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Emotional arousal and activation of the visual cortex: An fMRI analysis

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Abstract

Functional activity in the visual cortex was assessed using functional magnetic resonance imaging technology while participants viewed a series of pleasant, neutral, or unpleasant pictures. Coronal images at four different locations in the occipital cortex were acquired during each of eight 12-s picture presentation periods (*on*) and 12-s interpicture interval (*off*). The extent of functional activation was larger in the right than the left hemisphere and larger in the occipital than in the occipitoparietal regions during processing of all picture contents compared with the interpicture intervals. More importantly, functional activity was significantly greater in all sampled brain regions when processing emotional (pleasant or unpleasant) pictures than when processing neutral stimuli. In Experiment 2, a hypothesis that these differences were an artifact of differential eye movements was ruled out. Whereas both emotional and neutral pictures produced activity centered on the calcarine fissure (Area 17), only emotional pictures also produced sizable clusters bilaterally in the occipital gyrus, in the right fusiform gyrus, and in the right inferior and superior parietal lobules.

Descriptors: fMRI, Emotion, Pictures, Pleasure, Arousal, Attention

Pictures evoke a spectrum of measurable emotional reactions. Previous research has shown clear differences in autonomic, somatic, and myographical responses as a function of the pleasure and arousal of emotional pictures (e.g., Lang, Greenwald, Bradley, & Hamm, 1993). In this study, we investigated the extent and anatomical location of functional activity in the visual cortex when people process photographic pictures that differ in emotionality.

In our investigation, we evaluated the visual cortex to determine whether effects of emotional valence or arousal are observable in primary and secondary visual processing areas, which are relatively early "stops" in the processing chain involving these types of visual stimuli. Evidence from a recent positron emission tomography (PET) study (Lane et al., 1997) suggests that activation of visual cortex may be greater when people view emotional than when they view neutral pictures. Using pictures selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997a), changes in cerebral regional blood flow using PET methodology were measured in 12 women. Significantly greater blood flow was observed in Brodmann's areas 18 and 19 (visual cortex) for unpleasant than for neutral pictures. However, there were no differences in activity between pleasant and neutral stimuli in these areas of the visual cortex. Skin conductance recordings taken coincident with the PET measurement indicated that, for these women, pleasant pictures led to significantly less electrodermal activity than did unpleasant materials, suggesting that functional brain differences are associated with stimulus arousal. Studies of electroencephalogram activity during picture processing are consistent with this conclusion, in that emotional pictures show larger P300 responses and a sustained positive slow wave that is not obtained for emotionally neutral materials (Cuthbert, Schupp, Bradley, & Lang, 1997).

In the current study, we extended the neuroimaging exploration of brain activity during emotional picture processing by utilizing functional magnetic resonance imaging (fMRI) to assess regions of increased brain activity, measured as an increase in blood oxygen concentration. Among the potential methodological advantages of the fMRI technique are (a) improved spatial resolution, permitting more precise localization of specific anatomical regions involved in processing emotional, as compared with neutral, pictures, (b) the ability to use briefer periods of

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emotional stimulus exposure and temporally more proximal control periods, and (c) no need for introducing radioactive agents into the body. To permit an exploration of possible gender differences in emotional picture processing, both men and women participated in the current study.

The experiment was conducted in two phases, both in the same experimental session, with the participants positioned continuously in the bore of the magnet. In Phase l, subjects observed flashing checkerboard stimuli, which were presented in the center, the left side, or the right side of the visual field. This initial procedure was included as a methods check to confirm activation of the appropriate hemisphere(s) by center or half-field stimulation (Schneider, Noll, & Cohen, 1993) and to provide an estimate of base reactivity to visual content, against which activation to affectively meaningful pictures can be assessed. In Phase 2, participants viewed three sequences of meaningful pictures (12-s presentation), with a blank screen presented for an equal duration between picture presentations. The three sequences consisted of eight neutral pictures (household objects, neutral faces), eight pleasant pictures (sports events, erotic couples, appetizing food, happy babies), or eight unpleasant pictures (human violence, mutilated bodies, contaminated food, filth and squalor).

Magnetic resonance images during stimulus processing were compared with intervals with no visual stimulation, and differences in intensity (reflecting differences in blood oxygen level) were calculated for a series of coronal images in the occipital cortex sampled during each of the six stimulus conditions (left, right, center, pleasant, neutral, and unpleasant) to identify areas of functional activity. To evaluate the hypothesis of differential brain activity for emotional stimuli, we assessed the extent of functional activation (a) for emotional (pleasant and unpleasant) as compared with neutral stimuli; (b) for unpleasant as compared with pleasant pictures, and (c) for neutral pictures compared with nonmeaningful centrally presented checkerboard stimuli. The results were expected to replicate the PET finding of more activation for unpleasant than for neutral pictures in the visual cortex (Lane et al., 1997) and to provide more specific information regarding which anatomical regions are implicated in processing aversive materials. We also planned to reassess the impact of pleasant pictures on functional activity using the superior localization techniques of fMRI. Gender differences in functional activity also were assessed to determine whether men and women show differential activity in response to emotional pictures in the visual cortex.

In Experiment 2, we simulated the fMRI environment in a psychophysiology lab to record skin conductance and eye movements using the same methodology as in Experiment 1. The goal of Experiment 2 was to assess whether eye movement artifact was responsible for the pattern of functional activity obtained in Experiment 1 and to determine whether the expected differences in arousal for the set of IAPS pictures used in Experiment 1 were obtained in the skin conductance measure.

EXPERIMENT 1

Method

Participants

Twenty (12 men, 8 women) normal volunteers were paid $10.00 each for their participation. The data from 4 additional volunteers were not used because of equipment error ($n = 2$), falling asleep in the scanner ($n = 1$), and no detectable functional activation ($n = 1$).

Materials and Design

Stimuli were checkerboards and pictures selected from the IAPS.[1] Both types of stimuli were in color, and all stimuli were presented at a 3 Hz flashing rate.[2] Mean pleasure ratings for the pleasant, neutral, and unpleasant pictures used were 6.6, 5.5, and 2.3, respectively, and mean arousal ratings were 5.6, 3.3, and 6.7 for pleasant, neutral, and unpleasant pictures, respectively, based on the IAPS norms (Lang et al., 1997a). There were six blocks in the experiment, each consisting of eight cycles of a 12-s intertrial interval (*off*) and a 12-s stimulus presentation period (*on*). All stimulus events were time-locked to the scanning sequence via a PC-compatible computer interfaced with the scanner, running VPM stimulus control software (Cook, Atkinson, & Lang, 1987). The three checkerboard conditions consisted of stimuli presented to the left, center, or right visual field, with order counterbalanced across participants. The three picture conditions consisted of center presentation of pleasant, neutral, or unpleasant pictures, with order counterbalanced across participants. The three checkerboard conditions were always conducted before the three picture conditions.

Images were acquired using a specially built quadrature head coil that was seated in a football helmet. A bitebar was attached to the helmet coil to help stabilize the head and to discourage head movements while in the scanner. For each participant, an impression of the upper palate was made by asking the subject to bite down on a warm malleable mold for about 1 min until it cooled. This dental impression was then mounted in an apparatus that could be moved in all three dimensions when relocating the upper palate imprint in the scanner, affording maximum comfort. An adjustable mirror, mounted on top of the helmet, allowed viewing of visual stimuli that were rear-projected on a screen located at the participant's feet. A red fixation dot was illuminated in the center of the screen throughout the session. The screen size was 57 $\times$ 57 cm, with the centrally presented stimuli 57 m wide $\times$ 37 cm high when projected on the screen, subtending a visual angle of 20°.

