

# Brain potentials in perception: Picture complexity and emotional arousal

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## Abstract

Event-related potentials (ERPs) were measured while participants viewed affectively arousing and neutral pictures depicting either simple figure–ground compositions or more complex scenes to assess the timing and topography of perceptual and emotional modulation. Emotional pictures elicited a larger late positive potential than neutral pictures in a 400–700-ms window over centro-parietal sensors both for pictures with simple figure–ground composition and for more complex scenes. Picture composition affected ERPs beginning earlier (around 150 ms), with simple figure–ground compositions eliciting less positivity over posterior sensors and less negativity over frontal sensors. Emotionality had little effect on modulation of these early ERPs. These data suggest that the late centro-parietal positive potential primarily reflects motivational relevance, and that earlier posterior (and anterior) components reflect, at least in part, differences in a picture's perceptual organization.

When people view emotionally engaging stimuli, a large late positive potential is elicited that is typically maximal over centro-parietal areas in a window from about 400–700 ms after picture onset (e.g., Cacioppo, Crites, Gardner, & Berntson 1994; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Huang & Luo, 2006; Keil et al., 2002; Palomba, Angrilli, & Mini, 1997) that is often interpreted as indexing heightened processing for motivationally relevant stimuli. We have hypothesized that cues activating defensive or appetitive neural systems (i.e., those that signal threatening or life-sustaining events) prompt reflexive orienting responses related to sensory intake, increased resource allocation, and heightened processing that facilitate selection of appropriate actions to protect the life of the individual and the species (e.g., Lang, Bradley, & Cuthbert, 1997). In the current study, we explored the affective specificity of the modulation of the late positive potential, determining if it also varies with perceptual properties of pictures, such as contrast, spatial frequency, and figure–ground composition.

From the viewpoint of a human observer, and as initially articulated by Gestalt psychologists, one of the earliest stages in perceptual processing is the segregation of an object from its background. Photographs of natural scenes vary in the degree to which the central information is clearly separable from its back-

ground, and it might be expected that pictures having a relatively clear figure–ground composition are resolved more easily than those that depict multiple objects that are less clearly distinct from a uniform background. If pictures of emotionally engaging natural scenes were, on average, perceptually more complex than pictures depicting neutral situations (i.e., common objects and neutral people), it is possible that the late positive potential could also be reflecting differences in picture composition. In the current study, we explored how picture composition affects the ERPs elicited during affective picture viewing by varying whether pictures were (or were not) perceived to be simple figure–ground compositions.

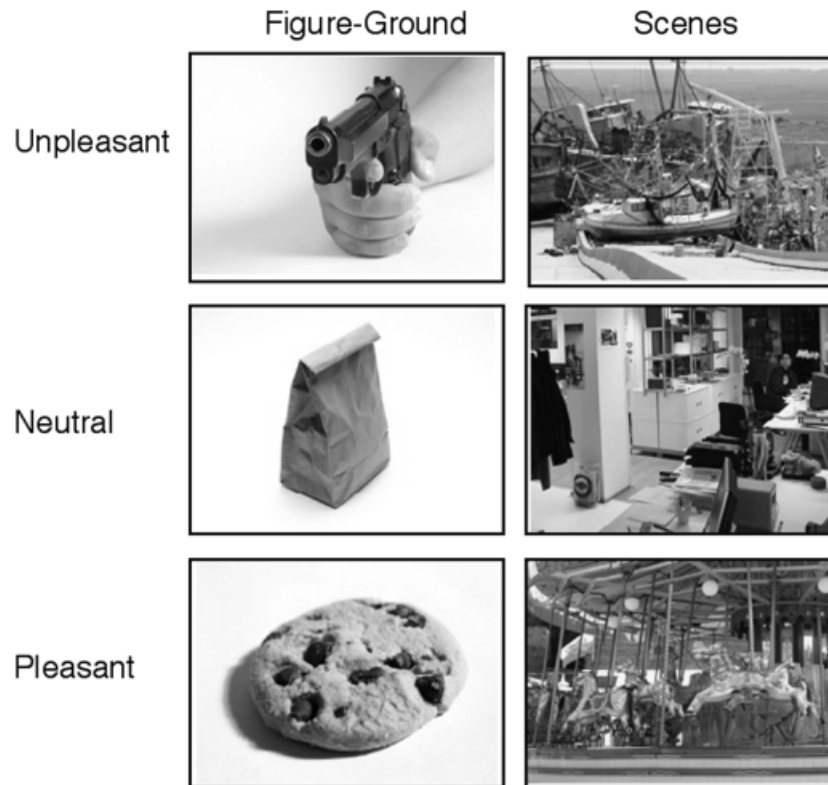
To begin, we selected pleasant, neutral, and unpleasant pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) judged either to have a figure–ground composition or to be lacking a clear figure–ground composition (termed “scenes”). Pictures depicting more complex scenes did not have either a constant background or an obvious central figure (see Figure 1) and, in general, could be considered to be perceptually more “noisy.” An independent sample of participants was asked to rate picture complexity to gauge the adequacy of this *a priori* selection. In terms of measurable physical differences, pictures selected to depict simple figure–ground compositions differed from complex scenes along a number of relevant physical dimensions. For example, complex scenes were, on average, higher in spatial frequency than figure–ground compositions, whereas figure–ground compositions were higher in contrast than scenes. These physical differences in picture composition were also explored as they affected ERPs during picture viewing.

We expected to replicate previous studies that found a larger late positive potential when viewing emotional, compared to neutral, pictures regardless of picture composition, as this

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**Figure 1.** Pictures were selected that varied in hedonic valence (pleasant, neutral, and unpleasant) and picture composition (figure-ground or scene). The pictures used in the study (see footnote 1) were selected from the International Affective Picture System (IAPS; Lang et al., 2005). Because IAPS pictures are not intended for publication, the pictures in this figure were drawn from public domain photographs available on the Internet simply to illustrate the type of pictures used in the experiment.

component is hypothesized to reflect heightened intake and orienting to motivationally relevant content. If the late positive potential additionally reflects enhanced processing requirements when viewing more complex visual stimuli, we expected that simple figure-ground pictures would elicit overall smaller late positive potentials than those depicting more complex scenes. On the other hand, we also conjectured that ERP effects arising due to differences in picture composition might more reasonably be found earlier in the ERP waveform, as the sensory/perceptual features of a picture must be resolved before its semantic/affective content can be fully apprehended. Thus, ERP components that have been sensitive to sensory differences among visual stimuli, such as spatial frequency, are typically elicited earlier (less than 200 ms following onset) in the ERP, and are often occipitally predominant (for an overview, see Hessefeld, Kene-mans, Kok, & Molenaar, 1997). We therefore hypothesized that picture composition would affect ERPs during picture viewing in time windows earlier than 400 ms after picture onset and would be observed over posterior sites.

