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## The Common Neural Bases Between Sexual Desire and Love: A Multilevel Kernel Density fMRI Analysis

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### ABSTRACT

**Introduction.** One of the most difficult dilemmas in relationship science and couple therapy concerns the interaction between sexual desire and love. As two mental states of intense longing for union with others, sexual desire and love are, in fact, often difficult to disentangle from one another.

**Aim.** The present review aims to help understand the differences and similarities between these two mental states using a comprehensive statistical meta-analysis of all functional magnetic resonance imaging (fMRI) studies on sexual desire and love.

**Methods.** Systematic retrospective review of pertinent neuroimaging literature.

**Main Outcome Measures.** Review of published literature on fMRI studies illustrating brain regions associated with love and sexual desire to date.

**Results.** Sexual desire and love not only show differences but also recruit a striking common set of brain areas that mediate somatosensory integration, reward expectation, and social cognition. More precisely, a significant posterior-to-anterior insular pattern appears to track sexual desire and love progressively.

**Conclusions.** This specific pattern of activation suggests that love builds upon a neural circuit for emotions and pleasure, adding regions associated with reward expectancy, habit formation, and feature detection. In particular, the shared activation within the insula, with a posterior-to-anterior pattern, from desire to love, suggests that love grows out of and is a more abstract representation of the pleasant sensorimotor experiences that characterize desire. From these results, one may consider desire and love on a spectrum that evolves from integrative representations of affective visceral sensations to an ultimate representation of feelings incorporating mechanisms of reward expectancy and habit learning. **Cacioppo S, Bianchi-Demicheli F, Frum C, Pfaus JG, and Lewis JW. The common neural bases between sexual desire and love: A multilevel kernel density fMRI analysis. J Sex Med 2012;9:1048–1054.**

**Key Words.** Neuroimaging; Sexual Medicine; Insula; Love; Desire

### Introduction

Although both love and desire sit on top of the main emotional experiences that are investigated in couple therapy and sexual medicine, there are still debates about the nature and the origin of these two subjective experiences [1–5]. The specificity of love and sexual desire is a critical question

in sexual medicine as these two phenomena also occurs in concert, making it difficult for a clinician to dissociate what phenomenon modulates the source of a couple's difficulties. Although love is not a prerequisite for sexual desire, recent evidence from both human and nonhuman animal studies shows a tight correlation between love and sexual desire. For instance, studies show a positive

relationship between love, desire, and orgasm [6–8]. To another extent, Regan et al. showed variations of desire levels as a function of the relationship between the partner (e.g., the greater the desire for the partner, the less often participants thought about ending their current relationship [9]).

Different from love, which is defined here as “a state of intense longing for union with another” [10–12], sexual desire is characterized by an interest or an increase in the frequency and the intensity of sexual thoughts/fantasies (either spontaneous or in response to erotic stimuli) and corresponds more to an urge that impels individuals to interact with others and initiate and/or to respond to sexual stimulation rather than a long-lasting emotional state as love can be [1,13–16]. Along these lines, sexual desire is defined as an awareness of wanting or wishing to attain a potentially short-term pleasurable goal that is currently unattainable.

From a neurobiological point of view, recent studies using neuroendocrinal techniques and/or functional imaging techniques, such as functional magnetic resonance imaging (fMRI), electroencephalogram, and positron emission tomography, have also brought some interesting insights in sexual medicine [12–14,17]. Overall, results show that sexual desire and love, as two highly rewarding experiences, share similar biochemical, neuroendocrine pathways [18,19]. In line with Komisaruk and Whipple’s hypothesis [7], the similarities between love and sexual desire also suggest that both sexual desire and love may have common or may be driven by similar goal-directed/motivation components. Interestingly, fMRI studies have also begun to unravel the neural substrates mediating love and sexual desire, respectively.

Nevertheless, the fact that these fMRI studies on love and sexual desire have been done separately with different subjects, it is difficult to have a general picture of the statistical differences between each neural network. To address this specific question, an fMRI meta-analysis allowing a direct statistical comparison between all these studies is needed. In order to statistically explore the neural similarities and differences of the neural bases between sexual desire and love, we thus performed a statistical multilevel kernel density meta-analysis of fMRI studies on evoked sexual desire or love.