The scanning sequence began with the acquisition of a 66-image (ear-to-ear) sagittal scout set, using a standard T1-weighted sequence. This series of scout images was used (a) to indicate ("prescribe") where in the brain the functional images would be located and (b) to register (off-line) each subject's brain in the standard Talairach–Tournoux (1988) space. The first coronal image was prescribed 10 mm from the occipital pole, orthogonal to the magnet field (see Figure 2, left). Thus, the most anterior image was nearly centered on the calcarine fissure in primary visual cortex (Brodmann area 17). Subsequent images extended through areas 18 and 19, with the superior portion of the final image generally including substantial tissue anterior to the occipitoparietal fissure. High resolution anatomical images for use in overlaying the functional maps were acquired at each of these four coronal image locations before the functional series began, also using a standard T1-weighted scanning sequence.

[1] The IAPS (Lang, Bradley, & Cuthbert, 1997) is available on CD-ROM and as photographic slides. The IAPS and technical manuals can be obtained on request from the authors at the NIMH Center for the Study of Emotion and Attention, Box 100165 HSC, University of Florida, Gainesville, FL 32610-0165, USA. IAPS catalog numbers for pictures used in this study are as follows: pleasant: 4002, 4003, 4220, 4611, 4660, 7410, 8260, 8510; neutral: 1810, 5500, 7009, 7034, 7090, 7140, 7207, 7510; unpleasant: 1080, 3000, 3030, 3102, 3120, 6230, 6560, 9622.

[2] Consistent with prior work on lateralized visual presentations of checkerboards, stimuli were presented at a rapid flashing rate (i.e., 3 Hz). To compare picture presentations with checkerboard stimuli, pictures were also presented at the same flashing rate.

The functional images were acquired using a multislice spiral scan technique (Noll, Cohen, Meyer, & Schneider, 1995) on a conventional 1.5T GE Signa scanner. The functional scans were 5 mm thick with a 1.5 interslice gap, 128 × 128 voxels (1.4 × 1.4 mm in plane resolution), 18 mm field of view, TE = 35, TR = 720, and a flip angle of 45°. Four coronal images (approximately 3 s/image acquisition) were collected during each of eight 12-s picture presentation periods and eight 12-s interpicture periods in each block of trials, resulting in a set of 64 images at each coronal location per block (32 during stimulus presentation, 32 during intertrial intervals).

After the functional series ended, a set of four phase contrast magnetic resonance angiogram (MRA) images were acquired at each of the four coronal locations. These images were used in later data analyses to identify and remove from consideration voxels in areas associated with large venous flow.

Procedure

After signing an informed consent form, a check for metallic objects was undertaken, with participants removing all objects containing ferrous material and placing them in a box. In addition, the experimenter inquired about the possible existence of internal metallic objects, such as plates, bullets, medical screws. Following determination that no ferrous objects were present, each participant was acclimated to the scanner by entering the scanning room, laying on the scanning table, and being moved into the center of the bore. If any discomfort in the scanning environment was expressed at this time, the volunteer was excused from participating in the study. After resting comfortably in the scanner for 2–3 min, each participant was removed from the magnet and taken into another room where the dental impression of the upper teeth for the bitebar apparatus was made.

Upon returning to the scanning room, the experimenter explained that it was extremely important that movement be inhibited while in the scanner and that the most important task at this time was to get as comfortable as possible. Participants were then instructed that during much of the procedure, they could simply relax while the scanner was operating. Towards the middle of the procedure, however, a series of slides would be presented on a screen that was located near the participant's feet on the scanning table. At this time in the procedure, the participants were to keep their eyes comfortably focused on a red dot (laser pointer) in the center of the screen. It was explained that the eyes should remain focused on the red dot both when a picture was on the screen and when it was off the screen and that the only time during this part of the procedure that the participant could relax fixation was when the scanner noise stopped for brief periods between the pictures (i.e., between stimulus conditions).

Participants were given earplugs to dampen the noise of the scanning equipment and a black call button to hold that could be used to alert the experimenter to any problems. They also were told that two-way voice contact was available at all times through a microphone in the center of the scanner. After ascertaining that there were no further questions, the participant laid supine on the scanning table, moving the head as far as possible into the helmet coil. The bitebar was adjusted by the participant to achieve maximum comfort and was clamped into place by the experimenter. The participant was instructed to "hang" from the bitebar using the upper palate rather than actively biting down on the bitebar. All participants easily understood this instruction; each one was able to drop the lower jaw, swallow, talk, and breathe while the upper jaw was firmly attached to the bitebar apparatus, which greatly assisted in restricting head movement.

After the participant was moved into the center of the scanner, a checkerboard stimulus was displayed on the slide screen to adjust the focus and position of the slide on the projection screen for each participant. The experimenter then returned to the console room and, after establishing voice contact, encouraged the participant to relax during the first imaging series. The lights in the scanning room were left on during the first series of 66 sagittal images (5 min) and were turned off just prior to acquiring the four high resolution images in the coronal plane (about 2 min) and remained off throughout the rest of the experiment. During the functional series (six blocks, each requiring about 4 min), the experimenter vocally reminded the participant to focus on the central fixation dot at the beginning of each block. After the last functional scan, the participant was instructed to relax while a final series (four phase contrast blood flow) of images were acquired (about 10 min). All together, the entire protocol required approximately 45 min in the scanner.

Following completion of the imaging sequences, the participant was removed from the scanner, debriefed, paid, and thanked.

Data Reduction and Analysis

In the main analysis, we assessed the extent of activation detected in each stimulus condition by dividing the sampled brain into eight regions, defined by hemisphere (left, right), dorsal–ventral areas (occipital, occipitoparietal), and anterior–posterior regions (anterior, posterior; reduced to two levels by averaging over the two posterior and two anterior images) for each participant in each condition.

Functional activity in each region was determined as follows. Using the set of 64 images (32 *on*, 32 *off*) collected in each block of the experiment for each participant, the difference in mean signal intensity during the picture presentation periods and during the interpicture interval was computed. To take into account the phase lag in blood flow, the lag was determined by computing a cross-correlation at a range of lags for each voxel using a square wave reference function that represented the sequence of experimental and control (e.g., *on–off*) stimulus events. The maximum correlation between this reference function and signal intensity typically occurred at a lag of two images (approximately 6 s), which was taken into account when computing the mean difference scores by omitting the first two images and designating sequences of eight images as four *off* and four *on* throughout the remaining 62-image set. A *t*-statistic was used to evaluate the mean difference in signal intensity between these averaged epochs for each voxel.[3] Then, these functional *t*-statistic maps were thresholded for each participant and condition at a level of $p < .01$ and constrained to include four contiguous voxels in the final map, which effectively reduces the rate of false positives. Constraining the final maps on the basis of cluster size allows fMRI analyses to control for multiple comparisons without the concomitant loss of power that would occur with a Bonferroni correction method (Forman et al., 1995).

[3]The entire set of functional analyses described and reported here was also conducted using a cross-correlation procedure to identify active voxels. In these analyses, a cross-correlation was computed for each voxel using a square wave reference function that represented the sequence of experimental/control (e.g., *on–off*) stimulus events. The cross-correlation at a range of lags was computed for each voxel, and the maximum correlation was used in a final statistical parametric map that was thresholded at a value of 0.5 and constrained to include four contiguous correlated voxels in the final map. As in the *t*-test maps, phase contrast (MRA) images were used to remove active voxels in the cross-correlation maps that were in areas dominated by large flow. Although some of the details differ, in all major respects the outcomes of the two analyses were the same.

