Emotion and Attention Interaction Studied through Event-Related Potentials

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Abstract

■ Several studies on hemodynamic brain activity indicate that emotional visual stimuli elicit greater activation than neutral stimuli in attention-related areas such as the anterior cingulate cortex (ACC) and the visual association cortex (VAC). In order to explore the temporo-spatial characteristics of the interaction between attention and emotion, two processes characterized by involving short and rapid phases, event-related potentials (ERPs) were measured in 29 subjects using a 60-electrode array and the LORETA source localization software. A cue/target paradigm was employed in order to investigate both expectancy-related and input processing-related attention. Four categories of stimuli were presented to subjects: positive arousing, negative arousing, relaxing, and neutral. Three attention-related components were finally analyzed: N280pre (from pretarget ERPs), P200post and P340post (both from posttarget ERPs). N280pre had a prefrontal focus (ACC and/or medial prefrontal cortex) and presented significantly lower amplitudes in response to cues announcing negative targets. This result suggests a greater capacity of nonaversive stimuli to generate expectancy-related attention. P200post and P340post were both elicited in the VAC, and showed their highest amplitudes in response to negative- and to positive-arousing stimuli, respectively. The origin of P200post appears to be located dorsally with respect to the clear ventral-stream origin of P340post. The conjunction of temporal and spatial characteristics of P200post and P340post leads to the deduction that input processing-related attention associated with emotional visual stimulation involves an initial, rapid, and brief 'early' attentional response oriented to rapid motor action, being more prominent towards negative stimulation. This is followed by a slower but longer 'late' attentional response oriented to deeper processing, elicited to a greater extent by appetitive stimulation. ■

INTRODUCTION

Current Data and Open Issues

Though the neural activity associated with emotion and related to attention have mainly been studied separately, they constitute closely interrelated and mutually dependent processes. In natural environments, attention is preferentially sustained by stimuli that have affective significance, in contrast to routine, emotionally neutral events (e.g., Lang, Bradley, & Cuthbert, 1997). Some recent experiments using hemodynamic neuroimaging methods provide interesting data indicating that certain attention-related brain areas increase their activity in response to emotional visual stimuli. Firstly, there is a group of studies showing that several areas of the visual association cortex (VAC) are more highly activated in response to both positive (or pleasant) and negative (or unpleasant) images than in response to neutral pictures (Lane, Chua, & Dolan, 1999; Lang et al., 1998; Reiman et al., 1997). Another group of data, also obtained through functional hemodynamic methods, has indicated activation in the anterior cingulate cortex (ACC) in response to emotional visual stimulation, positive and negative (Northoff et al., 2000; Teasdale et al., 1999; Canli, Desmond, Zhao, Glover, & Gabrieli, 1998). Both groups of results have been interpreted as indicating increased attention towards affective stimuli.

Results obtained in relation to hemodynamic changes associated with attention towards visual emotional stimulation should be complemented by data recorded using temporally agile physiological signals. Both attention and emotion are characterized by involving short, rapid subprocesses, some of the most important occurring within the first 500 msec after stimulus onset (e.g., Mangun & Hillyard, 1995; Halgren & Marinkovic, 1994). High temporal-resolution techniques are necessary to study several unexplored important issues. Firstly, it is necessary to study which aspects or types of attention are associated with the areas found to be activated in response to emotional visual stimuli. Usual tasks employed in neuroimaging studies are characterized by the presentation of sets of pictures (with relatively long interstimulus intervals) during several seconds or even minutes, and probably involve different types of attention. In this regard, though the involve-

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ment of both the VAC and ACC in attention to visual stimulation has received solid theoretical and experimental support (Sturm et al., 1999; Luck, Chelazzi, Hillyard, & Desimone, 1997; Shulman et al., 1997; Mangun & Hillyard, 1995; Posner & Raichle, 1995), they have been proposed to reflect different aspects of attention and to be preferentially activated with different task requirements or periods. According to Posner and Petersen (1990), we can distinguish between "a general alert state and one in which attention is clearly oriented and engaged in processing information" (p. 33). Tasks or phases within a task in which a significant level of expectancy or alertness is necessary, such as those related to target detection, have been proposed to elicit the former type of attention (which may appear even in the absence of stimulation), and involve the activation of the anterior cingulum (Posner & Petersen, 1990). The involvement of the ACC in alertness has been supported experimentally (e.g., Sturm et al., 1999). On the other hand, tasks requiring recognition of already presented visual stimuli are associated with the second type of attention, involving an increase in the activation of the VAC (Posner & Petersen, 1990; Posner & Raichle, 1995). Several experiments clearly support this involvement of the VAC in input processing-related attention towards visual stimuli (see review by Mangun & Hillyard, 1995). It is important to distinguish both types of attention in response to emotional images because they have separate functions. In order to achieve this distinction, it is necessary to analyze separately the activity in expectancy-related and in input processing-related periods of the experimental task through high temporal resolution signals.

Secondly, the temporal characteristics of subprocesses within each type of attention to emotional stimulation should be described. For example, it is necessary to determine whether or not the attentional reactions to positive and to negative stimuli are produced at the same moment. The fact that hemodynamic neuroimaging methodologies have not found temporal differences in responses to the two types of emotional stimulation may be due to the fact that they record an accumulation of activity over relatively long periods. In this regard, several behavioral studies suggest that negative events elicit more rapid or more prominent emotional responses (involving cognitive and physiological changes) than neutral or positive events (see reviews by Cacioppo & Bernston, 1994; Cacioppo & Gardner, 1999; Taylor, 1991). Recent brain activation data obtained with high temporal resolution methodologies (magnetoencephalography, in this particular case) support this 'negativity bias' (Northoff et al., 2000). Attention-related brain activity in relation to this bias has not yet been studied directly, though the privileged access of negative stimulation to attentional resources has been indirectly suggested by studies on autonomic physiological responses (Öhman, Esteves, Flykt, & Soares, 1993) and behavioral studies using reaction time (Pratto & John, 1991) or visual fixation (Fiske, 1980) as dependent variables. The adaptive and evolutionary advantages of this bias are obvious: The consequences of a dangerous or injurious event are often much more dramatic than the consequences of ignoring or reacting slowly to neutral or even appetitive stimuli (e.g., Ekman, 1992; Öhman, 1992).

The combination of high spatial and high temporal resolution may provide information on a third important issue: which areas are activated in each subprocess within each type of attention to emotional stimulation. Data exist indicating that, in the VAC alone, emotional stimuli elicit activity in more than 15 sources or 'clusters' along with those activated by all (emotional and neutral) visual stimuli (see, e.g., Lang et al., 1998). It is important to investigate which subprocess of attention they reflect (if any) by studying their temporal characteristics. This issue may be closely related, first, to time-related negativity bias, since circuitry that computes urgent utility (e.g., avoidance of a dangerous event) often diverges from the circuitry subserving deep identification and discrimination (Shizgal, 1999). Secondly, it may also be related to the current debate on whether the evaluative systems (and the neural substrates) involved in the processing of positive and negative stimuli are independent or overlapping. Emotional content of stimulation has been traditionally assumed to be defined by two dimensions, valence (whose extremes are positive- negative) and arousal (calming- arousing). Initially proposed by Russell (1979), the 'valence × arousal' or 'circumplex' model considers that both positive and negative events are processed (and trigger emotional reactions) in the same, and single, valence-related evaluative circuit. The idea that positive and negative situations activate different evaluative systems (associated, at least in part, with separate neural mechanisms) has recently been defended (Cacioppo & Gardner, 1999; Davidson & Irwin, 1999; Tellegen, Watson, & Clark, 1999). This perspective has received experimental support (Northoff et al., 2000; Lane, Reiman, Ahern, Schwartz, & Davidson, 1997; LeDoux, 1995). The use of a methodology with both high temporal and relatively high spatial resolution may facilitate the exploration of spatial differences even in the rapid and transient attentional subprocesses, whose involvement in this positive- negative 'spatial independence' has not yet been defined.

The Present Study

Electroencephalographic (EEG) recording of event-related brain potentials (ERPs) constitutes a powerful and necessary tool for exploring these important issues concerning the interaction of attention and emotion. Apart from high temporal resolution, ERPs are able to provide acceptable spatial information if a dense and wide distribution of electrodes is used and subsequent recordings are analyzed through source localization algorithms. To the best of our knowledge, and surprisingly, ERP data on the interaction between emotion and visual attention have not been provided to date. Therefore, the main goal of the present study was to remedy this situation. A wide conception of this interaction should take into account several forms of attention. In this regard, the first specific objective was to explore the two types of attention previously mentioned: expectancy-related and input processing-related attention. The second objective was to study the temporal characteristics of both types of attention, and particularly those associated with the positive or negative valence of the emotional stimulation. Finally, the third objective was to explore the possibility that subprocesses within each type of attention present, to some extent, different brain sources.

Expectance is usually elicited in ERP research through the experimental paradigm employed to evoke the contingent negative variation (CNV). In its traditional form, this paradigm (that, due to its timing characteristics, cannot be employed in hemodynamic studies) requires the presentation, in each trial, of a warning signal (S1) and subsequently of an 'imperative' stimulus (S2) (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The onset of S2 requires a rapid response from subjects (e.g., to press a button as rapidly as possible in order to terminate S2). During the interval between S1 and S2, in which the subject is alert, the CNV appears, terminating just after S2 onset. CNV amplitude relates directly to expectancy-related attention to S2 (McCallum, 1988). If S2 consists of a visual image, and if its visual exploration is required by the task, ERP elicited by this second stimulus is also able to reflect input processing-related attention.

Four emotional categories were studied in the present experiment, in which an S1 (hereafter labeled 'cue')- S2 ('target') type task was employed: arousing-positive (A+), arousing-negative (A−), neutral (N) and relaxing (R). These categories are intended to cover the main combinations of positivity, negativity, and arousal in order to study their influence on attention (as explained elsewhere [Lang et al., 1997], certain combinations, such as R−, are virtually impossible). Cue stimuli were simple white-on-black schematic line drawings or symbols. As described in detail in the Methods section, each symbol was identified in the instructions with a particular object or motif (e.g., insect, building, etc.). Cue presentation consisted of two drawings or symbols belonging to the same emotional category, one above the other (see Figure 12). The ideographic-type structure of cues ensured that the stimuli were physically homogeneous, with no significant differences in their complexity, color, brightness, contrast, or size. Also, this type of visual cue was preferred to other types, such as words, because they provided the pictorial nature of the target stimuli (consisting of photographs, as explained below), thus facilitating the involvement of similar processing systems in response to both cue and target stimuli. Moreover, simple ideographic stimuli would be less prone to having deep intrinsic emotional significance, at least by comparison with photographs or realistic drawings. A color photograph (target), was presented 1750 msec later (see Figure 11). Photographs always represented one of the motifs symbolized by the two drawings of the cue presentation. Participants were told to identify verbally which of the two drawings of the cue corresponded to the target (verbal response was given 2 sec after target onset). The instructions did not explicitly establish that the experiment dealt with emotional reactions, and, as explained, the cue indicated only in an implicit way the emotional category of the following target. This strategy had two advantages. First, it helped to avoid a situation whereby participants considered that some of the stimuli were more important for the task than others (e.g., emotional stimuli more important than neutral ones), and thus to avoid a relevance-for-task effect, often described in previous studies (e.g., Duncan-Johnson & Donchin, 1977: the stimuli on which the task focuses tend to elicit the highest amplitudes in certain endogenous ERP components). Second, homogenization of cognitive demands makes it easier to reach more solid conclusions about the emotion-related causation of possible attentional differences.

In general, tasks in which target information is predicted (100% correctly announced) by a cue have a characteristic that is very interesting and relevant to the present study: They allow for the random presentation of different stimuli minimizing the effect of the orienting response, at least in its relation to novelty or nonexpectance of stimulation. Since only active, selective attention was of interest in the present study, the orienting response could represent an important interference for posttarget ERPs. Moreover, in natural environments, situations in which subjects perceive some cues or signals that trigger affective-related expectance and prepare them for possible forthcoming emotional events are relatively frequent. These situations have as yet scarcely been investigated in relation to brain activity. The study of input processing-related attention required that only attended stimuli (cues and targets) were analyzed. To ensure this, recordings obtained in trials in which subjects responded erroneously were eliminated. It was also necessary to avoid emotional categories being heterogeneous with respect to the level of attention needed to carry out the task correctly: differences should be due to the affective content of each category, but not to its difficulty with respect to the task. Control analyses were planned in order to discard, if necessary, those categories differing in this aspect from the rest.

