7/8). The most parsimonious conclusion is that these enhanced early ERP components reflect increased neuronal responsivity of the directly stimulated cortical regions, an inference also supported by spatiotemporal analyses showing that pi occurs at shorter latencies over the contralateral than over the ipsilateral hemisphere (Tucker, Liotti, Potts, Russell, & Posner, 1994).

#### ***Hemispheric Asymmetries of Late ERP Components Associated With Lateralized Stimulus Input***

Late P3 and slow wave were largest over the hemisphere ipsilateral to the stimulated hemifield, as has been previously reported (e.g., Kok & Rooyackers, 1986; Schweinberger & Sommer, 1991; Schweinberger et al., 1994). The dominance of ipsilateral effects in the late ERP may reflect increased effort for processing information in the ipsilateral hemisphere (i.e., operating only on "second-hand" information). Alternatively, these components could be generated by the "underside" of dipole generators oriented across the midline (i.e., the generator is located in the directly stimulated hemisphere). Although these possibilities cannot be evaluated from the present data, a more convincing interpretation has been suggested by Schweinberger and colleagues (Schweinberger & Sommer, 1991; Schweinberger et al., 1994). Using an average reference, they found that the contralateral input was associated with a long-lasting negativity and that the sustained negativity was superimposed on the other ERP components of the waveforms. Although some long latency negativities might be a consequence of the particular experimental paradigm, for example, a CNV or a readiness potential in anticipation of a sensorimotor task or the next trial (e.g., Donchin et al., 1977; Rockstroh, Elbert, Lutzenberger, Birbaumer, & Roberts, 1988), this concern does not apply to the present paradigm because a long interstimulus interval was used and no behavioral response was required.

ERP waveforms were re-referenced to the average activity of all EEG channels to facilitate a direct comparison to the data of Schweinberger and Sommer (1991) and Schweinberger et al. (1994). The component structure of the re-referenced ERP waveforms was comparable to those reported by Schweinberger and collaborators and revealed a sustained negativity at occipital (O1/2) and lateral-temporal (P7/8) sites to contralateral stimulations.

A sustained positivity was superimposed on this hemifield-dependent negativity at medial electrode locations (particularly at P3/4). We conclude that the putative late P3 and slow wave enhancements

observed with ipsilateral visual-field exposures are a direct consequence of a long-lasting hemifield-dependent negativity, presumably reflecting endogenous processes (Schweinberger & Sommer, 1991). However, the exposure of negative and neutral visual stimuli per se resulted in positive late ERP components, as was found by Johnston et al. (1986) for dermatological slides, which overlap the hemifield-dependent negativity. Despite this superimposed negativity, late P3 and slow wave were sensitive to the other experimental condition, that is, to emotional content, and had separable topographies. Therefore, whereas the shorter latency ERP components are related to the emotional content, the hemifield-dependent negativity arises directly from the visual half-field stimulation.

#### **Conclusions**

The findings of the present study provide evidence for a differential hemispheric contribution in the regulation of affect, which was distinct from a greater overall involvement of the right hemisphere for perceptual processing of face-like stimuli. In accordance with predictions from numerous studies of the lateralization of emotion (e.g., reviewed by Davidson, 1984, 1995; Etcoff, 1989; Gainotti, 1989; Heller, 1993; Silberman & Weingartner, 1986; Tucker, 1981), a right hemispheric superiority for the perception of negative versus neutral stimuli was apparent for long latency components of the ERP waveforms (i.e., N2 and early P3). In particular, the right parietal region showed a prominent, differential responsivity to affective stimulus features in this study. This region has been found to be linked closely to autonomic arousal (e.g., reviewed by Gainotti, 1987; modeled by Heller, 1993), and skin conductance responses indicative of stimulus significance appear to require intact cortical structures of the right inferior parietal region (Tranel & Damasio, 1994).