Functional activity in regions dominated by flow in large vessels (determined using the MRA images) were excluded from the final maps.

Regions of interest were defined for each of the four functional images sampled for each participant (see Figure 1, right), which can be loosely described as right occipital, right occipitoparietal, left occipital, and left occipitoparietal in each coronal slice. These regions were determined by dividing each of the four high resolution coronal images into right and left hemisphere regions and then dividing each hemispheric region into an upper occipitoparietal region and a lower occipital region. The left/right determination was accomplished manually by dividing each image at the longitudinal fissure and including only cortical tissue in the each region. The occipital and occipitoparietal regions were divided by determining the maximum extent of the cortical surface (in each hemisphere) from superior to inferior and assigning 40% to the occipitoparietal region and 60% to the occipital region. Data were averaged over the two most posterior images to form a single estimate of posterior activation and averaged over the two most anterior images to create a single estimate of anterior activation, resulting in eight regions of interest. In general, the occipital regions in this analysis included the primary visual cortex along the calcarine fissure, particularly in the posterior images. It also included the pathways to the inferior temporal cortex concerned with the analysis of color and form and crucial to object recognition. The occipitoparietal regions encompassed more of the dorsal stream to the caudal parietal lobe, which is involved in spatial recognition (Nieuwenhuys, Voogd, & van Huijzen, 1988).

The extent of activation in each region of interest was calculated as the number of active voxels (determined by the *t*-test) in each of the eight regions, expressed as a proportion of the number of voxels in the entire region.

Separate mixed-design analyses of variance (ANOVAs) were conducted on extent of activation for checkerboard and for picture stimuli, using gender as a between-subjects variable, and four repeated measures of hemisphere (left, right), dorsal–ventral region (occipital, occipitoparietal), anterior–posterior region (posterior, anterior), and stimulus content (left, center, right for checkerboard conditions; pleasant, neutral, unpleasant for picture conditions). For effects involving repeated measures, the Greenhouse–Geisser correction was used to correct for violations of sphericity. This primary analysis is based on the untransformed functional data and is therefore the most valid spatial representation of actual blood oxygen effects. Because of the variations in brain shape and size among individuals, however, these data require transformation to be used for group localization of specific structures. To meet this need, the functional data for individual participants were transformed to approximate a common anatomical configuration, and a new analysis of specific anatomical sites was undertaken.

Anatomical Localization

This procedure was used to identify specific anatomical structures involved in processing the different picture contents and consisted of normalizing the anatomical and functional scans into the standard stereotaxic space defined by Talairach and Tournoux (1988), using the Medical College of Wisconsin-AFNI software package (Cox, 1996). The 66-slice two-dimensional sagittal scout scan for each participant was transformed into a three-dimensional image, which was used to reconstruct the axial and coronal views. The anatomical scans for 5 subjects were not complete, resulting in 15 participants in these analyses. Fiducial marks were then made on the anterior commissure, posterior commissure, two points in the midsagittal plane, and on the envelope of the brain (e.g., most posterior, anterior, superior, inferior, left-most, and right-most points), which were used to standardize each participant's anatomy in a normalized space. Functional maps for each participant, block, and slice location were the *t*-statistic maps registered in the Ta-

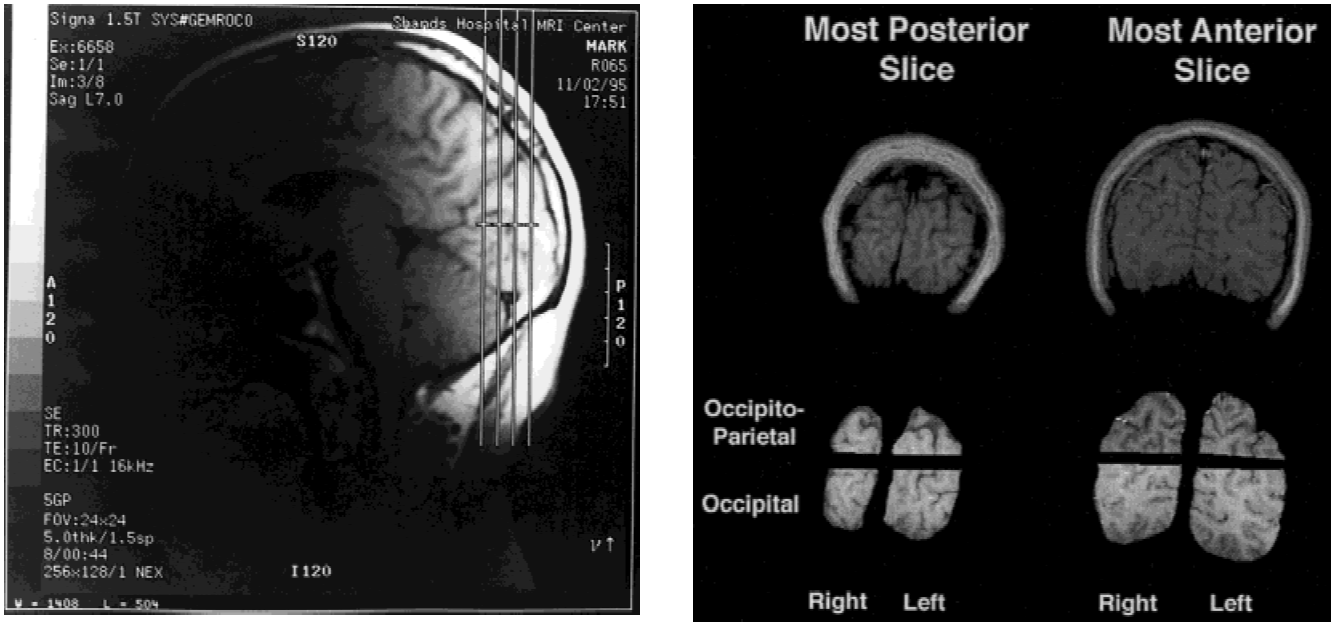

Figure 1. Left panel. Example of a sagittal scout scan, with location of the four coronal images acquired during the functional series, which were prescribed starting 10 mm anterior to the occipital pole. Right panel. Example of the coronal images and the eight regions of interest defined for use in the main inferential analyses. Each of the four coronal images was divided into four regions defined by hemisphere (left, right) and extent along the superior-inferior axis (upper region = occipitoparietal, lower region = occipital). Functional activity in each of these four regions was averaged over the two most posterior and two most anterior images to form eight regions of interest.

Table 1. *Spatial Extent of Activation for Each of the Three Checkerboard Conditions*

	Posterior				Anterior			
	Occipital		Occipitoparietal		Occipital		Occipitoparietal	
Stimulus presentation field	Right	Left	Right	Left	Right	Left	Right	Left
Left	.09 (.01)	.02 (.01)	.03 (.01)	.01 (.004)	.02 (.01)	.01 (.01)	.00 (.001)	.00 (.001)
Center	.09 (.01)	.08 (.01)	.04 (.01)	.03 (.01)	.02 (.01)	.02 (.01)	.00 (.001)	.00 (.001)
Right	.03 (.01)	.06 (.01)	.01 (.003)	.03 (.01)	.01 (.01)	.02 (.004)	.00 (.003)	.00 (.002)

Note: Scores are the mean (*SEM*) proportion of each region that is activated.

lairach and Tournoux space. Following the methodology of Binder et al. (1997), functional maps were averaged across participants, excluding voxels with negative or zero values. Zero values could occur for voxels in parts of the brain that were not sampled (e.g., the 1.5-mm interslice gaps) or for voxels in regions of large venous flow, which had been masked (i.e., recoded as zero) on the basis of the phase contrast images prior to averaging. Active areas were identified in the averaged maps by thresholding the averaged *t*-statistics at a value of 2.9 and defining a cluster on the basis of nearest neighbor connectivity and a minimum size of 50 μl (mm^3).[4]

Results

Checkerboard Stimulation

Table 1 lists the mean proportion of active voxels in each of the eight regions of interest for the left, center, and right checkerboard conditions.[5] In the full analysis of extent of activation, the four-way interaction of hemisphere, dorsal–ventral region, anterior–posterior region, and stimulus type was significant, $F(2,36) = 7.29$, $\epsilon = 0.93$, $p = .002$, as well as many of the lower order main effects and interactions. To follow up the four-way interaction, three-way ANOVAs were conducted separately for the posterior and anterior regions.