Our first hypothesis is that expectancy-related and input processing-related phases of the task, which, as explained, associate with different types of attention, will be characterized by the activation of different brain areas. The former should associate with the activation of prefrontal areas, involving the ACC, and the latter with VAC areas. Secondly, we consider that expectancy-related attention, elicited by cues, and input processing-related attention, elicited by targets, will be differentially affected by the negativity bias. Previous data on expectance towards emotional stimuli indicate that cues announcing the presentation of stimuli to subjects who have previously rated them as highly negative elicit lower CNV (particularly lower early CNV) amplitudes than nonnegative pictures (Yee & Miller, 1987; Klorman & Ryan, 1980). On the other hand, ERP signs of greater and more prominent responses after the presentation of negative stimulation have been recently reported (Carretié, Mercado, Tapia & Hinojosa, 2001; Ito, Larsen, Smith, & Cacioppo, 1998). These data suggest that biases favoring an urgent motor response to negative (e.g., aversive) stimulation mainly occur when the stimulus has already appeared. On the other hand, the cue is a signal, not to respond, but rather to process forthcoming stimuli. Therefore, this second hypothesis may be formulated indicating that negativity bias will affect posttarget ERPs to a greater extent than pretarget recordings. The third hypothesis deals with the spatial location of each subphase of the attention-related activity. We expect spatial characteristics of attention to be parallel to temporal characteristics and to negativity bias, i.e., spatial differences will be related to urgency of withdrawal motivation (when avoidance stimulation is presented) or to the need for deeper processing (when nonaversive stimulation is presented), and will also affect preferentially posttarget ERPs.

RESULTS

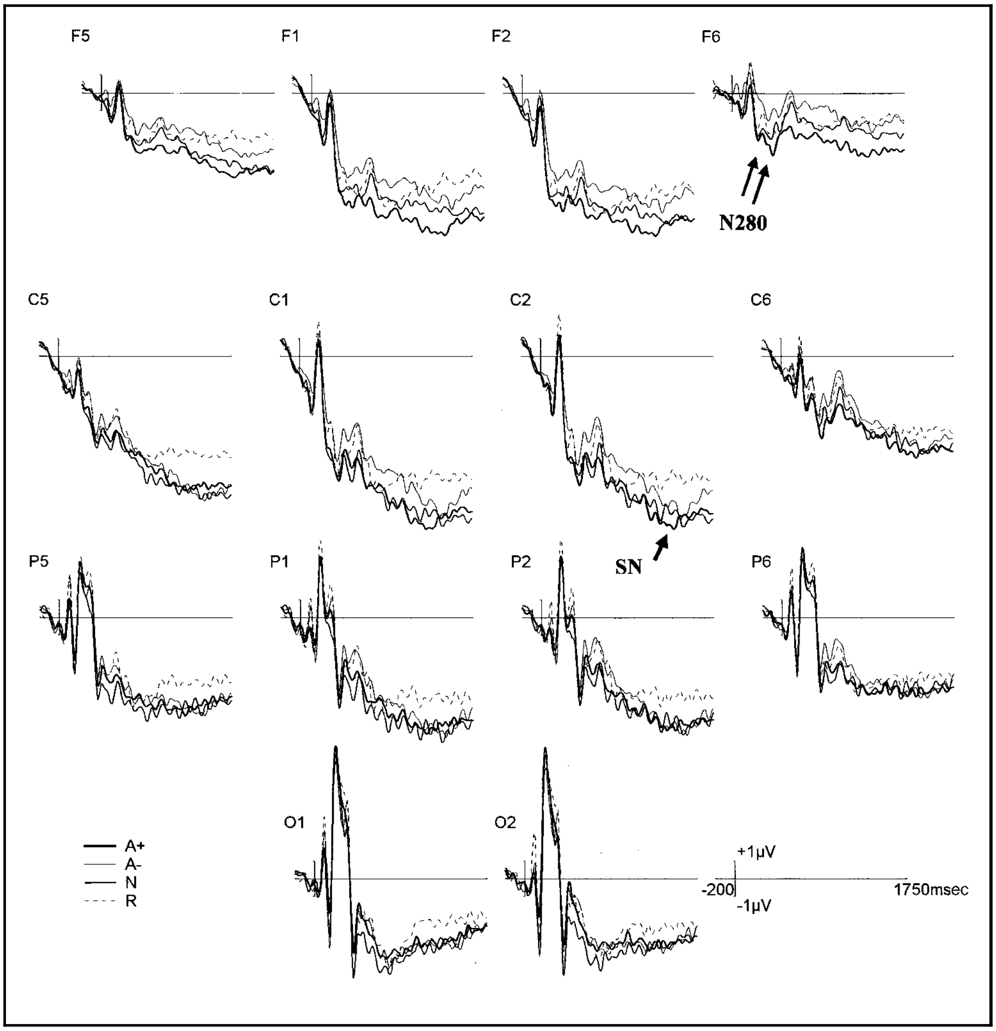
Figures 1 and 2, in which 14 widely distributed recording channels have been selected from the 58 channels actually used, show the grand averages of pre- and posttarget (respectively) recordings once the baseline had been subtracted from each ERP.

Selection of Components

Temporal Principal Component Analyses

Components explaining most pre- and posttarget ERP variance were extracted through temporal principal component analyses (tPCAs). Two covariance-matrix-

Figure 1. Grand averages in response to the four groups of cue (pretarget ERPs) obtained from the 29 subjects at 14 selected scalp locations from the 58 locations actually employed. A+ = arousing-positive; A− = arousing-negative; N = neutral; R = relaxing.



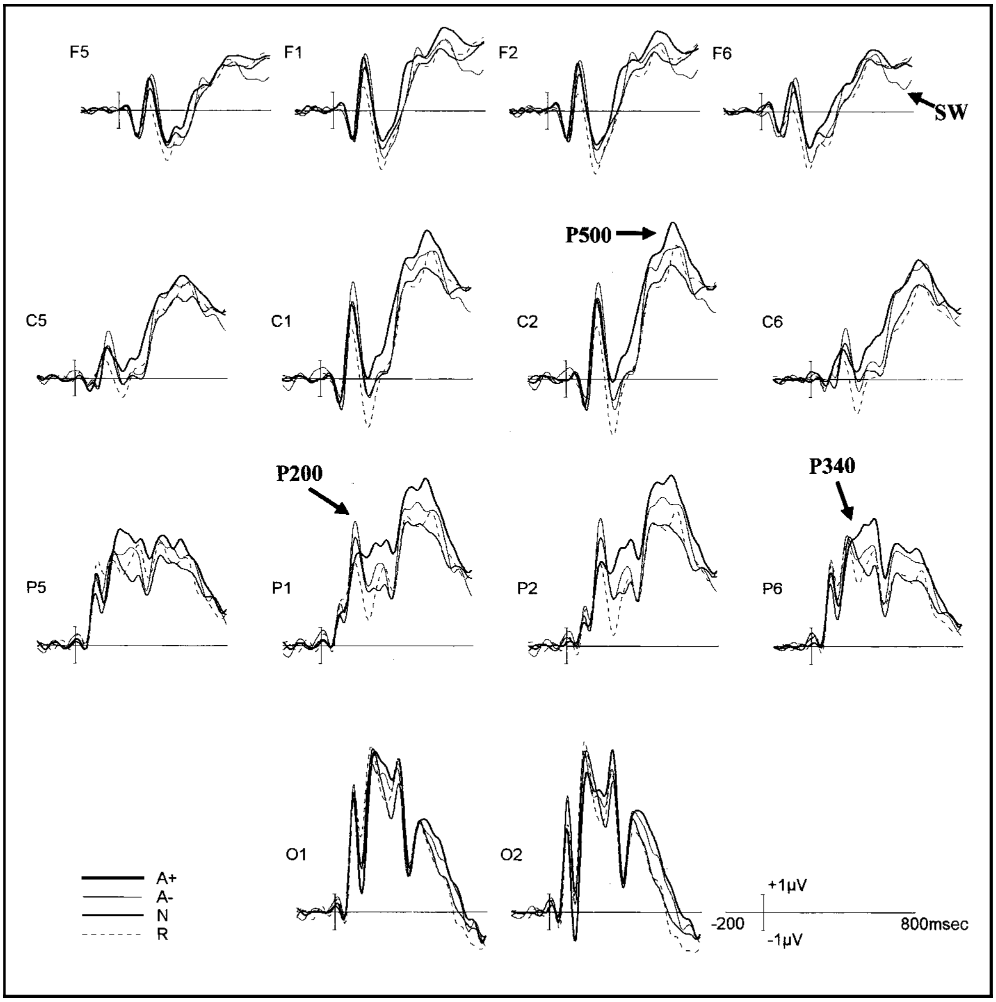


Figure 2. Grand averages in response to the four groups of targets obtained from the 29 subjects at 14 selected scalp locations from the 58 locations actually employed. A+=arousing-positive; A−=arousing-negative; N=neutral; R=relaxing.

based tPCAs were carried out, one for pre- and the other for posttarget ERPs. Since the original number of cases (58 channels × 29 subjects × 4 stimulus conditions) and the number of variables (487 digitized points for pre- and 250 points for posttarget ERPs) were excessive for computations, two operations for data reduction, maintaining the relevant ERP information, were carried out. Firstly, a representative, widely distributed sample of 28 channels was selected (see Methods). Secondly, to reduce the amount of data (only for tPCAs), we averaged each five adjacent digitized points for each ERP (each five adjacent points represent 20 msec). The decision on the number of components to select was based on the scree test (see, e.g., Cliff, 1987, for a description). Extracted components were then submitted to varimax rotation.

Following this selection criterion, two components or factors were extracted from pretarget ERPs. Factor 1 explained 95.97% of total variance and Factor 2 explained 1.24% (65.81% and 31.40%, respectively, after rotation). Figure 3 shows the rotated loadings plotted over time for these two components. Additionally, Figure 4 presents the mean factor scores for each scalp location and for both components. Basically, factor scores, which are calculated for each individual ERP, reflect the product of point loading by point amplitude. Therefore, amplitude and factor score are directly-related parameters. Analysis of peak latencies observed in Figure 3 and topography deduced from Figure 4 associate Factor 1 with the homogeneously distributed, long latency negative variation marked with an arrow labeled slow negativity (SN) in grand averages (Figure 1), and Factor 2 with a relatively early negativity (peaking at 280 msec), with frontal midline dominance (see the most negative locations in Figure 4), signaled as N280 in grand averages.

With respect to posttarget ERPs, selection yielded four factors. Factor 1 explained 50.62% of total variance, Factor 2 explained 25.99%, Factor 3 explained 5.32%, and Factor 4, 3.42% (35.95%, 34.44%, 10.73%, and 4.24%, respectively, after rotation). Figure 3 shows the rotated loadings plotted over time for these four components. Mean factor scores for each recording channel are shown in Figure 4. Factor peak latency and topography characteristics associate Factor 1, maximal at central locations, with the negative slow wave signaled with an

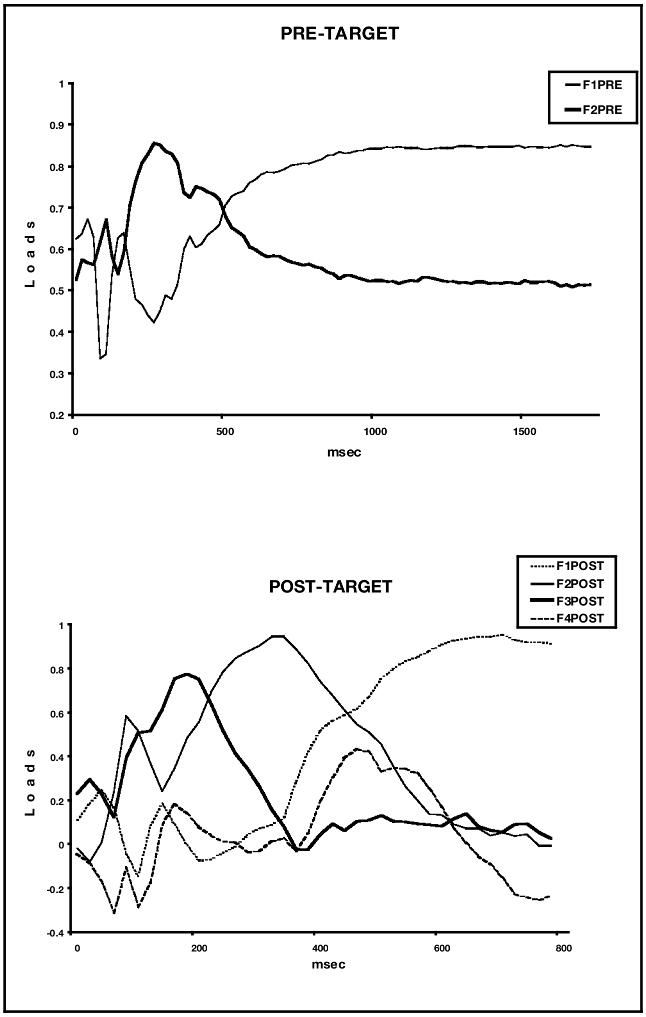


Figure 3. tPCA analysis: factor loadings after Varimax rotation. Top: pretarget ERPs. Bottom: posttarget ERPs.

arrow labeled SW in grand averages (Figure 2). Factors 2 (340 msec) and 3 (200 msec), both maximal at parietal and parieto-occipital sites, can be associated with deflections marked as P340 and P200, respectively, in Figure 2. Finally, Factor 4 (peak at 500 msec), maximal at centro-parietal sites, with a slow positive deflection labeled as P500 in grand averages. These labels will be employed hereafter to make results more understandable, and do not necessarily imply the identification of these factors with 'classical' components such as P300 or traditional SW (in the present case, SW could simply reflect a CNV release).