## Aim

The main aim of the present article is to provide a comprehensive statistical meta-analysis of all fMRI

studies to date on sexual desire and love to better understand the different brain activations and the common pathways of sexual desire and love. The recent development of neuroimaging provides a new, objective, and powerful way to identify the differences and similarities between patterns of neural activation associated with these two cognitive and emotional states.

## Main Outcome Measures

fMRI analyses of human brain activation were compared quantitatively and reviewed.

## Methods

### Search Procedures

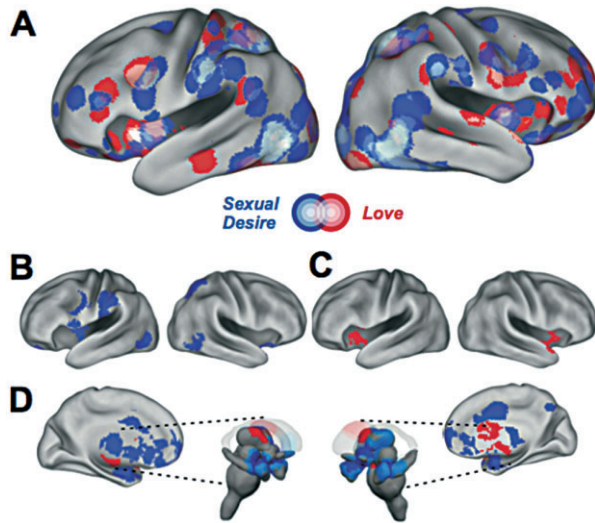
We performed a systematic review of functional neuroimaging studies of sexual desire and love. For the fMRI studies of love, we reviewed studies evaluating brain responses evoked in response to partner-related stimuli (including viewing pictures or videos of loved ones, names, or other references to loved ones). For the fMRI studies on sexual desire, we reviewed studies evaluating brain activation evoked in response to desirable stimuli including pictures or videos depicting sexual activities with differing grades of intensity. All papers and books in the literature published through 2010 (inclusive) were considered for this review, subject to two general limitations: the scientific publication had to be a manuscript, chapter, or book; and the title and abstract had to be available in English. Materials were identified through computer-based search, as described below.

### Computer Search Procedures

A systematic computer-based search of the literature was performed using the local university electronic database. We searched the MEDLINE library through PubMed. We used the following keywords: “human,” “love,” “brain,” “neuroimaging,” “sexual desire,” and “sexual medicine.” We also searched the reference lists of articles identified by this search strategy.

### Selection Criteria

The set of publications identified was then subjected to the following narrower criteria: (i) the studies had to be reported with a neuroimaging exam; (ii) no participants had any history of schizophrenia, neurological disease, drug abuse, or alcohol abuse; and (iii) all studies had to be con-



**Figure 1** Brain networks related to sexual desire (blue) vs. love (red). (A) Surface model illustrating results from all studies based on a qualitative analysis. The color hues in the “heat maps” depict an increasing number of paradigms that activated a given portion of cortex. (B) Lateral view of regions uniquely activated by desire based on the quantitative multilevel kernel density analysis. (C) Regions uniquely activated by love. (D) Medial view and brainstem view of regions uniquely activated by desire vs. love. (See Method section for further details).

ducted in line with ethical standards and under the supervision of the responsible human subject’s committees. Only fMRI neuroimaging studies were included, as the present review focuses on brain networks.

*Statistical Multilevel-kernel-density fMRI Meta-analysis*

To provide readers with a synthesized and statistical view of the common and different brain networks mediating love and sexual desire, we performed a first meta-analysis approach, for illustration purposes only (Figure 1A). This first quali-

tative meta-analysis revealed the global patterns of activation related to sexual desire and love by overlaying reported activation foci onto a volumetric and surface model of the cortical hemispheres. We converted all reported coordinates (e.g., see Table 1 referenced articles) into Talairach coordinate space (Analysis of Functional NeuroImages [AFNI]-Talairach). Using rigorous techniques reported previously [12,20], activation volumes (“centroids,” centers of mass) were approximated by spheres to match the size and location of illustrated results and projected these data into a brain volume space using AFNI software [21]. These volumetric data were then projected onto the Population-Average, Landmark and Surface-based (PALS) atlas cortical surface models (left and right hemispheres), using freely available Caret software (Van Essen Laboratory at the Washington University School of Medicine in Saint Louis, MO, USA <http://brainmap.wustl.edu>) [22]. The spherical volumes and/or location of some reported foci were slightly modified such that they would project more clearly onto the PALS cortical surface models to be consistent with what was illustrated in figures included for each study. All reported brain activation foci were equally weighted in this meta-analysis. The extent of cortex reported to be activated was dependent on statistical threshold settings adopted by each study paradigm, which varied across studies. Thus, this source of variability placed limits on detailed analyses of the functions of subdivisions within regions of interest (ROIs).