To index emotional reactions to simple and complex affective pictures, we also measured heart rate and skin conductance during picture viewing. We expected to replicate commonly reported effects of greater heart rate deceleration specifically when viewing unpleasant pictures and increased electrodermal reactivity when viewing arousing (pleasant or unpleasant) pictures (for an overview, see Bradley & Lang, 2000), regardless of picture composition, as these peripheral physiological measures are presumed to be mediated by differences in affective, rather than perceptual, content.

## Method

### Participants

Forty participants (31 women) from the University of Florida participated as part of a General Psychology course requirement.

### Stimuli and Design

Stimuli were 192 pictures<sup>1</sup> selected from the International Affective Picture System (IAPS; Lang et al., 2005). Of the 192 pictures, half were selected on the basis of having a figure-ground composition and half were selected that did not have a clear figure-ground composition (scenes). Figure 1 illustrates the type

<sup>1</sup>The International Affective Picture System (IAPS; Lang et al., 2005) can be obtained upon request from the authors. IAPS pictures used in this study were: Figure-Ground: Pleasant: 1500, 1610, 2304, 2510, 2650, 4608, 4640, 4651, 4653, 5000, 5030, 5300, 5480, 5890, 7260, 7270, 7330, 7352, 7400, 7460, 7470, 8041, 8120, 8161, 8200, 8280, 8300, 8320, 8330, 8465, 8502, 8531. Neutral: 2190, 2200, 2210, 2214, 2215, 2221, 2230, 2270, 2271, 2280, 2440, 2495, 2516, 2570, 2810, 2830, 6150, 7010, 7100, 7110, 7130, 7140, 7150, 7175, 7190, 7211, 7224, 7233, 7235, 7490, 7705, 7950. Unpleasant: 1050, 1120, 1300, 1930, 2120, 2520, 2800, 3030, 3100, 3168, 3170, 3181, 3266, 3400, 3550, 5970, 6020, 6230, 6250, 6260, 6300, 6370, 9006, 9008, 9010, 9180, 9405, 9432, 9440, 9560, 9561, 9800. Scenes: Pleasant: 1340, 1850, 1920, 2208, 2501, 2560, 2791, 4617, 4666, 4681, 4687, 5200, 5600, 5621, 5779, 7280, 7282, 7284, 7286, 7289, 7350, 7481, 8080, 8090, 8116, 8162, 8180, 8370, 8380, 8400, 8420, 8510. Neutral: 2206, 2381, 2383, 2410, 2480, 2514, 2518, 2580, 2749, 2752, 2850, 2870, 3210, 5120, 5395, 5455, 5731, 6000, 7180, 7205, 7234, 7495, 7496, 7500, 7510, 7550, 7560, 7590, 7595, 7700, 9210, 9700. Unpleasant: 1051, 1280, 1303, 2205, 2590, 2691, 2730, 3015, 3064, 3500, 3530, 5971, 6211, 6212, 6821, 6830, 6831, 6838, 7380, 9001, 9090, 9102, 9181, 9252, 9290, 9300, 9470, 9480, 9592, 9611, 9912, 9921.

**Table 1.** Mean Pleasure and Arousal Ratings from the IAPS (Lang et al., 2005) for Pleasant, Neutral, and Unpleasant Pictures Selected to Depict Simple Figure–Ground Compositions and More Complex Scenes, and Mean Picture Composition Ratings (Ranging from 1 = Figure–Ground Composition to 9 = Scene) from an Independent Sample of Participants<sup>a</sup>

	Figure-ground	Scenes
Pleasure ratings		
Pleasant	6.96 (.08)	7.01 (.09)
Neutral	4.87 (.08)	4.98 (.11)
Unpleasant	2.73 (.14)	2.79 (.13)
Arousal ratings		
Pleasant	4.87 (.18)	5.15 (.20)
Neutral	3.07 (.12)	3.66 (.13)
Unpleasant	5.89 (.17)	5.62 (.16)
Picture composition ratings		
Pleasant	2.22 (.08)	4.95 (.09)
Neutral	1.32 (.08)	5.07 (.10)
Unpleasant	2.21 (.09)	5.30 (.10)

<sup>a</sup>Standard errors are in parentheses.

of pictures included in each of the six content categories defined by crossing picture composition (figure-ground, scene) with hedonic valence (pleasant, neutral, unpleasant). Of the 96 figure-ground compositions, 32 were pleasant, 32 were neutral, and 32 were unpleasant, and, within each hedonic content, pictures were balanced such that approximately half of the pictures either depicted people or did not. The same content breakdown occurred for the 96 scenes. Table 1 lists the pleasure and arousal ratings for stimuli in each of the unpleasant, neutral, and pleasant sets, which were matched such that there were no significant differences in affective ratings for pictures of a specific hedonic content in the figure-ground and scene stimulus sets.

**Rating study.** To assess the a priori selection of pictures on the basis of picture composition, 117 participants (64 female) from the University of Florida General Psychology course participated in small groups that were asked to rate the selected pictures in terms of picture composition. Each participant rated half (96) of the pictures, balanced for picture emotionality (pleasant, neutral, unpleasant) and a priori picture composition (figure-ground, scene). Participants were given examples of simple figure-ground compositions (IAPS #6610 [gun], #2070 [baby], and #3225 [dead woman]) and of more complex scenes (IAPS #9050 [plane crash], #2593 [outdoor cafe], and #7036 [shipping port]) and were explicitly asked to ignore the hedonic content of the picture in their ratings. A 9-point Likert scale was used to rate each picture, with *figure-ground* anchoring one end of the scale and *scene* anchoring the other end. Each trial included a 2-s warning signal, a 4-s picture presentation, and a 8-s rating interval in which the picture was not on the screen. Pictures were presented such that there was one picture of each hedonic valence and each composition in each subblock of six and two orders counterbalanced the position of specific pictures in the sequence.

**Psychophysiological study.** In the main experiment, participants completed the trials individually in the psychophysiological laboratory. Each picture was presented for 6 s, followed by a 6–14 s intertrial interval. The pictures were displayed on a 49 cm monitor for 6 s, with a maximum size of 27 × 37 cm, and presented approximately 1.25 m from the participant's eyes with a visual angle of 16° horizontally and 12° vertically. Pictures were

counterbalanced such that there was one picture of each hedonic valence and each composition in each subblock of six. Across participants, pictures were viewed in one of two different orders, with a specific picture viewed in either the first half or the second half, across orders.