Selection of VAC- and/or ACC-Related Components

Though the experimental design ensured that subjects attended to the stimuli, the extent of the association of the six components extracted by the tPCAs with the attentional processes we are studying could vary considerably. Before submitting factors to analyses on the experimental effects, it was necessary to discard those mainly reflecting the activity of brain areas different from those under study. As explained in the Introduction, the focus of our interest were those components reflecting activation of visual cortices (input processing-related attention) and/or prefrontal structures associated with expectancy-related attention such as the ACC. In order to analyze the extent to which each factor was associated with these relevant brain areas, topographic and source-localization analyses were carried out, taking into account voltages recorded in the 58 original recording channels. Figure 5 shows the maps of the average activity in the 200- 520- and 740- 1750-msec periods of pretarget ERPs (corresponding to N280 and SN, respectively), and in the 176- 224-, 312- 368-, 472- 528-, and 620- 800-msec periods of posttarget ERPs (P200, P340, P500, and SW, respectively). The size of these windows was proportional to the component period, both with respect to its absolute value and in relation to the total ERP epoch, and shape of components was also taken into account. For example, N280pre presents two high-loaded peaks, not separable according to tPCAs that should be included in the window in order to correctly take into account the main activity of this component.

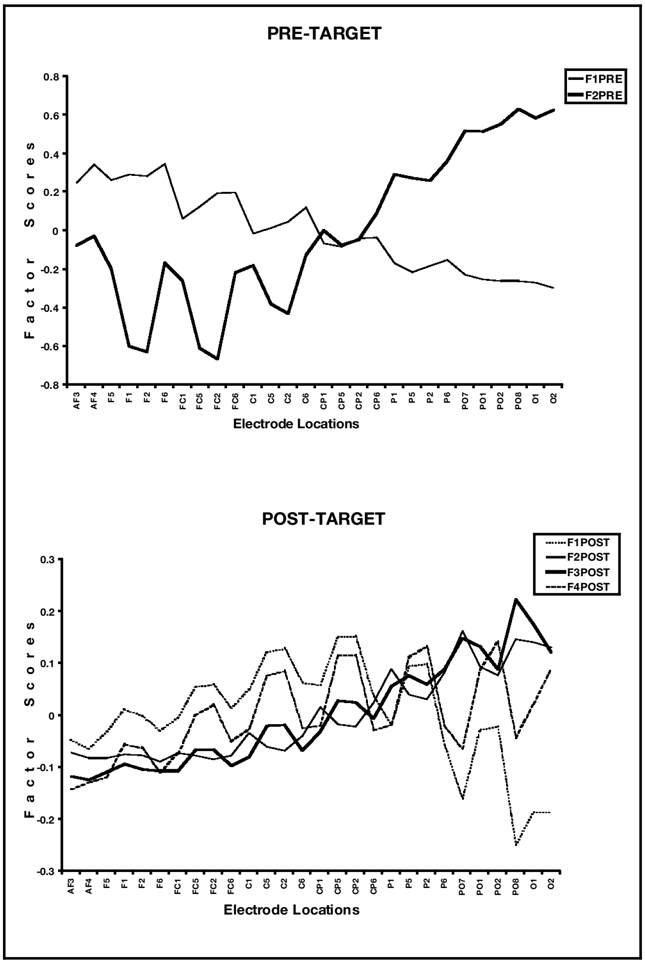


Figure 4. tPCA analysis: mean factor scores corresponding to the 28 recording channels taken into account in this analysis. Top: pretarget ERPs. Bottom: posttarget ERPs.

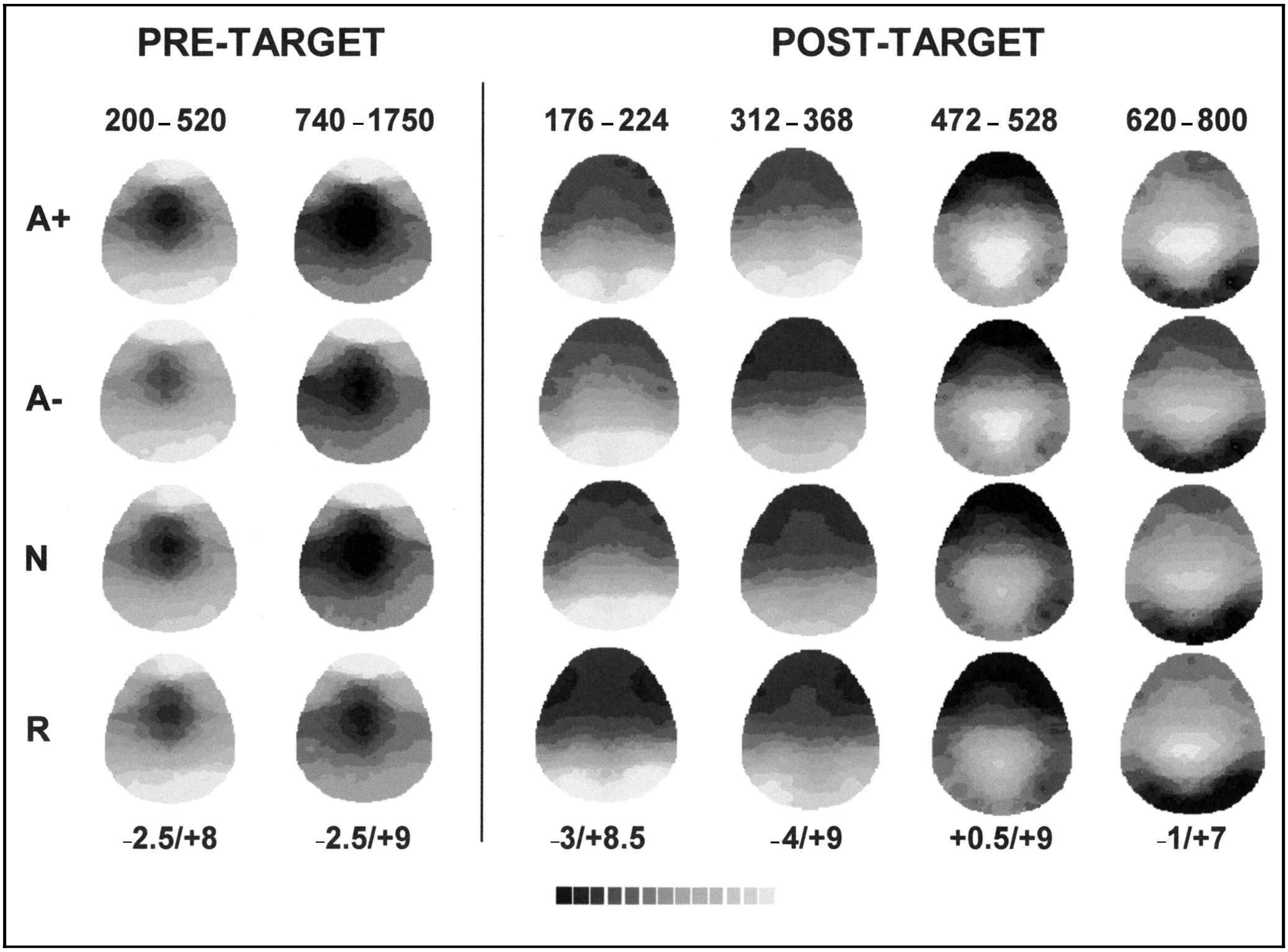


Figure 5. Topographic maps representing the mean values (in microvolts) for the periods (in milliseconds) indicated at the top of each column. These windows correspond, respectively, to N280 and SN from pretarget recordings, and to P200, P340, P500, and SW from posttarget recordings. A+ =arousing-positive; A− =arousing-negative; N=neutral; R=relaxing.

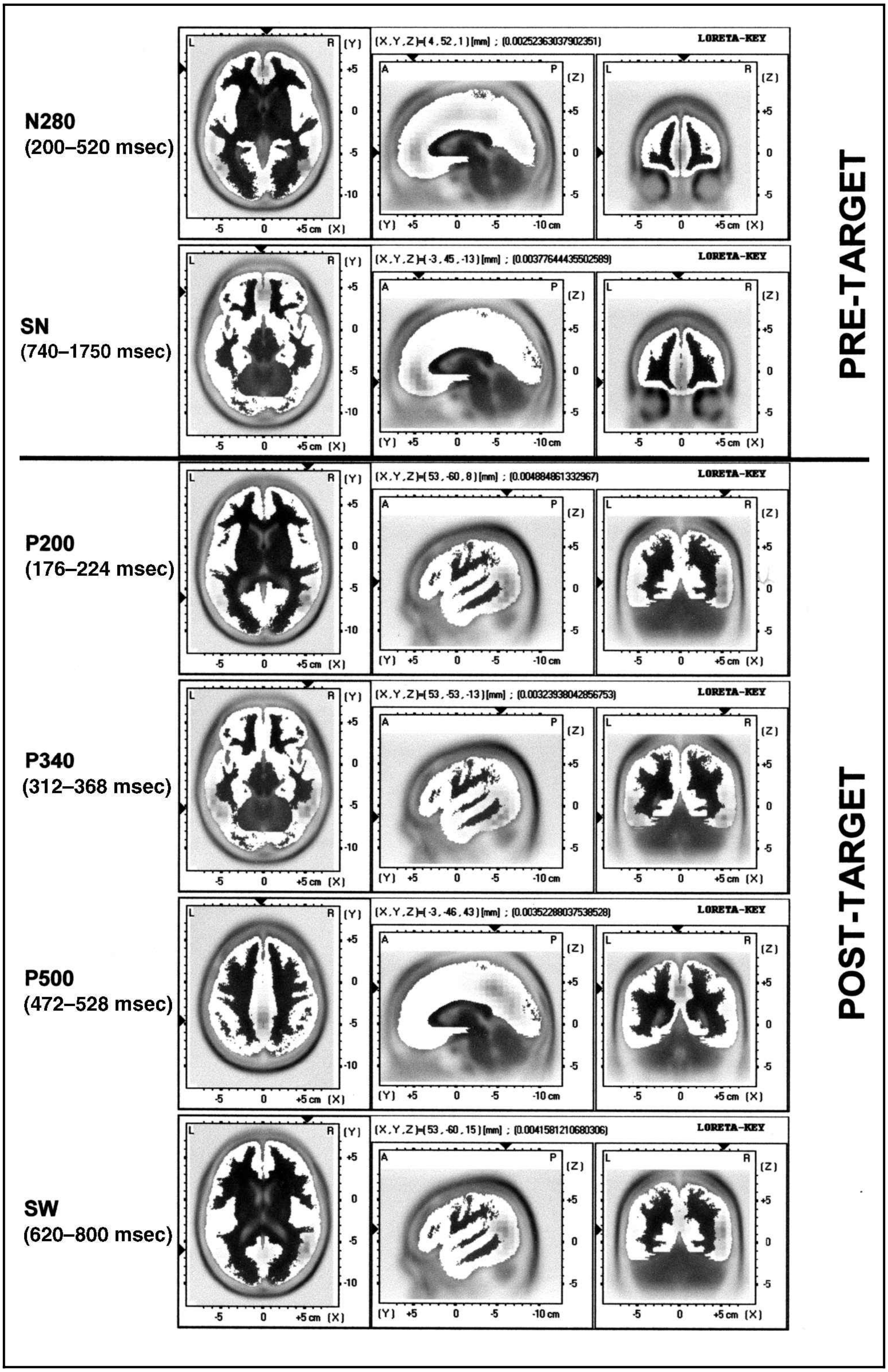
Additionally, low-resolution brain electromagnetic tomography (LORETA) was applied, a 3-D, discrete linear solution for the EEG inverse problem (Pascual-Marqui, Michel, & Lehman, 1994; Pascual-Marqui, 1999). In its current version, LORETA refers to a three-shell spherical model registered to the Talairach human brain atlas (Talairach & Tournoux, 1988). Solution is given, therefore, in three coordinates: x is the distance in millimeters to the right (+) or left (−) of midline, y is the distance anterior (+) or posterior (−) to the anterior commissure, and z is the distance superior (+) or inferior (−) to a horizontal plane through the anterior and posterior commissures. Registration between spherical and the realistic head model in which solutions are given by LORETA used EEG electrode coordinates reported by Towle et al. (1993). Figure 6 illustrates the sources of activity for the six components as calculated by LORETA. Source analysis were carried out on the average ERPs in response to the four groups of stimuli. Scalp distribution and source analyses suggest that P500 is not originated in visual cortices or in the ACC or related prefrontal areas (see Table 1). Therefore, components selected for later analyses on the experimental effects were N280 and SN from pretarget recordings, and P200, P340 and SW from posttarget recordings.