In the posterior region, the expected effects of stimulus presentation were obtained, as evidenced by a significant two-way interaction involving hemisphere and stimulus presentation, $F(2,36) = 17.63$, $\epsilon = 0.71$, $p < .005$. As Figure 2 illustrates, left hemisphere activation was more extensive when stimuli were presented to the right, as compared with the left, visual field, $F(1,18) = 13.64$, $p = .002$. Conversely, right hemisphere activation was more extensive when stimuli were presented to the left, as compared with the right, visual field, $F(1,18) = 33.72$, $p < .001$. The extent of contralateral activation for the right and left checkerboard conditions did not significantly differ from that produced in each hemisphere during processing of center checkerboards. A significant 3-way interaction involving dorsal–ventral region, hemisphere, and stimulus $F(2,36) = 9.44$, $\epsilon = 0.89$, $p = .001$, indicated larger effects of lateralized presentation in the occipital than in the occipitoparietal regions (see Table 1).

In the anterior region, the interaction of hemisphere and stimulus content was not significant, but a similar three-way interaction between dorsal–ventral region, hemisphere, and stimulus type was obtained, $F(2,36) = 4.29$, $\epsilon = 0.63$, $p = .02$. Followup tests indicated no effects of stimulus presentation in the upper occipitoparietal region and a marginally significant interaction between hemisphere and stimulus presentation in the lower occipital region, $F(2,36) = 3.25$, $\epsilon = 0.65$, $p = .05$. Small effects similar to those obtained in the posterior region (i.e., more activation in the contralateral hemisphere for half-field presentations) occurred in the anterior occipital region (Table 1).

Picture Processing

Figure 3 illustrates the proportion of active voxels in each of the eight regions of interest during pleasant, neutral, and unpleasant picture processing. Each of the three main effects associated with brain localization was significant, indicating that there was more activation (a) in the right than in the left hemisphere, hemisphere $F(1,18) = 18.62$, $p < .001$, (b) in the occipital than in the occipitoparietal region, dorsal–ventral region $F(1,18) = 24.23$, $p < .001$, and (c) in the posterior than in the anterior region, anterior–posterior region $F(1,18) = 84.76$, $p < .001$. A significant interaction of hemisphere and anterior–posterior region, $F(1,18) = 5.00$, $p = .038$, indicated that differences in the extent of activation in the right and left hemispheres were more pronounced in the posterior, $F(1,18) = 10.74$, $p = .004$, than in the anterior region, $F < 1$.

[4]The averaged data were inspected at thresholds of $t = 3.4$ to $t = 2.4$, with the number of clusters meeting criteria ranging from 4 ($t > 3.4$) to 22 ($t > 2.4$) in the unpleasant picture condition, for example. The selected criteria of $t > 2.9$ together with a cluster size of 50 was selected because (a) this threshold of the averaged *t*-statistic adequately represented clusters that were consistently identified at various levels of thresholding without including those that were only apparent at lower levels of thresholding, and (b) this cluster size identified relatively smaller, and larger, clusters that consistently appeared across different levels of thresholding. Nonetheless, particular structures that are not implicated in analyses using the current thresholding can appear when the thresholding level is reduced. In the absence of a known distribution for determining the appropriate threshold for averaged *t*-maps (Binder et al., 1996), our criteria were determined by an in-depth assessment of the data at multiple thresholding levels, and a conservative judgment regarding the reliability of clusters was based on these analyses.

[5]In addition to assessing the spatial extent of functional activity, we also analyzed another common measure of fMRI activity—the strength of signal change in active regions (i.e., the difference in signal intensity during picture and interpicture intervals). The mean change in signal intensity across all the active voxels (i.e., averaged across all eight regions) was 2.7% for pleasant pictures, 2.5% for neutral pictures, and 2.6% for unpleasant pictures and did not differ significantly. Although the strength of signal change did differ significanlty in different regions of the brain (e.g., anterior vs. posterior), there were no significant effects involving picture emotionality. These data suggest that picture emotionality exerts its effects less by affecting the intensity of activation than by activating a broader area of the visual cortex.

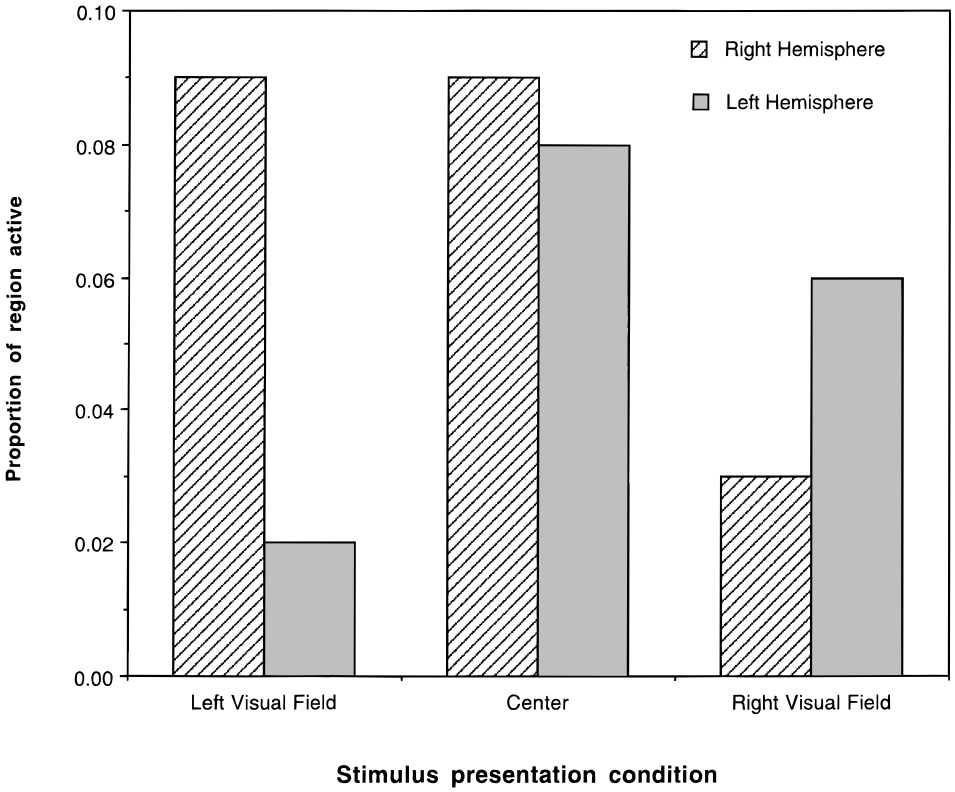

Figure 2. The spatial extent of functional activity (defined as the proportion of active voxels in each region) in the posterior regions during processing of checkerboards presented to the left or right visual fields was greater in the contralateral hemisphere and did not differ from the extent of activation in that hemisphere for checkerboards presented centrally.

