Research report

Brain activation evoked by erotic films varies with different menstrual phases: An fMRI study

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Abstract

In humans, fluctuating hormone levels throughout the menstrual cycle are believed to regulate many cyclical sexual behaviors and motivational processes. However, there is a dearth of research investigating the neural correlates of this phenomenon. We used functional magnetic resonance imaging to identify brain regions involved in sexual arousal’s regulatory process. Fifteen female participants were scanned while viewing erotic film excerpts at three time points during a single menstrual cycle: ovulation, menstruation, and at one additional time point. Tripled two-group differences analysis revealed that significant activation in the comparison was observed in non-ovulatory phases of the menstrual cycle in parts of the right inferior frontal gyrus, right lateral occipital cortex, and left postcentral gyrus, as well as in the bilateral superior parietal lobule. Thus, our results indicate that brain activity differs in the ovulatory phase of the menstrual cycle compared to during other menstrual phases. This finding provides neurological evidence for the ovulatory cycle’s modulation of the processing of the sexual arousal in female human brain.

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1. Introduction

A rapidly growing literature documents sexual influences on brain structure, chemistry, and function [6]. The cortical activation patterns of human sexual arousal were first investigated by Stoleru et al. [39] using positron emission tomography (PET). More recently, functional imaging techniques have been widely used to investigate the neurophysiology of sexual function [4,10,11,13,14,18,25,27,29,30]. Brain structures implicated in human sexual behavior include the right frontal cortex, the inferior temporal cortex, the left anterior cingulate cortex, the right insula, the occipitotemporal, medial prefrontal, orbitofrontal, pre- and post-central cortices, hypothalamus, thalamus, cerebellum and amygdala.

Gonadal hormones are likely candidates for biological influences on the cognitive component of sexual arousal. Plasma concentration of gonadal hormones such as estradiol and progesterone vary systematically during menstrual cycle, with low concentrations during menstruation, high preovulatory estradiol concentration, and high concentrations of both progesterone and estradiol during the luteal phase after ovulation [2]. This changing hormonal milieu has been posited to be responsible for some cyclic cognitive, sensory, and emotional changes throughout the menstrual cycle [9]. However, contradictory results have also been reported regarding the influence of menstrual cycle on the sexual behavior in humans, based on the results of questionnaires, diary studies, and the self-rating of photographs ([20,22,23]; or reviews [32]). This suggests that the relationship between menstrual cycle and sexual behavior is complex and requires further investigation. The human estrous cycle is very different from that of most other primates. For instance, in gorillas and chimpanzees, conspicuous behavioral and/or morphological changes serve as indicators of the fertile phase of the female cycle. The absence of such indicators in human and some primate species is referred to as “concealed ovulation,” and is believed not to have been characteristic of our primate ancestors [40].

To date, the neural mechanism of the influence of the menstrual cycle on sexual behavior has, with few exceptions [11,12], received little investigation. The objective of this study is to evaluate the difference in brain activation when viewing erotic film excerpts throughout the course of the menstrual cycle. Functional magnetic resonance imaging (fMRI) was used to measure changes in cerebral activity during sexual arousal evoked in heterosexual females by...
watching a pornographic movie. The experimental methods used in the current study have greater precision than those employed in previous studies. For instance, studies using only the calendar method [11] are less accurate in determining ovulation time. Additionally, a novel data analytic method allowed us to compare more phases within the menstrual cycle. We hypothesized that there might be differences in the pattern or magnitude of brain activation in cortical and subcortical brain structures between different phases of menstrual cycle. The current results will shed light on the understanding of cerebral processes in female subjects’ dependent on the hormonal cycle.

