

A Quantitative Meta-Analysis on Cue-Induced Male Sexual Arousal

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ABSTRACT

Introduction. Visually induced sexual arousal is a common occurrence in human behavior. The cerebral underpinnings of this response have been explored in recent neuroimaging studies.

Aim. We set out to test the strength of evidence for the presence of a core network of brain regions involved in male sexual arousal elicited by erotic stimuli.

Methods. Eleven functional magnetic resonance imaging studies that presented erotic visual stimuli and compared the associated brain activity with the brain activity elicited by neutral visual stimuli were identified.

Main Outcomes Measures. Activation likelihood estimation was employed to perform quantitative meta-analyses on coordinates of brain activation in order to assess significant concordance across studies.

Results. The meta-analysis included studies on heterosexual males and revealed consistent activation in the hypothalamus, thalamus, amygdala, anterior cingulate gyrus (ACC), insula, fusiform gyrus, precentral gyrus, parietal cortex, and occipital cortex across studies. Moreover, we explored brain responses associated with a physiological marker of sexual arousal (penile tumescence) and found concurrence in hypothalamus, thalamus, bilateral insula, ACC, postcentral gyrus, and occipital gyrus.

Conclusions. This is the first quantitative meta-analysis on sexual cue reactivity and identifies a neural network consisting of cognitive (parietal cortex, ACC, thalamus, insula), emotional (amygdala, insula), motivational (precentral gyrus, parietal cortex), and physiological (hypothalamus/thalamus, insula) components constituting a core circuit of male sexual arousal in humans. **Kühn S and Gallinat J. A quantitative meta-analysis on cue-induced male sexual arousal. J Sex Med **,**:**-**.**

Key Words. Quantitative Meta-Analysis; fMRI; Sexual Arousal; Erotic Stimuli; Cue-Induced Sexual Arousal

Introduction

Sexual behavior is one of the most important goal-directed behaviors that are associated with the survival of the species. According to sociobiology (e.g. [1]) the pressure of natural selection has supported the emergence of brain systems that promote sexual behaviors that increase fitness, namely the aptitude to transmit one's genes. Especially during the initial approach phase processing of external sexual stimuli is of utmost importance. In mammals, it has been shown that sexual behavior in male mammals is promoted by odors that indicate the reproductive state of females [2]. In

animals, the role played by subcortical structures, particularly the amygdala and hypothalamus, in sexual behavior has been well documented [3]. However, it has been remarked that human sexual behavior comprises unique characteristics that distinguish it from the homologous behavior in other species, such as the cognitive aspects of sexuality [4]. With the aim of exploring the neural correlates of sexual arousal as elicited by external sexual stimuli consisting of still images or videos, also referred to as "cues," several neuroimaging studies have investigated the cerebral activation during erotic visual stimulation. Many of the studies using cue-reactivity paradigms comprising sexual stimuli

implicitly assume that the experimental setup elicits sexual arousal. Although there is little consensus on the concept of sexual arousal we use this term to describe an appetitive motivational state of sexual excitement or desire comprising a cognitive, emotional, motivational, and physiological component. In line with the assumption that sexual stimuli elicit sexual arousal, we aimed at testing whether brain areas that consistently show increased activity in response to sexual cues overlap with brain areas that are consistently correlated with a physiological measure of sexual arousal, namely penile turgidity. Studies using cue-reactivity paradigms have highlighted a complex neural circuitry involved in the human sexual response (e.g. [5–8]). In order to provide a systematic assessment of brain regions involved in cue-induced sexual arousal, we performed a quantitative meta-analysis. We included functional magnetic resonance imaging (fMRI) studies that presented erotic visual stimuli to male subjects and compared the associated brain activity with the brain activity elicited by neutral visual stimuli in order to assess the correspondence of neural activation across multiple neuroimaging studies. We present a meta-analysis on studies including male subjects with heterosexual orientation. Moreover, to relate brain activation during the observation of sexual cues with a physiological marker of sexual arousal, we conducted a second meta-analysis on whole brain correlations with penile turgidity. By means of the activation likelihood estimation (ALE) approach [9–11] we explored statistically significant concordance of activated voxels across numerous studies while controlling for chance clustering. ALE tests for statistically reliable clustering of activations in standardized locations avoiding spatial distinction errors and problematic

incongruence of labeling across studies that could have befallen narrative-based reviews and tabular meta-analytic approaches on cue-induced sexual arousal that have been published previously.