Effects of Emotional Content on Selected Components

Control Analyses

In order to better interpret the results on the effects of emotional stimulation on selected VAC- and/or ACC-related components, two control analyses were previously carried out. Firstly, ANOVAs on the assessments given by subjects to each group of stimuli were computed in order to confirm that their affective content was the one supposed a priori. As explained in the Methods section, each subject filled out a bidimensional scaling test for each group of pictures after the recording sessions. This test assessed the valence and the arousal content of the pictures presented as targets. Table 2 shows means and standard error of means for each type of stimulus. One-way repeated-measure ANOVAs were

Figure 6. Images of neuronal electric activity, averaging the responses to the four types of stimuli, computed with LORETA for the periods and components (both pre- and posttarget) indicated at the left side of the figure. For each component, three orthogonal brain views in Talairach space are shown, sliced through the region of the maximum activity. Left slice: axial, seen from above, nose up; center slice: saggital, seen from the left; right slice: coronal, seen from the rear. Talairach coordinates: *x* from left (L) to right (R); *y* from posterior (P) to anterior (A); *z* from inferior to superior. The location of maximum activity is given as (*x*,*y*,*z*) coordinates in Talairach space, and is graphically indicated by black triangles on the coordinate axes. Anatomical distribution of the most active neuronal generators is shown in Table 1.



computed for valence and for arousal dimensions, using Stimuli (four levels: A+, A−, N, and R) as factor. The Greenhouse-Geisser (GG) epsilon correction was applied to adjust the degrees of freedom of the *F* ratios. Post hoc comparisons were made to determine the significance of pairwise contrasts, using Tukey's one-factor HSD procedure ($\alpha = .05$). ANOVAs indicated that Stimuli differed in valence as in arousal [$F(3,84) = 79.50$, $p < .001$, GG $\varepsilon = 0.73$ and $F(3,84) = 78.65$, $p < .001$, GG $\varepsilon = 0.86$, respectively]. Post hoc contrasts indicated that A+ and A− significantly showed distinct valence but not distinct arousal. A+ and A− differed from N and R in arousal. On the other hand, A+ and R did not differ with respect to valence, but both differed from N and A− in this dimension. N and R were distinct in both dimensions.

Table 1. Solutions Provided by LORETA with Respect to Components Extracted by the tPCA Both for Pre- and for Posttarget Components

	Component	*x, y, z*	*Close Regions (d < 5 mm)*
PRE	N280 (200- 520)	4, 52, 1	BA10 (medial frontal gyrus)
			BA32 (ACC)
	SN (740- 1750)	−3, 45, −13	BA11 (medial frontal gyrus)
POST	P200 (176- 224)	53, −60, 8	BA39 (posterior middle temporal gyrus)
			BA37 (posterior middle temporal gyrus)
	P340 (312- 368)	53, −53, −13	BA20 (inferior temporal gyrus)
			BA37 (fusiform gyrus)
	P500 (472- 528)	−3, −46, 43	BA7 (precuneus)
			BA31 (posterior cingulate gyrus)
	SW (620- 800)	53, −60, 15	BA22 (superior temporal gyrus)
			BA19 (middle temporal gyrus)
			BA39 (middle temporal gyrus)
			BA44 (superior temporal gyrus)

Talairach coordinates: *x* from left to right, *y* from posterior to anterior, *z* from inferior to superior. In brackets, and just after the component names, the temporal interval (in msec) of the analyzed windows.

Secondly, differences with respect to the task difficulty associated with each group of pictures were analyzed in order to ensure that the possible effects elicited by the stimuli were not due to this factor. The presence of differences may indicate that level of difficulty and, therefore, of attention demands is different for each stimulus category. Therefore, the number of errors in the task with respect to each group of stimuli was analyzed via one-way repeated-measures ANOVA on factor Stimuli (means, standard error of means, and standard deviations of incorrect answers in the task appear in Table 2). Differences were not significant [$F(3,84) = 1.31, p > .25$].

ANOVAs on Experimental Effects

Two-way repeated measures ANOVAs were computed on factor scores (as explained, directly related to amplitudes) for selected components. The factors were Stimuli (four levels: A+, A−, N and R) and Channel (28 levels corresponding to the same sample of 28 channels previously analyzed through tPCA). Also in this case, the GG epsilon correction was applied to adjust the degrees of freedom of the *F* ratios. Post hoc comparisons were made to determine the significance of pairwise contrasts, using the Bonferroni correction ($\alpha = .05$). Table 3 shows main results of these ANOVAs. With respect to pretarget ERPs, factor Stimuli produced significant effects only in N280. Post hoc comparisons indicated that this negative component presents its higher amplitudes in response to A+, which differed significantly from amplitudes to A− but not from those to N and R. The interaction Stimuli × Channel was also significant. Figure 7 shows locations where post hoc comparisons found significant differences between stimuli in the Stimuli × Channel interaction, mainly pro-

Table 2. Means and, in Brackets, Standard Error of Means, (1) of Assessments Given by Subjects to Stimuli (Arousal and Valence) in the Scaling Test, and (2) of Errors Committed in the Task (Percentages with Respect to the Total Number of Trials Are Also Provided)

	Arousal (Relaxing −2, Arousing 2)	*Valence (Negative −2, Positive 2)*	*Number of Errors*
Arousing-positive	0.586 (0.131)	1.172 (0.139)	0.379 (0.135) [0.296%]
Arousing-negative	0.983 (0.123)	−0.948 (0.145)	0.172 (0.071) [0.134%]
Neutral	0.000 (0.093)	0.000 (0.124)	0.207 (0.077) [0.162%]
Relaxing	−1.293 (0.125)	1.638 (0.082)	0.379 (0.104) [0.296%]

Table 3. Results of ANOVAs on Component Scores both with Respect to Factor Stimuli and with Respect to the Interaction Stimuli by Channel

	Component	*Factor Stimuli (df = 3,84)*	*Interaction Stimuli × Channel (df = 81,2268)*
PRE	**N280**	**$F = 3.21, p < .05$**	**$F = 2.34, p < .05$**
		GG $\varepsilon = 0.82$	**GG $\varepsilon = 0.08$**
	SN	$F = 1.75$, *ns*	$F = 1.78$, *ns*
		GG $\varepsilon = 0.78$	GG $\varepsilon = 0.08$
POST	**P200**	**$F = 4.12, p < .02$**	**$F = 4.65, p < .001$**
		***GG* $\varepsilon = 0.78$**	**GG $\varepsilon = 0.08$**
	P340	**$F = 7.02, p < .005$**	**$F = 2.75, p < .05$**
		***GG* $\varepsilon = 0.68$**	**GG $\varepsilon = 0.06$**
	SW	$F = 1.82$, *ns*	$F = 2.04$, *ns*
		GG $\varepsilon = 0.70$	GG $\varepsilon = 0.07$

Significant contrasts are in **bold**.

df = degrees of freedom; GG = Greenhouse- Geisser; *ns* = nonsignificant.

duced at frontal and central sites, bilaterally. Post hoc analyses also indicated that differences between hemispheres (between symmetrical locations) were not significant for Factor Channel or for the Stimuli × Channel interaction.

With respect to posttarget ERPs, factor Stimuli produced significant effects in P200 and P340. This factor had opposite effects on both components: P340 revealed that the highest amplitudes were produced in response to A+, which significantly differed from those elicited by A−, N and R. On the other hand, A− elicited the highest amplitudes in P200. These amplitudes were significantly different from those elicited by A+. The interaction Stimuli × Channel was also significant for the two factors. As Figure 7 illustrates, P340 shows its main divergences with respect to stimulation at central, parietal, and occipital areas. P200 also presents its greatest differences between conditions at those scalp areas, but in this case they appear mainly at midline and right hemisphere regions. Post hoc analyses indicated that, also in this case, differences between symmetrical locations were not produced for Factor Channel or for the interaction Stimuli × Channel in any of the two components.

Additional Spatial Analyses on N280pre, P200post and P340post

Additional analyses were carried out in order to more precisely define the spatial characteristics of N280pre, P200post, and P340post, the three components that showed significant amplitude differences as a function of the experimental effects. Firstly, LORETA was again applied to these three components. This time, only responses to the maximum-effect stimulus (according to ANOVAs) were analyzed. The scope of these new localization analyses on the responses to the stimuli eliciting the highest amplitudes in each of these components was to ensure the best signal-to-noise ratio for the localization of sources. Therefore, inverse solutions were calculated from the ERPs elicited by A+ in N280pre and P340post windows, and by A− in P200post window (Figure 8). With respect to the 200- 520-msec window of pretarget ERPs (corresponding to N280pre), solution provided by LORETA is a prefrontal focus located near midline ($x = 4$, $y = 45$, $z = 8$), less anteriorly located than in the analyses on the average of all the stimuli (Table 1, Figure 6). This point is within the ACC; Brodmann's area (BA) 24 ($d < 1$ mm) and BA 32 ($d < 4$ mm) are located within a radius of 5 mm from it. Moreover, BA 10, corresponding to medial frontal gyrus, is also close to the solution given by LORETA ($d < 4$ mm). Main sources provided for the two windows of posttarget ERPs are the same that were calculated by analyses on the average of all the stimuli (Table 1, Figure 6). Two focuses are provided as solutions for the window corresponding to P200post. The main focus is more dorsally located ($x = 53, y = -60, z = 8$) than the second ($x = 53, y = -60, z = -6$). The posterior middle temporal gyrus (BA 39, $d < 5$ mm; BA 37, $d < 5$ mm) is the closest area to first focus. The second focus is in the middle occipital gyrus (BA19, $d < 3$ mm, BA37, $d < 3$ mm). Finally, LORETA's solution for the window corresponding to P340post, also posterior ($x = 53, y = -53$, $z = -13$) is clearly ventral. Inferior temporal gyrus (BA 20, $d < 3$ mm) and fusiform gyrus (BA 37, $d < 4$ mm), both in the temporal lobe, are the closest matches for that source.