An acoustic startle probe was presented either at 800 ms or 1800 ms; these data are not reported here.

### Physiological Recording and Data Reduction

Event-related potentials were collected from the scalp using a 129-channel system (Electrical Geodesics, Inc., Eugene, OR) running NetStation software on a Macintosh computer. Scalp impedance for each sensor was kept below 50 kΩ. The EEG was recorded continuously with a sampling rate of 250 Hz, the vertex sensor as reference electrode, and on-line bandpass filtered from 0.01 to 100 Hz.

Off-line, the data were reduced and analyzed using a MATLAB based program (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). Continuous EEG data were low-pass filtered at 50 Hz using digital filtering before stimulus synchronized epochs were extracted from 100 ms before until 700 ms after picture onset (to avoid including ERPs to the startle probe). Single trial epochs were corrected for vertical and horizontal eye movements using a correlative eye movement algorithm (Miller, Gratton, & Yee, 1988). The raw EEG epochs were passed through a artifact-detection algorithm that uses statistical parameters to determine trials with artifacts (Junghöfer et al., 2000). Data were transformed to an average reference and baseline corrected (100 ms before picture onset) prior to subject averaging and analysis.

Stimulus control and physiological data acquisition were accomplished using an IBM-compatible computer running VPM software (Cook, 1997). Skin conductance activity was recorded using electrodes filled with the recommended 0.05 M NaCl Unibase paste, and placed adjacently on the hypothenar eminence of the left palmar surface. The signal was acquired with a Coulbourn V71-22 skin conductance coupler. Data were reduced off-line to half-second averages, and deviated from a 1-s baseline preceding picture onset. The maximum change score in a window from 1 to 4 s after picture onset was used in analyses of skin conductance change.

The electrocardiogram was recorded from the left and right forearm using Ag/AgCl standard electrodes, filled with electrolyte paste. The signal was filtered using a Coulbourn S75-01 bioamplifier, and a Schmitt trigger interrupted the computer each time it detected a cardiac R-wave. Interbeat intervals were recorded to the nearest millisecond and reduced off-line by using VPM software (Cook, 1997) into heart rate in beats per minute, in half-second bins, and then deviated from a 1-s baseline preceding picture onset. The average change score over the 6-s viewing period was used in analyses of heart rate change.

### Procedure

After arrival at the laboratory, participants signed an informed consent form. Participants were then seated in a recliner in a small, sound-attenuated, dimly lit room, and electrodes and the EEG sensor net were attached. The participants were then instructed that a series of pictures would be displayed and that they should view each picture the entire time it was displayed, keeping their eyes comfortably focused on a small dot on the center of the screen. In addition, they were told to keep their eyes on the fixation dot when the picture was off the screen and to ignore any

noises heard over headphones. Following the picture trials, participants were debriefed, paid, and thanked.

## Results

### Complexity Ratings

Table 1 lists the ratings of picture composition from the independent sample of participants. Corroborating the a priori categorization of the pictures, pictures with figure-ground composition were rated as differing from scenes in perceptual composition with extremely high reliability,  $F(1,117) = 747$ ,  $p < .0001$ . The difference in ratings between figure-ground and scene compositions was highly significant for pleasant pictures,  $F(1,117) = 615$ ,  $p < .0001$ , neutral pictures,  $F(1,117) = 824$ ,  $p < .0001$ , and unpleasant pictures,  $F(1,117) = 527$ ,  $p < .0001$ . An interaction of picture composition and emotionality,  $F(2,117) = 89$ ,  $p < .0011$ , indicated that, for scenes, unpleasant pictures were rated as slightly lower in figure-ground composition than pleasant pictures,  $F(1,117) = 31$ ,  $p < .0001$ , whereas there was no difference for figure-ground compositions. Taken together, pictures selected to depict simple figure-ground compositions were overwhelmingly rated as significantly lower in perceptual complexity than pictures that depicted more complex scenes.

### Event-Related Potentials

**Picture emotionality.** Figure 2 illustrates grand average ERPs for pleasant, neutral, and unpleasant pictures averaged over a set of midline, left, and right sensors for centro-parietal, frontal, and occipital sensors. ERPs for emotional (pleasant and unpleasant) pictures diverged from neutral stimuli around 400 ms after picture onset over centro-parietal sensors, as illustrated in the topographical voltage map of the difference between emotional (pleasant and unpleasant) and neutral pictures in the late positive potential time window (see Figure 2, top right). To determine sensor groupings for testing differences in the late positive potential, a spatial principal components analysis was conducted on the difference in voltage change between emotional (pleasant or unpleasant) and neutral pictures, using the data from all participants and all time points in the 400–700 ms window. As expected, the first spatial factor indicated high loadings for the centro-parietal sensors contributing to the late positive potential. Accordingly, for analysis, sensors loading greater than .9 on the first spatial factor (see Figure 3, top right) were averaged for each subject, picture content, and picture composition.

The late positive potential was modulated by picture emotionality,  $F(2,38) = 44.72$ ,  $p < .001$ . Both pleasant and unpleasant pictures prompted a larger late positive potential than neutral pictures (unpleasant:  $F[1,39] = 84.76$ ,  $p < .001$ ; pleasant:  $F[1,39] = 15.54$ ,  $p < .001$ ). Moreover, in this study, unpleasant pictures prompted somewhat larger late positive potentials than pleasant pictures,  $F(1,39) = 20.91$ ,  $p < .001$ . The main effect of picture emotionality was significant for both figure-ground compositions,  $F(2,38) = 30.13$ ,  $p < .001$ , and for scenes,  $F(2,38) = 12.5$ ,  $p < .001$ , as depicted in Figure 3 (top left). The same pattern of affective modulation was obtained regardless of perceptual composition: Compared to neutral pictures, larger late positive potentials were obtained when viewing unpleasant ( $F[1,39] = 55.4$ ,  $p < .001$  for figure-ground,  $F[1,39] = 24.7$ ,  $p < .001$  for scenes) or pleasant pictures ( $F[1,39] = 14.5$ ,  $p < .001$  for figure-ground,  $F[1,39] = 3.9$ ,  $p = .056$  for scenes). In addition, for both types of pictures, unpleasant pictures prompted larger late positive potentials than pleasant pictures

( $F[1,39] = 19.6$ ,  $p < .001$  for figure-ground,  $F[1,39] = 6.34$ ,  $p < .05$  for scenes).

