

Cerebral Activation Associated with Sexual Arousal in Response to a Pornographic Clip: A ^{15}O – H_2O PET Study in Heterosexual Men

M. Bocher,* R. Chisin,*¹ Y. Parag,† N. Freedman,* Y. Meir Weil,‡ H. Lester,* E. Mishani,* and O. Bonne‡

*Department of Medical Biophysics and Nuclear Medicine/HBRC, Hadassah Hebrew University Hospital, Jerusalem 91120 Israel;

†The Hebrew University-Hadassah School of Medicine, Jerusalem, Israel; and ‡Department of Psychiatry, Hadassah Hebrew University Hospital, Jerusalem, Israel

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This study attempted to use PET and ^{15}O – H_2O to measure changes in regional cerebral blood flow (rCBF) during sexual arousal evoked in 10 young heterosexual males while they watched a pornographic video clip, featuring heterosexual intercourse. This condition was compared with other mental setups evoked by noisy, nature, and talkshow audiovisual clips. Immediately after each clip, the participants answered three questions pertaining to what extent they thought about sex, felt aroused, and sensed an erection. They scored their answers using a 1 to 10 scale. SPM was used for data analysis. Sexual arousal was mainly associated with activation of bilateral, predominantly right, inferoposterior extrastriate cortices, of the right inferolateral prefrontal cortex and of the midbrain. The significance of those findings is discussed in the light of current theories concerning selective attention, “mind reading” and mirroring, reinforcement of pleasurable stimuli, and penile erection.

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INTRODUCTION

“The most important sex organ is . . . the brain.” Laymen and professional therapists alike frequently use this popular aphorism. In spite of such an intuitive notion that links human sexuality to emotional and cognitive brain processes, surprisingly little biological evidence exists that explicitly describes cerebral and especially cortical activation during sexual arousal. Phenomenologically, human sexuality, like some other human behaviors, appears to have a dual nature: on the one hand, a physiological-genital activity and on the other, a fundamental psychological process that is

intricately related to the core of being. Tragic examples of this body–mind dichotomy are observed in men who have suffered injury to the spinal cord: mechanical rubbing of the penis can induce erection and ejaculation even without the patient being aware of the occurrence. On the other hand, such patients may experience “phantom orgasms,” i.e., mental orgasmic experience without any genital occurrence (Comarr, 1970). Using biological methodologies, a large body of data related to the physiology of sexual behavior has been accumulated, mainly, but not exclusively, in animals (Beach, 1952; Everitt, 1990; Pfaus, 1999). This data relates to hormonal and vascular mechanisms as well as to neural modules, primarily at the following sub cortical levels: spinal, midbrain, hypothalamus, ventral striatum, septal nuclei, and the amygdaloid complex. Only scarce and rather crude data exist that are relevant to the cerebral and especially to the cortical role in human sexuality. Most are related to neuropathological or surgical case descriptions, epilepsy manifestations, or EEG studies. So far, the attempts to connect subjective human sexual experience with a simultaneous whole brain, high resolution biological recording have been limited (Tiisonen *et al.*, 1994; Rauch *et al.*, 1999; Stoleru *et al.*, 1999; Redouté *et al.*, 2000). The last two authors, who belong to the same group, also used PET, and the intent of both studies was comparable to ours, although the details of the study design differ.

The recent availability of fMRI and PET potentially allows for such imaging and also for correlation between the imaged data and the reported experience. The aim of our study was to take one of the first steps into this essentially under-explored field. We attempted to use PET and ^{15}O – H_2O to measure changes in regional cerebral blood flow (rCBF) during sexual arousal evoked in young heterosexual males while they watched a pornographic video clip. We present here our results and propose our interpretations of the findings.

¹To whom correspondence and reprint requests should be addressed at the Department of Medical Biophysics and Nuclear Medicine/HBRC (Director: H. Atlan), Hadassah Hebrew University Hospital, P.O.B. 12000, Jerusalem 91120, Israel. Fax: 972-2-6421203. E-mail: chisin@hadassah.org.il.

METHODS

Subjects

The subject group consisted of ten right-handed, heterosexual male students, aged 24–32 (average 27). All participants were physically healthy and did not suffer from any psychiatric illness. They did not use any medications or mind affecting drugs. All volunteers described themselves as being definitely heterosexual and likely to be sexually aroused while watching a pornographic clip featuring heterosexual intercourse. Personal information gathered during the study was kept confidential. The ethical committees of Hadassah Hospital and the Ministry of Health in Israel approved the study and participants signed an informed consent.

Video Clips and Participants Observation Scores

Following the injection of $^{15}\text{O}-\text{H}_2\text{O}$, PET data were acquired under four types of mental conditions, each pertaining to a particular video clip that the participants were shown in the following order: (1) Baseline clip (**B**-condition), presenting a white central cross, surrounded by randomly appearing dots with a white noise auditory background. (2) Nature clip (**N**-condition), showing tropical fish swimming in an aquarium with background music. (3) Talkshow clip (**T**-condition), featuring a conversation between two people. (4) Visual-auditory pornographic clip (**S**-condition), featuring heterosexual intercourse. PET acquisition was performed once for each of the first three conditions followed by three acquisitions during the **S**-condition clip, which the participants watched continuously for half an hour. The same clip sequence was used for all subjects, since it was thought that the brain activation associated with the **S**-condition might be long lasting and therefore cause interference if presented before the “sexually neutral” films. Immediately after each PET acquisition, the participants were asked to answer the following same three questions and to score their answers in the range 1 to 10: (1) To what extent did you think about sex while you watched the clip? (2) To what degree did you feel sexually aroused? (3) Did you sense any erection?

PET Acquisition

Images representing rCBF were acquired on a Positron Corporation HZL/R scanner, with a 16.6 cm axial field of view (covering the whole brain), 6.2-mm in-plane resolution and 6.3-mm axial resolution. Acquired counts were corrected for random coincidences, measured tissue attenuation, scatter, detector sensitivity, dead-time, decay and gantry wobbling. Slices were reconstructed by filtered back projection using a Butterworth filter (order 10, cutoff $.07\text{ mm}^{-1}$) with a 2.57-mm slice thickness.

