Sexual motivation is reflected by stimulus-dependent motor cortex excitability

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Sexual behavior involves motivational processes. Findings from both animal models and neuroimaging in humans suggest that the recruitment of neural motor networks is an integral part of the sexual response. However, no study so far has directly linked sexual motivation to physiologically measurable changes in cerebral motor systems in humans. Using transcranial magnetic stimulation in heterosexual and homosexual men, we here show that sexual motivation modulates cortical excitability. More specifically, our results demonstrate that visual sexual stimuli corresponding with one’s sexual orientation, compared with non-corresponding visual sexual stimuli, increase the excitability of the motor cortex. The reflection of sexual motivation in motor cortex excitability provides evidence for motor preparation processes in sexual behavior in humans. Moreover, such interrelationship links theoretical models and previous neuroimaging findings of sexual behavior.

Keywords: sexual motivation; cortical excitability; transcranial magnetic stimulation; motor evoked potentials

INTRODUCTION

Sexual behavior involves a state of sexual excitement induced by preferred sexual stimuli. Based on neuroimaging studies investigating neural networks for sexual stimulus-driven processing, a neurobehavioral model of sexual arousal proposed autonomic, cognitive, emotional and motivational components (Stolér et al., 2012). This neurobehavioral model is commensurate with an information processing model that distinguishes between automatic, pre-attentive stages of stimulus appraisal and subsequent emotional and motivational states (Janssen et al., 2000). A comprehensive theoretical framework for sexual motivation, arousal and behavior integrates biological and cognitive-emotional aspects by focusing on the pathway between incentive and response (Toates, 2009). It follows incentive motivation theories and highlights that sexual motivation emerges from an interaction of external incentives and internal states (Singer and Toates, 1987). In this context, motivation directs thoughts and behavior to a sexual goal, including the perceived urge to express sexual behavior (Stolér, 2014), and is mediated by cortico-basal ganglia loops (Tanaka et al., 2004; Künn and Gallinat, 2011; Stolér, 2014). The notion of motivation representing an integral part of sexual behavior is endorsed by meta-analytic evidence for the recruitment of basal ganglia and cerebral motor regions during sexual stimulation (Stolér et al., 2012; Poeppl et al., 2014). In this regard, it has also been noted that the functional neuroanatomy of sex is remarkably similar to that of other incentives such as food (Georgiadi and Kringelbach, 2012). Moreover, animal research suggests that generalized brain arousal characterized by increased motor activity and responsivity to sensory stimuli impacts sexual behavior (Weil et al., 2010).

Cortical excitability depends on cortical arousal level (Fischer et al., 2008) and is modulated by motivational states particularly within the motor system (Kapogiannis et al., 2008; Gupta and Aron, 2011). Importantly, no study has as yet investigated the link between sexual motivation and cortical excitability in the motor system. Therefore, this study sought to test the hypothesis that sexual motivation induced by appropriate sexual stimuli is reflected by changes in excitability of the motor cortex. Motor-evoked potentials (MEPs) are electromyographic markers for motor cortex excitability and can be non-invasively elicited by single pulses of transcranial magnetic stimulation (TMS) over the corresponding area of the motor cortex. More specifically, a single TMS pulse over the motor cortex induces electric currents in the brain that can depolarize neurons. Transsynaptically, the excitation propagates via pyramidal motor neurons to the periphery and finally results in a contraction of corresponding muscles contralateral to the stimulated motor cortex, which can be recorded as MEP by surface electrodes (Hallett, 2007; Rossini and Rossi, 2007). The amplitude of the MEP hence represents an aggregate measure of the excitation state of efferent cells in the motor cortex (Rothwell et al., 1991; Wassermann and Zimmermann, 2012). Alterations in cortical excitability have been demonstrated in clinical populations (for a review see Bunse et al. (2014)) and also following therapeutic interventions (Frank et al., 2014; Schecklmann et al., 2014). In addition, cortical excitability has been shown to depend on cognitive and emotional mental states including motivation (Gupta and Aron, 2011; Klein et al., 2012; Borgomaneri et al., 2014). We used TMS-induced MEP measurements during visual sexual stimulation in healthy heterosexual and homosexual men to assess the relationship between cortical excitability and stimulus-induced sexual motivation. Subjects were presented with non-explicit but sexually arousing pictures and neutral control pictures, while motor cortex excitability was measured (Figure 1). After the experimental procedures, pictures were rated with respect to emotional valence, sexual arousal and sexual urge.