A significant interaction between picture emotionality and picture composition,  $F(2,38) = 4.64$ ,  $p < .05$ , primarily indicated larger late positive potentials for pleasant and unpleasant pictures that had a clear figure-ground composition, compared to scenes, as illustrated in Figure 3 (bottom). Thus, whereas neutral pictures elicited similar late positive potentials regardless of composition ( $p = .31$ , see Figure 3), the late positive potential was larger for figure-ground, compared to scenes, for both pleasant,  $F(1,39) = 10.94$ ,  $p < .01$ , and unpleasant,  $F(1,39) = 25.3$ ,  $p < .001$ , pictures (see Figure 3).

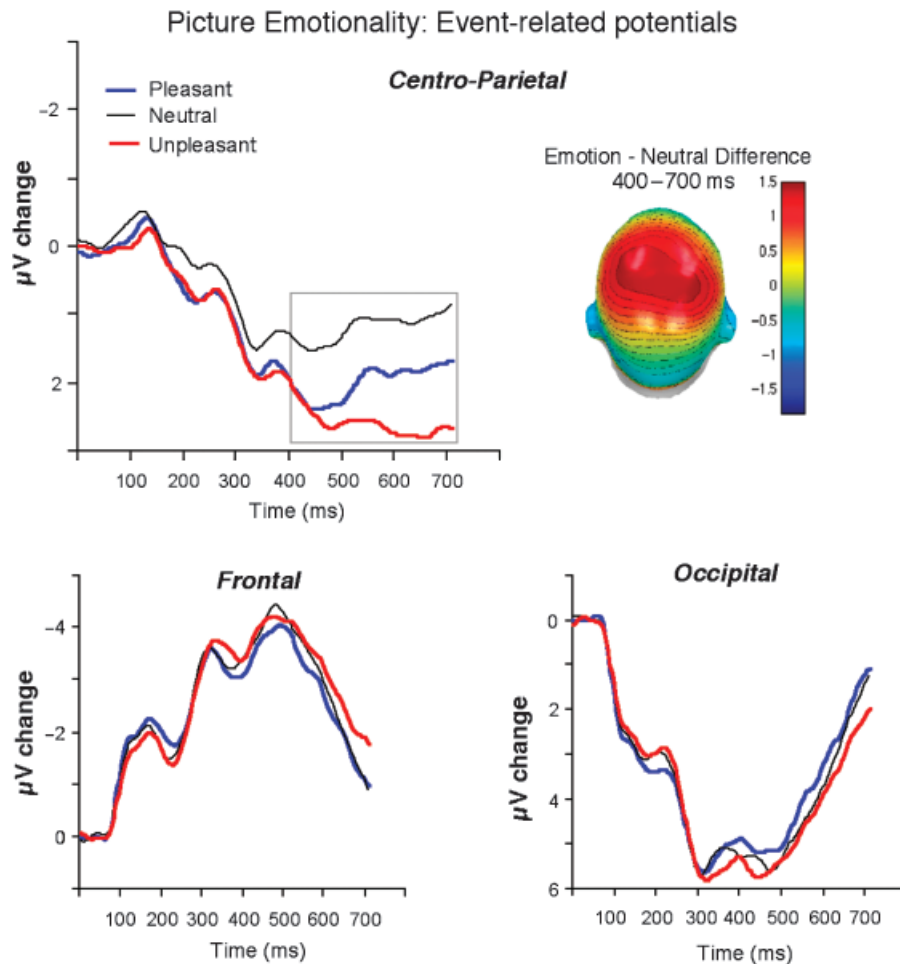
**Picture composition.** Figure 4 (left and right panels) illustrates that differences in the grand average ERPs for figure-ground pictures and scenes emerges in the ERP around 150 ms over both occipital and frontal sensors. The topographical plot of the difference in voltage between figure-ground compositions and scenes in a time window from 150 to 250 ms is plotted in Figure 4 (middle panel) and illustrates that figure-ground pictures prompted less positivity bilaterally over occipital sensors than sensors more complex scenes, as well as less negativity over frontal sensors. To determine appropriate sensor groupings for testing differences in this early component, a spatial principal components analysis was conducted on the difference in voltage change between figure-ground and scenes, using the data from all participants and all time points in the 150–250-ms window. Posterior sensors loading  $> .9$  on this factor (see Figure 5) and frontal sensors loading  $< -.9$  were then separately averaged by picture content and perceptual composition for each participant.

ERPs measured when viewing figure-ground pictures differed in the 150–250 ms window from that measured when viewing complex scenes, prompting significantly less positivity over occipital sensors,  $F(1,39) = 34.2$ ,  $p < .001$ , and less negativity over frontal sensors,  $F(1,39) = 42.0$ ,  $p < .001$ . Importantly, picture emotionality did not have an effect on this early component, and neither the main effect of picture emotionality nor its interaction with picture composition were significant for ERPs measured over either occipital or frontal sites. Thus, as illustrated in Figure 5, ERPs in this early time window differed only in terms of picture composition: Compared to scenes, figure-ground pictures prompted less occipital positivity and frontal negativity in the 150–250 ms window for pleasant pictures,  $F_s(1,39) = 9.56$  and  $11.63$ , respectively,  $p_s < .01$ , neutral pictures,  $F(1,39) = 13.4$  and  $14.2$ , respectively,  $p_s < .01$ , and unpleasant pictures,  $F(1,39) = 13.5$  and  $6.9$ ,  $p_s < .01$ .

There were no differences in the ERPs as a function of picture composition prior to 150 ms. On the other hand, significant effects of picture composition were obtained for all 100-ms time windows from 150 to 650 ms following picture onset for both posterior ( $F_s[1,39] > 7.5$ ,  $p_s < .05$ ) and frontal sensors ( $F_s[1,39] > 5.4$ ,  $p_s < .05$ ).

**Other picture properties.** There was no difference in average brightness<sup>2</sup> for pictures depicting figure-ground compositions or scenes. On the other hand, figure-ground pictures were higher in contrast than were the scenes,  $F(1,190) = 23.30$ ,  $p < .01$ , due to

<sup>2</sup>Brightness was defined as the mean RGB value for each pixel, averaged across all pixels; for contrast, the standard deviation of the mean RGB values was computed across pixels for each column and the standard deviation of these was used as an index; for spatial frequency, the frequency of the median FFT power was determined for each row and column, and then averaged.