The PET room was dimly lit and quiet, the participant's head was restrained using a head holder, and interference with his privacy was kept to a minimum throughout the experiment. The video clips were shown on a 14-inch TV monitor, set on a holder above the subject's abdomen. Since the PET gantry limited the participants' field of view, we provided them with prism eyeglasses that redirected the oncoming light rays by 90° , enabling them to watch the video clips while looking straight ahead.

Following a 15-min transmission scan, six $^{15}\text{O}-\text{H}_2\text{O}$ emission scans were performed, one for each condition. While the subject was engaged in watching the pertinent clip, a 925–1110 MBq (25–30 mCi) bolus of $^{15}\text{O}-\text{H}_2\text{O}$ was injected and 20 s later acquisition was started for 1 min. The time interval between injections was 10 min.

Data Analysis

The 1999 version of Statistical Parametric Mapping (SPM) software (Friston *et al.*, 1995), implemented on a Matlab platform, was used for data analysis. In order to allow pixel-by-pixel intersubject statistical analysis, all images were realigned with a generic $^{15}\text{O}-\text{H}_2\text{O}$ PET image that was stereotactically registered to the Montreal Neurological Institute (MNI) brain atlas. Coordinates of interest on this atlas were transformed eventually to the Talairach atlas (Talairach and Tournoux, 1988) coordinate system. Images were smoothed with an isotropic Gaussian kernel with a full width at half maximum of 10 mm and were resampled to a new voxel size of $2 \times 2 \times 2\text{ mm}$. Each image was normalized to the total activity within the brain. In order to avoid analysis of regions belonging to white matter, all pixels whose average counts across all subjects and all conditions were below 80% of the total average pixel count, were eliminated and excluded from evaluation. For all SPM analysis, we used a threshold of $p < 0.001$, equivalent to Z score > 3.09 , uncorrected for multiple sampling, and a cluster size > 50 pixels (400 mm^3), as critical thresholds. Since a preliminary analysis showed no significant difference between the images of the three **S** conditions, those images were treated as one pool for all further subtractive analysis. The SPM subtractive approach was used, employing the PET “multisubject conditions and covariates” model, to find both relative increases and relative decreases in rCBF when the **S** condition was compared to the **B**, **N**, or **T** conditions. Additionally, using the same SPM critical thresholds, we searched for significant regional correlation between the changes in relative rCBF across the seven conditions and the corresponding changes in participants' scoring, for each of the three questions.

TABLE 1
Participants' Observation Scores

Condition	Thinking about sex	Sexual arousal	Erection sensation
B	2.00 (1.89)	1.80 (1.93)	1.00 (0.00)
N	1.60 (1.08)	1.10 (0.32)	1.00 (0.00)
T	2.00 (1.56)	1.50 (0.97)	1.10 (0.32)
S	8.47 (1.16)	7.53 (1.67)	5.1 (2.13)

Note. Average and (standard deviation) of participants' observation scores.

RESULTS

Table 1 summarizes the scored answers participants gave to the three questions following each of the four types of mental conditions. A paired *t* test analysis showed that the **S** condition scores were significantly higher ($p < 0.001$) than the scores of any of the other three conditions **B**, **N**, and **T**.

Tables 2–4 highlight the significantly activated brain areas resulting from the subtractive approach of SPM, comparing the **S** condition to the **B**, **N**, and **T** conditions, respectively. Relative increases and decreases in rCBF, during the **S** condition, are portrayed in Figs. 1 and 2, respectively. Table 5 and Fig. 3 demonstrate the regions with significant correlation, across the 10 subjects, between the changes in relative rCBF across the six conditions and the corresponding changes in participants' scoring for questions 1 to 3.

In general, the **S** condition was characterized by bilateral widespread activation of the inferior lateral occipital and posterior temporal cortices, associated with the extrastriate visual brain areas. This was observed with minor variations when the **S** condition was compared to all three other mental conditions. The phenomenon was more prominent in the right hemisphere. Other activation areas were the right inferior lateral prefrontal cortex (**S** – **B**), left superior post central gyrus (**S** – **B**), right inferior parietal lobule (**S** – **N**), and left superior and inferior parietal lobules (**S** – **T**). The correlation of rCBF and the scores of sexual arousal (Table 5 and Fig. 3) pointed again to the extrastriate cortices and to the left postcentral gyrus and in addition revealed significant activation in the midbrain (Figs. 3 and 4) and in the frontal pole (Brodmann area 10) of the left prefrontal cortex (Fig. 3).

Relative rCBF decreases during the **S** condition were noted bilaterally in the medial prefrontal/anterior cingulate areas, posterior cingulate, and posterior aspects of the superior prefrontal areas and in addition in the right medial orbitofrontal area.

DISCUSSION

When we planned and launched the project, our initial objective was to perform groundwork, exploratory study with only a vague prior conjecture, regarding brain areas that we expected to see activated. This reflected our overall impression regarding the paucity

TABLE 2
Changes in rCBF between S and B Conditions

Brain region	<i>X</i>	<i>Y</i>	<i>Z</i>	<i>Z</i> score	Cluster size
S minus B					
Left occipitotemporal gyrus	–38	–74	–10	6.61	984
<i>Left inferior temporal gyrus</i>	–47	–68	0	5.53	
<i>Left medial occipital gyrus</i>	–32	–80	10	3.5	
Left inferior occipital gyrus	–24	–97	–5	4.75	398
Left superior postcentral gyrus	–29	–37	42	4.95	234
Right medial occipital gyrus	45	–74	–6	7.87	2021
Right superior parietal lobule	34	–60	47	3.51	53
Right inferolateral prefrontal cortex	36	21	8	4.24	77
B minus S					
Left posterior cingulate gyrus	–10	–50	30	4.20	300
Left middle frontal gyrus	–32	16	46	4.23	59
Right posterior cingulate gyrus	10	–54	6	4.5	522
<i>Right cuneus</i>	15	–68	0	3.5	
Right middle frontal gyrus	19	29	47	4.05	59
Right medial prefrontal/A. Cingulate	6	37	10	3.94	238
<i>Left medial prefrontal/A. Cingulate</i>	–1	43	21	3.82	
Right medial orbitofrontal cortex	1	12	–12	3.46	84

Note. Brain clusters with above threshold significant change in relative rCBF during the pornographic clip (S) compared to the baseline condition (B). Cluster size is given in pixels. For each cluster, the anatomical regions, *Z* score, and the Talairach coordinates (*X*, *Y*, *Z*) of the pixels with the highest *Z* score are given. The positive direction of *X* is to the right of midline, of *Y* is anterior to the anterior commissure, and of *Z* is superior to the bicommissural plane. Locations printed in italics refer to additional maxima within the same cluster that is printed above them. The table describes both relative rCBF increases ("sex minus baseline") as well as decreases ("baseline minus sex").