For the central question of picture emotionality, a significant main effect was obtained for stimulus content, $F(2,36) = 4.66$, $\epsilon = 0.88$, $p = .016$, which indicated that there was more activation for emotionally arousing pictures, either pleasant or unpleasant, than for neutral materials, quadratic trend $F(1,18) = 14.34$, $p = .001$ (Figure 3). An interaction involving stimulus content and anterior–posterior region, $F(2,36) = 3.32$, $\epsilon = 0.99$, $p = .047$, indicated that the emotionality effect was somewhat stronger in the posterior, $F(2,36) = 4.82$, $\epsilon = 0.98$, $p = .014$, than in the anterior region, $F(2,36) = 1.96$, $\epsilon = 0.76$, $p = .156$, although the quadratic trend test comparing activation for emotional (pleasant and unpleasant) to that for neutral pictures was highly significant in both regions, $F(1,18) = 10.86$, $p = .004$, for posterior and $F(1,18) = 8.17$, $p = .01$, for anterior, suggesting that the general pattern of activation was similar throughout the brain regions sampled in this study.

Differences as a function of gender in response to emotional pictures were apparent in a significant three-way interaction involving hemisphere, picture content, and gender, $F(2,36) = 4.74$, $\epsilon = 0.94$, $p = .015$ (Figure 4). For functional activation in the left hemisphere, there were no differences as a function of gender, $F(2,36) < 1$. However, in the more highly active right hemisphere, men and women tended to differ in the extent of activation for pleasant and unpleasant pictures, $F(1,18) = 4.31$, $p = .05$. Women showed significantly more activation for unpleasant than for pleasant pictures, $F(1,7) = 10.30$, $p = .015$, whereas men showed a nonsignificant trend towards more functional activity for pleasant than for unpleasant pictures. Consistent with the group data, however, both men and women showed generally more functional activity for emotional than for neutral materials across both hemispheres, quadratic trend test $F(1,11) = 6.03$, $p = .03$ for men and $F(1,7) = 11.97$, $p = .01$ for women.

Significant two-way interactions involving gender and dorsal–ventral region, $F(1,18) = 7.96$, $p = .01$, and gender and anterior–posterior region, $F(1,18) = 6.07$, $p = .024$, indicated that although men and women did not differ in the extent of activation in the posterior region or in the occipital region (i.e., in primary sensory cortex), women showed more activity in the occipito–parietal region, $F(1,18) = 5.45$, $p = .03$, and marginally more activity in the anterior region, $F(1,18) = 3.86$, $p = .065$, than did men.

Neutral Pictures Versus Center Checkerboards

Functional activation for emotionally neutral picture stimuli and centrally presented checkerboard stimuli was compared to assess activation unique to picture processing. Table 1 lists the mean extent of activation for each of these conditions in each of the eight regions of interest. In general, neutral pictures produced significantly more activation than processing checkerboard stimuli, $F(1,18) = 19.10$, $p < .001$. The only other significant effect involving stimulus type was a three-way interaction of anterior–posterior region, dorsal–ventral region, and stimulus type, $F(1,18) = 8.60$, $p = .009$, which simply indicated that the size of the difference in extent of activation for neutral pictures and checkerboard stimuli differed in different regions. That is, whereas neutral pictures led to significantly more activation than did checkerboard stimuli in all regions (e.g., the occipital and occipitoparietal regions in both the posterior and anterior of the brain), the largest difference occurred in the posterior occipitoparietal region.

Anatomical Normalization and Localization

Table 2 lists the clusters meeting criteria in the unpleasant, neutral, and pleasant picture conditions. The size of the cluster and the location of the center of each cluster in Talairach-Tournoux coor-

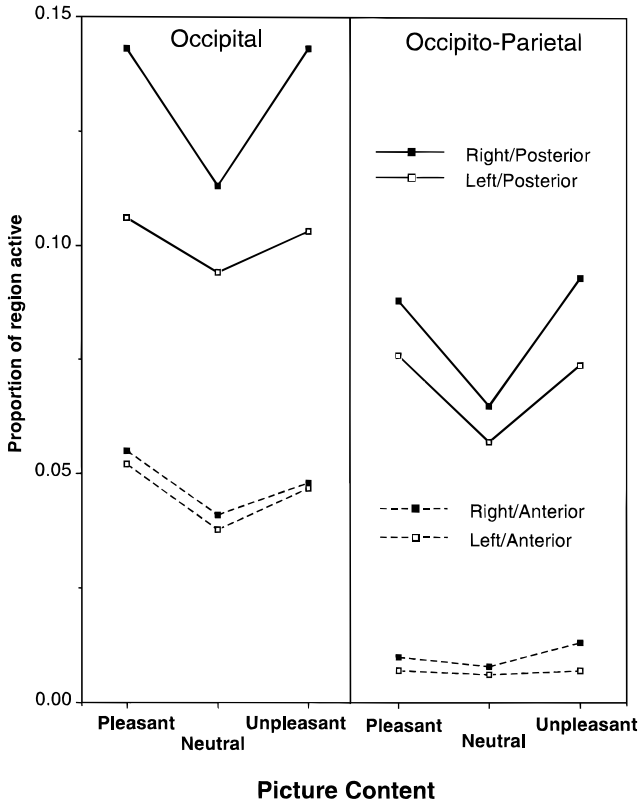

Figure 3. Functional activity in the eight regions defined by crossing hemisphere (left, right), dorsal–ventral region (occipital, occipitoparietal), and anterior–posterior region (anterior, posterior) for pleasant, neutral, and unpleasant pictures show that the spatial extent of functional activity is greater for emotional (pleasant or unpleasant) pictures than for neutral pictures in each region.

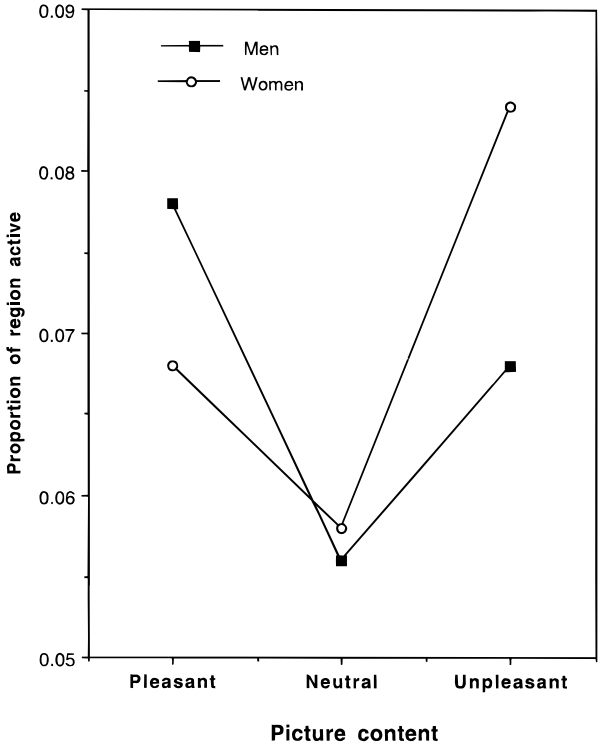

Figure 4. Functional activity in the *right posterior* regions during processing of emotional and neutral pictures for men and women illustrates that women show a bias toward more activation for unpleasant than for pleasant pictures and men show a tendency in the opposite direction.

dinates indicates where and how large each cluster was in each condition.