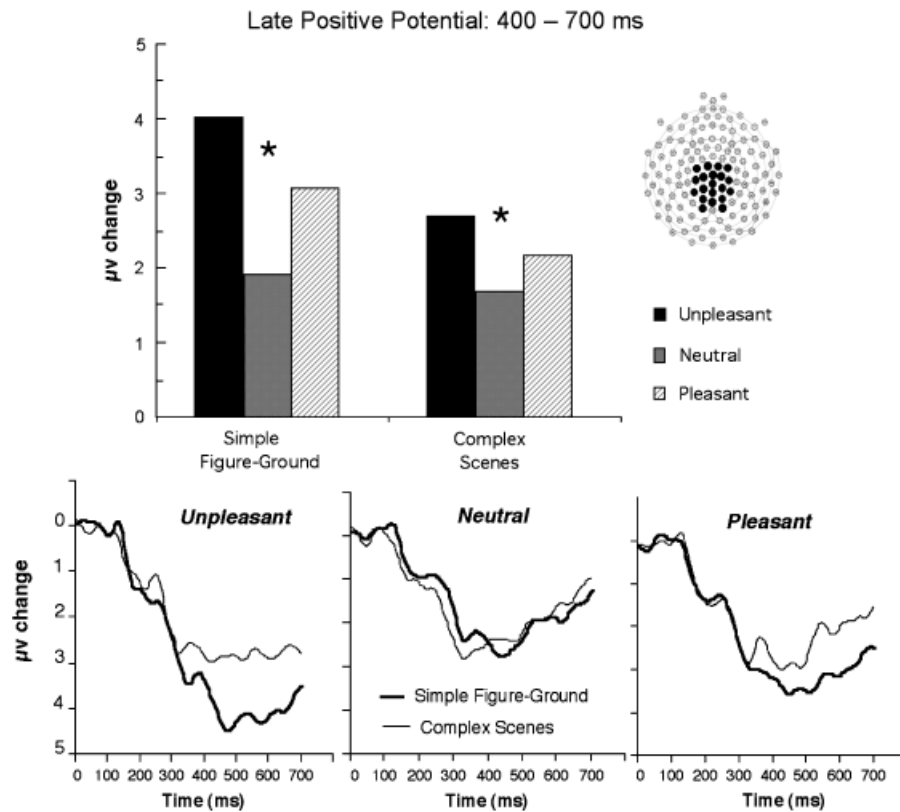
**Figure 2.** Event-related averages from illustrative centro-parietal, frontal, and occipital sites for pleasant, neutral, and unpleasant pictures show greater positivity over centro-parietal sensors for emotional, compared to neutral, pictures in a 400–700-ms time window after picture offset. Top right: Top view of the scalp distribution of the difference in positivity in the 400–700 ms between emotional and neutral picture processing.

the defining feature of a more constant background, and scenes were significantly higher in spatial frequency than figure-ground pictures,  $F(1,190) = 16.21$ ,  $p < .01$ . When pictures selected to represent either figure-ground or scenes are plotted in a two-dimensional space defined by their contrast and spatial frequency as in Figure 6 (top left), however, there was no exact correspondence between picture composition (i.e., figure-ground or scene) and either contrast or spatial frequency. Aside from a small set of figure-ground pictures that were low in spatial frequency and high in contrast, the remaining simple and complex pictures were scattered throughout this space.

Nonetheless, to determine the extent to which differences in the early ERP are mediated by differences in contrast or spatial frequency, the data were reaveraged for each participant, dividing the set of 192 pictures into those that were low or high in contrast and low or high in spatial frequency, based on a median split for each variable. For ease of exposition, the ERP data measured in the 150–250 ms window over posterior sensors were used in these analyses. As illustrated in Figure 6 (bottom left), picture contrast did not affect this early ERP component, but spatial frequency affected ERPs,  $F(1,39) = 12.7$ ,  $p < .001$ , with pictures low in spatial frequency showing less posterior positivity in this early time window, consistent with the previous analyses demonstrating that simple figure-ground pictures prompt less posterior positivity.

To determine the extent to which differences in early posterior ERPs that vary with picture composition (i.e., figure-ground or scenes) are related to differences in spatial frequency, the data were reaveraged for each participant, covarying picture composition and spatial frequency (based on a median split). Figure 6 (top right) illustrates the mean waveforms resulting from this analysis. Regardless of spatial frequency, the waveforms continue to separate on the basis of whether pictures depict simple figure-ground compositions or more complex scenes. Analysis of the mean change in the 150–250 ms time window (see Figure 6, bottom right) confirmed these impressions, indicating a strong effect of picture composition,  $F(1,38) = 27.92$ ,  $p < .001$ , and no effect of spatial frequency. A marginal interaction of picture composition and spatial frequency,  $F(1,39) = 4.08$ ,  $p = .05$ , indicated that spatial frequency had no effect on this early component when viewing simple figure-ground pictures, but that scenes lower in spatial frequency prompted slightly less positivity over posterior sensors in this early time window, compared to scenes higher in spatial frequency,  $F(1,39) = 7.03$ ,  $p < .05$ .

**Skin conductance.** Figure 7 (left panel) illustrates the waveforms for skin conductance as a function of picture emotionality and composition. Skin conductance change varied with picture



**Figure 3.** Top: The mean late positive potential (400–700 ms) over central parietal sensors (inset) for figure-ground and scene compositions shows heightened positivity for emotional, compared to neutral, pictures regardless of picture composition. Bottom: Averaged ERP waveforms for unpleasant, neutral, and pleasant pictures that vary by picture composition.

emotionality,  $F(2,38) = 11.78$ ,  $p < .001$ , but was not affected by picture composition. A significant quadratic trend indicated larger changes when viewing either pleasant or unpleasant, compared to neutral, pictures,<sup>3</sup>  $F(1,39) = 21.85$ ,  $p < .001$ . In this study, unpleasant pictures also prompted somewhat larger skin conductance changes than pleasant pictures,  $F(1,39) = 7.11$ ,  $p = .01$ , whereas both pleasant and unpleasant pictures prompted significantly larger changes than neutral pictures,  $F_s(1,39) = 8.90$ ,  $p < .01$ , and  $23.61$ ,  $p < .001$ , respectively.

**Heart rate.** Figure 7 (right panel) illustrates cardiac waveforms during the picture viewing period. A main effect of picture valence,  $F(2,36) = 9.20$ ,  $p < .01$ , replicates many previous findings of greater cardiac deceleration when viewing unpleasant, compared to pleasant or neutral, pictures,  $F(1,37) = 12.93$ ,  $p < .005$ , and  $F(1,37) = 13.45$ ,  $p < .005$ . Picture composition had no effect on cardiac orienting, as evidenced by the lack of a main effect and interaction. Separate tests indicated no differences in heart rate when viewing simple figure-ground or scene compositions for pictures in any of the three valence categories.