2. Subjects and methods

2.1. Subjects

Subjects were enrolled through advertisements on campus. 17 healthy heterosexual right-handed female volunteers, all free of neurological or psychiatric history and without any hormonal therapy (contraceptive), took part in this study. During the study, all participants were either married (2) or had a boyfriend (15). Due to technical difficulties, two participants’ data were corrupted and not included in the analysis. All fifteen participants (mean age 26.3 years; SD = 3.8), were ethnically Chinese females born in China and postgraduate medical students of Peking University. All reported a regular menstrual cycle (mean duration 31.9 days; SD = 3.6). No participant revealed any brain tissue abnormality on anatomical MRI.

Each participant was measured three times throughout the course of one menstrual cycle: during ovulation (OVU), during menstruation (MEN), and at one other time at their convenience (OTH). The ovulation time was determined by luteinizing hormone (LH) urine test paper (One Step LH Ovulation Test, manufactured by Runbio Biotech Co., Ltd., Shantou, China), which was reported to have a high accuracy in predicting women’s ovulation within 24 h [17], and the MR scan, which was performed on the next day of the test paper’s color change. The menstruation time was reported by the participants themselves, with testing performed on the second day from the beginning of menstruation. In addition to these two fixed time points, the participants were allowed to choose the third time point, OTH, at their convenience, given that it was not during menstruation and at least 3 days away from ovulation. Six participants’ OTH fell during their follicular phase while the remaining 11 participants’ OTH occurred during their luteal phase.

This study was approved by the local ethics committee. All participants provided informed consent and received compensation for their participation in this study.

2.2. Experimental setting

Visual tasks were displayed by a computer via back-projection onto a translucent screen. While lying on the scanner bed, subjects viewed the screen through a mirror fixed on the head coil and were required to concentrate on the presentation on the screen. The study was performed according to a standard block paradigm which consisted of five 72-s blocks, each comprising: one 30-s emotionally neutral video clip, followed by a question about this clip which lasted 6 s, then a 30-s erotic video clip, followed by another 6-s question. The questions were simple statements such as, “Do you recognize the men/women in the film?”, which only required the subjects to select true or false by pressing an MRI compatible push-button near her right hand. The purpose of these questions was to keep the participants’ attention focused on the video clips and to disengage them from the content of the neutral or erotic visual stimuli. For this reason, the participants’ responses were recorded but not used in analysis.

All five erotic video clips were selected from commercial adult films containing consensual sexual interactions between one man and one woman, of which two were non-intercourse (petting) and three were vaginal intercourse scenes. The five emotionally neutral video clips showed scenes such as people working or talking without any erotic connotations, which included at least one man and one woman. All film excerpts were selected from a number of possible films by female postgraduate students (totally 6) in our research group.

All subjects viewed the same visual stimuli “block” in their three scans, albeit in varying order. Three of the participants had their first session in OVU, two during MEN and the rest during OTH.

2.3. Data acquisition

All MR images were acquired using a 3.0T GE Signa MR scanner (3.0T Signa Excite system, GE Medical Systems, Milwaukee, WI). A quadrature birdcage coil was used for both excitation and reception of the signals. Subjects underwent an 133-volume (399 s) whole-brain functional run (pulse sequence: gradient recall echo, echo planar imaging [GRE-EPI]; TE = 30 ms, TR = 3000 ms, flip angle = 90°, 64 × 64 matrix, 29 transaxial contiguous 5-mm slices, FOV = 24 cm × 24 cm, interleaved acquisition) which were sensitive to blood oxygenation level dependent (BOLD) contrast; followed by a high-resolution T1-weighted anatomical scan using inversion recovery-prepared 3D spoiled gradient recalled (IRP-SPGR) sequence (TE/TR/TI/FOV = flip angle/matrix size = 3.0 ms/7.4 ms/450 ms/24 cm × 18 cm/200 × 256) with 124 contiguous axial slices and a slice thickness of 1.4 mm.

The presentation of visual stimuli was controlled by Presentation software (version 7.0, http://www.neurobs.com/presentation) running on a PC connected to the MR scanner. The time of each pulse of MR and the time of the beginning of each visual stimulus was recorded by this software and used for data analyses.