Consistent with the previous analyses, the total number of voxels occurring in active clusters was larger for emotional (1,290 voxels for pleasant; 1,469 for unpleasant) than for neutral (512 voxels) pictures. There was impressive overlap in the location of the largest clusters found in the three picture conditions, suggesting that these areas are involved in picture processing in general. As expected for these visual stimuli, the largest clusters in each of the picture conditions were those centered in the calcarine fissure in the posterior occipital cortex (see Figure 5, top row), the cortical site that first receives visual input. A secondary visual area that was also generally involved in picture processing included a posterior portion of Brodmann's Area 18, approximately 24 mm superior to the calcarine fissure (see Figure 5, bottom row).

Particular sites involved in processing emotional (pleasant and unpleasant) pictures, as compared with neutral pictures, included the right fusiform gyrus and clusters in the right inferior and superior parietal lobules. Bilateral activity in the orbital gyrus was absent when processing neutral pictures but was obtained during emotional picture processing (see Figure 5, bottom row), as was activation of a portion of Brodmann's Area 19, approximately 50 mm superior to the anterior commissure. In general, these data corroborate the previous analyses, which indicated that emotional differs from neutral picture processing in leading to more functional activity, and also specify particular regions active when processing emotional pictures.

Certain anatomical locations were active during unpleasant picture processing that were not active during pleasant picture processing, and vice versa. Unpleasant pictures led to activation in (a) the right fusiform gyrus that was more posterior (i.e., 87 mm) than the common fusiform gyrus activation obtained for emotional pictures in general (i.e., 69 mm), (b) a portion of Brodmann's Area 18 on the right side, and (c) a right hemisphere cluster that was anterior and centrally located. However, only pleasant pictures involved activity in (a) the left fusiform gyrus, (b) the right lingual gyrus, and (c) a portion of Brodmann's Area 19 in the right hemisphere.

EXPERIMENT 2

Processing emotional pictures as compared with neutral pictures produced more functional activation across the brain regions sampled, which in turn produced more activation than processing centrally presented checkerboard stimuli. One hypothesis is that primary and secondary visual areas are more involved in processing emotionally interesting material because of reentrant processing associated with attention and/or motivation, that is, because more anterior structures such as the cingulate (Posner, 1996) or the amygdala (Amaral, Price, Joseph, Pitkanen, & Carmichael, 1992) have projections to these sensory areas. However, a difference in eye movements during emotional and neutral picture processing also could contribute to the pattern of findings. Despite the instruction to keep the eyes fixated throughout picture presentation, scanning eye movements may have accompanied stimulus processing in Experiment 1. To the

Table 2. *Anatomical Locations of Clusters for Pleasant, Neutral, and Unpleasant Picture Viewing Conditions*

Cluster volume (no. voxels)	Center of cluster[a] (mm)			Picture condition	Brain region[b]
	x: Right (−)/left (+)	*y*: Posterior (−)/anterior (+)	*z*: Inferior (−)/superior (+)		
All pictures					
134	−7	−91	27	pleasant	R BA 18
213	−8	−91	28	neutral	
143	−10	−91	26	unpleasant	
104	−8	−91	13	pleasant	R calcarine fissure
219	−2	−90	6	pleasant	R calcarine fissure
119	−8	−92	5	neutral	R calcarine fissure
68	−6	−91	15	neutral	R calcarine fissure
112	−7	−93	7	neutral	R calcarine fissure
455	−8	−91	9	unpleasant	R calcarine fissure
137	1	−93	2	unpleasant	L calcarine fissure
Pleasant and unpleasant					
101	−35	−60	38	pleasant	R inferior parietal lobulus
102	−34	−61	36	unpleasant	
54	−7	−60	51	pleasant	R superior parietal lobulus
59	−7	−56	58	unpleasant	
73	−31	−92	6	pleasant	R occipital gyrus
70	−31	−93	5	unpleasant	
103	29	−90	17	pleasant	L occipital gyrus
56	28	−91	16	unpleasant	
66	−38	−69	−12	pleasant	R fusiform gyrus
50	−37	−69	−12	unpleasant	
96	−3	−84	39	pleasant	R BA 19
192	−6	−80	45	unpleasant	
Unpleasant only					
72	−22	−87	−11	unpleasant	R fusiform gyrus
54	−24	−57	40	unpleasant	R parietal lobulus
79	−29	−92	15	unpleasant	R BA 18
Pleasant only					
91	−31	−81	30	pleasant	R BA 19
67	−6	−89	−11	pleasant	R lingual gyrus
182	30	−75	−14	pleasant	L fusiform gyrus

[a]Talairach–Tournoux coordinates. [b]R = right hemisphere, L = left hemisphere.

extent that differential eye movement occurred for emotional materials, one might expect more extensive activation in the occipital cortex because the effect of eye movement might be to move the representation of the picture stimulus on the cortical surface.

To test this hypothesis, in Experiment 2 we measured horizontal and vertical eye movements in an environment built to simulate the scanning context. In this study, each participant laid supine on a "scanning" table, with the head in the helmet coil and viewed pictures projected on a screen at their feet. A bitebar apparatus, the sound of the scanner, and a constructed scanner shell completed the simulated MRI environment. The same set of six stimulus conditions were presented in the same orders as presented to participants in Experiment 1. To the extent that differences in eye movement are not found for emotional as compared with neutral pictures and for neutral pictures as compared with checkerboard stimuli, a hypothesis that this effect mediated the fMRI data from Experiment 1 is not supported.

Method

Participants

Eighteen individuals (12 men, 6 women) from the University of Florida General Psychology Pool participated to fulfill a course requirement.

Materials and Design

The stimulus materials and design were exactly as described for Experiment 1.

Important features of the MRI scanning context were duplicated as closely as possible in a separate psychophysiology laboratory. The same helmet coil used in the scanner, with head-mounted mirror, was bolted onto a cot on which participants were supine throughout the experiment. A rigid shell, with the same dimensions as the magnet bore (83.8 cm in diameter and 121.9 cm in length), was constructed that was positioned over the head