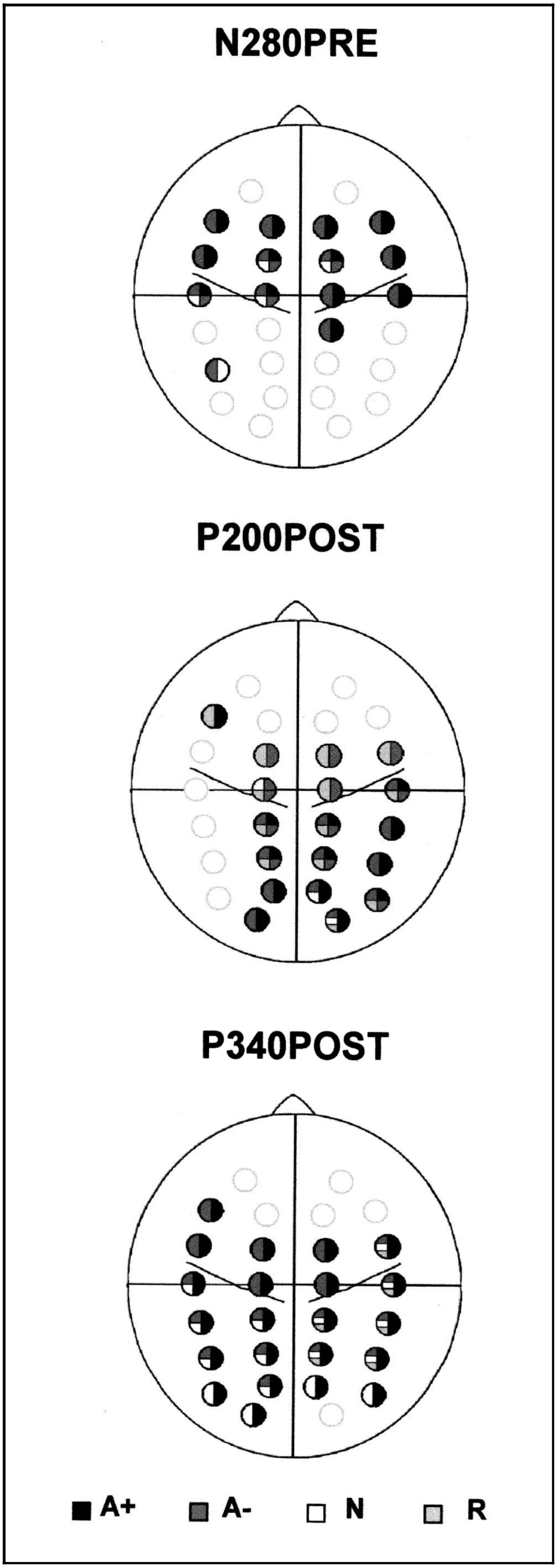


Figure 7. Schematic representation of scalp locations where differences among stimuli were significant in the interaction Channel × Stimuli (Bonferroni correction, $\alpha = 0.05$). 'Heads' correspond to N280pre (top), P200post (middle) and P340post (bottom). Only locations where differences among stimuli were produced are clearly visible. Differences in color for each location represent differences among stimuli. A+, arousing-positive; A−, arousing-negative; N, neutral; R, relaxing. Example: upper-left scalp location of first head has shown a significant difference between A− and A+.

Windows selected for source analyses may reflect the activity of different components. Though these windows involve the peak of components to analyze, the rest of components could also present significant activity in them. Moreover, sources provided by these analyses may correspond to components that, though present in the window, are not those that are sensitive to the experimental manipulations. In order to test these possibilities, covariance-matrix-based spatial principal component analyses (sPCAs) were computed on these three windows, and one-way repeated-measures ANOVAs on resulting spatial component scores using Stimuli (four levels A+, A−, N and R) as factor were carried out. Variables in sPCAs were average recordings in each of the 58 channels. Extracted components were submitted to varimax rotation. Also in this case, the decision on the number of components to select was based on the scree test. According to this criterion, two components were extracted for each window. Figure 9 shows, in the form of scalp maps, the loadings for each channel in each of the spatial factors. The existence of a prefrontal focus of activity in N280pre window and an occipito-parietal source both for P200post and P340post windows was confirmed by sPCAs. Additionally, ANOVAs confirmed that these spatial factors were sensitive to the experimental manipulations, as can be seen in Table 4.

Regression Analyses

An important question is to estimate the stimulus aspects explaining the differences observed in ANOVAs. Though it is reasonable to deduce from these analyses that valence more than arousal explains results concerning the three components, since differences between A+ and A− are clear in them, these trends must be statistically confirmed. Therefore, the association between ratings given by subjects to stimuli in the questionnaire (valence and arousal) and temporal factor scores was analyzed via multiple regression. Three analyses were carried out, one for each component (N280pre, P340post, and P200post). For each, eight locations with maximum temporal factor scores were selected among those showing significant differences between conditions (see Figure 7) in order to analyze the 'most responsive' areas. Mean temporal factor score corresponding to these locations was the dependent

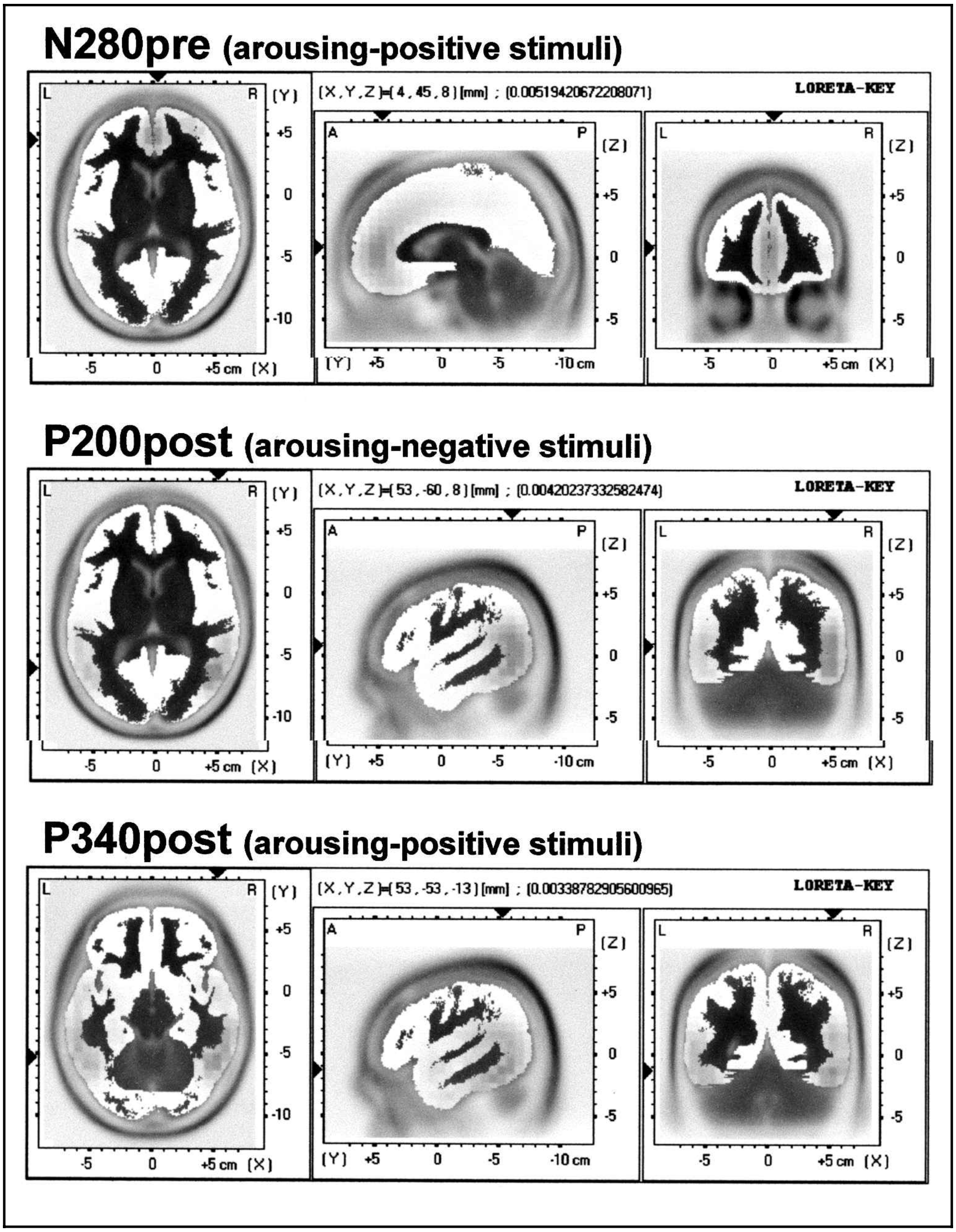


Figure 8. Images of neuronal activity, taking exclusively into account responses to the type of stimulus eliciting the highest signal-to-noise ratio (in brackets, after each component's name), computed with LORETA on components sensitive to the experimental effects.

N280pre (arousing-positive stimuli)

P200post (arousing-negative stimuli)

P340post (arousing-positive stimuli)

variable for each component. Predictor (or independent) variables were arousal (−2, calming to +2, arousing) and valence (−2, negative to +2, positive) ratings in questionnaire. Firstly, the separate influence of these two dimensions was calculated. Valence ratings associated significantly ($p < .05$) with the three factors: N280pre [$\beta = -0.19$, $F(1,127) = 4.76$], P200post [$\beta = -0.20$, $F(1,127) = 5.36$), and P340post [$\beta = 0.17$, $F(1,127) = 3.94$]. Arousal ratings did not significantly associate with any of the three factors ($p > .20$ in all cases). Figure 10 illustrates the linear association pattern between valence and the amplitudes of the three components.

Nevertheless, valence and arousal are usually interrelated (Lang et al., 1997), and, in fact, this was also the case in the present experiment: Ratings to each type of stimuli in both dimensions were significantly correlated ($r = -0.45$, $p < .05$). In other words, the effect of both variables on recordings may not be 'pure' but mediated by their association to each other. Therefore, it was necessary to partial out the influence of arousal on valence- ERP association. When analyses simultaneously entered both dimensions in the regression model controlling or 'discounting' their mutual influence, 'pure' valence maintained its significant association ($p < .05$) with N280pre [$\beta = -0.22$, $F(1,127) = 5.29$] and with P340post [$\beta = 0.20$, $F(1,127) = 4.35$], but was lost with P200post. In other words, while N280pre and P340post amplitude depends almost exclusively on valence content of stimuli, P200post appears to depend on the

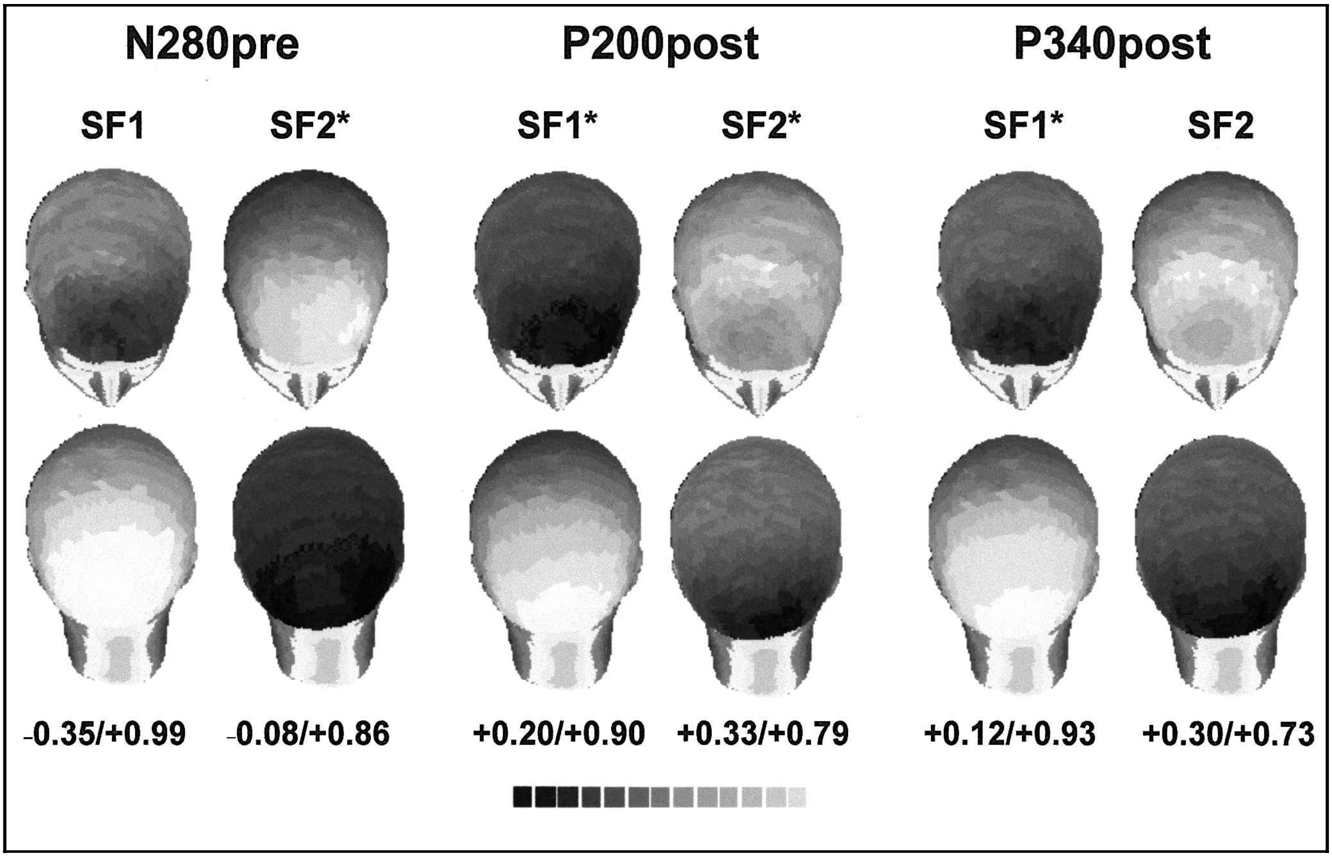


Figure 9. Topographic representation of factor loadings for the spatial factors (SF) or components extracted through sPCAs. *Spatial factors that, according to ANOVAs (see Table 4), were sensitive to the experimental effects.