TABLE 3

Changes in rCBF between S and N Conditions

Brain region	X	Y	Z	Z score	Cluster size
S minus N					
Left occipital temporal gyrus	-40	-76	-10	4.80	461
Left occipital temporal gyrus	-50	-66	-4	4.78	
Right occipital gyrus	26	-85	25	3.83	97
Right medial temporal gyrus	47	-58	2	5.86	1528
Right medial occipital gyrus	48	-74	-10	4.85	
Right occipital temporal gyrus	45	-66	-14	4.82	
Right superior parietal lobule	34	-56	41	3.58	56
N minus S					
Left medial temporal gyrus	-48	4	-20	3.96	50
Left superior temporal gyrus	-45	-8	-3	3.77	85
Left lateral sulcus	-50	-8	10	3.20	
Right posterior cingulate gyrus	12	-56	7	3.95	61
Right posterior superior frontal gyrus	13	23	52	4.00	183
Right superior temporal gyrus	52	-4	-4	4.08	86
Right medial aspect frontal lobe	1	52	20	3.95	187
Right anterior superior frontal gyrus	4	56	25	3.73	

Note. Brain clusters with above threshold significant change in relative rCBF during the pornographic clip (S) compared to the nature clip condition (N). See Table 2 for details.

of unambiguous knowledge relating directly to the subject.

The similarities between the findings of Stoleru *et al.* (1999) and our results support the existence of definite patterns of brain activation related to sexual arousal elicited by a pornographic clip. A major difference between our study and theirs was the more than twice larger (16.6 vs 7.2 cm) axial field of view of our PET scanner, enabling us to see brain regions higher than 4 cm above the bicommissural line, not covered by their scanner. Recently, another study was published by the same group (Redouté *et al.*, 2000) that differed significantly both from their original work and from ours. Major differences were the higher resolution of the

PET scanner, three-dimensional acquisition, an older patient cohort and stimuli that included both still pictures of women as well as clips of heterosexual intercourse. The most significant cognitive difference is probably the time that elapsed between the start of the sexual clip presentation and acquisition: 60 s in Redouté *et al.* (2000), 6 min in Stoleru *et al.* (1990), and three acquisitions during 30 min continuous watching, with scans at 10, 20, and 30 min in our study.

We shall now review the most prominent brain areas associated with sexual arousal in our study and try to elucidate their neurocognitive significance. It should be noted that in this study relative and not absolute changes in rCBF are discussed throughout. In a situ-

TABLE 4

Changes in rCBF between S and T Conditions

Brain region	X	Y	Z	Z score	Cluster size
S minus T					
Left inferior occipital gyrus	-41	-80	-6	4.97	420
Left inferior temporal gyrus	-45	-66	0	3.80	
Left superior parietal lobule	-27	-56	48	4.36	232
Left inferior parietal lobule	-31	-43	43	3.45	
Right medial occipital gyrus	27	-80	3	4.09	181
Right inferior occipital gyrus	40	-81	-10	4.08	297
T minus S					
Left superior temporal gyrus	-55	-23	2	5.57	2387
Left medial temporal gyrus	-48	4	-20	5.14	
Left medial aspect frontal lobe	-1	54	27	4.26	184
Right superior temporal gyrus	52	-6	-3	6.06	3024
Right medial temporal gyrus	59	-27	2	5.73	52
Right inferior temporal gyrus	48	-8	-20	5.85	

Note. Brain clusters with above threshold significant change in relative rCBF during the pornographic clip (S) compared to the talk show condition (T). See Table 2 for details.

ation where there may be changes in global CBF, e.g., in response to sexual arousal, interpretation of changes in relative rCBF may not be simple, since if global CBF increases, areas with less increase in rCBF may be classified as areas with decreases.

Extrastriate visual cortices and left postcentral gyrus. During the S condition, after which subjects reported having been sexually aroused, wide regions of significant brain activation were detected bilaterally in the extrastriate visual cortices. The wide activation seen included and tended to circumscribe the human visual motion area, human area V5 (Watson, 2000). Our findings replicate those of Stoleru *et al.* (1999). The entirety of the activated regions is known to consist of modules associated with several aspects of visual processing.

Phenomenologically, arousal in response to a sexually explicit clip implies concentration on the clip and attention to the inner emotional response experienced usually as a pleasurable reinforcing occurrence. Within this phenomenological context, it is interesting to compare our findings to numerous neuroimaging studies that have shown that the degree of activational response of the extrastriate system, to apparently similar visual inputs, may vary according to the context. The level of attention is one of the best-described factors influencing the response (Corbetta *et al.*, 1990, 1991; Heinze *et al.*, 1994; Woodruff *et al.*, 1996; O'Craven *et al.*, 1997). Corbetta *et al.* (1990, 1991) showed that neural activity as measured by rCBF PET was increased in the extrastriate areas as a function of focused attention toward specific features of visual stimuli. The areas identified in this top-down activation were in concordance with the results of earlier bottom-up PET paradigms that used simple visual stimuli without attentive anticipation. Recently, the same group reviewed evidence from a number of studies for top-down effects on sensory cortex (Shulman *et al.*, 1997). One way to interpret such findings, as well as ours and that of Stoleru, would be to assume that perception is recruited by a hierarchically separate cognition system, working through a dedicated attention module activating visual processing. In the context of sexual arousal, this would imply the recruitment of a dedicated attentional subsystem by a supervising network (e.g., the limbic-paralimbic system) that assesses the relevance of stimuli and provides emotional responses. An alternative way to interpret this preferential increase in rCBF in the extrastriate cortex is that the activation emerges in a bottom-up fashion, as a result of the cooperativity of multiple, single, predominantly local, visual modules. The same network might be utilized also in situations of sexual intercourse or involving visual memory and imagery of sexual events. Deciding which of the two approaches is closer to the neurobiological truth is far beyond the

limitations of our preliminary study, but the relative lack of activation in central classical limbic structures in our study may tilt the balance slightly towards the second interpretation. It is also possible that the extrastriate activation observed results from both top-down and bottom-up mechanisms. The activation we, as well as Redouté (2000), found in the posterior part of the left postcentral gyrus can be explained in a similar way.