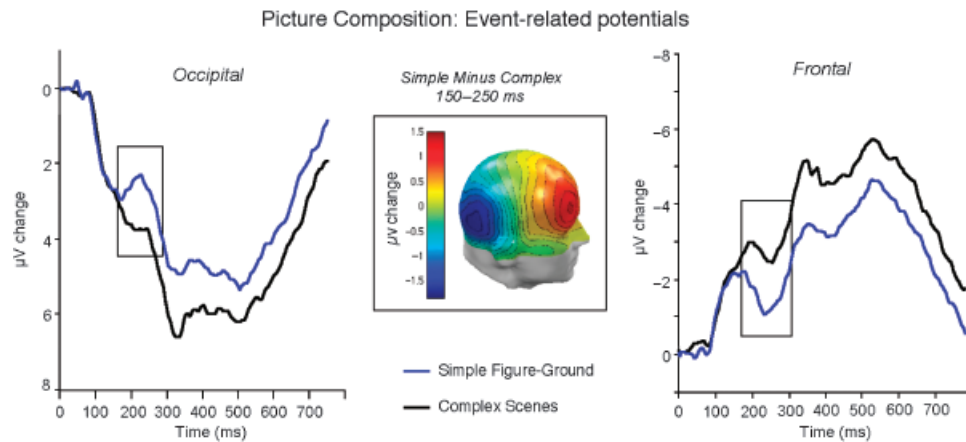
## Discussion

In this study, ERPs evoked during affective picture viewing were assessed while participants viewed pictures with simple figure-

ground composition and those representing more complex scenes. An independent group of participants corroborated the a priori grouping, reliably judging the figure-ground compositions to be simpler in picture composition than scenes. The late positive potential of the ERP, measured over centro-parietal sensors in a window from 400 to 700 ms after picture viewing, was larger when viewing emotional (unpleasant or pleasant), compared to neutral pictures—both for pictures composed of simple figure-ground compositions and for the more perceptually complex scenes. And, rather than being accentuated when pictures were perceptually more complex, the late positive potential was specifically enhanced when viewing simple figure-ground pictures that depicted emotional content. For neutral pictures, on the other hand, there was no difference in the magnitude of the late positive potential as a function of picture composition. Taken together, the data indicate that the late positive potential is primarily related to differences in picture emotionality regardless of whether a picture is relatively easier or harder to perceptually parse. This finding supports the hypothesis that this late component is sensitive to affective information in the visual array rather than to differences in perceptual composition.

In the current study, the late positive potential was somewhat larger for aversive, compared to pleasant, pictures, regardless of perceptual composition, whereas, in previous studies, this component is often of equivalent magnitude for pleasant and unpleasant images (e.g., Cuthbert et al., 2000; Palomba et al., 1997). On the other hand, the late positive potential is particularly heightened for pictures with erotic/romantic content (De Cesarei & Codispoti, 2006), which also garner high

<sup>3</sup>The same pattern of modulation as a function of emotionality was obtained for skin conductance regardless of whether a startle probe was presented early or late on a trial for both figure-ground and scene compositions, hedonic valence quadratic  $F_s(1,39) > 4.2$ ,  $p_s < .05$ .

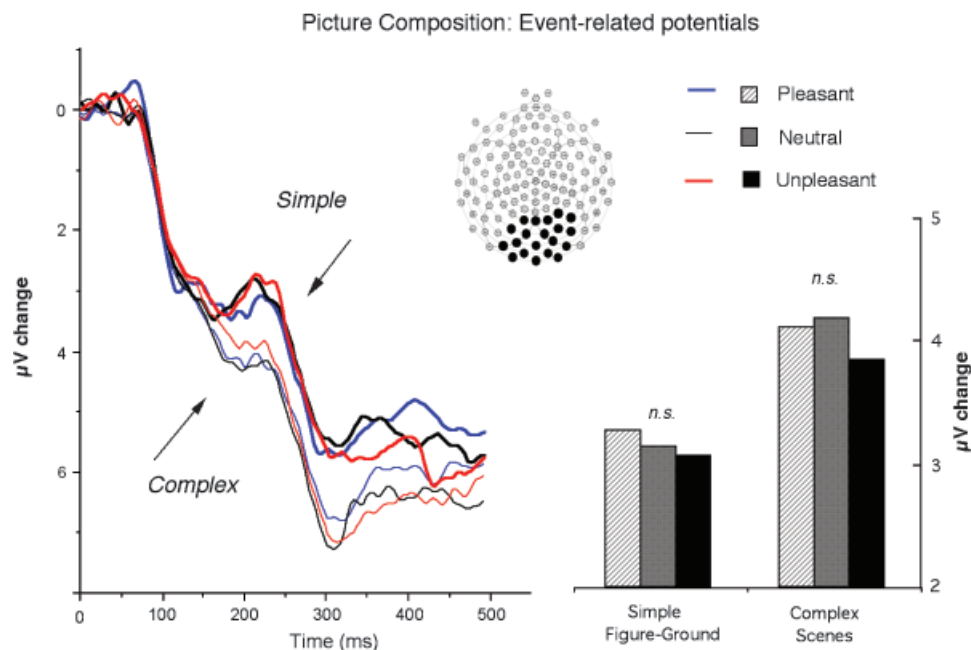


**Figure 4.** Left and right panels: Event-related averages from illustrative posterior and frontal sites for simple figure-ground and more complex scenes. Middle panel: The scalp distribution of the difference between simple figure-ground and more complex scenes in the 150–250-ms time window.

arousal ratings and high skin conductance reactions (Bradley, Codispoti, Cuthbert, & Lang, 2001). Because erotic/romantic pictures tend to be simple in perceptual composition (with relatively few pictures of erotic content involving more complex visual scenes), the number of exemplars from this content category was small in the current stimulus set. As a result, the a priori IAPS arousal ratings (Lang et al., 2005) were somewhat higher for unpleasant, compared to pleasant, pictures in this study, and this arousal difference was subsequently confirmed by finding larger skin conductance responses (and a larger late positive potential) for unpleasant pictures. Nonetheless, even in the absence of many erotic exemplars, the late positive potential was significantly enhanced when viewing pleasant, compared to neutral, pictures regardless of picture composition.