The design of this study reduces the feasibility of interpretations that focus on cognitive aspects of stimulus processing. However, even the subtle physical differences between our negative and neutral stimuli could arguably be conceptualized in terms of attention, recognition difficulty, or stimulus complexity rather than to affective value. In as much as any of these constructs have been associated with hemispheric asymmetries (e.g., Bryden, 1982; Jutai, 1984), they are potential confounds (but see also reviews by Campbell [1982] and Etcoff [1989] for inconsistencies with these constructs in the context of emotional lateralization). The crucial problem is how to provide an operational definition of interrelated theoretical constructs such as attention, emotion, and cognition, without implying that they are clearly separable. The present paradigm was designed to enhance affective rather than cognitive information processing, thereby exploiting the inherent affective significance of the stimuli rather than relying on imposed task characteristics; however, a complete discussion of cognitive-emotional interactions is well beyond the scope of this paper (e.g., see reviews by Feyereisen, 1989; Gray, 1990; LeDoux, 1989; Leventhal & Scherer, 1987; Scherer, 1993; Tucker, 1989; Tucker & Williamson, 1984).

Arguing on the basis of our data, there was no indication that early ERP components (P1, N1), which presumably reflect differences in physical stimulus characteristics (Hillyard & Picton, 1987) and attentional processes (Näätänen, 1992), were affected differentially by negative and neutral stimuli. Differences in emotional content were clearly present in the late positive complex of the ERP, which is in agreement with previous reports (Johnston et al., 1986; Johnston &

Wang, 1991; Laurian et al., 1991). However, asymmetries in emotional processing were restricted to the time period including N2 and early P3, which is consistent with the idea of a basic lateralized neuronal mechanism being responsible for an involuntary classification (N2) and evaluation (early P3) of the affective significance of the stimulus and is analogous to the classic N2-P3a (Hillyard & Picton, 1987). In contrast, further stimulus elaboration, as indexed by the later portions

of the late positive complex, revealed no affect-related asymmetries. Because caution is required in generalizing the results beyond the processing of negative affective stimuli, inferences about ERP concomitants linked to the lateralized processing of emotional stimuli per se must be deferred until future research in which stimuli of positive valence are used in a comparable paradigm.

