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Men and women differ in amygdala response to visual sexual stimuli

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Men are generally more interested in and responsive to visual sexually arousing stimuli than are women. Here we used functional magnetic resonance imaging (fMRI) to show that the amygdala and hypothalamus are more strongly activated in men than in women when viewing identical sexual stimuli. This was true even when women reported greater arousal. Sex differences were specific to the sexual nature of the stimuli, were restricted primarily to limbic regions, and were larger in the left amygdala than the right amygdala. Men and women showed similar activation patterns across multiple brain regions, including ventral striatal regions involved in reward. Our findings indicate that the amygdala mediates sex differences in responsiveness to appetitive and biologically salient stimuli; the human amygdala may also mediate the reportedly greater role of visual stimuli in male sexual behavior, paralleling prior animal findings.

Functional neuroimaging studies have identified a growing number of sex differences in human brain function. In addition to cognitive differences[1–3], men and women also differ markedly in aspects of sexual behavior, such as the reportedly greater male interest in and response to sexually arousing visual stimuli[4–6]. Animal studies have identified several sex differences in limbic brain regions that mediate reproductive behavior, which may provide clues to brain regions underlying sex differences in human sexual response. In rats, for example, male but not female appetitive responses to distal olfactory and visual sexual signals are critically mediated by the medial amygdala[7]. Lesions to the medial amygdala in male but not female rats disrupt appetitive, sexual behaviors involved in gaining access to a receptive mate, but these lesions leave consummatory, copulation-related behaviors intact[7]. In addition, male and female rats' reproductive functions are controlled by different hypothalamic regions[7]. Although the amygdala and hypothalamus have also been linked to male responses to sexually arousing stimuli in neuroimaging studies[8,9] and these structures are considerably influenced by sex hormones[10,11], it remains unclear whether sex differences in the function of these regions also exist in humans.

Here we examined human sex differences in reactions to visual sexual stimuli using fMRI, contrasting neural responses of healthy men and women to sexually arousing photographs and control stimuli. To permit sex differences in neural responses to be characterized while controlling for possible differences in brain response related to typically higher arousal levels for males, we selected stimuli through prior testing that yielded equivalent sexual attractiveness and physical arousal ratings from both sexes. On the basis of converging evidence from earlier studies[7–11], we were particularly interested in whether males would show greater activation in the amygdala and hypothalamus.

Twenty-eight young adults (14 female) passively viewed alternating short blocks of four types of photographic stimuli via video goggles: two types of sexually arousing stimuli, including heterosexual couples engaged in sexual activity ('couples' stimuli) and sexually attractive opposite-sex nudes ('opposite-sex' stimuli), and two types of control stimuli, including pleasant scenes depicting non-sexual male-female interaction, such as therapeutic massage (neutral stimuli), or a fixation cross (fixation). Subjects were screened to verify that they were heterosexual and found visual erotica sexually arousing. Each block contained five stimuli of the corresponding type. Two runs were presented, each containing four blocks of each type, and ratings of sexual attractiveness and physical arousal were assessed after scanning. We found that the amygdala and hypothalamus were more activated in men than in women when viewing identical sexual stimuli, even when females reported greater arousal.

RESULTS

Females and males rated the sexual stimuli as equivalently sexually attractive and physically arousing, and both sexes reported the couples stimuli as more attractive and arousing than the opposite-sex stimuli (**Fig. 1**). A two-factor analysis of variance (ANOVA; sex × stimulus type) conducted separately for attractiveness ratings and physical arousal ratings showed a main effect of stimulus type, with couples stimuli rated higher in attractiveness ($F_{1,26} = 8.08$, $P < 0.01$) and physical arousal ($F_{1,26} = 17.88$, $P < 0.001$) than opposite-sex stimuli. However, there was no difference between females and males in overall ratings for either attractiveness ($F_{1,26} = 1.21$, $P > 0.28$) or physical arousal ($F_{1,26} = 1.01$, $P > 0.32$), and there was no interaction between sex and stimulus type for either attractiveness ($F_{1,26} = 1.06$, $P > 0.31$) or physical arousal ($F_{1,26} = 2.04$, $P > 0.17$). Thus, although the females seemed to show a somewhat larger dif-