2.4. Data analysis

Preprocessing and analysis were carried out by means of the FSL software package (version 4.0.4, FMRIIB Software Library, Oxford Center for Functional Magnetic Resonance Imaging of the Brain, Oxford University, Oxford, U.K.) [38]. For each subject, preprocessing began with motion correction with FSL’s MCFLIRT [15] by maximizing the correlation ratio between each time point and the middle volume, followed by slice timing correction to the first slice and non-brain substance removal using BET program [37]. The images were then smoothed with an 8-mm full-width at half maximum (FWHM) smoothing kernel and were temporally high-pass filtered with a cutoff period of 100 s. After preprocessing, statistical analyses were performed at the single-subject level by using the general linear model within FSL (FEAT, FMRI Expert Analysis Tool, version 5.9.8), with each event was modeled with FSL’s canonical gamma hemodynamic response function (HRF) along with temporal derivative. For each subject, statistical maps were generated to show contrast of activation during erotic clips (on) relative to emotion neutral clips (off).

These were then affinely registered via the subject’s high-resolution T1-weighted anatomical image to the Montreal Neurological Institute (MNI)-152 template (FSL’s MNI avg152, T1, 2 mm × 2 mm × 2 mm) by using 12-parameter affine transformation with the FSL FLIRT registration tool [16]. Mixed-effects group analyses were performed by using FSL’s FLAME (FMRIIB’s local analysis of mixed effects) stages 1–2, to output the tripled two-group difference (“tripled” t-test, see supplementary material for details) of the three phases of the menstrual cycle, which reveals the difference between each two phases simultaneously.

Additionally, an overall average image across subject and phase was calculated by first performing a fixed-effects analysis on within-subjects data to estimate each subject’s mean activation across the menstrual cycle, followed by mixed-effects group analyses on subjects’ means to estimate the group mean activation using FLAME stages 1 + 2. This image is used to mask out the brain areas that do not relative to sexual arousal from the above images.

Higher level statistical maps were thresholded by using clusters determined by Z(Gaussianized T/F) > 2.3 and a (corrected) cluster significance threshold of P = 0.05, using the Gaussian random field theory (GRFT).

3. Results

3.1. Average activation

The overall average across subjects and phases is calculated using the procedure mentioned above. Our results (Fig. 1 represents the overall average) reproduce previous findings indicating that the viewing of sexual visual stimuli is associated with the activation of a set of bilateral brain areas including the inferior lateral occipital cortex, the anterior supramarginal gyrus, the parietal operculum cortex, the superior parietal lobules, the right inferior frontal gyrus, pars opercularis, the cerebellum, the hypothalamus, the thalamus, the amygdala and the dorsal portion of upper pons and midbrain. Conversely, the viewing of sexual visual stimuli is also correlated with a bilateral deactivation of some areas located in the temporal lobe together with the postcentral gyrus and the posterior cingulate/precuneous.

3.2. Activation difference across the menstrual phase

Regarding the main hypotheses in this study, Table 1 and Fig. 2 show the activation differences between different menstrual phases. Tripled two-group t-test (“tripled” t-test) reveals the difference in each two-way comparison, and we find that there is no significant difference between MEN and OTH, while there are some clusters showing significant activation in the comparison between MEN/OTH and OVU. These clusters are found in the right inferior frontal gyrus, pars opercularis and right lateral occipital cortex, inferior division, as well as left postcentral gyrus and bilateral superior parietal lobules. Importantly, the original statistical
maps contain some clusters outside the overall average activation/deactivation area. They are pre-masked by the overall average activation plus deactivation image, as we are primarily interested in the brain areas involved in sexual arousal.

**Fig. 3** shows the mean % BOLD signal changes on the overall average activation areas and deactivation areas (areas which shown in **Fig. 1**), respectively. Results show a decreasing trend of brain activation in OVU compared to MEN and OTH, in both overall average brain activation and deactivation areas.