## REFERENCES

- Barrett, S.E., Rugg, M.D., & Perrett, D.I. (1988). Event-related potentials and the matching of familiar and unfamiliar faces. *Neuropsychologia*, 26, 105-117.
- Beaumont, J.D. (Ed.) (1982). *Divided Visual Field Studies of Cerebral Organization*. London: Academic Press.
- Begleiter, H., Porjesz, B., & Wang, W. (1993). A neurophysiologic correlate of visual short-term memory in humans. *Electroencephalography and Clinical Neurophysiology*, 87, 46-53.
- Boucsein, W. (1992). *Electrodermal activity*. New York: Plenum Press.
- Bruyer, R. (1986). *The Neuropsychology of Face Perception and Facial Expression*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Bryden, M.P. (1977). Measuring handedness with questionnaires. *Neuropsychologia*, 15, 617-624.
- Bryden, M.P. (1982). *Laterality: Functional asymmetry in the intact brain*. New York: Academic Press.
- Bryden, M.P. (1988). Cerebral specialization: Clinical and experimental assessment. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology (Vol. 1)* (pp. 143-159). Amsterdam: Elsevier.
- Bryson, S.E., McLaren, J., Wadden, N.P., & MacLean, M. (1991). Differential asymmetries for positive and negative emotion: Hemisphere or stimulus effects? *Cortex*, 27, 359-365.
- Campbell, R. (1982). The lateralization of emotion: A critical review. *International Journal of Psychology*, 17, 211-229.
- Carretié, L., & Iglesias, J. (1995). An ERP study on the specificity of facial expression processing. *International Journal of Psychophysiology*, 19, 183-192.
- Curran, T., Tucker, D.M., Kutas, M., & Posner, M.I. (1993). Topography of the N400: Brain electrical activity reflecting semantic expectancy. *Electroencephalography and Clinical Neurophysiology*, 88, 188-209.
- Davidson, R.J. (1984). Affect, cognition, and hemispheric specialization. In C.E. Izard, J. Kagan, & R.B. Zajonc (Eds.), *Emotion, Cognition and Behavior* (pp. 320-365). New York: Cambridge University Press.
- Davidson, R.J. (1995). Cerebral asymmetry, emotion, and affective style. In R.J. Davidson & K. Hugdahl (Eds.), *Brain Asymmetry* (pp. 361-387). Cambridge, MA: MIT Press.
- Davidson, R.J., & Tomarken, A.J. (1989). Laterality and emotion: An electrophysiological approach. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology (Vol. 3)* (pp. 419-441). Amsterdam: Elsevier.
- De Pascalis, V., Morelli, A., & Montiroso, R. (1990). Word recognition time and event related potentials during emotional word processing. *Journal of Psychophysiology*, 4, 229-240.
- Dixon, W.J. (Ed.) (1985). *BMDP Statistical Software*. Berkeley, CA: University of California Press.
- Donchin, E. (1979). Event-related potentials: A tool in the study of human information processing. In H. Begleiter (Ed.), *Evoked brain potentials and behavior*. New York: Plenum Press.
- Donchin, E., Kutas, M., & McCarthy, G. (1977). Electrodermal indices of hemispheric utilization. In S.R. Harnad, R.W. Doty, L. Goldstein, J. Jaynes, & G. Krauthammer (Eds.), *Lateralization in the Nervous System* (pp. 339-384). New York: Academic Press.
- Ekman, P., & Friesen, W.V. (1976). *Pictures of Facial Affect*. Palo Alto, CA: Consulting Psychologist Press.
- Ellis, H.D. (1983). The role of the right hemisphere in face perception. In A.W. Young (Ed.), *Functions of the Right Cerebral Hemisphere* (pp. 33-64). London: Academic Press.
- Erdmann, G. & Kayser, J. (1990). Hemisphärenunterschiede beim Erkennen des emotionalen Ausdrucks von Gesichtern: Emotionserkennen oder Mustererkennen? [Hemispheric differences in the recognition of facial emotional expressions: Emotion or pattern recognition?] *Zeitschrift für Neuropsychologie*, 1, 45-56.
- Etcoff, N.L. (1989). Asymmetries in recognition of emotion. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology (Vol. 3)* (pp. 362-382). Amsterdam: Elsevier.
- Feyereisen, P. (1989). What can be learned from lateral differences in emotional processing? In G. Gainotti & C. Caltagirone (Eds.), *Emotion and the Dual Brain* (pp. 121-146). Berlin: Springer.
- Friedman, D., Vaughan, H.G., & Erlenmeyer-Kimling, L. (1981). Multiple late positive potentials in two visual discrimination tasks. *Psychophysiology*, 18, 635-649.
- Gainotti, G. (1987). Disorders of emotional behaviour and of autonomic arousal resulting from unilateral brain damage. In D. Ottoson (Ed.), *Duality and Unity of the Brain* (pp. 161-179). New York: Plenum Press.
- Gainotti, G. (1989). Disorders of emotions and affect in patients with unilateral brain damage. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology (Vol. 3)* (pp. 345-361). Amsterdam: Elsevier.
- Gainotti, G., Caltagirone, C., & Zoccolotti, P. (1993). Left/right and cortical/subcortical dichotomies in the neuropsychological study of human emotions. *Cognition and Emotion*, 7, 71-93.
- Gray, J.A. (1990). Brain systems that mediate both emotion and cognition. *Cognition and Emotion*, 4, 269-288.
- Heller, W. (1993). Neuropsychological mechanisms of individual differences in emotion, personality, and arousal. *Neuropsychology*, 7, 476-489.
- Hellige, J.B. (1995). Hemispheric asymmetry for components of visual information processing. In R.J. Davidson & K. Hugdahl (Eds.), *Brain Asymmetry* (pp. 99-121). Cambridge, MA: MIT Press.
- Hertz, S., Porjesz, B., Begleiter, H., & Chorlian, D. (1994). Event-related potentials to faces: The effects of priming and recognition. *Electroencephalography and Clinical Neurophysiology*, 92, 342-351.
- Hillyard, S.A. & Picton, T.W. (1987). Electrophysiology of cognition. In F. Plum (Ed.), *Handbook of Physiology. Section 1. The Nervous System, Vol. 5. Higher Functions of the Brain* (pp. 519-584). Bethesda, FL: American Physiological Society.
- Jennings, J.R. (1987). Editorial policy on analyses of variance with repeated measures. *Psychophysiology*, 24, 474-475.
- Johnson, R. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology*, 30, 90-97.
- Johnston, V.S., Miller, D.R., & Burselen, M.H. (1986). Multiple P3s to emotional stimuli and their theoretical significance. *Psychophysiology*, 23, 684-693.
- Johnston, V.S. & Wang, X.-T. (1991). The relationship between menstrual phase and the P3 component of ERPs. *Psychophysiology*, 28, 400-409.
- Jutai, W.J. (1984). Cerebral asymmetry and the psychophysiology of attention. *International Journal of Psychophysiology*, 1, 219-225.
- Kayser, J. (1995). *Hemisphärenunterschiede, Emotion und bilaterale elektrodermale Aktivität* [Hemispheric differences, emotion, and bilateral electrodermal activity] (Europäische Hochschulschriften, Vol. 513). Frankfurt a.M., Germany: Peter Lang.
- Kayser, J., Tenke, C., Nordby, H., Hammerborg, D., Hugdahl, K., & Erdmann, G. (1995). Event-related potential (ERP) asymmetries to