combination of valence and arousal contents. In order to confirm this fact, the regression was calculated for P200post with respect to the Valence × Arousal product. In this case, arousal was rescaled from [−2 to +2] to [0 to +4] in order to avoid artificial balances among stimulus categories (with the original scale, R stimuli tend to be negative in arousal and positive in valence, while A− stimuli tend to be negative in valence and positive in arousal; the product of both dimensions would yield similar values for R and A−). The associ-

Table 4. Results of ANOVAs on Spatial Component Scores with Respect to Factor Stimuli

	Spatial Factor 1	*Spatial Factor 2*
N280pre	$F = 2.16$, *ns*	**$F = 3.17, p < .05$**
	GG $\varepsilon = 0.89$	**GG $\varepsilon = 0.90$**
	[97.36%, 94.98%]	**[4.92%, 2.54%]**
P200post	**$F = 5.08, p < .01$**	**$F = 10.20, p < .001$**
	GG $\varepsilon = 0.71$	**GG $\varepsilon = 0.87$**
	[97.31%, 67.40%]	**[2.47%, 32.38%]**
P340post	**$F = 3.07, p < .05$**	$F = 2.66$, *ns*
	GG $\varepsilon = 0.79$	GG $\varepsilon = 0.67$
	[98.16%, 76.88%]	[1.66%, 22.85%]

In brackets, the percentage of variance explained before and after rotation, respectively. Significant contrasts are in **bold**.

df = 3.84 in all cases; GG = Greenhouse-Geisser; *ns* = nonsignificant.

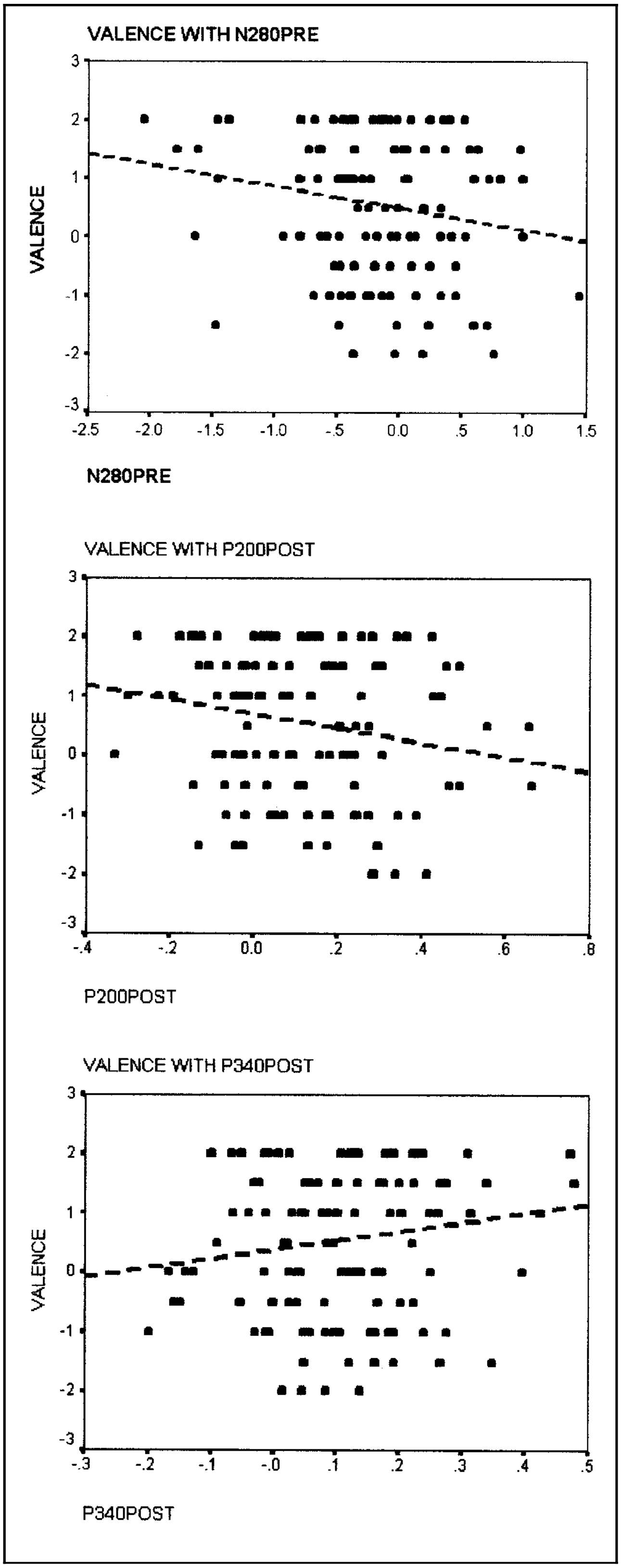


Figure 10. Scatterplots of valence assessments and N280pre (top), P200post (middle) and P340post (bottom) factor scores. Regression lines are also shown.

ation of P200post with [Valence × Arousal] was significant [$\beta = -0.18$, $F(1,127) = 4.44$, $p < .05$].

DISCUSSION

Attention-related ERP activity shows differences that depend on the emotional content of the stimulation. These differences have been produced even when stimuli are physically similar (cues), and in a task in which the four stimulus categories may be considered identical with respect to their cognitive requirements (attention demanded by task, perceptive and discriminative complexity, cue memory encoding, etc.). Valence of the emotional stimulation appears to be the aspect that preferentially explains the differences observed in the attention-related ERP components selected in the present study. However, as regression analyses have demonstrated, the influence of arousal through its interaction with valence was also significant for P200post.

Pretarget Activity

The lowest amplitude of N280pre was elicited by A−. The task requirements lead to the consideration that the type of attention reflected in this component should be expectancy-related. The possibility that the observed N280pre effects associate with the input processing-related attention to the cues themselves seems improbable. Cues are simple and homogeneous drawings (Figure 10), and it is difficult to find a characteristic in A+, N, and R cues themselves that could capture attention to a greater extent than A− cues. Secondly, input processing-related attention should associate, preferentially, with the VAC, but experimental effects have been observed in the frontal spatial component of N280pre. Source analysis suggests that this spatial component originates in the ACC and medial prefrontal cortex.

The ACC is associated, as explained in the Introduction, to expectancy-related attention. Additionally, the ACC has been reported to be activated in anticipation of affective events (Ploghaus et al., 1999; Murtha, Chertkov, Beauregard, Dixon & Evans, 1996). Coordinates given by LORETA for the frontal focus in the two analyses (on average recordings for all the stimuli and on recordings elicited by the stimulus evoking the highest N280pre amplitudes) mark a point in the vicinity of the ‘affective division’ of the ACC (ACad), one of the two functional and cytoarchitectural regions (the other is the ‘cognitive division’) in which recent studies suggest that the ACC could be subdivided (Bush, Luu & Posner, 2000). In fact, the ACad significantly increases its activity in tasks in which emotional information is involved (e.g., emotional Stroop tasks: Whalen et al., 1998). The medial prefrontal cortex is activated in a number of neuroimaging studies presenting emotional stimulation (Teasdale et al., 1999; Lane, Reiman, et al., 1997; Reiman et al., 1997). It is important to underline here that recent data suggest it plays an important role in visual attention processes in rodents (Bussey, Muir, Everit & Robbins, 1997), and its close relation with the ACC (particularly BA 32) and attentional processes in humans has been proposed (Lane, Fink, Chau, & Dolan, 1997; Lane et al., 1999). Additionally, it has been reported that the ventromedial sector of the prefrontal cortex is also involved in the anticipation of future affective consequences (see a review in Bechara, Damasio & Damasio, 2000; in relation to this, the possibility that anticipation of the emotional state evoked by the thought of targets contributes to the activity reflected in N280pre should be taken into account). All these functional profiles describing the ACC and medial prefrontal cortex make them candidate areas to develop an important role in relation to emotion and attention interactions in expectancy and anticipatory processes such as those facilitated by present task. In this particular case, results indicate that, at least in anticipatory processes, the activity in these areas decreases as threat value of expected stimulation increases.

It has been indicated that error-related negativity (ERN), a negative ERP component that appears when subjects make an erroneous response (Gehring, Goss, Coles, Meyer & Donchin, 1993), originates in the vicinity of the ACC (Dahaene, Posner & Tucker, 1994). ERN has been related to negative affect (Luu, Collins & Tucker, 2000), a result that could be interpreted as opposed to present data. However, both the experimental methodology by which the ERN is evoked (conspicuously different from the one employed here) and the functional and anatomical richness of the ACC (which is capable of eliciting processes of very diverse nature in its different areas), make it improbable that N280pre and ERN are related components. N280pre should be related to CNV. As explained in the Introduction, this negative component appears in S1- S2 experimental paradigms, such as the one used here, and has often been described as an 'expectancy' wave. The relationship of CNV amplitude to expectancy-related attention to S2 is direct (for a review on attention and CNV, see McCallum, 1988). Particularly, N280pre could be identified as an early CNV. While late CNV, mainly reflecting preparation to respond to S2, is maximal at central- parietal locations, early CNV is mainly found over the frontal lobes (Leynes, Allen, & Marsh, 1998; Damen & Brunia, 1994; Rohrbaugh & Gaillard, 1983). Dipole localization studies have placed the origin of early CNV in prefrontal areas (Basile, Rogers, Bourbon, & Papanicolau, 1994). Previous ERP data also suggest that early CNV decreases its amplitude when S2 consists of negative images. Klorman and Ryan (1980), and later Yee and Miller (1987), presented tones as S1 and slides of negative and nonnegative images as S2. Early CNV amplitude was significantly lower when forthcoming S2 was an unpleasant image in subjects who ranked those images as highly negative. These data and those of the present study support the idea that ACC/medial frontal cortex activity decreases when negative events are expected or anticipated, though results on ERN suggest that a different pattern of activity may be produced in these frontal regions in nonanticipatory affective processes. This 'double behavior' could explain why some hemodynamic studies fail to find significant differences in the response of these areas to positive and negative stimuli (emotional vs. neutral differences being the only found in them: Lane, 1999; Reiman et al., 1997).

Posttarget Activity

The task requirements lead to the consideration that the type of attention reflected in P200post and P340post is mainly associated with input processing-related attention: At this point of the task, subjects had to process a relatively complex image (as compared to cue stimuli) in order to provide a correct response. Moreover, components selected from these posttarget ERPs originated in the VAC, which is related to this sort of attention. It is difficult to compare the present data with those obtained from previous ERP studies, and identification of present components with previously reported components cannot be direct. As explained in the Introduction, and to our knowledge, experiments specifically oriented to the study of visual attention and emotion interaction have not been carried out up to the present. Thus, attentional components are usually outside the analyses of ERPs elicited by emotional images, and emotional visual stimuli are usually not employed in ERP studies on attention. Additionally, the experimental tasks differ greatly, in the majority of cases, from the one employed here. Task is a critical factor, and its design (physical complexity of stimulation, interstimulus interval, sensory category of the stimulation, stimulus parameter to be attended, type of response—if any: manual, verbal, etc.) significantly influences the characteristics (amplitude or latency) of recorded components; some components, such as CNV or P3b, may not even appear at all. For example, current P200post presents a similar latency to that of P2 (sometimes labeled 'selection positivity'), often obtained in ERP research on selective attention to nonemotional parameters of visual stimulation. However, it is typically maximal at frontal scalp sites (see, e.g., the review by Mangun & Hillyard, 1995), so that current P200post and 'traditional' P2 cannot be identified as the same component. On the other hand, P340post presents similar latency to that of P3a (Squires, Squires, & Hillyard, 1975), but the latter presents its maximum at fronto-central sites. Moreover, as indicated, P2 and P3a usually appear in tasks that are markedly different from that used here. Consequently, current P200post and P340post, which could be defined as components related to visual attention to previously announced emotional stimuli, with a maximum in parieto-occipital areas and originating in the VAC, will be discussed without reference to previous ERP data.