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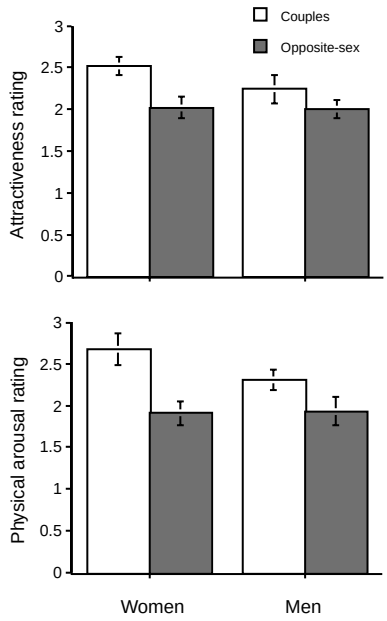

Figure 1 Women's ($n = 14$) and men's ($n = 14$) ratings of visual stimuli according to attractiveness and physical arousal. Each subject rated 40 couples stimuli and 40 opposite-sex stimuli. A Likert-type rating scale was used: 0 (lowest) to 3 (highest). Top, immediate post-scan ratings of sexual attractiveness. Bottom, post-experiment ratings of experienced physical arousal. Error bars indicate the standard error of the mean (s.e.m.).

ference between their ratings for opposite-sex and couples stimuli (**Fig. 1**), this difference was not significantly greater than the difference shown by the males.

Following spatial pre-processing of the functional images, activation contrasts between conditions were estimated for each subject at each voxel using linear regression, producing statistical parametric *t*-statistic maps[12]. Sex differences in activation were assessed using second-level, mixed-effects *t*-tests. We focused on responses to the couples stimuli because these stimuli elicited the highest arousal and allowed us to directly compare female and male responses to identical stimuli. The entire brain was examined for regions where differential activity surpassed a statistical threshold of $P < 0.001$ (uncorrected for multiple comparisons) and spanned a minimum of five contiguous 64-mm^3 voxels.

Men had greater neural responses in the bilateral amygdala and hypothalamus than did women to the couples stimuli ($P < 0.001$; **Fig. 2a**). Sex differences were restricted to these regions, with the exception of the right cerebellum (**Fig. 2a**) and right posterior thalamus (data not shown; $P < 0.001$). Within the *a priori* regions of interest (ROIs), the differential activations also survived a more stringent statistical correction for multiple spatial comparisons: left amygdala, $P < 0.001$, corrected; maxima at –20, –4, –20 (*x*, *y*, *z* in MNI space, see Methods; $Z = 3.95$) and –16, 0, –16 ($Z = 3.77$); right amygdala, two clusters, $P < 0.05$, corrected; maxima at 24, –4, –24 ($Z = 3.43$) and 16, 0, –16 ($Z = 3.32$); hypothalamus, $P < 0.001$, corrected; maximum at 4, 0, –16 ($Z = 3.58$). Notably, in no region did females show significantly greater activation than males at this statistical threshold. These sex differences were also evident when the couples vs. fixation contrast was examined separately in each group in these same regions (**Fig. 2b,c**). For males, the left and right amygdala and the hypothalamus were significantly activated (left amygdala, $P < 0.001$, corrected; right amygdala, $P < 0.001$, corrected; hypothalamus, $P < 0.01$, corrected; one group *t*-test), whereas females showed no significant activations in these regions.