Our second meta-analysis entailed a quantitative and more objective approach using a multilevel kernel density analysis (MKDA) [23]. This method, using the reported Talairach coordinates from the studies listed in Tables 1 and 2, tested for consistency and specificity of regional activation related to desire or love (Figure 1B–D). This analysis assesses the distribution of peak coordinates from published studies across the brain,

**Table 1** List of love activation studies

Study (first author listed)	Year	#foci		#Subjects	Experimental comparison
		Left	Right		
Aron	2005	2	9	17	Pictures of beloved > pictures of a familiar neutral acquaintance
Bartels	2000	6	7	17	Pictures of beloved > pictures of friends
Bartels	2004	13	14	20	Mothers viewing their own child > age and familiarity matched acquainted child
Beauregard	2009	5	6	17	Unconditional love > passive viewing of pictures of children and adults
Noriuchi (contrast 1)	2008	6	8	13	Mothers viewing their own infant vs. other infants
Noriuchi (contrast 2)		6	6		
Ortigue	2007	11	15	36	Subliminal names of the beloved > familiar neutral acquaintances
Total		49	65	120	

**Table 2** List of desire activation studies

Study (first author listed)	Year	#foci		#Subjects	Experimental comparison
		Left	Right		
Arnou	2008	35	24	30	Viewing of erotic images/films > sport images/films
Beauregard	2001	0	5	10	Viewing erotic films > neutral films
Buhler	2008	4	6	10	Viewing erotic > neutral images
Ferretti (contrast 1)	2005	8	9	10	Viewing of erotic images/films > sport images/films
Ferretti (contrast 2)		13	13		
Ferretti (contrast 3)		11	15		
Gizewski (contrast 1)	2006	4	4	44	Viewing erotic film > neutral films; males vs. females in luteal phase
Gizewski (contrast 2)		4	4		
Gizewski (contrast 3)		2	2		Viewing erotic film > neutral films
Karama (contrast 1)	2002	7	7	20	Viewing erotic films > neutral films, females
Karama (contrast 2)		9	9		
Kawabata	2008	1	4	18	Desirable persons > undesirable persons
Kim	2006	1	12	10	Viewing sexual videos > neutral videos
Mouras (contrast 1)	2003	6	5	8	Sustained activity to viewing sexual images > neutral images
Mouras (contrast 2)		1	1		
Mouras (contrast 1)	2008	6	8	16	Viewing erotic film > neutral or humorous films
Mouras (contrast 2)		7	9		
Ponseti	2006	5	8	53	Viewing sexual images > nonsexual images
Stark	2005	0	5	24	Viewing erotic images > neutral images
Stoleru	2003	5	3	15	Viewing video clips of sexual stimuli > neutral documentary
Walter (contrast 1)	2008	5	10	21	Viewing of erotic (bodily) images > nonemotional (nonbodily) images
Walter (contrast 2)		1	5		
Walter (contrast 3)		2	1		
Walter (contrast 4)		5	5		
Total		142	174	309	

taking into consideration differences in how the results from different studies had been analyzed, including the total number of regions reported, whether they used fixed vs. random effects models. Using a spherical kernel (11 mm Gaussian), we calculated the number of statistical contrast maps that activated each voxel in the brain. Thresholds were determined using a Monte Carlo procedure (10,000 iterations), and a null hypothesis that activated regions in the resulting pairwise contrast maps are not spatially consistent (i.e., they are randomly distributed throughout the brain). Resulting contrast maps were projected onto the PALS atlas database and onto a subcortical surface model [23].

## Results

Results are illustrated in Figure 1. All data in Figure 1 are  $P < 0.001$ , corrected. We found a total of 20 studies [11,24–42]. The number of participants included in each study, which involved one or multiple paradigms, ranged from 8 to 53 (total of 309 participants; see Tables 1 and 2). The reported group averaged data from each paradigm were compiled and analyzed in two ways.