The first of the two posttarget VAC-related components has mainly reacted, around 200 msec, to negative stimulation. This result suggests that, at this stage, negative stimuli elicit, to a greater extent than the other stimuli, the mobilization of visual processing resources. This 'early' attentional response is followed by a 'late' attentional response, some 140 msec later, characterized by the opposite trend (from the point of view of stimulus valence), since it reflects the highest mobilization of perceptive resources towards appetitive (i.e., positive and arousing) stimuli. Another important time-related difference exists between P200post and P340post: The period is shorter in the former component (Figure 3). It can be clearly appreciated in parietal and occipital recordings that ERPs to A+ maintain a relatively constant level of amplitude for more than 200 msec, peaking in P340 (Figure 2). On the other hand, A− elicits a high response in P200 but it decreases rapidly, in about 50 msec. Since period of component may be understood to reflect the duration of the subjacent neural processes, the present results suggest that the early attention response reflects a briefer and, probably, less acute, mobilization of visual processing resources towards the stimulation. Taken together, latency and period data support the idea, mentioned in the Introduction, that the neural response to negative stimulation is more rapid and shorter than the response to other types of stimulation, and that this 'negativity bias' is already reflected in attentional phases.

Along with this temporal distinction between maximal response to A+ and maximal response to A−, an interesting result of the present experiment is that a spatial distinction has also been observed. Thus, the main focus for P200post was located in posterior areas of the middle temporal gyrus (BA 39 and 37). Meanwhile, the source for P340post was located in the inferior temporal gyrus or in the fusiform gyrus (BA 20 and 37). Even assuming the highest margin of error in EEG-based source localization, it can be established that P200post and P340post originated in different sources, and that the early attentional component appears to present one focus dorsally located with respect to the focus of the late attentional component. The proposed focus for the latter component is located in the 'ventral' visual stream, which projects from V1 to the temporal pole, and is preferentially involved in the discrimination of objects, analyzing attributes such as color or shape (Zeki & Shipp, 1988; Livingstone & Hubel, 1987). The proposed focus for P200post, the early attentional component, is a relatively wide area known as the posterior middle temporal gyrus, which belongs to the 'dorsal stream' (see, e.g., Tootell, Dale, Sereno, & Malach, 1996), a projection of fibers from the striate visual cortex to the parietal lobe. Thus, a spatial distinction appears to occur between 'early attention,' a rapid subphase, and 'late attention,' a slower and longer subphase presumably oriented to detailed processing. As a consequence, and indirectly, this differentiation is also present between maximum response to negative and maximum response to positive stimulation.

The main role of the dorsal stream has been identified as the processing of motion and spatial location. However, these are far from being its sole functions. For example, the processing of visual attributes 'typically' belonging to the ventral pathway, such as shape, has been found to be carried out in the dorsal stream of nonhuman primates (Sereno & Maunsell, 1998). In humans, data also exist that show high activation of dorsal stream areas (including posterior middle temporal gyrus) in response to static visual stimuli presented with invariant spatial locations (Mummery, Patterson, Hodges, & Price, 1998; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Wiggs, Ungerleider, & Haxby, 1996). In relation to emotional stimulation, activation of dorsal stream areas such as the middle temporal gyrus (Kosslyn et al., 1996) and inferior parietal lobe (Lang et al., 1998) has been observed to be greater (as the present data also suggest) in response to negative than to positive and neutral stimulation. A possible explanation is that the dorsal stream appears to be activated in response to visual stimuli with motor action-associated meaning, regardless of whether they are physically in motion or not. For example, static words associated with action elicit the activation of this stream (Mummery et al., 1998; Martin et al., 1995, 1996).

Conclusion

A description of the complete 'picture' of the processes observed in present research could be as follows. Expectancy-related attention, associated with N280pre, appears to activate the ACC and/or medial prefrontal areas responsible for organizing the processing of forthcoming events and the reaction to them (Posner & Raichle, 1995). Cues announcing nonharmful events generate greater activation of these cortices, particularly as compared with negative events. That is to say, expectancy-related attention towards nonharmful stimuli is greater than towards negative stimuli. In a different, input processing-related process (once the stimulus appears), attention is responsible for organizing sensory resources and mobilizing them at the time and place that they are necessary in order to adequately process the emotional visual events, and it also decides the extent to which this mobilization must take place to be effective. The VAC is, in this type of attention, the key brain area. The onset of a negative event announced by a cue may enhance the early attentional response reflected in P200post, originated in the dorsal stream. The objective of this early attentional response would be not a deep processing, but a rapid motoric and autonomic response. Appetitive events enhance the late attentional response reflected in P340post, longer and more thorough, carried out in the ventral pathway and

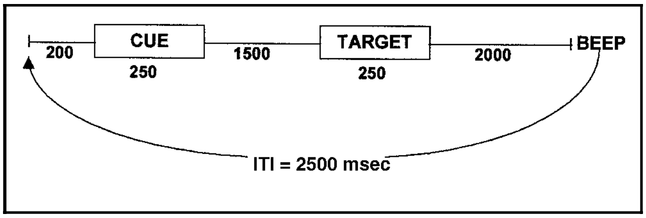


Figure 11. Schematic representation of the experimental paradigm employed in the present experiment. ITI = intertrial interval.

oriented to deeper processing of stimuli that typically trigger approaching behavior.

Main conclusions derived from present results are, firstly, that expectancy-related and input processing-related phases of the task appear to activate different brain areas: the former would associate with the activation of the ACC and/or medial prefrontal areas, whereas the later would activate the VAC regions. Secondly, clear signs of a negativity bias have been observed in brain responses reflecting input processing-related, but not vigilance-related, attention. Finally, results suggest that certain aspects within the neural substrates involved in the processing of positive and negative stimulation are spatially segregated. The actual range of these conclusions must be established taking into account two constraints inherent to the methodology employed in this study. On one hand, it should not be discarded that processes other than affective and attentional could contribute to configure the effects observed here. Thus, the use of emotional pictures could bear the risk that some stimulus properties other than those controlled in this study may influence the ERP shape. On the other hand, though the conclusions dealing with the spatial origin of the observed activity have been reached by means of some of the most sophisticated tools available to obtain spatial information from the ERPs (LORETA and sPCAs), the fact that they constitute indirect approaches to source localization must be remembered here. Future research using more direct methodologies should contrast these findings.

METHOD

Subjects

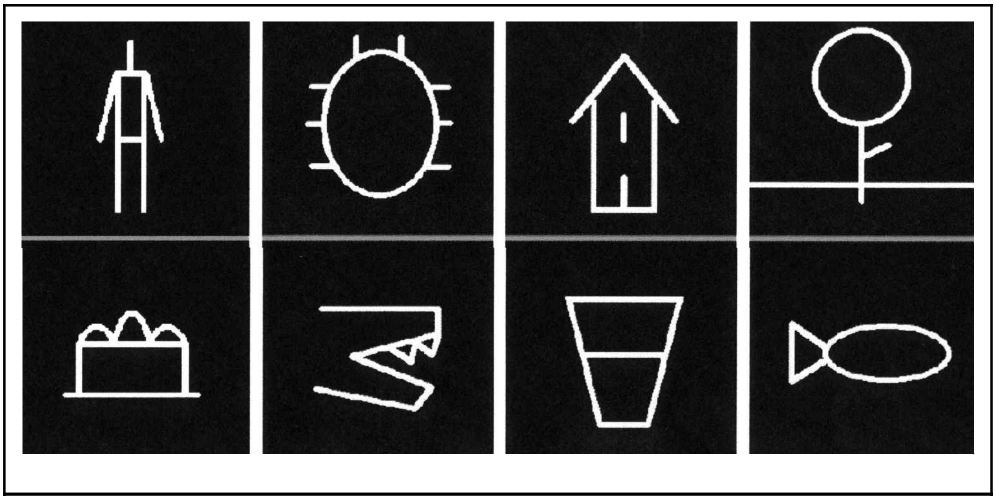
Thirty right-handed students from the Universidad Autónoma de Madrid took part in this experiment. The data from only 29 of them were eventually analyzed, as explained later. These 29 subjects, 23 women and 6 men, were aged between 18 and 30 years (mean = 22.4). They took part voluntarily in the experiment.

Stimuli and Procedure

Figure 11 shows, schematically, the structure of the experimental paradigm employed in the present experiment. Due to the symbolic, scarcely realistic characteristics of the drawings used as cues, subjects had the opportunity to see them, to identify their meaning and to associate them with targets before the recording session, guided by the experimenter. Two drawings or symbols were designed for each category. The two drawings corresponding to A+ represented a "nude person" and a "cake," those corresponding to A− represented an "insect" and a wolf "jaw," those belonging to the N category represented a "building" and a "glass" and, finally, "forest" and "submarine" landscapes were represented by the two drawings of the R group. Cue presentations consisted of the two drawings belonging to each category, one above the other (see Figure 12). This presentation lasted 250 msec. The dimensions of each cue presentation were 1.69 × 3.39 cm.

A color photograph (target) was presented 1750 msec later (2.85 × 4.23 cm). Color photographs were an opposite-sex nude or an ice cream cake if an A+ cue was presented, a tropical ortopteroid insect or an open mouth of a wolf in an aggressive expression if the cue belonged to the A− category, a glass or a flat building for N-type cues, and wood or underwater images for R cues. In other words (as subjects were told in the instructions), photographs represented always one of the objects or motifs represented by the two drawings

Figure 12. Stimuli used as cue. From left to right, first cue announced an arousing-positive target, second announced an arousing-negative target, third announced a neutral target, and fourth announced a relaxing target.



of the cue presentation. Therefore, the cue implicitly informed about the emotional content of the target. Two seconds after the end of the target presentation, a beep was presented to the subjects. If the photograph corresponded to the drawing that appeared at the top of the cue presentation, they were instructed to say "A," and if it corresponded to the bottom drawing of the cue, they had to say "B." Participants were instructed to look continuously at a small mark located in the center of the screen and to respond and to blink only after the beep. Intertrial interval lasted 2500 msec. Thirty-two trials were presented for each of the four groups of stimuli: A+, A−, N, and R (i.e., a total of 128 trials was presented).

Subjects completed a bidimensional scaling test for each group of pictures after the recording sessions. This test assessed the valence and the arousal content of the pictures, two affective dimensions considered to explain the principal variance of the emotional meaning (Lang, Greenwald, Bradley, & Hamm, 1993; Smith & Ellsworth, 1985; Russell, 1979; Osgood, Succi, & Tannenbaum, 1957). Since analyses of ERPs were carried out grouping the recordings elicited by the stimuli of each category, the assessments, made for each image separately, were also averaged for each category before being entered in statistical analyses.

Recording and Data Analysis

Electroencephalographic data were recorded using an electrode cap (ElectroCap International) with tin electrodes. A total of 58 scalp locations were used: Fp1, Fpz, Fp2, AF3, AF4, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, PO1, POz, PO2, PO4, PO8, O1, Oz, and O2. All scalp electrodes, as well as one electrode at the left mastoid (M1), were originally referenced to one electrode at the right mastoid (M2). Electrooculographic (EOG) data were recorded supra- and infra-orbitally (vertical EOG) and from the left versus right orbital rim (horizontal EOG). Electrode impedances were always kept below 3 k . A bandpass of 0.1 to 50 Hz (3 dB points for −6 dB/octave roll-off) was used for the recording amplifiers. The channels were continuously digitizing data at a sampling rate of 250 Hz for the duration of complete recording session.