MATERIALS AND METHODS

Subjects

For this study, we recruited 23 heterosexual and 17 homosexual healthy men without any record of psychiatric or neurological disorders, who fulfilled the safety criteria for TMS. All participants were examined by a trained psychiatrist and completed a screening standard questionnaire assessing eligibility for TMS (Rossi et al., 2009). Subjects...
with past or current psychiatric or neurologic disorders did not enter the study. Similarly, candidates taking any medication or with contraindications for TMS were not eligible. Participants’ sexual orientation was self-reported using the Sell Assessment of Sexual Orientation (Sell, 1996), which revealed a clear distinction between groups with mean scores of 7.6 ± 1.2 SD for the heterosexual and −4.8 ± 2.8 for the homosexual participants (positive values indicate heterosexual, while negative values indicate homosexual orientation; \( P < 0.001 \)). All subjects were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). Both groups were comparable [mean (M) ± SD] with respect to age (years; 23.7 ± 3.1 vs 24.7 ± 4.2), intelligence (IQ; 109.0 ± 17.3 vs 115.4 ± 14.0) (Oswald and Roth, 1987), and days since last sexual intercourse (30.4 ± 48.0 vs 26.5 ± 39.8) and masturbation (11.4 ± 37.8 vs 2.2 ± 2.5) (all \( P \)-values > 0.232). There were also no differences with respect to days since last sexual outlet (4.2 ± 8.3 vs 1.3 ± 1.2; \( P = 0.166 \)).

All participants gave written informed consent after comprehensive explanation of the procedures. The study was approved by the ethics committee at the University of Regensburg.

**Paradigm**

Subjects were presented with 120 non-explicit but sexually arousing pictures and 60 neutral control pictures during the experimental session. Sexual stimuli comprised 60 photographs of adult females and 60 photographs of adult males. The images had an identical background color and black bars covering the genitalia (Santtila et al., 2009). Neutral pictures had been generated from a random selection of half of these (30 female and 30 male pictures) with a Fourier transformation, scrambling the figural shapes but keeping the amplitude spectrum and the overall color appearance of the images (Näsänen, 1999; Poepppl et al., 2011). After the experimental procedures, pictures were also rated with respect to emotional valence (unpleasant–pleasant), sexual arousal (not at all–extremely arousing) and sexual urge (none–highly motivated to see the person completely naked) on five-point Likert scales.

Before the experiment, subjects were instructed that they would have to answer the question ‘Do you want to see this person naked?’ after each stimulus. Stimuli were presented in random order (same for all subjects). Each experimental session consisted of 180 trials of the following sequence: After presentation of the stimulus for 2 s, a blank was shown for 1 s, during which a TMS pulse was applied (500 ms after blank onset) and the MEP assessed. Since actual active response to an incentive may boost its effect on changes in cortical excitability (Gupta and Aron, 2011), subjects then had to respond within 1 s to the question whether they wanted to see the depicted person naked by pressing the left or right arrow button of a common computer keyboard with
the index finger. The answers ‘yes’ or ‘no’ were randomly presented on
the left or right side of the visual field and participants had been in-
structed to choose the button corresponding to their response. Each
trial ended with a jittered blank screen (0.5–1.5 s) (Figure 1A). Stimuli
and instructions were presented via video goggles (EVG920V; Prober
Industrial Ltd., China). Prior to the actual experiment, subjects were
familiarized with the paradigm in a short practice session using 12
novel sexual and neutral stimuli.