Methods

Study Selection

Studies were selected using a systematic search of peer-reviewed articles published in English until August 2010. We used two separate databases (Pubmed, ISI Web of Knowledge) with the keywords “neuroimaging” or “fMRI” and “sexual arousal” or “sexual cues.” The reference lists of these selected papers were searched for additional studies that fit these criteria. From the resulting articles, we selected those that presented visual cues with sexual content and compared these with neutral nonsexual cues and compared the accompanying brain activity within-subject. We included increases in brain activation during sexual cues only. Moreover, only studies of which we were able to obtain either Talairach [12] or Montreal Neurological Institute (MNI) coordinates were included. An analysis on heterosexual females only was not conducted because only two studies reported separate results for female participants [13,14].

Into the first analysis we entered studies on male participants with heterosexual orientation. We included eight studies with 203 foci and altogether, 154 participants (Table 1). In order to relate brain activation observed during the presentation of sexual cues with physiological markers of sexual arousal, we conducted a second meta-analysis on coordinates resulting from whole brain correlations with penile turgidity. Altogether, four studies were entered with 94 foci and 39 participants (Table 2).

Table 1 List of studies on cue-induced sexual arousal on heterosexual males

Study	Stimulus modality	Stimulus content	N	FOCI
Brunetti et al. (2008) [39]	Videos	Consensual sexual interactions between one man and one woman > rugby or football scenes with men and women	18	26
Bühler et al. (2008) [40]	Pictures	Erotic IAPS > neutral IAPS	10	14
Ferretti et al. (2005) [41]	Videos, Pictures	Consensual sexual interactions between one man and one woman > rugby or football scenes with men and women	10	43
Karma et al. (2002) [7]	Videos	Erotic > emotionally neutral	40	32
Kim et al. (2006) [42]	Videos	Sexually arousing erotic scenes > sports highlights	10	13
Glucken et al. (2009) [43]	Pictures	Consensual sexual interactions between one man and one woman > men and women in neutral scenes	44	26
Moulier et al. (2006) [45]	Pictures	Women wearing swimsuit or nude > women fully dressed	10	24
Paul et al. (2008) [46]	Videos	Erotic stimuli depicting preferred stimuli > neutral	12	25

IAPS = International Affective Picture System.

Table 2 List of studies reporting whole brain correlations with measures of sexual arousal

Study	Stimulus modality	Measure of sexual arousal	N	FOCI
Arnow et al. (2002) [5]	Videos	Penile turgidity	11	21
Ferretti et al. (2005) [41]	Videos, Pictures	Penile turgidity	10	28
Moulier et al. (2006) [47]	Pictures	Penile turgidity	10	31
Mouras et al. (2008) [37]	Videos	Penile turgidity	8	14

Creation of ALE Maps

ALE provides a voxel-based meta-analytic technique for functional neuroimaging data [9,11]. By means of the software Brainmap GingerALE (<http://brainmap.org/ale/>), statistically significant concordance in the pattern of brain activity among several independent experiments was computed. ALE maps were derived based on foci of interest, which comprise statistically significant peak activation locations from multiple studies. Coordinates reported in Talairach were converted to MNI space using Matthew Brett's transformation script ([23]; <http://imaging.mrc-cbu.cam.ac.uk/downloads/MNI2tal/mni2tal.m>). In the approach taken by ALE, localization probability distributions for the foci are modeled at the center of 3-D Gaussian functions, where the Gaussian distributions are summed across the experiments to generate a map of inter-study consistencies that estimate the likelihood of activation for each voxel as determined by the entire set of studies. The full width at half maximum of the kernel is adjusted based on the number of subjects in each experi-

ment. The false discovery rate (FDR) method was employed to correct for multiple comparisons at a significance threshold of $P < 0.01$ and a cluster threshold of 100 adjacent voxels. This thresholding procedure controls the expected proportion of incorrectly rejected null hypotheses (type I errors) and the cluster threshold ensures that the clustering of the significant voxels observed is above chance.