To establish that the observed sex differences were related specifically to the sexual aspects of the couples stimuli, we contrasted the responses to the couples stimuli with responses to the more closely matched neutral, non-sexual stimuli that depicted male-female interaction. This contrast controlled for non-sexual attributes of the couples stimuli, including pleasant, non-sexual physical interaction between males and females. We further restricted this contrast to those regions where sex differences were previously identified in the sex-differences analysis for the couples stimuli vs. fixation contrast (masked at $P < 0.01$). This served to isolate group differences that resulted from greater increases for the sexual stimuli relative to the neutral stimuli as well as those that resulted from increases relative to the fixation baseline. This contrast revealed more focal differential activations (men > women) at a lower statistical threshold ($P < 0.005$, at least five contiguous voxels) in left amygdala and right amygdala (**Fig. 2d**; the same contrast without masking identified similar but more extensive regions of differential activation, see **Supplementary Fig. 1** online), as well as in the hypothalamus, bilateral posterior thalamus and left hippocampus (data not shown). As before, no regions were observed in which females showed significantly greater activation than males at the same threshold. The left amygdala differential activation (men > women) survived a more stringent correction for multiple spatial comparisons (left amygdala, $P < 0.05$, corrected; maximum at –16, 0, –20; $Z = 3.23$), the right amygdala activation was marginally significant ($P = 0.06$; maximum at 16, 0, –16; $Z = 2.89$), and the hypothalamic activation did not reach significance. The absence of differential hypothalamic activation in this latter analysis stemmed largely from low-level activation (at $P < 0.05$, uncorrected) detected in the hypothalamus for non-sexual stimuli, in men but not women, possibly related to a greater propensity for the males to appraise the nominally non-sexual scenes as weakly sexually appetitive. Sex differences were also evident when the couples stimuli versus neutral stimuli contrast was examined separately in each group in these same regions (**Fig. 2e,f**). For males, the left and right amygdala and the hypothalamus were significantly activated: left amygdala, $P < 0.01$, corrected; maximum at –16, 0, –24 ($Z = 3.64$); right amygdala, $P < 0.05$, corrected, maximum at –20, 0, –20 ($Z = 3.31$); hypothalamus, $P < 0.05$, corrected; maximum at –4, 0, –12 ($Z = 3.66$); in contrast, females showed no significant activations in these same regions.

To compare differences in fMRI signal change across all stimulus conditions and between brain regions, we calculated the average fMRI signal change relative to the fixation baseline for each subject for ROIs centered on the left and right amygdala and the hypothalamus. Males showed significantly greater activations in the left amygdala than did females for the couples stimuli ($P < 0.001$) and marginally greater activations in the right amygdala ($P = 0.11$) and the hypothalamus ($P = 0.11$; **Fig. 3**). The two sexes did not differ significantly in any ROI for the opposite-sex or neutral stimuli (see **Supplementary Table 1** online for a complete listing of all ROI contrast statistics). The sex difference in responses to the couples stimuli was marginally greater in magnitude ($P = 0.11$, $F_{1,26} = 2.71$) in the left amygdala than the right amygdala, and was larger in spatial extent in the left amygdala (**Fig. 2d**).

Men showed marginally greater activation for the couples stimuli versus opposite-sex stimuli in the left amygdala ($P = 0.10$) but not in the right amygdala or hypothalamus. Men also showed greater activation for the couples stimuli relative to neutral stimuli in the left amygdala ($P < 0.01$), right amygdala ($P < 0.05$) and hypothalamus ($P < 0.01$), but activations for opposite-sex stimuli relative to neu-