The continuous recording was divided into two epochs for each trial. The first epoch, which involved pretarget ERPs, lasted 1950 msec beginning 200 msec before the cue onset. The second epoch comprised posttarget ERPs, and lasted 1000 msec beginning 200 msec before the target onset. Trials where subjects answered incorrectly were eliminated. A visual inspection was also carried out, eliminating epochs with eye movements or blinks. Results from one of the initial 30 subjects had to be rejected due to the presence of an excessive rate of ocular artifacts in the recordings. ERP averages were categorized according to each type of stimulus. For the entire sample of cephalic electrodes, originally M2-referenced data were algebraically re-referenced off-line using a global average reference (Lehmann, 1987). ANOVAs and tPCAs required the selection of 28 from the original 58 channels in order to avoid the loss of statistical power. These 28 channels were: AF3, AF4, F5, F1, F2, F6, FC5, FC1, FC2, FC6, C5, C1, C2, C6, CP5, CP1, CP2, CP6, P5, P1, P2, P6, PO7, PO1, PO2, PO8, O1, and O2. They were selected on the basis that they are topographically alternating across the scalp in a way that every unselected scalp location is surrounded by at least one or two immediately adjacent selected locations (interelectrode distances were short enough to admit that the differences between adjacent locations would be minimal).

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REFERENCES

Basile, L. F. H., Rogers, R. L., Bourbon, W. T., & Papanicolaou, A. (1994). Slow magnetic flux from human frontal cortex. *Electroencephalography and Clinical Neurophysiology, 90,* 157-165.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex, 10,* 295-307.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4,* 215-222.

Bussey, T. J., Muir, J. L., Everitt, B. J., & Robbins, T. W. (1997). Triple dissociation of anterior cingulate, posterior cingulate, and medial frontal cortices on visual discrimination tasks using a touchscreen testing procedure for the rat. *Behavioral Neuroscience, 111,* 920-936.

Cacioppo, J. T., & Bernston, G. G. (1994). Relationship between attitudes and evaluative space: A critical review, with emphasis on the separability of positive and negative substrates. *Psychological Bulletin, 115,* 401-423.

Cacioppo, J. T., & Gardner, W. L. (1999). Emotion. *Annual Review of Psychology, 50,* 191-214.

Canli, T., Desmond, J. E., Zhao, Z., Glover, G., & Gabrieli, J. D. E. (1998). Hemispheric asymmetry for emotional stimuli detected with fMRI. *NeuroReport, 9,* 3233-3239.

Carretié, L., Mercado, F., Tapia, M., & Hinojosa, J. A. (2001). Emotion, attention, and the 'negativity bias,' studied through event-related potentials. *International Journal of Psychophysiology, 41,* 75-85.

Cliff, N. (1987). *Analyzing multivariate data.* New York: Harcourt Brace Jovanovich.

Dahaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science, 5,* 303- 305.

Damen, E. J. P., & Brunia, C. M. H. (1994). Is a stimulus conveying task-relevant information a sufficient condition to elicit a stimulus-preceding negativity? *Psychophysiology, 31,* 129- 139.

Davidson, R. J., & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences, 3,* 11- 21.

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology, 14,* 456- 457.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion, 6,* 169- 200.

Fiske, S. T. (1980). Attentional and weight in person perception: The impact of negative and extreme behavior. *Journal of Personality and Social Psychology, 38,* 889- 906.

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4,* 385- 390.

Halgren, E., & Marinkovic, K. (1994). Neurophysiological networks integrating human emotions. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1137- 1151). London: MIT Press.

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, 75,* 887- 900.

Klorman, R., & Ryan, R. M. (1980). Heart rate, contingent negative variation, and evoked potentials during anticipation of affective stimulation. *Psychophysiology, 17,* 513- 523.

Kosslyn, S. M., Shin, L. M., Thompson, W. L., McNally, R. J., Rauch, S. L., Pitman, R. K., & Alpert, N. M. (1996). Neural effects of visualizing and perceiving aversive stimuli: A PET investigation. *NeuroReport, 7,* 1569- 1576.

Lane, R. D. (1999). Functional neuroanatomy of pleasant and unpleasant emotion. *Dissertation Abstracts International, B: The Sciences and Engineering, 60,* 1907.

Lane, R. D., Chua, P. M. L., & Dolan, R. J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia, 37,* 989- 997.

Lane, R. D., Fink, G. R., Chau, P. M. L., & Dolan, R. (1997). Neural activation during selective attention to subjective emotional responses. *NeuroReport, 8,* 3969- 3872.

Lane, R. D., Reiman, E. M., Ahern, G. L., Schwartz, G. E., & Davidson, R. J. (1997). Neuroanatomical correlates of happiness, sadness, and disgust. *American Journal of Psychiatry, 7,* 926- 933.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation, and action. In P. Lang, R. F. Simons & M. T. Balaban (Eds.), *Attention and orienting: Sensory and motivational processes* (pp. 97- 135). Mahwah, NJ: Erlbaum.

Lang, P. J., Bradley, M. M., Fitzsimmons, J. R., Cuthbert, B. N., Scott, J. D., et al. (1998). Emotional arousal and activation of the visual cortex: An fMRI analysis. *Psychophysiology, 35,* 199- 210.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30,* 261- 273.

LeDoux, J. E. (1995). Emotion: Clues from the brain. *Annual Review of Psychology, 46,* 209- 235.

Lehmann, D. (1987). Principles of spatial analysis. In A. S. Gevins & A. Rémond (Eds.), *Handbook of electroencephalography and clinical neurophysiology* (vol. 1, pp. 309- 354). Amsterdam: Elsevier.

Leynes, P. A., Allen, J. D., & Marsh, R. L. (1998). Topographic differences in CNV amplitude reflect different preparatory processes. *International Journal of Psychophysiology, 31,* 33- 44.

Livingstone, M. S., & Hubel, D. H. (1987). Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. *Journal of Neuroscience, 7,* 3416- 3468.

Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. *Journal of Neurophysiology, 77,* 24- 42.

Luu, P., Collins, P., & Tucker, D. M. (2000). Mood, personality, and self-monitoring: Negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology, General, 129,* 43- 60.

Mangun, G. R., & Hillyard, S. A. (1995). Mechanisms and models of selective attention. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind* (pp. 40- 85). Oxford: Oxford University Press.

Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science, 270,* 102- 105.

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature, 379,* 649- 652.

McCallum, W. C. (1988). Potentials related to expectancy, preparation and motor activity. In T. W. Picton (Ed.), *Handbook of electroencephalography and clinical neurophysiology* (vol. 3, pp. 427- 534). Amsterdam: Elsevier.

Mummery, C. J., Patterson, K., Hodges, J. R., & Price, C. J. (1998). Functional neuroanatomy of the semantic system: Divisible by what? *Journal of Cognitive Neuroscience, 10,* 766- 777.

Murtha, S., Chertkow, H., Beauregard, M., Dixon, R., & Evans, A. (1996). Anticipation causes increased blood flow to the anterior cingulate cortex. *Human Brain Mapping, 4,* 103- 112.

Northoff, G., Richter, A., Gessner, M., Schlagenhauf, F., Fell, J., et al. (2000). Functional dissociation between medial and lateral prefrontal cortical spatiotemporal activation in negative and positive emotions: A combined fMRI/MEG study. *Cerebral Cortex, 10,* 93- 107.

Öhman, A. (1992). Orienting and attention: Preferred preattentive processing of potentially phobic stimuli. In B. A. Campbell, H. Haynes & R. Richardson (Eds.), *Attention and information processing in infants and adults. Perspectives from human and animal research.* Hillsdale, NJ: Erlbaum.

Öhman, A., Esteves, F., Flykt, A., & Soares, J. J. F. (1993). Gateways to consciousness: Emotion, attention, and electrodermal activity. In J. C. Roy, W. Boucsein, D. C. Fowles & J. H. Gruzelier (Eds.), *Progress in electrodermal research* (pp. 137- 157). New York: Plenum.

Osgood, C., Suci, G., & Tannenbaum, P. (1957). *The measurement of meaning.* Urbana: University of Illinois.

Pascual-Marqui, R. D. (1999). Review of methods for solving the EEG inverse problem. *International Journal of Bioelectromagnetism, 1,* 75- 86.

Pascual-Marqui, R. D., Michel, C. M., & Lehman, D. (1994). Low resolution electromagnetic tomography: A new method for localizing electrical activity in the brain. *International Journal of Psychophysiology, 18,* 49- 65.

Ploghaus, A., Tracey, I., Gati, J. S., Clare, S., Menon, R. S., et al. (1999). Dissociating pain from its anticipation in the human brain. *Science, 284,* 1979- 1981.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25- 42.

Posner, M. I., & Raichle, M. E. (1995). Images of mind. *Behavioral and Brain Sciences, 18,* 327- 383.

Pratto, F., & John, O. P. (1991). Automatic vigilance: The attention-grabbing power of negative social information. *Journal of Personality and Social Psychology, 61,* 380- 391.

Reiman, E. M., Lane, R. D., Ahern, G. L., Schwartz, E. G., Davidson, R. J., Friston, K. J., Yun, L. S., & Chen, K. (1997). Neuroanatomical correlates of externally and internally generated human emotion. *American Journal of Psychiatry, 154,* 918- 925.

Rohrbaugh, J., & Gaillard, A. (1983). Sensory and motor aspects of the contingent negative variation. In A. Gaillard & W. Ritter (Eds.), *Advances in psychology* (vol. 10, pp. 269- 310). Amsterdam: Elsevier.

Russell, J. A. (1979). Affective space is bipolar. *Journal of Personality and Social Psychology, 37,* 345- 356.

Sereno, A. B., & Maunsell, J. H. R. (1998). Shape selectivity in primate lateral intraparietal cortex. *Nature, 395,* 500- 503.

Shizgal, P. (1999). On the neural computation of utility: Implications from studies of brain stimulation reward. In D. Kahneman, E. Diener & N. Schwarz (Eds.), *Well-being: The foundations of hedonic psychology* (pp. 500- 524). New York: Russell Sage Foundation.

Shulman, G. L., Corbetta, M., Buckner, R. L., Raichle, M. E., Fiez, J. A., Miezin, F. M., & Petersen, S. E. (1997). Top-down modulation of early sensory cortex. *Cerebral Cortex, 7,* 193- 206.

Smith, C. A., & Ellsworth, P. C. (1985). Patterns of cognitive appraisal in emotion. *Journal of Personality and Social Psychology, 48,* 813- 838.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and Clinical Neurophysiology, 38,* 387- 4101.

Sturm, W., de Simone, A., Krause, B. J., Specht, K., Hesselmann, V., Radesmacher, I., Herzog, H., Tellmann, L., Mueller-Gaertner, H. W., & Willmes, K. (1999). Functional anatomy of intrinsic alertness: Evidence for a fronto-parietal-thalamic- brainstem network in the right hemisphere. *Neuropsychologia, 37,* 797- 805.

Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain.* Stuttgart, Germany: Thieme.

Taylor, S. E. (1991). Asymmetrical effects of positive and negative events. The mobilization- minimization hypothesis. *Psychological Bulletin, 110,* 67- 85.

Teasdale, J. D., Howard, R. J., Cox, S. G., Ha, Y., Brammer, M. J., Williams, S. C. R., & Checkley, S. A. (1999). Functional MRI study on the cognitive generation of affect. *American Journal of Psychiatry, 156,* 209- 215.

Tellegen, A., Watson, D., & Clark, L. A. (1999). On the dimensional and hierarchical structure of affect. *Psychological Science, 10,* 297- 309.

Tootell, R. B. H., Dale, A. M., Sereno, M. I., & Malach, R. (1996). New images from human visual cortex. *Trends in Neuroscience, 19,* 481- 489.

Towle, V. L., Bolanos, J., Suárez, D., Tan, K., Grzeszczuk, R., et al. (1993). The spatial location of EEG electrodes: Locating the best-fitting sphere relative to cortical anatomy. *Electroencephalography and Clinical Neurophysiology, 86,* 1- 6.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature, 203,* 380- 384.

Whalen, P. J., Bush, G., McNally, R. J., Wilhelm, S., McInerney, S. C., Jenike, M. A., & Rauch, S. L. (1998). The emotional counting Stroop paradigm: A functional magnetic resonance imaging probe of the anterior cingulate affective division. *Biological Psychiatry, 44,* 1219- 1228.

Yee, C. M., & Miller, G. A. (1987). Affective valence and information processing. *Electroencephalography and Clinical Neurophysiology* (Suppl. 40), 300- 307.

Zecki, S., & Shipp, S. (1988). The functional logic of cortical connections. *Nature, 335,* 311- 317.