Results

The quantitative meta-analysis on cue-induced male sexual arousal in heterosexual subjects revealed significant convergence in hypothalamus extending into thalamus, bilateral amygdala, anterior cingulate gyrus (ACC; extending into corpus callosum), bilateral fusiform gyrus, bilateral anterior insula, right mid-posterior insula, bilateral precentral gyrus, bilateral middle occipital gyrus, and additionally the right inferior and superior parietal cortex (Figure 1 in red). Coordinates of concurrence can be found in Table 3.

Figure 1 ALE meta-analysis maps for male sexual cue-induced brain activity. Red depicts concurrence in studies on heterosexual males (FDR-corrected, $P < 0.01$, cluster > 100 voxels). Blue depicts concurrence in functional magnetic resonance imaging studies that correlate brain activity during cue-reactivity with a physiological measure of sexual arousal (penile turgidity) (FDR-corrected, $P < 0.01$, cluster > 100 voxels). The overlap of both meta-analyses is depicted in pink. ACC = anterior cingulate cortex; ALE = activation likelihood estimation; CC = corpus callosum; FDR = false discovery rate; IPL = inferior parietal lobule.

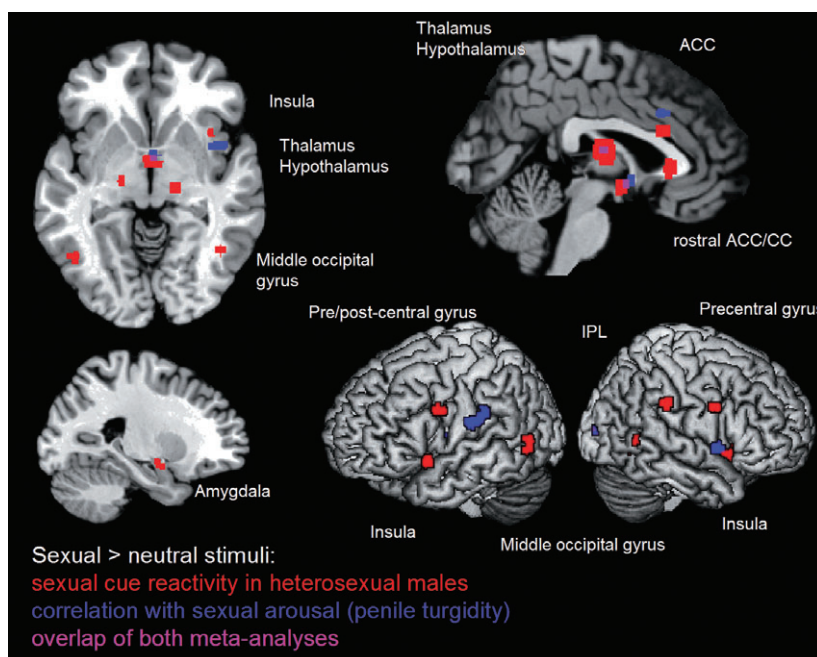


Table 3 Convergence across cue-induced sexual arousal studies including heterosexual males (FDR-corrected $P < 0.01$)

Anatomical region	Brodmann's area	Coordinates (MNI)			Volume (mm ³)
		x	Y	Z	
Thalamus		0	-14	10	2,120
Left amygdala		-20	-8	-13	1,104
Right amygdala		-18	-14	-11	808
Hypothalamus/thalamus		-1	-4	-10	792
Right fusiform gyrus	37	42	-50	-17	624
Left fusiform gyrus	37	-44	-50	-18	576
Anterior cingulate gyrus extending into corpus callosum	25	2	23	1	480
Left middle occipital gyrus	37	-48	-64	-3	112
Right middle occipital gyrus	19	24	-86	3	312
Anterior cingulate gyrus	24	1	19	22	304
Left precentral gyrus	6	-47	3	28	288
Left anterior insula	13	-40	9	-9	240
Right anterior insula	13	38	13	-9	240
Right fusiform gyrus	37	46	-58	-4	232
Right precentral gyrus	6	46	4	28	232
Right inferior parietal lobe	40	54	-31	31	232
Right superior parietal lobe	7	26	-54	43	152
Right mid-posterior insula	13	39	-2	6	112

To explore the effects of stimulus modality, we divided the studies of the first meta-analysis (Table 1) according into those that displayed pictures and those that presented videos. We found concurrence in bilateral precentral gyrus only in studies that presented videos not in studies that presented pictures.