**4. Discussion**

**4.1. Brain areas involved in sexual arousal**

The results of this study are consistent with previous work suggesting that both cortical and subcortical brain areas are involved in the processing of sexual arousal.

The activation of cortical areas such as visual cortex, cerebellum, superior parietal lobule is consistent with previous studies.

**Table 1**

<table>
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<tr>
<th>Contrast</th>
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<th>BA</th>
<th>Hemi</th>
<th>Size</th>
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<td>OTH versus OVU</td>
<td>Inferior frontal gyrus, pars opercularis</td>
<td>44, 48</td>
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<td>974</td>
<td>47</td>
<td>9</td>
<td>37</td>
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<td>Inferior/middle temporal gyrus</td>
<td>19, 37</td>
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<td>761</td>
<td>53</td>
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<td>5, 7</td>
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<td>463</td>
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<td>45</td>
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<td>Postcentral gyrus*</td>
<td>3, 4</td>
<td>L</td>
<td>388</td>
<td>−46</td>
<td>−18</td>
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<td></td>
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<td>7</td>
<td>R</td>
<td>131</td>
<td>18</td>
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<td></td>
<td>Middle occipital cortex</td>
<td>19, 37, 39</td>
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<td>120</td>
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<td>MEN versus OVU</td>
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<td>44</td>
<td>R</td>
<td>452</td>
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**Note:** Coordinates are defined in the MNI stereotactic space (Montreal Neurological Institute, Canada) and refer to the anterior commissure. x represents the lateral distance from midline (positive right); y is the anteroposterior distance from the anterior commissure (positive anterior); z represents the height relative to the intercommissural plane (positive above). Coordinates are calculated by FSL program automatically and the description/Brodmann areas are identified by atlas inside MRIcroN program.

BA, Brodmann area; Hemi, hemisphere; R, right; L, left; Cluster size is given in pixels and coordinate is given by the cluster’s central of gravity. Z is local maxima and P is corrected.

* This area overlap on deactivation area, while others all on activation area.
For analysis of the phase-specific activation, the images of the three phases of the menstrual cycle are entered into a tripled two-group difference test ("Tripled t-test") with a (corrected) cluster significance threshold of $P = 0.05$ and $Z > 2.3$. The map shows combination of these differences in which red color represents areas more prominently activated when scanned in subject’s menses (MEN) comparing to in ovulatory phase (OVU), green color represents the prominently activated areas when scanned in other time (OTH) comparing to in ovulatory phase, and yellow color indicates the areas where green and red areas overlap. The most significant areas are right inferior frontal gyrus and bilateral superior parietal lobules (with more left hemisphere than right). Map is pre-masked by the overall average activation plus deactivation image, and the underline anatomical image is FSL’s MNI avg152 template. Cycle-specified activation can be seen only in cortical areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

[1,3,4,19,25] which suggested that their activation might associate to the cognition aspect of the visual stimuli such as availability, motoric imagery, attention process, and so on. The activation of these areas of cortex is common in visual-task studies. The activation of subcortical structures, such as the hypothalamus, thalamus, amygdala and midbrain has been found in humans as well as animals in response to sexual stimuli. The thalamus, hypothalamus, amygdala and midbrain all belong to the limbic system, which plays a major role in the regulation of basic drives related to survival, including sex. Interestingly, amygdala activation was found to have gender difference in sexual arousal, both in animals[26] and humans [14].

There are some cortical areas that showed deactivation during the viewing of pornographic video stimuli compared to the neutral video clip. The deactivations located in the junction of the posterior cingulate and precuneous are commonly found in visual tasks, especially language related tasks (as reviewed in [33]), while the deactivation on the dorsal portion of anterior cingulate cortex (also characterized as affective division of anterior cingulate cortex [5]) is not very consistent with former studies in which activation instead of deactivation is found at this area [3,10,11]. Our result of increased activity during emotionally neutral films compared with erotic films in this area is somewhat counterintuitive as erotic films would seem to be more closely related to affective processing than emotionally neutral films. The bilateral deactivations of temporal areas may suggest that the alleviated inhibition from temporal lobes allows the development of sexual arousal.[29]. It is well known that there exists an inhibition pathway related to sex behaviors in the temporal lobes, as lesion of the temporal lobes can result in dramatic hypersexuality known as Kluver–Bucy syndrome. The current results support the notion that sexual arousal is a composite psychophysiological state correlated with the activation and deactivation of several brain areas that form a complex network.