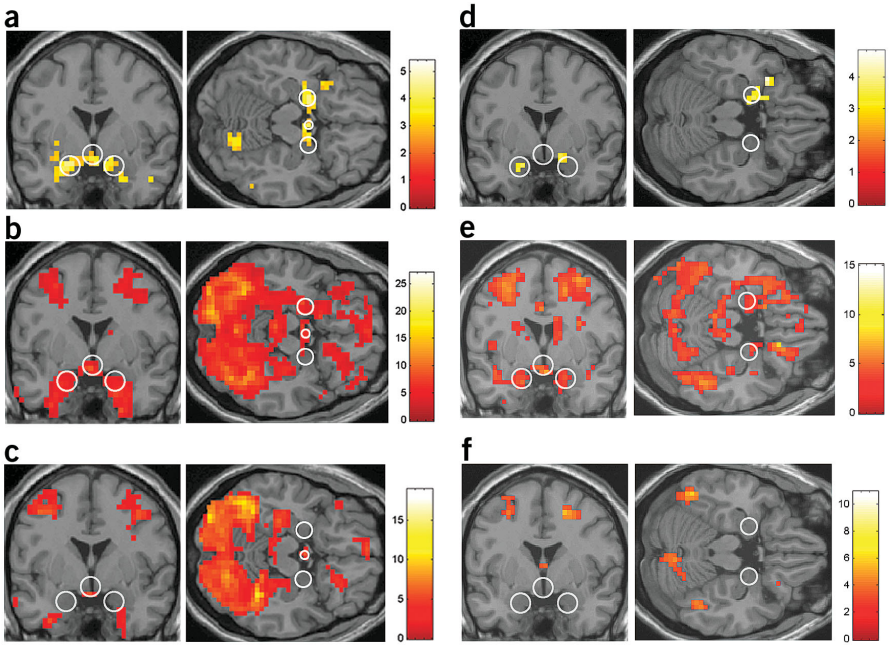

Figure 2 Regional activation maps. Activation contrast for the couples stimuli versus fixation (**a**–**c**) and the couples stimuli versus neutral contrast (**d**–**f**) ($P < 0.005$, minimum five contiguous voxels). White circles indicate the approximate location of the ROIs; the left and right circles and upper and lower circles show the left and right amygdala ROIs on the coronal and axial views, respectively. The medial circles show the hypothalamic ROI, which is not visible on the axial views at $z = -20$. Color bar indicates maximal Z values. Note that color scale bars vary from image to image. The right hemisphere is on the right of the coronal images and bottom of the axial images. (**a**) Left, coronal image ($y = 0$) showing greater bilateral amygdala and hypothalamic activations for males versus females for the couples versus fixation contrast. Right, axial view ($z = -16$) of the same contrast, showing additional right cerebellar activation. (**b**) Couples versus fixation contrast for males, at the same coronal and axial views. (**c**) The same contrast and views for females. (**d**) Left, coronal image ($y = 0$) showing greater bilateral amygdala activations for males versus females for the couples versus neutral stimuli contrast, within those regions showing greater activity for males versus females for the couples versus fixation contrast (at $P < 0.10$). The region of greater hypothalamic activation for males is not visible at this coronal level. Right, axial view ($z = -20$) of the same contrast, showing primarily left-sided amygdala activation. (**e**) Couples versus neutral stimuli contrast for males, at the same coronal and axial views. (**f**) The same contrast and views for females, showing an absence of differential activity in the ROIs.

tral stimuli did not reach significance for any ROI. Opposite-sex stimuli depicted isolated nudes, whereas couples stimuli depicted varied, explicit sexual activity. Because cross-cultural studies[13] report that males prefer sexual variety more than females do, greater male habituation[14,15] and lower arousal may have attenuated potential sex differences for the opposite-sex stimuli. Women showed the reverse pattern from males in the left amygdala, with greater activation for the less-arousing opposite-sex stimuli than for couples stimuli ($P < 0.05$); no corresponding differences were observed in the right amygdala or hypothalamus. Across all activation contrasts with the neutral stimulus condition, women showed greater activation for the couples stimuli (marginally, at $P = 0.07$) only in the hypothalamus ROI, whereas men showed greater activation for the couples stimuli vs. neutral stimuli in all ROIs. In summary, the pattern of results from the ROI analysis was consistent with the whole-brain analysis and revealed a left-sided lateralization of amygdala response to sexual stimuli for men.

Because reported sexual attractiveness and experienced physical arousal was equivalent in females and males, the greater activations for males were unlikely to be attributable to greater subjective arousal. Moreover, when one female subject in the current study who reported low arousal ratings for the couples stimuli was excluded from analysis, reported arousal was greater for females than males ($P < 0.005$), yet the activation differences favoring males remained unchanged.