To explore the relationship of brain regions involved in the observation of sexual cues with sexual arousal itself, we focused on concurrence in reported results of whole-brain correlations with a physiological marker of sexual arousal, namely penile turgidity. Concurrence was found in the hypothalamus extending into the thalamus, bilateral anterior insula, left mid-posterior insula, ACC, left postcentral gyrus, and right middle occipital gyrus (Figure 1 in blue, Table 4). These neural correlates of sexual arousal directly overlap with the results of the basic contrast comparing sexual with neutral stimuli and eliciting cue-induced brain activity in hypothalamus extending into thalamus and middle occipital gyrus. Close proximity though no direct overlap was found in ACC and bilateral insula.

Discussion

Within the scope of the present quantitative meta-analyses, we assessed the strength of evidence for the presence of a core network of brain

regions involved in the observation of sexual stimuli (including still pictures and videos) and the resulting cue-induced male sexual arousal. In the first analysis including studies on male heterosexuals, we identified the importance of the hypothalamus, thalamus, left amygdala, ACC, left anterior insula, bilateral fusiform gyrus, left precentral gyrus, parietal cortex, and bilateral middle occipital cortex. Because there was considerably less data on sexual cue-reactivity in women and homosexuals, we restricted our analysis to studies on male heterosexuals (for a study comparing homo- and heterosexuals, see [24]). A consistent relationship between brain activation and a physiological marker of sexual arousal was found in the hypothalamus extending into the thalamus, bilateral insula, ACC, left postcentral gyrus, and right middle occipital gyrus in a meta-analysis on whole brain correlations with penile turgidity.

Stoléru and colleagues [8,25] have proposed a neurobehavioral model of brain processes during cue-induced sexual arousal in humans comprising a cognitive, emotional, motivational, and physiological component. The cognitive component is thought to involve processes of appraisal through which a stimulus is categorized as a sexual incentive and evaluated as such. The emotional component, on the other hand, includes processing of the specific hedonic quality of the arousal and accompanying bodily changes, such as penile tumescence. The motivational component comprises processes that direct behavior to the sexual goal, including the perceived urge to express overt sexual behavior. The physiological component includes various autonomic processes such as cardiovascular, respiratory, and genital responses leading the subject into a state of bodily readiness for sexual behavior.

Table 4 Convergence across cue-induced sexual arousal studies focusing on correlations with measures of sexual arousal (FDR-corrected $P < 0.01$)

Anatomical region	Brodmann's area	Coordinates (MNI)			Volume (mm ³)
		x	Y	Z	
Right anterior insula	13	45	6	-3	720
Left postcentral gyrus	2/40	-53	-23	21	528
Hypothalamus/thalamus		3	0	-7	232
Anterior cingulate gyrus	32	2	19	32	168
Right middle occipital gyrus	18	26	-88	4	160
Left mid-posterior insula	13	-42	-2	6	152
Left anterior insula	13	-34	16	-1	128
Thalamus		0	-12	11	128

To proliferate our understanding of the functional involvement of the brain regions identified as being part of a core network of cue-induced sexual arousal. We will attempt to assign them to the four proposed components of sexual behavior.

The *cognitive component* might be reflected in concurrence observed in the inferior and superior parietal cortex, ACC, and thalamus. Activation in the parietal cortex has been associated with sustained visuospatial attention [26]. In particular, the right parietal cortex has been shown to be part of an interoceptive attention system monitoring bodily states such as heart beat [27]. The increased activation in extrastriate visual cortex could be the result of the automatic attention capture of erotic stimuli [28]. The ACC has been associated with self-monitoring functions. Especially the rostral-ventral affective subdivision of the ACC that we find in our meta-analysis extending close to and extending into the genu of corpus callosum has been shown to be involved in evaluation of emotional information and the regulation of the emotional response [29]. The thalamus has been understood as a hub through which any area of the cortex can communicate with any other area. The function of the thalamus, particularly the lateral geniculate nucleus has been described as a gatekeeper for sensory information [30]. Extensive thalamo-cortical interconnectivity has been theorized to constitute a neuronal basis for conscious awareness and might therefore be implicated in the cognitive dimension of cue-induced sexual arousal [31].

