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Review

Functional neuroimaging studies of sexual arousal and orgasm in healthy men and women: A review and meta-analysis

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ABSTRACT

In the last fifteen years, functional neuroimaging techniques have been used to investigate the neuroanatomical correlates of sexual arousal in healthy human subjects. In most studies, subjects have been requested to watch visual sexual stimuli and control stimuli. Our review and meta-analysis found that in heterosexual men, sites of cortical activation consistently reported across studies are the lateral occipitotemporal, inferotemporal, parietal, orbitofrontal, medial prefrontal, insular, anterior cingulate, and frontal premotor cortices as well as, for subcortical regions, the amygdalas, claustrum, hypothalamus, caudate nucleus, thalami, cerebellum, and substantia nigra. Heterosexual and gay men show a similar pattern of activation. Visual sexual stimuli activate the amygdalas and thalami more in men than in women. Ejaculation is associated with decreased activation throughout the prefrontal cortex. We present a neurophenomenological model to understand how these multiple regional brain responses could account for the varied facets of the subjective experience of sexual arousal. Further research should shift from passive to active paradigms, focus on functional connectivity and use subliminal presentation of stimuli.

Contents

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1. Introduction

About a hundred years ago, S. Freud started to develop a psychological theory where sexual drives played a key role both in healthy individuals and in psychopathological conditions. Although controverted, psychoanalytical theory has drawn the attention of generations of clinical psychologists, psychiatrists and of some prominent neuroscientists (e.g., Kandel, 1999) to the concept of sexual drives. "By an 'instinct' is provisionally to be understood the psychical representative of an endosomatic, continuously flowing source of stimulation, as contrasted with a 'stimulus', which is set up by single excitations coming from without. The concept of instinct is thus one of those lying on the frontier between the mental and the physical." (Freud, 1905). Later, he wrote: "The deficiencies in our description would probably vanish if we were already in a position to replace the psychological terms by physiological or chemical ones. [. . .] Biology is truly a land of unlimited possibilities. We may expect it to give us the most surprising information and we cannot guess what answers it will return in a few dozen years to the questions we have put to it." (Freud, 1920). It may well be that new insights drawn from functional neuroimaging investigations of sexual arousal (SA) – a method also lying on the "frontier between the mental and the physical" – support Freud's prediction.

SA may be broadly defined as the physical and psychological readiness to perform sexual behavior. Episodes of this psychophysiological state may be triggered by external stimuli or may occur without any apparent external cause. Manifestations of SA may be psychological, e.g., sexual desire, and/or physiological, e.g., genital responses. The highest level of SA reached during any particular episode may vary from a transient desire to maximum level of SA and orgasm. Congruent with the above manifestations, the measurement of the level of SA is based on self-report of psychological manifestations and on objective measurements of physiological responses, e.g., phallometry and vaginal photoplethysmography (Rosen and Beck, 1988).

The new frontier of the scientific investigation of human SA is the identification and understanding of its neural correlates. The human brain is involved in all the successive steps of human sexual behavior, from the assessment of the sexual relevance of external stimuli to the control of sexual behavior (Meisel and Sachs, 1994). A thorough study of the neural underpinnings of human SA is important for both theoretical and practical reasons. From a theoretical standpoint, the understanding of the neural correlates of SA should provide insights into human sexual motivation, human reproductive behavior, and about the processing of sexual incentives, which belong to primary reinforcers. From a practical point of view, a better understanding of the neural mechanisms of SA should contribute to solve public health problems such as sexual disorders and sexual offending. Before the development of brain functional imaging techniques, studies of the cerebral basis of human SA relied for a great part on animal models (Bancroft, 1989; Herbert, 1996; Meisel and Sachs, 1994). However, human sexual behavior has unique characteristics, e.g., sexual imagery, that distinguish it from the homologous behavior in other species. Therefore, studies on human beings are needed to characterize the regions of the brain involved in the species-specific aspects of human SA. A second source of knowledge on the brain basis of human SA has been the study of neurological patients, for instance those presenting epileptic seizures with sexual manifestations, or those presenting sexual symptoms associated with focalized or disseminated lesions (Rees et al., 2007). However, brain lesions are rarely restricted to regions of interest. Instead, many patients have diffuse damage resulting for instance from head trauma or stroke, and their lesions often encompass multiple brain regions. In postmortem studies, "psychological autopsies" are particularly difficult and uncertain in the domain of sexual behavior. Thus, those neurological studies, although useful, have been insufficient to describe the cerebral correlates of SA in healthy individuals. Thirdly, neurosurgery, whether by removing brain lesions or by inadvertently causing them, has provided findings relevant to the understanding of cerebral correlates of human SA (Burns and Swerdlow, 2003; Devinsky et al., 2010; Dieckmann et al., 1988; Freeman, 1973).

In the last decade, modern functional neuroimaging techniques have brought major advances in this domain of research for several reasons. Firstly, being minimally invasive, they may be used both in healthy volunteers and in patients with sexual disorders. Secondly, instead of being limited to the study of some specific areas, as are brain lesion studies, they allow for the study of the whole brain. Thirdly, functional neuroimaging techniques can be used to investigate cognitive aspects of sexual behavior. Finally, technological advances have improved both their spatial and temporal resolutions. The axial spatial resolution of the latest positron imaging (PET) devices is about 2.2 mm. Depending on technical characteristics, the spatial resolution of functional magnetic resonance imaging (fMRI) scanners is about 1–3 mm. PET and fMRI present different temporal resolutions, i.e., about 2–3 s for fMRI and about 1 min for [^{15}O] H_2O PET. Functional neuroimaging techniques have become, for the above reasons, one of the key approaches to understand the brain basis of SA both in healthy subjects and in sexual disorders. At present, 73 published original studies have used these techniques to specify areas that respond to sexual stimuli in healthy human subjects. Thus, this research field is now sufficiently mature for a detailed review to be performed. Hence, the purpose of this study is to review the functional neuroimaging studies of brain regions mediating SA in healthy men and women. Because of space limitations, functional neuroimaging studies of patients presenting sexual disorders, which are an important source of knowledge about the cerebral mechanisms of SA, will be the focus of a separate review.

Because this review showed that the consistency of findings of different studies varied across brain regions, findings were subjected to a meta-analysis, a technique used to identify areas of consistent activation (Turkeltaub et al., 2012).

2. Methods

2.1. Search strategy and selection criteria

We systematically searched peer-reviewed journals indexed in large databases (PubMed, PsychInfo, Ovid, Embase) for English-language published manuscripts of single photon emission tomography (SPECT), PET, fMRI, functional near-infrared spectroscopy and magnetoencephalography (MEG) studies of SA published between January 1994 and May 2010. The databases were searched for the following keywords or expressions: functional magnetic resonance imaging; or positron emission tomography; or magnetoencephalography; or single-photon computed tomography; or near-infrared spectroscopy; or neuroimaging; combined with