- emotional stimuli in a visual half-field paradigm. *Psychophysiology*, 32, S44.
- Kok, A. & Rooyakkers, J.A.J. (1986). ERPs to laterally presented pictures and words in a semantic categorization task. *Psychophysiology*, 23, 672-683.
- Kutas, M., Van Petten, C., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences. *Electroencephalography and Clinical Neurophysiology*, 69, 218-233.
- Lang, S.F., Nelson, C.A., & Collins, P.F. (1990). Event-related potentials to emotional and neutral stimuli. *Journal of Clinical and Experimental Neuropsychology*, 12, 946-958.
- Laurian, S., Bader, M., Lanares, J., & Oros, L. (1991). Topography of event-related potentials elicited by visual emotional stimuli. *International Journal of Psychophysiology*, 10, 231-238.
- LeDoux, J.E. (1989). Cognitive-emotional interactions in the brain. *Cognition and Emotion*, 3, 267-289.
- Leventhal, H. & Scherer, K.R. (1987). The relationship of emotion and cognition: A functional approach to a semantic controversy. *Cognition and Emotion*, 1, 3-28.
- Leventhal, H. & Tomarken, A.J. (1986). Emotion: Today's problems. *Annual Review of Psychology*, 37, 565-610.
- Liotti, M. & Tucker, D.M. (1995). Emotion in asymmetric corticolimbic networks. In R.J. Davidson & K. Hugdahl (Eds.), *Brain Asymmetry* (pp. 389-423). Cambridge, MA: MIT Press.
- Mangun, G.R. & Hillyard, S.A. (1988). Spatial gradients of visual attention: Behavioral and electrophysiological evidence. *Electroencephalography and Clinical Neurophysiology*, 70, 417-428.
- McCarthy, G., & Wood, C.C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, 62, 203-208.
- Molnár, M. (1994). On the origin of the P3 event-related potential component. *International Journal of Psychophysiology*, 17, 129-144.
- Näätänen, R. (1992). *Attention and Brain Function*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Näätänen, R. & Picton, T.W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology*, 24, 375-425.
- Naumann, E., Bartussek, D., Diedrich, O., & Laufer, M. (1992). Assessing cognitive and affective information processing functions of the brain by means of the late positive complex of the event-related potential. *Journal of Psychophysiology*, 6, 285-298.
- Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97-112.
- Papanicolaou, A.C., Levin, H.S., Eisenberg, H.M. & Moore, B.D. (1983). Evoked potential indices of selective hemispheric engagement in affective and phonetic tasks. *Neuropsychologia*, 21, 401-405.
- Picton, T.W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology*, 9, 456-479.
- Psychology Software Tools, Inc. (1990). *Micro Experimental Laboratory*. Pittsburgh, PA: Author.
- Rockstroh, B., Elbert, T., Lutzenberger, W., Birbaumer, N., & Roberts, L.E. (1988). Bilateral electrodermal and electrocortical activity in anticipation of sensorimotor tasks. *Psychophysiology*, 25, 185-192.
- Roschmann, R., & Wittling, W. (1992). Topographic brain mapping of emotion-related hemisphere asymmetries. *International Journal of Neuroscience*, 63, 5-16.
- Ruchkin, D. & Sutton, S. (1983). Positive slow wave and P300: Association and dissociation. In A.W.K. Gaillard & W. Ritter (Eds.), *Tutorials in event-related potential research: Endogenous components* (pp. 233-250). Amsterdam: North-Holland Publishing Company.
- Rugg, M.D. (1983). The relationship between evoked potentials and lateral asymmetries of processing. In A.W.K. Gaillard & W. Ritter (Eds.), *Tutorials in Event-related Potential Research: Endogenous Components* (pp. 369-383). Amsterdam: North-Holland Publishing Company.