In addition to characterizing sex differences, we also examined activations that women and men shared in common by computing the statistical conjunction between activation maps for the two groups for the couples stimuli versus neutral stimuli contrast (**Fig. 4**). Three regions of overlap were observed: (i) a large, bilateral parieto-temporal-occipital activation spanning regions associated with visual processing, attention, and motor and somatosensory function (**Fig. 4a**,**b**; $P < 0.0001$; corrected maxima at 36, –84, 12; 28, –52, 60; –28, –56, 52; $Z = 9.21$), (ii) the anterior cingulate, which is linked to emotion, attention and sexual motivation[9] (**Fig. 4a**; $P < 0.001$, corrected; maximum at 0, 40, 8; $Z = 5.91$); and (iii) the nucleus accumbens/ventral striatum (**Fig. 4a**; $P < 0.01$ corrected, maxima at 0, 16, –4 ($Z = 5.37$); –8, 24, 0 ($Z = 5.57$); 8, 20, –8 ($Z = 5.32$)). Because of the close association of the ventral striatum with reward processes[16–18], coactivation in this region suggests that the sexual stimuli were rewarding to a similar degree for both groups, corroborating the subjective reports from both groups that they found sexual stimuli significantly rewarding. The coactivation and lack of sex differences in these broadly distributed regions contrasts with the marked and regionally localized sex differences observed in the amygdala and hypothalamus. Thus, the sex differences we observed in the processing of visual sexual stimuli

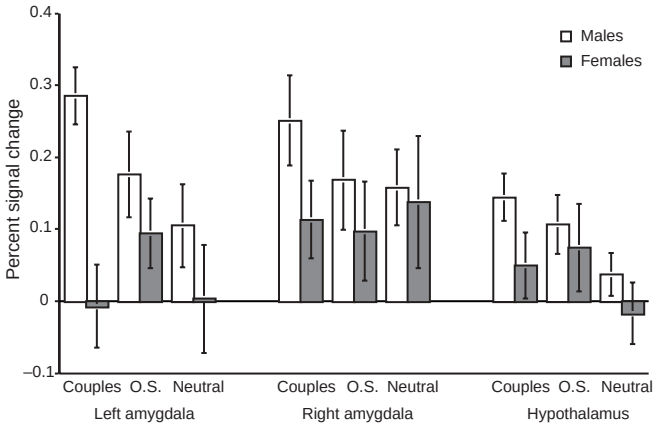

Figure 3 Average fMRI signal change for males and females for couples, opposite-sex and neutral stimuli (vs. fixation baseline), for ROIs in the left amygdala, right amygdala and hypothalamus. Couples = couples stimuli; O.S. = opposite-sex stimuli; Neutral = neutral stimuli. Error bars indicate s.e.m.

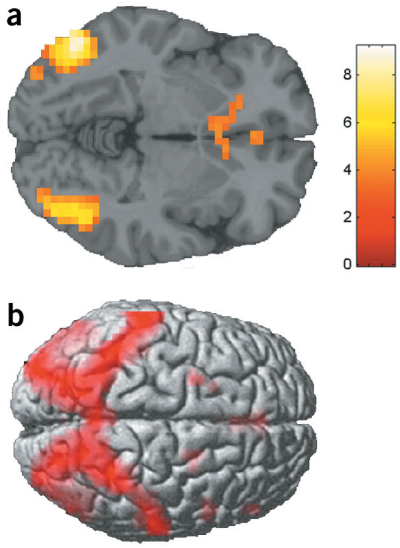

Figure 4 Regions of significant overlap (conjunction) between group activations for males and females. The statistical conjunction between the activation maps for males and females ($P < 0.05$ corrected, ≥10 contiguous voxels) for the couples stimuli versus neutral, non-sexual stimuli. (**a**) Axial view ($z = -4$) showing common activation in ventral striatum and occipital cortex. Color bar indicates maximal Z values. (**b**) Brain-surface rendered view of the same map, showing parieto-temporal-occipital and frontal activations spanning regions associated with visual processing, attention, and motor and somatosensory function. Regions in red surpassed a $P < 0.05$ corrected threshold. The right hemisphere is on the bottom of the image.

occurred against a background of considerable similarity in the processing of such stimuli by men and women.

DISCUSSION

Sex differences in activations to sexual stimuli could arise from differences in processing mode between men and women (*e.g.*, different cognitive styles or neural pathways), from activations related to higher arousal, irrespective of biological sex, or from a combination of these factors[1]. By the arousal hypothesis, when men and women are matched on levels of elicited arousal, sex differences in brain activation should be eliminated. In contrast, the processing-mode hypothesis predicts that men should still show greater brain activation than women in specific regions after controlling for arousal. Our present results support the second hypothesis. In addition, the highly localized nature of the sex differences is more consistent with the processing-mode hypothesis. Previous studies contrasting brain responses to affectively positive visual stimuli with those to less arousing stimuli consistently report arousal-related activations distributed across multiple regions[19,20]. This stands in marked contrast to the localized differences found here.