**MEP measurement**

Participants were seated in a reclining chair with electromyography
electrodes placed on the right hand. TMS was delivered by two
Magstim 200 stimulators (Magstim Co., UK) connected via a Bistim
module to a figure-of-eight coil (double-circular 70-mm coil). The coil
was held tangential to the skull, with the handle pointing backwards,
and 45° away from the midline. The optimal coil position for stimu-
lation was defined as the position above the left motor cortex for
eliciting MEP of maximal amplitude in the right first dorsal interosseus
(FDI) muscle (index finger). Once this position was found, it was
marked on a head cap and the coil was held in this position by the
investigator. The resting motor threshold (RMT) was determined as
the lowest stimulation intensity that evoked in at least four out of eight
consecutive trials a MEP of at least 50 μV in the resting FDI (Rossini
et al., 1994). MEPs were measured with a stimulation intensity of 110%
RMT and were recorded with surface cup electrodes placed over the
belly and tendon of the index finger with the ground placed on the
head of the radius. Data were registered with a V-Amp 16-channel
amplifier (Brain Products, Germany) and recorded with a band-pass
filter of 30 Hz–1 kHz with a sampling rate of 2 kHz. The signals of the
belly and tendon electrode were subtracted offline. MEP amplitudes
were measured peak-to-peak (Devanne et al., 1997). MEPs with
bimodal negative or positive peaks were excluded from analysis. The
experimental setup is illustrated in Figure 1B.

**Statistical analysis**

The medians of the MEP peak-to-peak amplitudes for the female, male
and control pictures, respectively, were used as dependent variables.
We normalized the female and male pictures condition (i.e. their MEP
medians) by dividing them by the neutral pictures condition (i.e. its
MEP median). Sexual motivation is regulated by the individual’s
sexual orientation insofar as sexual desire should only be observed in
response to sexual stimuli being in accordance with individual sexual
preference. To investigate the influence of sexual motivation on motor
cortex excitability (i.e. MEPs), we calculated a 2 × 2 analysis of vari-
ance with the within-subjects factor stimulus condition (female vs male
pictures) and the between-subjects factor sexual orientation (hetero-
vs homosexual). For post-hoc analyses we used Student’s t tests. The
significance threshold for all statistical tests was set to $P < 0.05$, two-

**RESULTS**

As expected, subjects rated the sexual stimuli according to their sexual
orientation: heterosexuals reported higher emotional valence
($P < 0.001$), sexual arousal ($P < 0.001$) and sexual urge ($P < 0.001$) for
female stimuli compared with male stimuli, while homosexuals’ ratings
showed the opposite pattern [all $P$-values $< 0.001$ except for emotional
valence ($P = 0.071$)]. That is, in line with the self-reported sexual
orientation female sexual stimuli increased sexual motivation in het-
erosexual men, while male sexual stimuli increased sexual motivation
in homosexual men. Therefore, the MEPs may be interpreted as re-
flecting the subjects’ response to the particular stimulus category (i.e.
sexually arousing pictures of males or females).

Several subjects responded with ‘no’ in the forced-choice task also to
stimuli corresponding with their sexual orientation (i.e. preferred
gender stimuli). The mean ratio between ‘yes’ and ‘no’ answers for
preferred gender stimuli was 68%. However, analysis of mean Likert
scores and coefficients of variation (M; CV) for stimuli corresponding
with subjects’ sexual orientation demonstrated that these stimuli were
rated equally as indicated by relatively low CV with respect to emo-
tional valence (3.17; 0.20), sexual arousal (3.31; 0.17) and sexual urge
(3.40; 0.18).

We found a significant crossed interaction effect between stimulus
condition and sexual orientation ($F = 7.966; df = 1.34; P = 0.008$).
Post-hoc tests indicated that this interaction was driven by stimulus-
specific MEP increases corresponding with the subjects’ sexual orien-
tation. Heterosexual subjects showed higher MEP amplitudes for female
in contrast to male stimuli ($P = 0.068$), while homosexual subjects showed the opposite response pattern with increased
MEP amplitudes for male stimuli ($P = 0.027$). MEP = motor evoked potential.

**DISCUSSION**

By using TMS for the assessment of stimulus-dependent MEP changes
in hetero- and homosexual men, we could demonstrate that cortical
excitability is modulated by sexual motivation. More specifically, the
results show that visual sexual stimuli corresponding with one’s sexual
orientation, compared with non-corresponding visual sexual stimuli,
increase the excitability of the motor cortex. These findings corrobor-
ate both psychological and neurobehavioral models of the human
sexual response.