We should also consider the possibility that the strong signal received in the extrastriate visual cortex is related to a difference in visual processing between the S condition and each of the other three conditions and not to sexual arousal. Perhaps a clip of human dyads engaged in non-sexual manner like dancing, fencing or wrestling could have provided a better control for the S condition in our study. Such a view is supported to some extent by the conclusions of Redouté *et al.* (2000). They reported similar activation of the same area during both sexual arousal and humorous conditions.

Our results indicate that the right extrastriate cortex showed stronger activation compared to the left, in terms of both signal intensity and cluster size. Stoleru *et al.* (1999) also found the same asymmetry. In an EEG study by Tucker and Dawson (1984), professional actors recalled experiences in order to create emotional states of sexual arousal or depression. Greater right hemispheric activation was observed for sexual arousal and analysis of coherence topography showed greater coherence in right central and posterior regions for the sexual arousal condition. Similar EEG right hemispheric preponderance was noted during self-stimulation orgasm provoked in healthy volunteers (Cohen *et al.*, 1976). It has been proposed (Weintraub and Mesulam, 1987), that the right hemisphere is equipped with neural mechanisms to attend to both visual fields, while the left hemisphere attends predominantly to the right visual field. Moreover, studies of split-brain patients (Sperry, 1996; Bogen, 1969; and Gazzaniga, 1970) suggest the possible coexistence of two independent consciousness systems, one in each hemisphere. In respect to visual processing, it is suggested that the right hemisphere preferentially processes the global aspect of complex visual scenes, while local aspects are preferentially processed by the left hemisphere (Rafal and Robertson, 1995; Fink *et al.*, 1996). Interestingly, a later study by Fink *et al.* (1997) suggests that this global/local laterality effect could change sides depending on stimulus category. Kosslyn (1987) made a distinction between categorical and self-referential spatial coordinate representations of objects and successfully tested the hypothesis that the left and right hemispheres respectively preferentially contribute to each representation mode (Kosslyn *et al.*, 1989). It may be inferred from all of the above that the preferential right hemispheric activation we observed reflects a relative bias of attention towards