4.2. Differences in activation throughout the menstrual cycle

As can be seen from the histogram of the statistical maps (Fig. 4), there is no significant difference between MEN and OTH; and in non-OVU there are brain areas showing significant activation in the comparison to the OUV, with most of them overlapped on the activation brain areas (including right inferior frontal gyrus, pars opercularis, right lateral occipital cortex, inferior division and bilateral superior parietal lobule), while only a few clusters located in the left postcentral gyrus (around the central sulcus) overlap on deactivation areas. The maps of MEN versus OUV and OTH versus OUV are rather similar with only small variance, as shown in Fig. 2. Significant activation in the comparison between non-OVU and OUV was observed in our experiment, which contrasts with the findings of Gizewski et al. [11]. These inconsistencies possibly result
Fig. 3. The mean % BOLD signal changes on (A) the overall average activation areas and (B) deactivation areas. The areas are shown in Fig. 1. Results show the depression tendency of brain activation in ovulatory phase (OVU) compared to menses time (MEN) and other time (OTH), both the overall average activation brain areas and the deactivation areas. But the difference is obviously not significant, in a large part by facts that this comparison is unpaired.

Another result inconsistent from prior literature [12] is that we find phase-specific brain areas mainly located on the cortical rather than the subcortical structures. A general decreased activation can be seen during ovulatory phase with respect to the other phase, as can be seen in Fig. 3, but the cortical structures are more significant than subcortical ones. This may suggest that this difference is more likely related to a higher brain function than a lower one because the differences are more significant in the cortical areas.

It is assumed, according to the Darwinian theory of natural selection, that females would have greater sexual arousal during ovulation, given that only copulation around this period can result in gestation: more mating in this time would more likely result in conception, which, would give the species a greater chance at survival. This theory holds true under some circumstances, especially in lower species. However, it does not obviously hold true in other cases, such as in humans, as mentioned in Section 1. For most mammalian species other than primates, the ability and willingness to copulate are restricted to during the fertile phase of the ovarian cycle, and are regulated by the gonadal hormones. For most primates, as reviewed in [41], mating can occur at any time even when the uterus is not optimal for fertility, with few exceptions (e.g., prosimian primates, lemurs, galagos, and lorises). The separation
of sexual behavior/motivation from the ability of gestation allows social experience and social context to exert a powerful influence on sexual behavior and sexual relationships, and vice versa [24]. This flexibility allows sex to serve more important social purpose, apart from reproduction [42].

There is evidence that primate sexual behavior is more dependent on social context than hormone levels [41]. The relationship between human sexual desire and gonadal hormones level has not been systematically investigated. In the current study, we find there is no noticeable difference between MEN and OTH of the menstrual cycle, suggesting that gonadal hormonal variation has almost no direct influence on the female sexual arousal’s corresponding cortical processing. As mentioned above, there are a lot of inconsistent research findings regarding the influence of menstrual cycles on sexuality. We believe that this inconsistency suggests that there is no significant relationship between these two variables in humans. Thus, the questions we need to address are (1) how could the female brain have been emancipated from hormonal control throughout the course of evolution and (2) how can we explain the finding of significantly greater activation in the comparison of women in MEN and OTH than women in Ovu?