Theoretical models of sexual motivation and behavior have been
based on the incentive theory of motivation (Toates, 2009). In brief,
it has been proposed that a sexual incentive triggers sexual motivation,
which in turn links to genital reactions through the autonomic nervous
system and to behavior via the somatic nervous system (i.e. voluntary
motor responses). Information on the consequences of the genital and
behavioral responses feed back to affect motivation (Toates, 2009).
Notably, according to this model, the translation of motivation into
behavior is mediated by the basal ganglia (Toates, 2009), which hold
strong structural and functional connections with motor areas
(Postuma and Dagher, 2006; Draganski et al., 2008) and together
with these areas play a pivotal role in motor preparation (Elsinger
et al., 2006; Monchi et al., 2006; Purzner et al., 2007). Our results
further place the basic incentive motivation model of sex on a neuro-
biological foundation to the extent that they provide a link between

![Fig. 2 Interaction effect. Crossed interaction between stimulus condition and sexual orientation ($P = 0.008$) driven by stimulus-specific MEP increases corresponding with the subjects’ sexual orientation. Heterosexual subjects showed higher MEP amplitudes for female in contrast to male stimuli ($P = 0.068$), while homosexual subjects showed the opposite response pattern with increased MEP amplitudes for male stimuli ($P = 0.027$). MEP = motor evoked potential.](Image)
sexual motivation and quantitatively measurable states of neural motor systems, specifically motor cortex excitability. In this regard, they also complement earlier findings showing that amplitudes of spinal reflexes, as a measure for motor preparation, are modulated by sexual motivation (Both et al., 2005).

A previous investigation into the relationship between motor cortex excitability and non-sexual motivation revealed that an increase in motor cortex excitability exclusively occurs in the phase of response preparation. However, it was demonstrated that such increase is not a function of response preparation per se but likely indexes the degree of motivation (Gupta and Aron, 2011). Accordingly, the observed stimulus-dependent changes of cortical excitability in this study should be linked to motor preparation processes relating to sexual motivation, although the present paradigm is not capable of isolating sexual motivation (i.e. urge) from sexual arousal. Visual sexual stimuli reliably activate basal ganglia and motor cortices (Kühn and Gallinat, 2011; Stolér et al., 2012; Poeppl et al., 2014). Such activity has been interpreted as a correlate of motor preparation in the context of motivational processes in a neurophenomenological model of sexual arousal (Kühn and Gallinat, 2011; Stolér, 2014). Since cortical excitability correlates with neuronal activity (Siebner et al., 2001; Takano et al., 2004), our finding of motor cortex excitability depending on sexual motivation corroborates the attribution of neuronal activity in corticobasal ganglia loops to the motivational component of sexual arousal (Kühn and Gallinat, 2011; Stolér, 2014). Moreover, the interdependence between motivation-dependent changes in cortical excitability and an urge to perform action (Gupta and Aron, 2011) suggests that neuronal activity in the motor system indeed relates to motor preparation within the motivational component of the neurophenomenological model of sexual processing (Stolér et al., 2012; Stolér, 2014).

It has to be noted that the effect of non-preferred stimuli on MEPs considerably contributed to the observed interaction. This holds particularly true for heterosexual men watching male stimuli. The corresponding MEP amplitudes being lower as compared with those in the neutral condition might reflect sexual aversion leading to less sexual readiness. Since preferred stimuli in contrast were associated with an increase in MEP amplitudes as compared with the neutral condition, the paradigm seems to capture both sexual motivation and sexual aversion. However, we cannot exclude that other processes account for the decreases in MEPs associated with stimuli non-corresponding with subjects’ sexual orientation. It seems conceivable that these decreases reflect suppression of a response (e.g. because heterosexual men tend to be afraid to show the wrong behavior, or because they secretly want to see the male stimuli naked). Such possibility certainly represents a limitation that future research needs to address. Future studies on the topic might for instance employ preferred gender stimuli that show high variability with respect to induced sexual urge and allow for the assessment of a linear relationship between cortical excitability and sexual motivation, as done in previous research on non-sexual motivation (Gupta and Aron, 2011). Moreover, it should be tested if the paradigm is robust against manipulation and deception.

In summary, this study provides strong evidence that stimulus-dependent cortical excitability reflects sexual motivation and preference. By demonstrating that sexual motivation induces physiological brain changes in the motor cortex, our findings fill the gap between theoretical models of sexual motivation and corresponding neuroimaging results that involve neural motor systems.

Conflict of Interest
None declared.

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