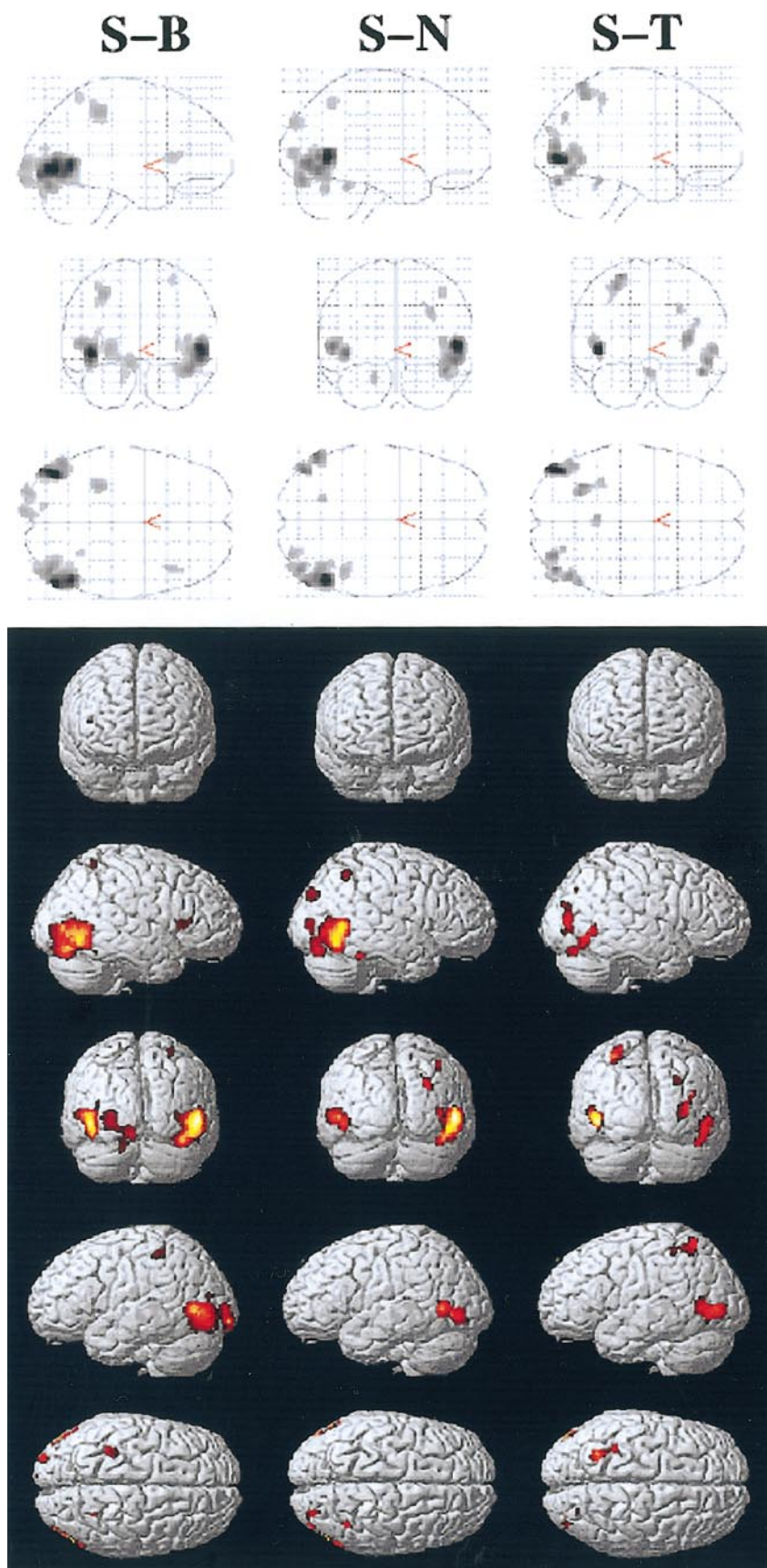


FIG. 1. Clusters with significant, above threshold, relative increases of rCBF during the S conditions, compared to the B, N, and T conditions (columns 1, 2, and 3, respectively). The upper three rows show the areas projected into an MNI atlas coordinate diagram. Top to bottom: sagittal, coronal, and transaxial planes. The lower five rows show the areas projected into a three dimensional surface rendering of the same atlas. Top to bottom: anterior, right lateral, posterior, left lateral, and top views.

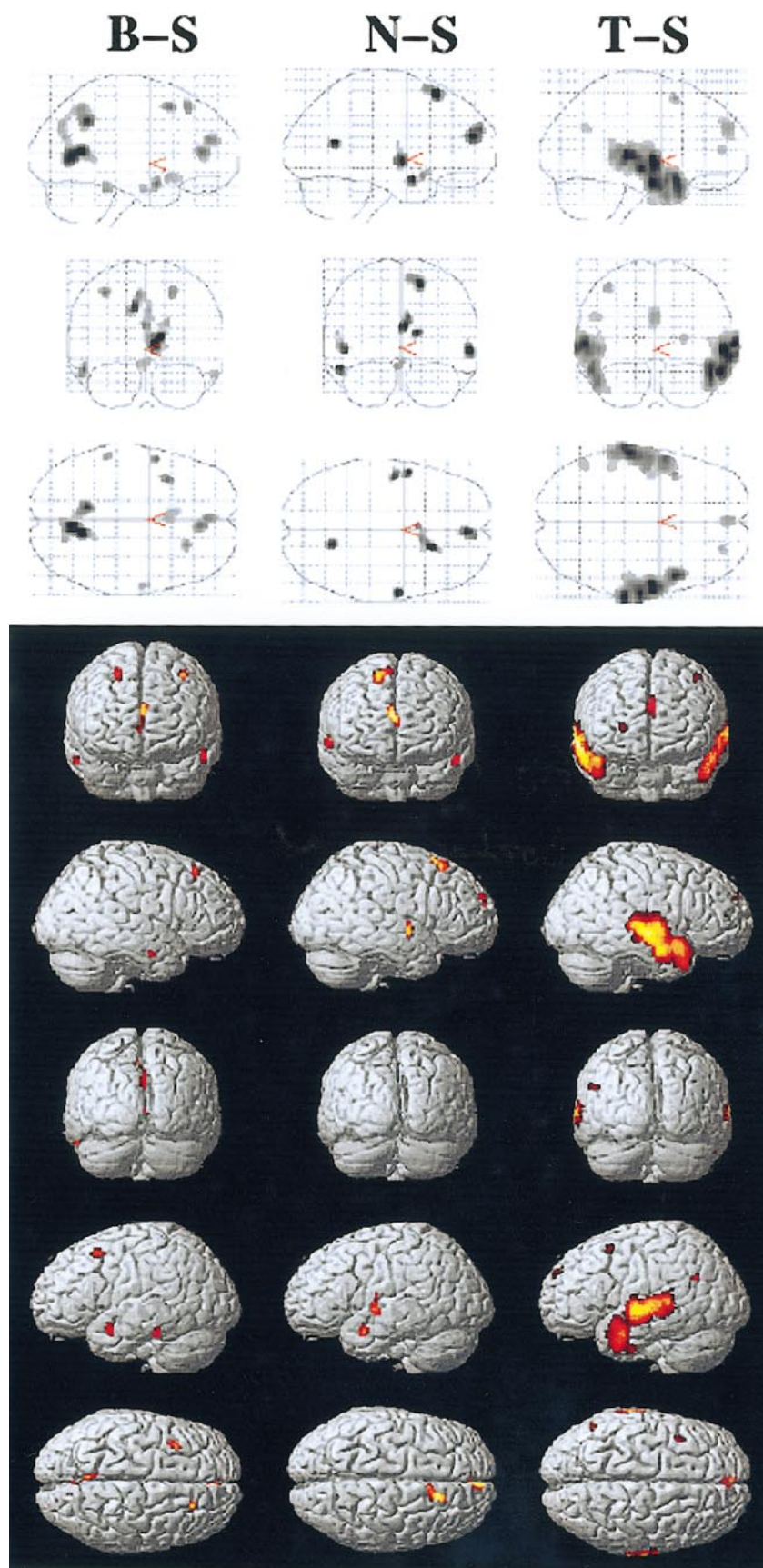


FIG. 2. Clusters with significant, above threshold, relative decreases of rCBF during the S conditions, compared to the B, N, and T conditions (columns 1, 2, and 3, respectively). For details see the legend to Fig. 1.