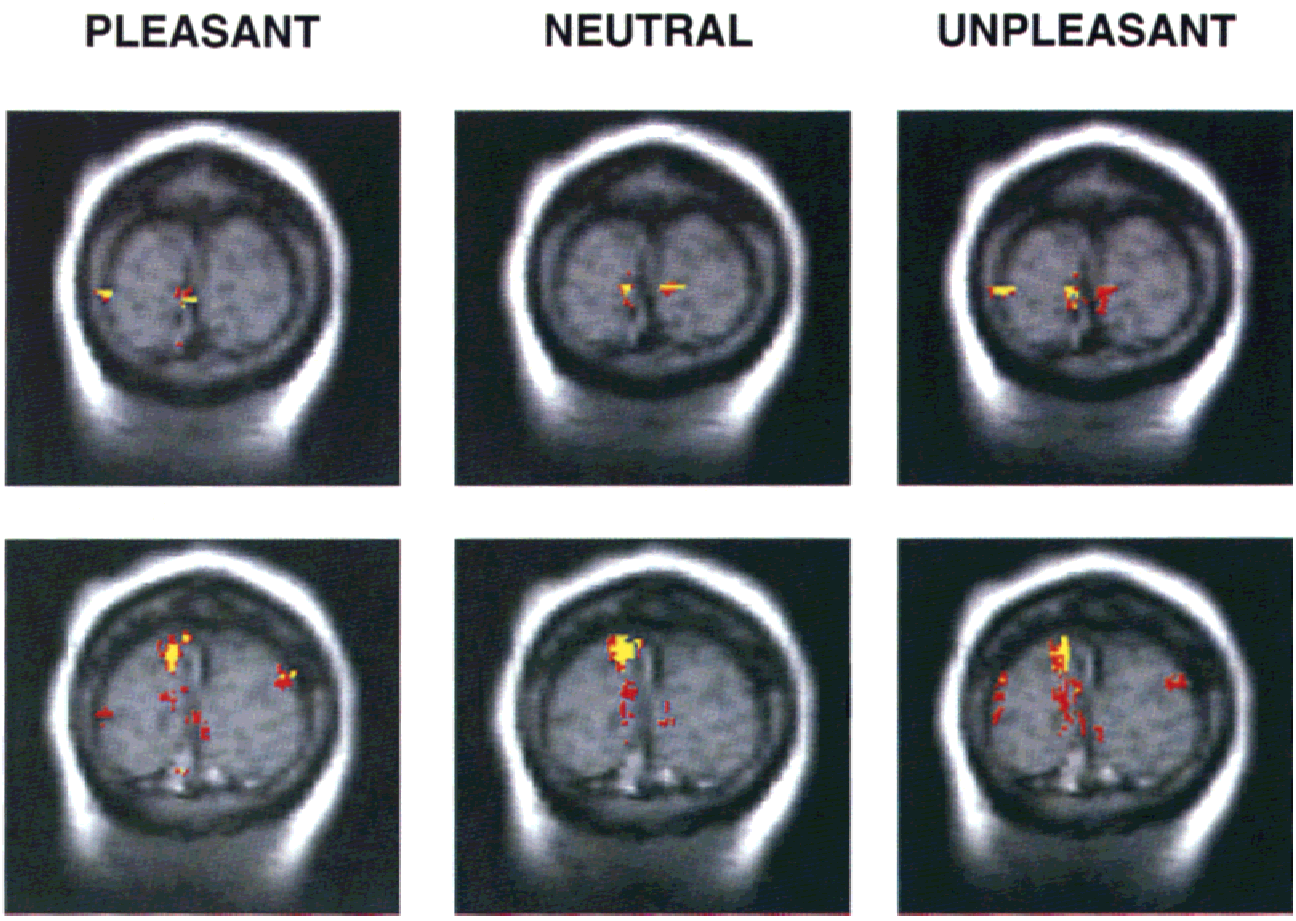

Figure 5. Sites of functional activity during processing of pleasant (left column), neutral (center column), and unpleasant (right column) pictures, as compared with no picture processing, as determined from averaging functional maps across participants. Clusters meeting criteria are depicted in red and yellow; yellow indicates a larger difference. Functional maps averaged over all participants are overlaid on a representative anatomical image for illustrative purposes. Top row: All picture contents show activity centered on the calcarine fissure; only emotional pictures are beginning to show activity in the right occipital gyrus. Bottom row: All picture contents continue to show activity centered on the calcarine fissure, as well as in a portion of Area 18 directly above the calcarine fissure. Only emotional pictures show bilateral activity in the occipital gyrus.

and upper body and rested on the floor. A bitebar simulated the scanner's bitebar assembly. The sound of the gradients firing during the functional imaging sequence (using the same spiral scan acquisition software) was recorded in the scanner environment and played back at 92 dB in the psychophysiology lab. Earplugs were given to each participant to block the sound of the recorded scanner noise, as in the magnet environment. As in the scanning context, a slide projector located in an adjacent room presented the visual stimuli on a slide screen with the same dimensions and positioned at the participant's feet. Participants were instructed to maintain focus on a centrally lit fixation dot throughout the slide series.

Stimulus control and physiological data acquisition were accomplished using VPM software (Cook et al., 1987) running on an IBM-compatible computer. Horizontal electrooculogram (EOG) was recorded using Ag/AgCl miniature sensors (Sensormedics) placed on the outer canthus of each eye. Vertical EOG was recorded with sensors placed above and below the left eye. Both EOG measures were acquired using a Coulbourn S75-07 direct coupled bioamplifier sampled at 100 Hz. Skin conductance electrodes were placed adjacently on the hypothenar eminence of the left palmar surface, using standard electrodes (Sensormedics) filled with paste prepared according to the recommendations of Martin and Venables (1966). The signal was acquired with a Coulbourn S71-22 skin conductance coupler, calibrated prior to each session to detect activity in the range of 0–40 μSiemens, sampled at 20 Hz, and reduced offline in half-second bins.

Procedure

After informed consent was obtained, sensors for physiological recording were attached while the participants sat on the cot, facing the experimenter. Subsequently, participants were given ear plugs to block out the "scanner" noise and helped into a supine position on the cot with the head inside of the helmet used in the actual scanner, and the simulated bitebar was put in place. Instructions were identical to those in Experiment 1. After ascertaining that there were no questions, the constructed shell was put in place, and the same set of six conditions as in Experiment 1 was presented. As in Experiment 1, all three of the checkerboard conditions (i.e., left, right, or center visual field presentation) were presented before the three picture conditions (i.e., pleasant, neutral, or unpleasant pictures), with the order of conditions within each

stimulus type counterbalanced across participants. After the "functional" series was completed, the experimenter returned to the room and removed the shell and sensors, and the participant was debriefed, paid, thanked, and allowed to leave.

Data Reduction and Analysis

The amount of eye movement occurring during each of the 12-s stimulus presentation (*on*) and 12-s interstimulus intervals (*off*) was estimated by computing the standard deviation of vertical and horizontal EOG activity during each period. Skin conductance responses were scored as the maximum half-second value across the 12-s stimulus or interstimulus interval. Separate mixed-design ANOVAs were conducted for each of the three dependent measures (vertical EOG, horizontal EOG, skin conductance responses) for checkerboard and picture conditions, with gender (male, female) as a between-subjects variable and presentation period (picture, interpicture interval), and stimulus content (left, center, right for checkerboard conditions; pleasant, neutral, unpleasant for picture conditions) as repeated measures, using the Greenhouse–Geisser correction for sphericity when appropriate.

Results

Vertical and Horizontal Eye Movements

Relatively more eye movement occurred during picture presentation periods than during the interpicture interval in both the vertical, $F(1,15) = 10.20$, $p < .005$, and horizontal, $F(1,15) = 6.26$, $p = .02$, directions. However, there were no significant differences in eye movement as a function of picture content (Table 3), indicating that horizontal or vertical eye movements were not different during emotional as compared with neutral pictures. Similarly, for checkerboard stimuli, relatively more eye movement occurred during stimulus presentations than during the interstimulus interval in both the vertical, $F(1,15) = 15.10$, $p < .005$, and horizontal, $F(1,15) = 7.61$, $p = .02$, channels, but again there were no other significant differences as a function of stimulus condition (i.e., left, right, or center presentation). In addition, the amount of eye movements occurring during neutral pictures and centrally presented checkerboards did not differ.

Skin Conductance

As expected, skin conductance activity was higher when processing a picture stimulus than when no stimulus was presented, $F(1,16) = 7.53$, $p = .01$. A main effect of stimulus content, $F(2,32) = 8.14$, $p = .001$, and a significant interaction of Stimulus Content × Presentation Period, $F(2,32) = 4.59$, $p = .02$, indicated that skin conductance responses varied as a function of emotion during picture presentation. Responses were larger to both pleasant and unpleasant as compared with neutral pictures, quadratic $F(1,16) = 8.41$, $p = .01$, and responses to unpleasant pictures were significantly larger than those to pleasant pictures, $F(1,16) = 7.24$. There were no differences as a function of gender.