A previous neuroimaging study examined sex differences in responses to sexual stimuli[21], but did not observe sex differences in the amygdala, possibly because its design rendered it less sensitive to fMRI signal changes in this structure (see **Supplementary Note** online). Arousal was also substantially higher for males than females in this earlier study. After controlling for arousal, the only sex difference observed (in the hypothalamus) was eliminated[21] (see **Supplementary Note** online). In our present study, reported arousal was equated for females and males. Moreover, when one female subject in the current study who reported low arousal ratings for the couples stimuli was excluded from analysis, reported arousal was greater for females than males, yet the activation differences favoring males remained unchanged. We note, however, that because sexual arousal has multiple psychological and physiological aspects, further study will be required to determine to what extent these other aspects may contribute to observed sex differences[22].

Strong positive correlations between emotional arousal and amygdala activity have been reported for both appetitive and aversive stimuli[23,24], and arousal has been suggested as the primary factor influencing amygdala activity in response to olfactory and visual stimulation. Here, however, amygdala responses to appetitive visual sexual stimuli were not solely determined by arousal, but instead were strongly influenced by the sex of the viewer. The amygdala has multiple functions, however, and although processes related to emotional arousal are clearly of prime importance, in specific contexts these other roles may take precedence in determining amygdala activity. For example, considerable evidence from humans and other animals points to a critical role for the amygdala in appetitive incentive motivation, whereby the amygdala mediates the acquisition of high motivational value by stimuli, which in turn drives instrumental behavior[17,18,25–27]. In this context, the greater amygdala activation in males observed here may in part reflect a greater appetitive incentive value of visual sexual stimuli, either intrinsic or learned, rather than greater emotional arousal. This would be consistent with the greater male motivation to seek out and interact with such stimuli. Notably, it has recently been reported that larger amygdala size is related to higher sexual drive in humans, further supporting a role of the human amygdala in sexual motivation[28]. It is also possible that sexual stimuli could represent a specific type of biologically salient stimulus that is processed differently from other types of appetitive visual stimuli, and for which the relation between arousal and amygdala activation is more complex.

The amygdala has an established role in processing biologically salient appetitive and aversive stimuli, and initiating rapid adaptive responses via activation of other brain regions including the hypothalamus[1,15,29–34]. The current results extend understanding of amygdala function by showing that the amygdala acts to mediate sex differences in responses to appetitive, emotionally positive stimuli. This accords with two reports that the amygdala mediates sex differences in memory for emotional visual stimuli, each of which found greater left-sided activation related to subsequent emotional memory in women but greater right-sided activation in males[1,2] and suggests that the amygdala may be implicated in a variety of sex differences in emotion processing. Here, sex differences between men and women were greater for the left amygdala than the right amygdala, consistent with the predominantly left-sided amygdala activations elicited by pleasant and unpleasant visual stimuli in previous reports[1,19]. The possible differential roles of the left and right amygdala in emotion processing have been discussed extensively in the context of aversive stimuli[34–36]. However, the differential roles of the left and right amygdala in processing appetitive emotional stimuli, and in mediating sex differences, remain unclear, in part because few studies have examined these issues to date. A parallel with the differential roles of the amygdala in male appetitive versus consummatory sexual responses highlighted in previous animal studies is suggested by a recent positron emission tomography (PET) study of brain activity in men during consummatory sexual behavior elicited by tactile stimulation by a female partner[37]. Relative to a resting baseline, consummatory male sexual behavior (erection and orgasm) elicited decreased activity in only one brain region, the amygdala,

bilaterally during erection and in the left amygdala during orgasm. Thus, whereas viewing appetitive sexual stimuli by males in the current study elicited highly localized increases in amygdala activation, consummatory sexual behavior elicited correspondingly focal deactivations in the amygdala. Further investigation will be required to determine whether such parallels indeed reflect a conservation of amygdala function across species.