TABLE 5

Correlation between rCBF Increases and Participants' Scoring

Brain region	X	Y	Z	Z score	Cluster size
Thinking about sex					
Left medial occipital gyrus	-40	-76	-6	5.11	887
Left inferior temporal gyrus	-48	-66	1	4.36	
Left postcentral gyrus	-54	-27	21	4.08	125
Right medial occipital gyrus	47	-60	-5	6.03	2173
Sexual arousal					
Left inferior occipital gyrus	-38	-76	-3	5.07	721
Left inferior temporal gyrus	-48	-64	0	4.24	
Left occipitotemporal gyrus	-40	-64	-16	3.33	
Left postcentral gyrus	-54	-27	21	3.74	98
Right medial occipital gyrus	47	-58	-3	5.67	2071
Right inferior occipital gyrus	34	-83	-3	4.52	
Middle midbrain	3	-21	-19	4.02	71
Sensation of erection					
Left medial frontal gyrus	-31	58	15	5.17	88
Left postcentral gyrus	-54	-25	21	4.46	231
Left medial occipital gyrus	-48	-58	-5	4.26	229
Left inferior temporal gyrus	-24	-87	0	3.74	129
Left cuneus	-27	-91	5	3.66	
Right inferior temporal gyrus	47	-60	-9	4.40	680
Right occipitotemporal gyrus	36	-62	-11	4.09	
Midbrain	3	-19	-19	4.28	108
Right inferior occipital gyrus	31	-81	-1	4.02	174

Note. Brain clusters with above threshold significant correlation between increases in relative rCBF and participants' scoring. See Table 2 for details.

processing global features in a self referential spatial coordinate representation of a moving, complex, visual scene. However, such a conjecture is only speculative. Specific, carefully designed paradigms are needed to test it.

Right inferolateral prefrontal cortex. A further phenomenological analysis of the specific nature of sexual arousal associated with our **S** condition, lead us to look for neuro-functional correlates of two facets of cognition that may be present in our study design: *Theory of mind* and *Mirroring*. Our participants' sexual arousal was provoked by watching movie actors engaged in sexual intercourse and not through direct sexual encounter with a real partner. *Theory of mind* or "mind reading" is an attribute of consciousness that enables humans (and also animals, see Premack and Woodruff, 1978; Premack, 1988; Brothers, 1995) to ascribe to others mental states such as emotions, thoughts, goals or beliefs. It is often used to explain the presumed deficit in autism (Frith *et al.*, 1991; Baron-Cohen *et al.*, 1993). Essentially, two not mutually exclusive theories were proposed to explain such phenomena. One theory assumes that people use implicitly known causal and/or explanatory laws to infer the relationship between observed stimuli, mental states and behavior (Astington *et al.*, 1988). The other asserts that people attribute mental states to others by using their own mental mechanism to simulate another's mental state (Carruthers and Smith, 1996). Both hypotheses are

compatible with the possibility that the neural correlate for modeling other minds is located in the frontal cortex. However, Gallese and Goldman (1998) have suggested that the second hypothesis may predict the participation of the inferior frontal cortex as the neural substrate of mind reading. SPECT (Baron-Cohen *et al.*, 1994) and PET (Fletcher *et al.*, 1995) studies, based on mind reading paradigms, have shown specific activation in areas adjacent to the inferior frontal cortex. In our study, sexual arousal is happening during the **S** condition without direct tactile stimulation, but rather through affiliation with the alleged mental state of the clip actors. Therefore, it is interesting to note the tandem activation of the bilateral extrastriate visual cortex with the right lateral inferior frontal cortex (Table 2 and Fig. 1). The significance of our finding is strengthened by the fact that it is a replication of that found by Stoleru *et al.* (1999) and similar findings were also reported by Redouté *et al.* (2000). This observation is in agreement with the second hypothesis of theory of mind and also with the prediction of lateral inferior frontal activation based on neurobiological data concerned with *Mirroring*. *Mirroring* is a neurobiological concept predicting the existence of neural modules that are based on a direct link between perception and action and provides a common substrate for mapping between observed movement and movement execution. Such a system may support abilities such as theory of mind (Gallese and Goldman, 1998) and imitation

(Meltzoff and Moore, 1997), both essential for learning and social interactions (Piaget, 1962). "Mirror neurons," found in the inferolateral frontal cortex of the monkey, fire similarly, both when the monkey grasps an object and when it sees the same action executed by another. Those neurons are not activated when the monkey simply sees the object without an action performed (Gallese *et al.*, 1996; Rizzolatti *et al.*, 1996a, 1998). Evidently, these neurons seem to play a role in a system that matches the observation and the execution of behavior. It has been suggested (Gallese and Goldman, 1998), that some of the neural components subservient to the capacity of mind reading in humans are phylogenetically evolved from the mirror neurons found in the monkey. PET studies (Rizzolatti *et al.*, 1996b; Grafton *et al.*, 1996), using execution and observation of object grasping, showed the activation of the left inferolateral frontal cortex (in addition to other areas) during observation of grasping but not during execution. It is interesting that imagery of grasping also caused activation of the same area (Grafton *et al.*, 1996). Phenomenologically speaking, sexual arousal provoked by watching actors perform sexual intercourse resembles a mirroring phenomenon. Mirroring, most likely, implies that the subject's sexual arousal while watching the dyadic interaction happens through the perspective of the male figure, although in theory a male may also have the neural capacity to mirror female actions and state of mind. However, one should also consider an alternative mechanism of arousal through a response to the female figure as a powerful stimulus in its own right. Such mechanism of arousal may be similar to the "cephalic phase" of appetitive response to food stimulus, i.e., without "reading the mind" of the food . . . Interestingly, Redouté *et al.* (2000), presenting both intercourse clips as well as motionless female figures of graded sexual intensity, found strong activation of the right orbitofrontal cortex during clip watching but not during watching the highly arousing but motionless female. Nevertheless, they did observed activation in the same area when the female figures were only moderately arousing. On the other hand, evidence suggests that the orbitofrontal cortex is activated in response to three types of primary reinforcers: smell, taste, and pleasant touch (Francis, 1999). It seems that future studies with meticulously designed paradigms are needed in order to estimate the neurocognitive significance of the difference between stimuli that have "automated" appetitive qualities, similar to food, and stimuli that possibly invoke "mind reading" through some form of mirroring. The activation of the right inferolateral frontal cortex in our study as opposed to the left, reported in the above-mentioned mirroring PET experiments, is noteworthy. This could be explained by the fact that right hand grasping is likely to preferentially activate the left hemisphere, while sexual arousal, as discussed before,

shows preponderance toward right hemispheric activation.