- Rugg, M.D. & Beaumont, J.G. (1978). Interhemispheric asymmetries in the visual evoked response: Effects of stimulus lateralization and task. *Biological Psychology*, 6, 283-292.
- Scherer, K.R. (1993). Neuroscience projections to current debates in emotion psychology. *Cognition and Emotion*, 7, 1-41.
- Schweinberger, S.R. & Sommer, W. (1991). Contributions of stimulus encoding and memory search to right hemisphere superiority in face recognition: Behavioral and electrophysiological evidence. *Neuropsychologia*, 29, 389-413.
- Schweinberger, S.R., Sommer, W., & Stiller, R.M. (1994). Event-related potentials and models of performance asymmetries in face and word recognition. *Neuropsychologia*, 32, 175-191.
- Semlitsch, H.V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, 23, 695-703.
- Semmes, J. (1968). Hemispheric specialization: A possible clue to mechanism. *Neuropsychologia*, 6, 11-27.
- Sergent, J. (1982). About face: Left-hemisphere involvement in processing physiognomies. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 1-14.
- Sergent, J. & Bindra, D. (1981). Differential hemispheric processing of faces: Methodological considerations and reinterpretations. *Psychological Bulletin*, 89, 541-554.
- Shearer, S.L. & Tucker, D.M. (1981). Differential cognitive contribution of the cerebral hemispheres in the modulation of emotional arousal. *Cognitive Therapy and Research*, 5, 85-93.
- Silberman, E.K., & Weingartner, H. (1986). Hemispheric lateralization of functions related to emotion. *Brain and Cognition*, 5, 322-353.
- Sobotka, S., Pizlo, Z., & Budohoska, W. (1984). Hemispheric differences in evoked potentials to pictures of faces in the left and right visual fields. *Electroencephalography and Clinical Neurophysiology*, 59, 441-453.
- Tranel, D., & Damasio, H. (1994). Neuroanatomical correlates of electrodermal skin conductance responses. *Psychophysiology*, 31, 427-438.
- Tucker, D.M. (1981). Lateral brain function, emotion, and conceptualization. *Psychological Bulletin*, 89, 19-46.
- Tucker, D.M. (1989). Neural substrates of thought and affective disorders. In G. Gainotti & C. Caltagirone (Eds.), *Emotion and the Dual Brain* (pp. 225-234). Berlin: Springer.
- Tucker, D.M., Liotti, M., Potts, G.F., Russell, G.S., & Posner, M.I. (1994). Spatiotemporal analysis of brain electrical fields. *Human Brain Mapping*, 1, 134-152.
- Tucker, D.M. & Newman, J.P. (1981). Verbal versus imaginal cognitive strategies in the inhibition of emotional arousal. *Cognitive Therapy and Research*, 5, 197-202.
- Tucker, D.M. & Williamson, P.A. (1984). Asymmetric neural control in human self-regulation. *Psychological Review*, 91, 185-215.
- Vanderploeg, R.D., Brown, W.S., & Marsh, J.T. (1987). Judgements of emotion in words and faces: ERP correlates. *International Journal of Psychophysiology*, 5, 193-205.
- Vasey, M.W. & Thayer, J.F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: A multivariate resolution. *Psychophysiology*, 24, 479-486.
- Vaughan, H.G., Ritter, W., & Simson, R. (1983). Neurophysiological considerations in event-related potential research. In A.W.K. Gaillard & W. Ritter (Eds.), *Tutorials in event-related potential research: Endogenous components* (pp. 1-7). Amsterdam: North-Holland Publishing Company.
- Wood, C.C. & McCarthy, G. (1984). Principal component analysis of event-related potentials: Simulation studies demonstrate misallocation of variance across components. *Electroencephalography and Clinical Neurophysiology*, 59, 249-260.

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