For males, more than for females, visual sexual stimuli seem to preferentially recruit an amygdalo-hypothalamic pathway. This accords with previous speculations that the amygdala is a critical initial structure in a processing pathway recruited in human males during the processing of sexually arousing visual stimuli[8]. It is also in line with findings from animal studies[7,18,25] and with the efferent connectivity from the amygdala to the hypothalamus, which controls physiological reactions associated with sexual arousal[7]. In summary, the current findings suggest a possible neural basis for the greater role of visual stimuli in human male sexual behavior[3–6]. Whether the sex differences observed here reflect inherent differences in neural function or stem from differential experience is a matter for further study.

METHODS

Subjects and task. Twenty-eight healthy subjects took part in the study, 14 female (mean age 25.0 years) and 14 male (mean age 25.9 years). All subjects gave informed consent to participate, and the study was approved by the Emory University human investigations committee. Subjects were pre-screened to verify that they were heterosexual (self-reported as having only opposite-sex sexual desire and sexual experiences), had experience viewing stimuli similar to those used in the study, and found such materials significantly sexually arousing. Thirty-four males were pre-screened: four (12%) were excluded because they reported same-sex desire or experience; no males were excluded because of insufficient response to erotica. Forty-five females were pre-screened: 16 (36%) were excluded because they reported same-sex desire or experience and 7 (16%) were excluded because of insufficient response to erotica. The remaining subjects who were not included in the analysis were excluded either because of technical difficulties with the scanner or video goggle system, fMRI signal drop-out, or because a sufficient number of subjects had already been tested.

Subjects viewed alternating 20.125-s blocks of four types of stimuli: heterosexual couples engaged in explicit sexual activity (couples stimuli), attractive opposite-sex nudes in modeling poses (opposite-sex stimuli), pleasant social interaction between partially or fully clothed males and females with minimal or no overt sexual content (neutral stimuli; therapeutic massage, dancing, weddings) or a visual fixation cross. Sexual stimuli were pre-selected so that they would be maximally attractive to females, in an effort to match females and males on elicited arousal. Selection was conducted via computerized anonymous ratings with a separate group of female subjects. Only sexual stimuli rated as highly sexually attractive and physically arousing were selected for use in the primary experiment; stimuli that elicited weak arousal or were rated as aversive or humorous were eliminated. Stimuli were presented via MRI-compatible goggles (Resonance Technology, Inc.). We presented stimuli rapidly, in alternating blocks of five stimuli of each type. Each block contained five stimuli of the corresponding type, with each stimulus presented for 3,750 ms followed by a fixation cross for 275 ms. Two runs were presented, each containing four blocks of each type presented in a pseudorandom order. Ratings of sexual attractiveness were assessed immediately after each scan; physical sexual arousal was assessed retrospectively immediately after all scanning had concluded. A Likert-type rating scale was used: 0 (lowest) to 3 (highest). For the re-analysis that omitted one female subject who reported very low arousal ratings, physical arousal ratings for females and males were 2.85 ± 0.10 and 2.31 ± 0.12 ($P < 0.005$), respectively. Physiological measurement of sexual response was not conducted because of incompatibility of female genital plethysmography with MRI scanning and the lack of commonly accepted methods for comparing magnitudes of male and female genital responses. Subjects were instructed to view each stimulus attentively and to experience whatever reactions the stimuli might elicit. Overt responses were not required, to avoid possible interference with emotional processes elicited by the stimuli. No stimuli were repeated during the experiment.

Imaging and data analysis. MRI scanning was performed on a 1.5-tesla Philips Intera scanner. After acquisition of a high-resolution T1-weighted anatomical scan, subjects underwent whole-brain functional runs (echo-planar imaging, gradient recalled echo; TR = 3,000 ms; TE = 40 ms; flip angle, 90°; 64 × 64 matrix, 25 5-mm axial slices) for measurement of blood oxygen level–dependent (BOLD) effects. The first four volumes were discarded to allow for T1 equilibration effects. Data were analyzed using SPM99 software (http://www.fil.ion.ucl.ac.uk/spm). Functional EPI volumes were realigned to the first volume and normalized to a standard EPI template volume using 4 mm × 4 mm × 4 mm voxels. Images were subsequently smoothed with an 8-mm isotropic Gaussian kernel and band-pass filtered in the temporal domain. Images were carefully inspected for regions of magnetic susceptibility induced signal dropout in the amygdala and hypothalamus. Three males and one female were scanned but had significant signal dropout in the amygdala or hypothalamus and were replaced by newly tested subjects. Thus, all 28 subjects reported here had minimal signal dropout in the regions of interest. Because only those voxels with sufficient signal in all subjects were included for analysis, any signal dropout would have tended to decrease the spatial extent of observed sex differences in activation.