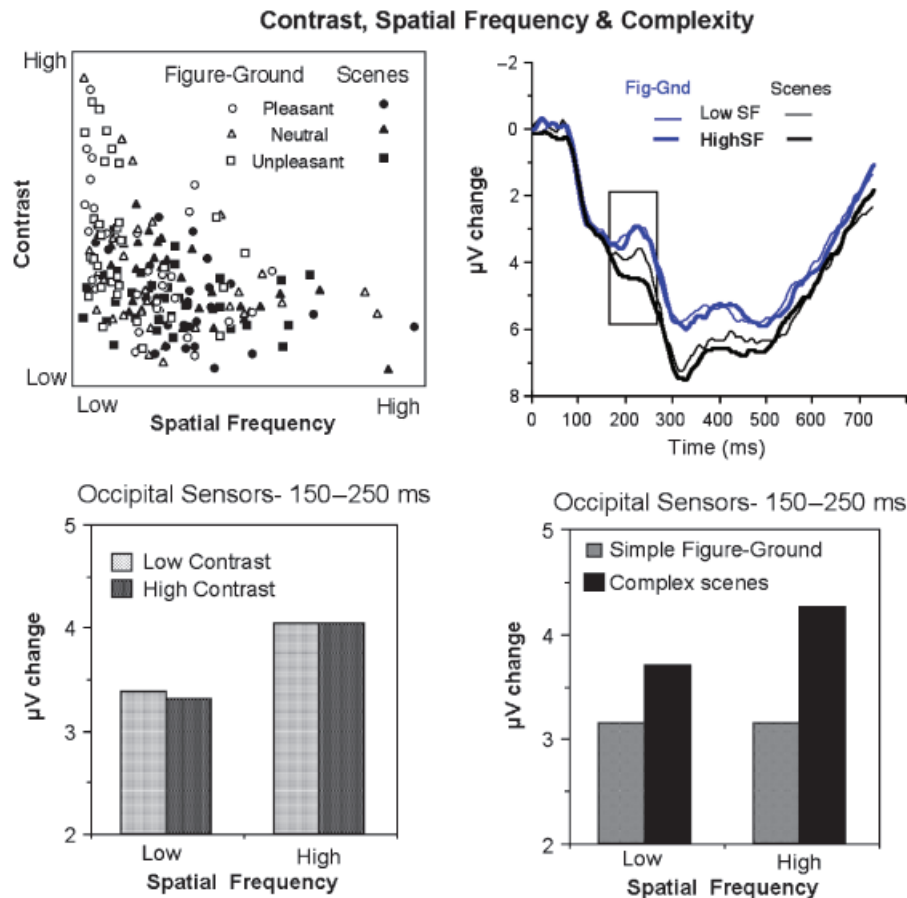
Picture composition had its largest effects earlier in the viewing interval, beginning in a time window around 150 ms after picture onset over both posterior and frontal sensors. Simple figure-ground pictures showed less positivity over posterior sensors and less negativity over frontal sensors, compared to pictures depicting more complex scenes. Importantly, there was no evidence that emotionality affected this early modulation by picture composition. Rather, the waveforms over posterior sensors for pictures of simple composition, for instance, were strikingly similar, regardless of the hedonic content of the picture, and picture emotionality similarly had no effect on posterior ERPs in this time window elicited when viewing more complex scenes.

The finding that picture composition affects ERPs early over posterior sensors is consistent with previous studies showing



**Figure 5.** Left panel: Waveforms for simple figure-ground pictures and more complex scenes over posterior sensors do not differ as a function of hedonic valence. Right panel: Mean ERP over posterior sensors (inset) in a 150–250 ms window following picture onset shows only an effect of picture composition.





**Figure 6.** Top left: A scatterplot of pleasant, neutral, and unpleasant pictures of figure-ground and scene composition in the two-dimensional space defined by contrast and spatial frequency. Bottom left: Mean posterior ERPs in the 150–250 ms window when the data were reaveraged by contrast and spatial frequency. Top right: Event-related averages for pictures defined by picture composition (figure-ground, scenes) and spatial frequency (low, high). Bottom right: Mean posterior ERPs in the 150–250 ms window for pictures defined by picture composition and spatial frequency.

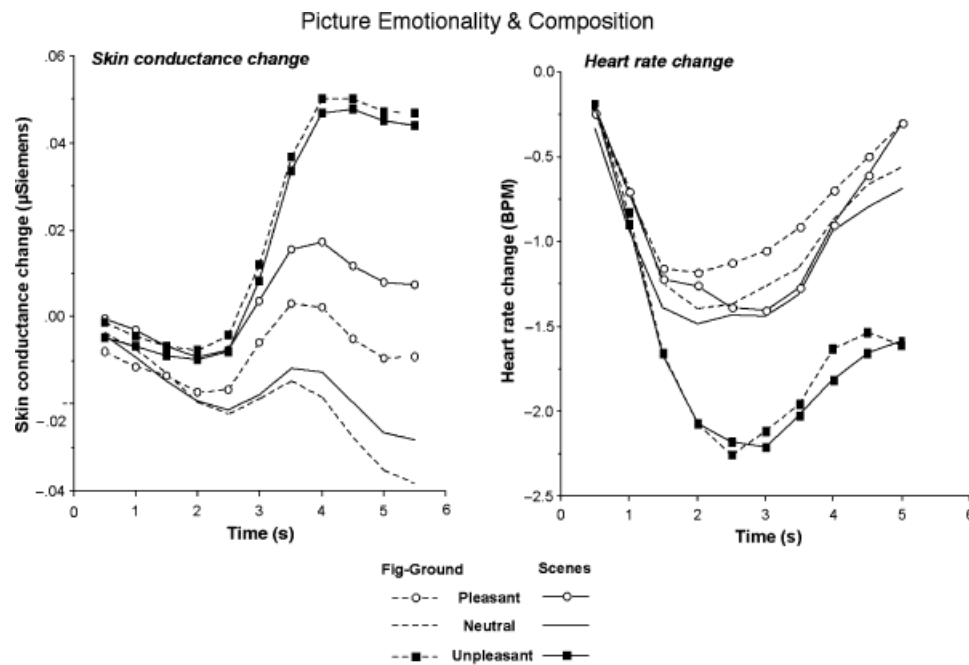
similar early effects due to specific perceptual features. For instance, Heslenfeld et al. (1997) designed a study to independently explore effects of perception and of selective attention on ERPs. In their study, participants were directed to attend to checkerboards either high or low in spatial frequency. Consistent with the current data, checkerboard patterns low in spatial frequency (i.e., simple) showed less positivity over posterior sites around 150 ms after stimulus onset (Experiment 1), compared to checkerboards higher in spatial frequency, regardless of selective attention, leading these authors to conclude that these early effects reflect automatic neural coding of perceptual features.

More recently, De Cesare and Codispoti (2006) found that modulation of an early (150–300 ms) occipito-temporal component by emotion was attenuated by a perceptual manipulation in which pictures were displayed very small, whereas the late positive potential prompted differentiation between emotional and neutral pictures regardless of picture size. Moreover, whereas modulation of the late positive potential declines with repetition (Codispoti, Ferrari, & Bradley, 2007), modulation of an early occipito-temporal ERP shows no habituation across blocks when pictures are repeatedly presented, consistent with the hypothesis that this earlier ERP component is related to obligatory processing necessary for encoding and recognizing picture content.