Midbrain. Correlation analysis, across the 10 subjects, between the changes in relative rCBF across conditions and the corresponding changes in participants' scoring, revealed additional activation in the midbrain particularly in respect to erection sensation (Table 5, Figs. 3 and 4). The midbrain is a relatively small region, surrounded by CSF and contains a large proportion of white matter. Moreover, cardiac related pulsatile brainstem motion might introduce further difficulty in mapping this structure (Guimaraes *et al.*, 1998). The very fact that a significant signal is detected in spite of all those limitations and the SPM filtering mechanisms, indicates that the original signal related to sexual arousal and erection sensation in the midbrain was probably very strong. This may be related to three types of neural connections:

1. The midbrain is the storehouse of dopaminergic (DA) neurons, located in the substantia nigra and in the ventral tegmental area, their axons dividing extensively, thus exerting their influence throughout the striatum, the limbic system and the cerebral cortex. In particular, the mesolimbic DA system appears to activate behavior in response to sensory cues that signal the availability of incentives or reinforcers. The terminal buttons of the mesolimbic DA neurons are located in the forebrain: nucleus accumbens (ventral striatum), amygdala, lateral septum, hippocampus, and the bed nucleus of stria terminalis. Midbrain DA neurons fire bursts of activity, brought about by cortically regulated afferents in response to sensory stimuli. The activity bursts give rise to a supra-additive release of dopamine and thus convey motivationally relevant information to the forebrain. In this respect, it is noteworthy that a variety of DA manipulations in the ventral striatum profoundly affect the display of appetitive elements of male sexual behavior in animals, yet, interestingly, they do not affect copulatory behavior (Everitt, 1990). For example, a marked increase in DA levels was detected in the nucleus accumbens of a male rat, when a female was introduced to him behind a wire screen. This elevated level was maintained during intromission but was reduced substantially on ejaculation, rising again immediately before the next copulatory act (Phillips, 1989).

2. The DA afferents from the midbrain to the medial preoptic nucleus (MPA) of the hypothalamus were shown to be essential for consummatory behavior of intromission and ejaculation (Hull, 1995).

3. The midbrain is also a station between the hypothalamus and the peripheral and autonomic nervous systems. It transmits somatosensory information from the genitals to the MPA via its reticular formation cells and connects the hypothalamus with autonomic centers via the periaqueductal gray matter.

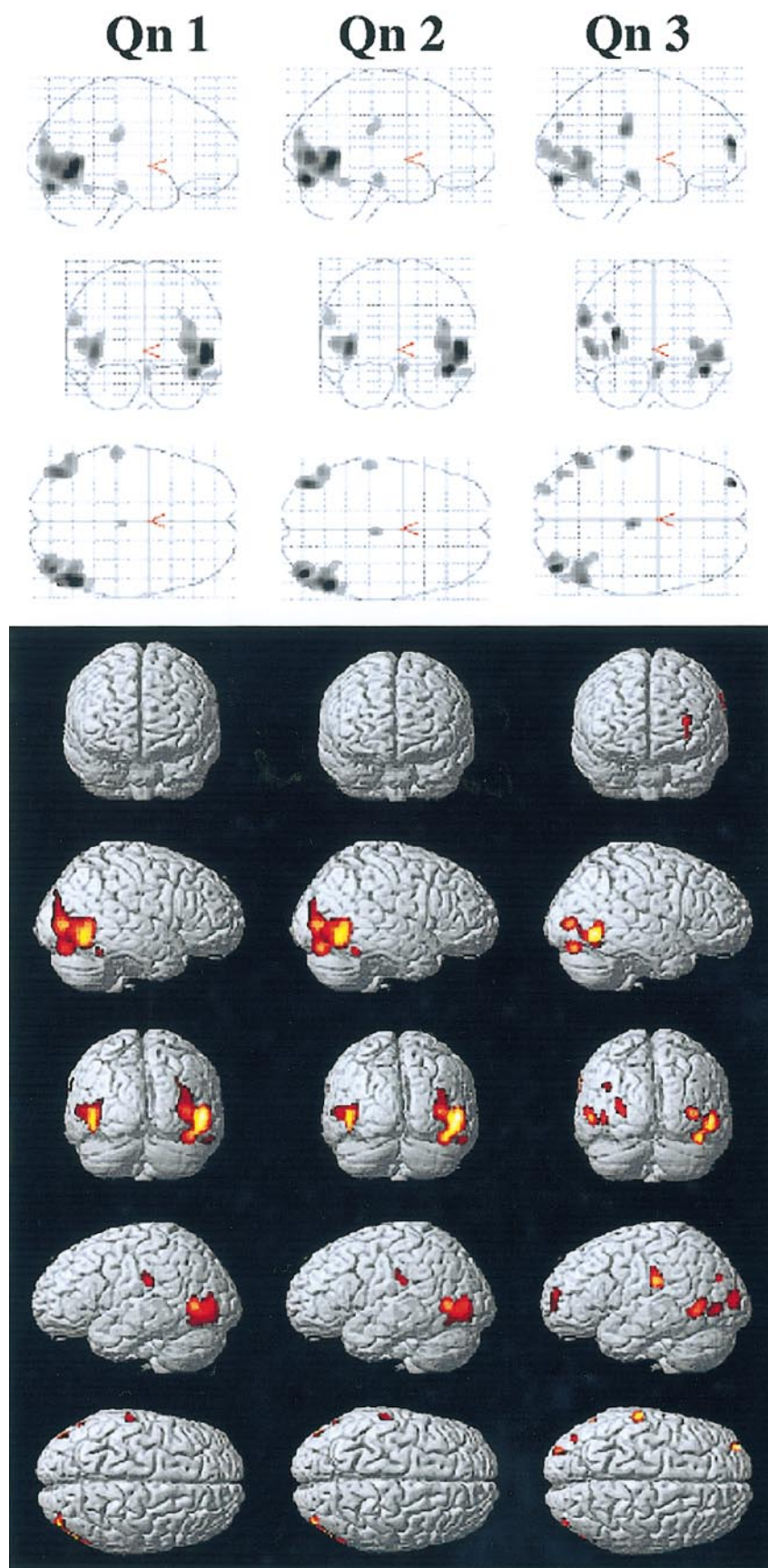


FIG. 3. Clusters with above threshold significant correlation between increases in relative rCBF and participants' scoring. Columns 1, 2, and 3 pertain to questions 1, 2, and 3, respectively. For details see the legend to Fig. 1.