While it was concluded that sexual behavior is not entirely dependent on hormonal control in humans, it is clear from an evolutionary standpoint that sexual behavior is coupled with fertility. The sexual conflict theory [8] suggests a corollary hypothesis in which males and females are jointly under selection to subvert the reproductive investment made by their sexual partners, and resist being subverted by them, thus generating sexually antagonistic coevolution for cognition and behavior [31]. This sexual conflict is found in many species and is hypothesized to be one of the reasons of their relatively larger brains than other species [28]. In many primate species, conspicuous behavioral and/or morphological changes are indicators of the fertile phase of the female cycle, however, several primate species, such as the Cebus capucinus [21] and humans [34], lack these cues. This is referred as “concealed ovulation” and is argued to be a reproductive strategy evolved in many multimale species that confuse paternity to promote paternal care or to lower male–male competition, thereby lowering the risk of infanticide (e.g., infanticide is most likely to occur when female gorillas move from one group to another with suckling infants; the killer being the male who is unlikely to have sired such infants, see [44] and [45] for review). If this strategy is employed in a species, the female must hide her ovulation from her partners (and in humans, even from herself [36]), while males may try to promote their reproductive success by developing the ability to detect female’s ovulation [7]. In order to hide her ovulation, many behavioral and physiological methods are employed in humans, such as an irregular cycle length and the spread of ovulation across the cycle [21]. Neither special physiological nor psychological indicators of ovulation can be precipitated as the result of this sexually antagonistic coevolution.

Brain activation associated with sexual arousal has been downregulated during ovulation, as can be seen from our results. Notably, this phase-specific brain activation is located in cortical areas rather than subcortical limbic structures, suggesting that this downregulation during ovulation could be regulated by evolutionarily newly developed neuropathways. The traditional temporal lobe inhibition pathway seems to show no significant difference across the menstrual cycle. The phase-specific brain area found in this study included right inferior frontal gyrus, pars opercularis and right lateral occipital cortex, inferior division, as well as left postcentral gyrus and bilateral superior parietal lobules. As discussed, the superior parietal lobules and lateral occipital cortex play a cognitive role in sexual arousal process, suggesting that the availability and attentional processes associated with sexual stimuli are downregulated during ovulation; the clusters located at postcentral gyrus (around central sulcus) seem to belong to the motor/sensory cortex and their role in sexual arousal modulation is unclear. The right inferior frontal gyrus (Brodmann area 44 and 45) is the most remarkable phase-specific brain cortex area but its role is not very well documented, while its homologue on the left hemisphere has been received carefully investigation and is widely known as Broca’s area, which is associated to another advanced social function—language.

However, in the current study we lack sufficient information to fully interpret the observed down-regulation. It should be noted that in the current study the ovulation is not completely concealed from the participant due to the use of the LH test strips. In humans, sex serves an important social purpose apart from reproduction [24]. This is supported by the finding that nearly one hundred acts of intercourse can result in a single gestation even in a society without contraception technology [43], whereas in ‘lower’ species, such as rats, one act of intercourse with ejaculation can guarantee gestation. Because being pregnant is associated with a great deal of inconvenience experienced for a long period of time, it is one of the main risks posed by sex [42]. In the current study, participants were all career-oriented women not using hormonal contraception. Thus, this risk may be particularly threatening to them. Involuntary or unconscious suppression of sexual interest during ovulation may have been one strategy employed to avoid this risk, which is reflected to the modulation of the brain activity associated with sexual arousal. Further studies are needed to examine whether the observed down-regulation of brain activation in response to sexual stimuli during ovulation is generalizable to all Chinese women, and if it is part of a reproductive strategy to minimize the risk of sex.

5. Conclusions

In the present study, we used fMRI to investigate women’s sexual arousal in response to visual sexual stimuli across the menstrual cycle. We found that compared with ovulation, significant activation in the comparison was observed in the rest of the menstrual cycle in some clusters located on the right inferior frontal gyrus, right lateral occipital cortex, and left postcentral gyrus and bilateral superior parietal lobule. Our findings suggested that brain activation associated with sexual arousal was modulated by the ovulatory cycle. This is posited to reflect a female reproductive strategy to minimize the risk of intercourse.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bbr.2009.09.027

References