In the current study, pictures that were rated as perceptually more complex were, on average, higher in spatial frequency than figure-ground compositions, whereas simple pictures tended to be higher in contrast (and lower in spatial frequency). This was not surprising given the criteria for selecting figure-ground compositions and scenes. Differences in contrast among pictures showed no reliable effects on early ERPs measured over posterior sensors. On the other hand, although the correlation between participants' ratings of picture complexity and spatial frequency was positive, it was low ( $r = .36$ ), and when picture composition and spatial frequency were covaried, picture composition, as judged by differences in figure-ground composition, rather than spatial frequency, showed the most reliable and largest modulatory early ERP effect. Moreover, when spatial frequency did affect ERPs over posterior sensors, it was only for pictures of complex scenes: Pictures that were perceptually simple to human observers did not show any differences as a function of sheer spatial frequency.

These data suggest that this early ERP component may reflect processing of particular object-based features, rather than a picture's nonobject relevant sensory features (e.g., spatial frequency). Thus, one hypothesis is that this early ERP component is related to the degree to which object-level features pop out of the visual display, perhaps reflecting the success of a perceptual process that maps sensory information onto a mental representation. If





**Figure 7.** Skin conductance change (left panel) and heart rate change (right panel) for pleasant, neutral, and unpleasant pictures that depicted simple figure-ground compositions or more complex scenes.

so, the current data would suggest that objects that are more easily mapped onto memory prompt increased negativity over posterior sensors, with a polarity reversal over more anterior sensors. Consistent with this hypothesis, pictures of familiar, compared to unfamiliar, objects prompt a similar (relative) negativity over posterior sensors in the same time window (Busch, Herrmann, Muller, Lenz, & Gruber, 2006). Moreover, when visual stimuli are displayed in a degraded format, Doniger et al. (2000) found increasing negativity over posterior sensors until the point at which a picture was successfully recognized, which they interpreted as indicating perceptual closure and access to semantic information. Source localization techniques suggested that this early effect was mediated by bilateral activity in the lateral occipital pathways presumed to be involved in object recognition. Using both dense sensor ERPs and fMRI, Sehatpour, Molholm, Javitt, and Foxe (2006) further suggested that converging streams of information from occipital and frontal regions are utilized for successful closure during perceptual recognition.

Using pictures of faces or cars that varied in phase coherence (i.e., blurriness), Philiastides, Ratcliff, and Sajda (2006) also reported similar early modulation, but instead emphasized the pattern obtained for images that were “difficult” to process, in which greater positivity was found posteriorly (and increased frontal negativity) in a window around 220 ms after picture presentation, a pattern similar to that obtained when viewing complex pictures in the current study. They argued that this early component reflects the difficulty of perceptual categorization, consistent with the idea that complex scenes are also more difficult to perceptually categorize. If objects in complex scenes must be accurately mapped onto multiple mental representations for successful perceptual recognition, one hypothesis is that variability in the completion of perceptual processing for more complex scenes produces time jitter in the perceptual closure process, prompting the differences found for posterior sensors.

In selective attention tasks, a posterior negativity occurring between 150 and 300 ms after stimulus onset, variously labeled as

N2, N2b, or selection negativity (Potts & Tucker, 2001), as well as an accompanying positive deflection over frontal sensors, is enhanced when processing salient target, compared to nontarget, stimuli. The topography and timing of these components resemble those that were accentuated here when simple pictures were the focus of current processing, and source estimation techniques similarly localize these effects over occipito-temporal regions (Codispoti, Ferrari, Junghofer, & Schupp, 2006). One possibility is that selection negativity also reflects, in part, the ease or success of perceptual recognition processes, in which the explicit targets in a task context are more easily mapped onto the “familiar” mental representation.

The timing and location of this early posterior component resembles a difference found between emotional and neutral pictures when pictures are presented extremely rapidly (e.g., three per second; Junghöfer, Bradley, Elbert, & Lang, 2001). With these rapid presentation rates, emotional pictures prompt an absolute negativity (rather than simply decreased positivity), compared to neutral pictures, that is maximal over posterior sensors and located, via source analysis, to the bilateral occipital cortex. More recent data suggest that this early difference is most pronounced for pictures of erotica (Flaisch, Junghöfer, Bradley, Schupp, & Lang, 2006; Schupp et al., 2007). When pictures are presented at a slower rate, similar differences in early ERPs between emotional and neutral pictures over posterior sensors have been reported, in which emotional pictures prompt less positivity over posterior sensors than neutral pictures (Schupp, Junghöfer, Weike, & Hamm, 2003). Again, this effect is most pronounced for erotic materials (De Cesarei & Codispoti, 2006).

As noted previously, the current study was not able to include a large number of erotic exemplars, perhaps contributing to the lack of affective modulation of this early component here. On the other hand, the current data suggest that, if erotic stimuli specifically prompt a more negative-going deflection early over posterior sensors (at fast or slow presentation rates), this effect may be related to the fact that erotic pictures tend to be

perceptually simple in organization, more reliably involving figure-ground compositions (or simpler features) than do pictures of other affective or neutral content. Consistent with this, we recently found that the difference in the early posterior negativity during rapid picture presentation is most pronounced for pictures that are simple (figure-ground) and complex (scene) in perceptual composition (Löw, Lang, & Bradley, 2005), supporting a hypothesis that features of simple pictures may pop out of a rapid visual stream.

In summary, whether a picture portrayed a relatively simple figure-ground composition or a more complex scene strongly affected ERPs in a window beginning around 150 ms, with simple pictures showing less positivity (more negativity) over posterior sensors and less negativity (more positivity) over frontal sensors. That perceptual properties such as picture composition and spatial frequency should have effects early in the viewing interval is reasonable, as pictures are visually complex stimuli that demand extensive perceptual processing prior to identifica-

tion of semantic/emotional content. Supporting this idea, when balanced for perceptual complexity, picture emotionality had little impact on this early component.

Effects due to the emotional content of pictures modulated later components of the ERP, beginning in a window around 300–400 ms after picture onset. Affective modulation of the centro-parietal late positive potential was highly significant for pictures that were either simple or complex in perceptual composition, and both peripheral cardiac and electrodermal responses showed affective differences that were unaffected by perceptual composition. In fact, the late positive potential was actually enhanced when processing emotional pictures that involved simple figure-ground compositions, suggesting relatively stronger affective engagement with pictures that starkly depict emotional content. Taken together, the data are consistent with the idea that perceptual differences dominate picture ERPs early in the temporal stream, with differences due to emotional arousal a relative latecomer to the brain's electrical activity measured on the scalp.

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