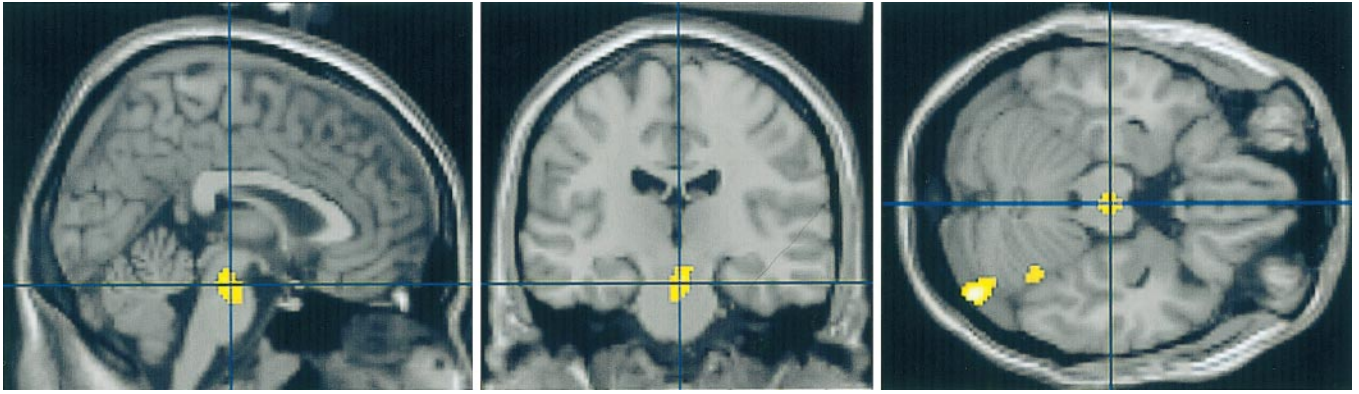


FIG. 4. Midbrain activation: above threshold significant positive correlation between midbrain rCBF and participants' scoring for erection sensation. The center of the cluster is located in the tegmentum.

Interestingly, Redouté *et al.* (2000) observed significant activation associated with sexual arousal in the striatum, including nucleus accumbens and the posterior hypothalamus. They did not report significant activation in the midbrain. The difference in our findings may be explained, in part, by the superior resolution and sensitivity of their scanner, but also by the brief exposure to the stimulus in their study as compared to the continuous 30-min stimulation in ours. It is possible that a signal in the midbrain dopaminergic system can be noted only after prolonged provocation, while the nucleus accumbens is rapidly adjusted via its strong cortical glutaminergic interactions. It would be interesting to investigate the correlation between relative rCBF and the corresponding changes in participants' scoring within the **S** condition, since the correlation analysis we performed across all conditions does not take into account the possibility that the effect might be nonlinear over the different conditions. However, since the participants were a homogeneous group with very similar responses, and the stimuli were identical over the three scans in the **S** condition, the data from the current study did not have the variability, which would lend itself to a linear correlation analysis only within this condition.

The limbic system and areas showing relative rCBF decrease. The above-mentioned regions activated during the **S** condition are known to be connected to the limbic system. However, the absence of significant increases in rCBF in our study in central limbic structures like the amygdaloid complex, the medial temporal, orbitofrontal and medial frontal cortices and in the anterior cingulum, is remarkable and needs to be discussed. In fact, a decrease in relative rCBF in the medial aspect of the frontal lobes and in neighboring anterior cingulate cortex was registered during the **S** condition in comparison with any of the other conditions (Fig. 2 and Tables 2–4). The amygdala plays a special role in physiological and behavioral responses to biologically relevant situations. The amygdaloid

complex receives multimodal sensory input, as well as input from the hippocampal formation, the thalamus and the association cortices; it relays processed information to the ventral striatum, hypothalamus, autonomic brain stem areas, and the prefrontal cortex (Pitkaenen *et al.*, 1995). The lack of activation in the amygdala may be attributed to limited sensitivity of our methods and may also be related to our study design. Our participants watched the pornographic video clip for 30 min and the first PET acquisition during the **S** condition happened 10 min into the film. Habituation of the signal in the amygdala might have occurred in the meantime. Habituation of the response to emotionally laden visual stimulation in the amygdala in the course of an fMRI study was demonstrated recently (Breiter *et al.*, 1996).

The relative decreases in rCBF, in the medial frontal/anterior cingulate cortices in the **S** condition contrasted with **B**, may be related to the phenomenological conflict between becoming sexually aroused and the technical and social impossibility to consequentially enact upon such arousal during the 30 min of watching the pornographic clip. The clips associated with the other conditions were more neutral and lasted less than 10 min. A functional heterogeneity is attributed to the anterior cingulate cortex with a major division between “affect” and “cognition-motor execution” components. It is possible that the decrease in blood flow is the overall result of emotional activation on the one hand and the inhibition of the consequential motor response on the other. It is also possible that a habituation-based learning has occurred. A recent study showed that anticipating an unpredictable and unlearned pain stimulus activated the right anterior cingulate cortex and the ventromedial prefrontal cortex, while anticipating a learned pain-stimulus resulted in decreased activity in those very same regions (Hsieh *et al.*, 1999). Again, the difference between our findings and those of Stoleru *et al.* (1999) and Redouté *et al.* (2000) may be related to the significant differences in

the time of exposure to the sexually arousing stimuli between the three studies.

CONCLUSIONS

Sexual arousal, as provoked in our study, was associated mainly with bilateral activation of the inferoposterior extrastriate visual cortices with right predominance, of the right inferolateral prefrontal cortex, and of the midbrain. Those areas are known to participate in networks responsible for the emergence of phenomena like selective attention, mind reading, mirroring, reinforcement of the response to pleasurable stimuli, and penile erection. All those phenomena are relevant to the paradigm of sexual arousal used in our study. In this essentially unexplored field, those conjectures remain speculative and require meticulously designed studies in order to test them.

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