The *emotional component* might be reflected in concurrence found in amygdala and insula. Activation of the amygdala has been shown to be associated with arousal caused by appetitive as well as aversive stimuli [32,33]. Moreover, it has been proposed that the amygdala exerts modulatory influence onto other brain regions involved in visual processing of arousing emotional stimuli [34]. The insula has been understood as a critical neural substrate in conscious emotional experience. Damasio et al. [35] hypothesized in his somatic marker hypothesis that emotional feelings arise when the physiological state is perturbed by an emotional stimulus, as in our case an erotic stimulus. It has been suggested that brain regions that “map” the body, such as the insula, represent these bodily changes elicited by emotional stimuli, and this mapping gives rise to conscious feeling [36]. On the other hand, the insula might be considered as being part of the physiological as well as of the

cognitive component of cue-induced sexual arousal. Craig [37] highlighted the role of the insula in body state representation. He proposed that insula maps the ongoing physiological state of the body and that this process enables conscious interoception, particularly within the right anterior insula [38]. The joint activation of anterior insula and ACC has previously been associated with the experience of pain [37,39]; moreover, anterior insula has been shown to be involved in passionate love [40].

The *motivational component* involves the perceived urge to engage in sexual behavior. This urge could be based on simulation processes and motor imagery when viewing erotic stimuli. It has been shown that watching somebody act automatically provokes a simulation of this action within the motor system of the observer [41]. The so-called mirror neuron system has not only been implicated in the simulation of movement, but has also been proposed as the basis of empathy [42]. The concurrence observed in precentral gyrus as well as in inferior parietal lobe and ACC could be interpreted in the same line because they have been reported to be part of the motor imagery network that could be triggered by the observation of sexual behavior [42]. In order to explore this assumption, we divided the studies of the first meta-analysis according to stimulus modality into those that displayed pictures and those that presented videos. In line with the notion that videos contain more cues for action, we found concurrence in bilateral precentral gyrus only in studies that presented videos, not in studies that presented pictures.

The *physiological component* could be related to concurrence found in the hypothalamus/thalamus and insula (see above). A number of animal studies have linked the hypothalamus to sexual responses. Electrical stimulation of the paraventricular nucleus of the hypothalamus has been shown to elicit erections in rats [43].

To our surprise, we found concurrence in studies correlating brain activity with behavioral measures of sexual arousal in the sensorimotor cortex in postcentral gyrus, but not as hypothesized within regions that represent genitals (which are located medially in the paracentral lobule), but more lateral within regions that represent the viscera, throat, and the tongue and lips. Contrary to some previous studies on cue-induced sexual arousal, we did not find concurrence in orbitofrontal cortex (OFC). Several studies reported activity—predominantly in lateral—OFC and

interpreted it as reflecting evaluation processes [7,8,25]. This inconsistency might be due to the fact that we restricted our meta-analysis to fMRI studies, whereas most studies reporting OFC activation were positron emission tomography studies that are known to be less susceptible to artifacts in the OFC [13,14]. But a previous meta-analysis on electroencephalographic source localization studies on sexual arousal also failed to find evidence for the involvement of OFC [44].

Altogether, one should take into account that the finding that certain brain regions are active when participants view visual sexual stimuli does not necessarily mean that these responses are the cause of sexual desire or sexual arousal; they might well be involved in higher level monitoring processes of these bodily changes.

Therefore, the results of our quantitative meta-analysis on sexual-cue reactivity identifying a neural network consisting of the hypothalamus extending into the thalamus, amygdala, ACC, insula, precentral gyrus, inferior and superior parietal cortex, fusiform, and middle occipital gyrus as the core circuit of cue-induced male sexual arousal in humans should be interpreted as the full spectrum of brain regions involved in cognitive, emotional, motivational, and physiological components of sexual arousal, not as the sole generator of the sexual response.

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Statement of Authorship

Category 1

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(b) Acquisition of Data

Not valid

(c) Analysis and Interpretation of Data

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Category 2

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Category 3

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