Skin conductance responses were also significantly larger during presentation of checkerboard stimuli than during the interstimulus interval, $F(1,16) = 7.53$, $p = .01$. There were no significant differences as a function of presentation condition (i.e., left, center, or right visual field), and skin conductance responses for centrally presented checkerboards did not differ from those for neutral pictures.

GENERAL DISCUSSION

Using functional magnetic resonance imaging, differences in activation of the primary and secondary visual cortex were found as a function of the emotional valence and arousal of IAPS pictures. Across all of the regions sampled in this study, emotional stimuli, either pleasant or unpleasant, prompted significantly more activity than did neutral pictures. As a methods check, we included conditions in which flashing checkerboard stimuli were presented to the left or right visual field, and, as expected, functional activity in these conditions was primarily located in the contralateral hemisphere, and was equivalent to activity in that hemisphere when checkerboards were presented centrally. These results validate our acquisition and data reduction methodology, supporting the conclusion that emotional and neutral pictures differ in the extent of functional activity in the visual system.

One difference occurring as a function of picture emotionality was related to gender. In the more active right hemisphere, women showed significantly more activity for unpleasant than for pleasant stimuli, whereas men tended to respond in the opposite direction.

Table 3. *Mean (SD) Horizontal and Vertical EOG Activity and Skin Conductance Responses (SCR)*

	EOG (μV)					
	Horizontal		Vertical		SCR (μs)	
Stimulus position/type	Stimulus	ITI[a]	Stimulus	ITI	Stimulus	ITI
Left	72.1	59.1	122.1	93	0.14	0.01
	(40)	(33)	(56)	(50)	(0.16)	(0.02)
Center	62.5	55.7	107.7	77	0.15	0.01
	(35)	(27)	(47)	(32)	(0.23)	(0.01)
Right	65.8	51.1	104.6	82.8	0.16	0.02
	(35)	(21)	(46)	(45)	(0.16)	(0.05)
Pleasant	72.4	54.6	139.4	95.4	0.24	0.04
	(33)	(21)	(73)	(38)	(0.29)	(0.06)
Neutral	77.8	58.5	133	97.6	0.17	0.04
	(44)	(28)	(61)	(47)	(0.18)	(0.01)
Unpleasant	74.9	59.4	128.4	92.4	0.35	0.04
	(38)	(25)	(58)	(40)	(0.36)	(0.10)

[a]ITI = interstimulus interval.

This difference is consistent with data from recent picture perception studies (Lang et al., 1993), in which women have been more reactive than men to aversive stimuli. In addition, these data are consistent with Lane et al.'s (1997) finding that PET activation differences were greatest during unpleasant picture viewing in their female participants. In the current study, although somewhat less activity occurred in the pleasant than in the unpleasant condition for women, functional activity was nonetheless significantly more extensive for pleasant pictures than for neutral pictures. Thus, the effect of emotion in terms of increased functional activation in the visual cortex is generally similar for both men and women. The relatively rapid fMRI assessment method may result in greater sensitivity to picture differences than the longer temporal presentation intervals used in PET research.

During aversive stimulation, PET researchers have also found significant increases in blood flow in the visual cortex. Fredrickson and colleagues (1993) reported occipital activation to unpleasant films. They studied six snake-fearful women who met criteria for simple phobia, according to the Diagnostic and Statistical Manual for Mental Disorders (American Psychiatric Association, 1994). These women viewed a neutral film, a film with unpleasant but not phobic content, and a film about snakes while tomographic data were recorded. Significantly greater regional blood flow was found in visual association cortex (Brodmann's Areas 18 and 19) during the snake film than during the other film stimuli. The authors speculated that this result reflected "stimulus significance or enhanced processing in the stimulated modality" of the emotionally evocative phobic material (Fredrickson et al., 1993, p. 129). Similarly, Reiman, Lane, Ahern, and Schwartz (1997) found greater blood flow in the occipital region when participants viewed emotional films (mainly evoking negative affect) as compared with neutral films in a PET study of 12 normal volunteers. Rauch et al. (1996) studied 8 individuals (6 women, 2 men) with posttraumatic stress disorder while they imagined trauma-related or neutral nonaffective experiences. As in the studies of film stimuli, emotional content (traumatic images) prompted significantly greater blood flow in the occipital region (Brodmann's Area 18) than was observed for neutral imagery.

The present research confirms these findings using fMRI methodology and suggests further specification in terms of localizing effects of emotion in the visual cortex. Whereas the previously observed activation of Areas 18 and 19 was replicated, the current data indicate that processing emotional stimuli (nonmoving photographs) involves activity in several specific sites, including the left and right occipital gyrus, the right fusiform gyrus, and the right inferior and superior parietal lobules. In addition, potential differences in the visual processing of pleasant and unpleasant stimuli were suggested, with only pleasant pictures prompting sizable activation in the left fusiform gyrus, for example.

Taken together, the data clearly indicate that emotional stimuli prompt greater activation in visual cortical areas. Experiment 2 indicated that this finding is not an artifact of differential eye movements during emotional as compared with neutral pictures. Rather, emotionally arousing stimuli appear to induce more extensive activity in early perceptual processing areas of the brain. Although differences in complexity might be proposed as the underlying mediator of this effect, defining complexity for the photographic pictures used here is not itself a simple task. Perceptual complexity might be defined in terms of differences in color, amount of detail, number of contours, or other perceptually relevant features. The pictures used here, however, were all in color, and all involved relatively simple figure-ground contrast between the object depicted and the background. If, however, complexity is defined semantically (in terms of meaning, number of associations, elaborative connections, etc.), this definition, in large part, also defines emotion (Lang, 1994). Clearly, however, these data need to be replicated using different picture sets of comparable pleasure and arousal. Furthermore, effects of perceptual and semantic complexity also need to be defined and assessed within a systematic program of experiments.

The increased activity found here in perceptual processing areas for emotional as compared with neutral stimuli implies reentrant processing from sites more anterior in the brain. For example, Posner and Raichle (1995) postulated an attention center in the anterior cingulate that may prime the visual cortex for processing important input. Amaral et al. (1992), in studies of the monkey brain, noted that multiple projections exist from the amygdala back to V1 and V2. Thus, once appetitive or aversive stimuli are initially identified, motivational centers may act to enhance early processing. Similar reentrant projections may be engaged when humans process symbolic representations of affectively arousing stimuli, such as the emotional pictures used here. This type of motivated attention, a natural selective attention, has clear adaptive significance (Lang, Bradley, & Cuthbert, 1997b).

Future activation studies using emotional stimuli should determine for each participant the specific locations of functional centers involved in vision. Methodologies now exist that permit exact specification of functional anatomy (e.g., Schneider et al., 1993). In subsequent testing with affective input, it could then be determined whether some or all of these centers are differentially involved in affective processing, which would help illuminate the mechanisms involved. Furthermore, with whole-brain imaging becoming more practical, one can examine the cingulate and amygdalar sites that have been hypothesized as critical in mediating effects of attention and emotion.

In conclusion, the present research emphasizes the value of employing adjunct psychophysiological measures in studies of brain mapping. The eye movement data assessed here were vital in establishing that differences between emotional and neutral picture processing were not likely to be attributable to an eye-scanning artifact. Similarly, the skin conductance data provided important support that picture differences are attributable to emotional arousal. Psychophysiological measurement is a critical methods check in the imaging environment, whether done off line in a simulated MRI environment or combined directly with the acquisition of functional imaging data.

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