Condition effects for the stimulus conditions were estimated using box-car regressors convolved with a canonical hemodynamic response function, separately for each subject at each voxel according to the general linear model (GLM), and regionally specific effects were compared using linear contrasts[12]. Contrasts between conditions produced statistical parametric maps for each subject of the *t*-statistic at each voxel. Sex differences in activation were assessed with a second-level, mixed-effects analysis with subjects as the random-effects factor, using a two-group unpaired *t*-test on the individual subject-specific contrast images, yielding statistical parametric maps. The second-level mixed-effects conjunction analysis was conducted with the individual subject-specific contrast images contrasting the couples condition with the neutral condition, using linear regression ($P < 0.05$, corrected for spatial comparisons across the whole brain, extent threshold ≥10 voxels).

For the whole-brain analysis, we thresholded these summary statistical maps at a voxel-wise intensity threshold of $P < 0.001$ (uncorrected for multiple comparisons) with a spatial extent threshold of ≥5 contiguous voxels. For the comparison between males and females on the couples versus neutral stimuli contrast (**Fig. 2d**), a $P < 0.005$, ≥5 contiguous voxels threshold was used, masked inclusively by the group comparison for the couples versus fixation contrast at a lenient $P < 0.01$ threshold (**Fig. 2a**). Based on previous studies, we defined the amygdala and hypothalamus as ROIs. We did a correction for multiple spatial comparisons within each region, as a more stringent test of our *a priori* hypotheses. The amygdala region was defined as an 8-mm sphere centered on the following coordinates: left amygdala, –20, –4, –20; right amygdala, 20, –4, –20. The hypothalamic ROI was an 8-mm sphere centered on the coordinates 0, –4, –8. For visualization of activation extent, the group activation maps were thresholded at $P < 0.005$ uncorrected, with a five-voxel extent threshold, and they were overlaid on a representative high-resolution structural T1-weighted image from a single subject from the SPM99 canonical image set, coregistered to Montreal Neurological Institute (MNI) space—a widely used approximation of canonical Talairach space[38]. All coordinates are reported in MNI space, and may be converted to Talairach space using the freely available MNI2TAL program (http://www.mrc-cbu.cam.ac.uk/Imaging/Common/mnispace.shtml). Anatomical localization of group activations was assisted by reference to the atlas of Duvernoy[39].

For the ROI-averaged analysis, to examine differences in the magnitude of fMRI signal change across all stimulus conditions and between different brain regions, we calculated the average fMRI signal change relative to the fixation baseline for each subject. We did this for each stimulus condition for 8-mm-radius spherical ROIs centered on the left amygdala, right amygdala and hypothalamus. Specifically, for each subject, hemodynamic response functions for each condition type were estimated across each ROI using a finite impulse response formulation of the GLM, partialling out the modeled effects of the other conditions, as implemented in R. Poldrack's SPM ROI Toolbox (http://spm-toolbox.sourceforge.net). Parameter estimates for this model are

estimates of the temporally evolving response magnitude across each point in peristimulus time, averaged across all occurrences of that peristimulus time interval. Response estimates were averaged across the five peristimulus time points occurring from 6 to 18 s after the onset of each 20.125-s block (at 3-s intervals). This is the temporal window where the average signal was predicted to be maximal based on the canonical hemodynamic lag. Statistical comparisons between conditions, regions and groups were conducted using these averaged values from each subject using *t*-tests and ANOVAs using a criterion of $P < 0.05$ (two-tailed).

Note: Supplementary information is available on the Nature Neuroscience website.

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COMPETING INTERESTS STATEMENT

The authors declare that they have no competing financial interests.

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