Our present multilevel kernel density meta-analysis of fMRI studies of sexual desire and love

revealed statistical evidence that both states activate a specific and similar neural network (Figure 1A). This sexual desire-related network includes the insula, hypothalamus, ventral striatum, ventral tegmental area (VTA), amygdala, thalamus, hippocampus, plus limbic and cortical areas (such as the anterior cingulate, specific regions of occipital and temporal cortex, middle frontal gyrus, superior temporal and precentral gyrus, temporo-parietal junction [TPJ], somatosensory cortex, and inferior parietal lobule [IPL]; Figure 1). Those regions, in part, mediate emotion, motivation, somatosensory and visceral integration, and social cue detection, along with possible mirroring mechanisms and perception of other's emotions, desires and intentions, and body language [12,43]. Thus, these results suggest that sexual desire activates brain areas mediating not only the perception of one's own somatosensory stimulations and emotions but also the interpretation of social cues and emotions/desires and intentions of others.

An MKDA analysis that contrasted brain networks associated with desire versus love (Figure 1B–D) revealed intrinsic differences within a large area common to both desire and love, i.e., the anterior insula. Interestingly, the anterior part of the insula (Figure 1C, red) was

activated significantly by feelings of love, whereas the posterior part of the left insula was activated significantly by feelings of sexual desire. Thus, substructures in the insula appear to track sexual desire and love selectively. This posterior-to-anterior insular distinction between sexual desire and love reinforces the neurofunctional characteristic of a posterior-to-anterior progression of integrative representations of affective bodily feelings to an ultimate representation of all feelings [44]. This is in line with the view that love is an abstract construct, which is partly based on the mental representation of repeated past emotional moments with another [10–12,45].

Furthermore, we found that sexual desire shares with love a broader commonly activated matrix within the striatum, thalamus, hippocampus, anterior cingulate cortex (ACC), middle frontal gyrus (MFG), superior temporal gyrus (STG), precentral gyrus, TPJ, and occipito-temporal cortices (Figure 1A). The coactivation of subcortical emotion-related areas and higher order cortical areas that mediate more complex cognitive functions (e.g., body image, mental associations, and self-representation) reinforces the top-down neurofunctional model of interpersonal relationships and the potential role of past experiences on emotional feelings.

Comparing love with sexual desire (Figure 1B–D), activity in the ventral striatum, hypothalamus, amygdala, somatosensory cortex, and IPL was diminished. Those reductions are in keeping with sexual desire as a motivational state with a very specific, embodied goal, whereas love could be thought of as a more abstract, flexible, and behaviorally complex goal that is less dependent on the physical presence of another person. Love was associated with a more intense ( $P < 0.001$  corrected) activation of the VTA, and a specific recruitment of activity in more dorsal regions of the right striatum (Figure 1D) red, two dopamine-rich regions involved generally in motivation, reward expectancy, and habit formation. Those findings reinforce the importance of specific goal-directed incentives for one's mind to fall "head over heels in love." [46]

## Discussion and Conclusion

Together these findings highlight a shared brain network between love and sexual desire (see overlapping colored regions in Figure 1A), which reinforces several studies emphasizing the similarities between love and desire. The present shared

pattern of activation within emotional, motivational, and cognitive brain areas is in line with previous studies suggesting that both love and desire are more than a basic emotion in the sense that they both also mediate complex rewarding emotions, goal-directed motivations, and cognition. Along these lines, love and sexual desire can both be characterized by a complex functional whole including subjective feelings and by rewarding goal-directed behaviors that call for some of the main evolutionary social functions, such as reproduction, mating selection, and courtship behavior.

In line with studies suggesting differences between love and desire, the present review also revealed specific patterns of activation for each one of these two phenomena. In particular, the activation within the insula, with a posterior-to-anterior pattern, from desire to love suggests that love might grow out of and is a more abstract representation of the pleasant sensorimotor experiences that characterize desire. This suggests that love may build upon a neural circuit for emotions and pleasure, adding regions associated with reward expectancy, habit formation, and feature detection. From these results, one may consider desire and love on a spectrum that evolves from integrative representations of affective visceral sensations to an ultimate representation of feelings incorporating mechanisms of reward expectancy and habit learning.

Then, the dissociative activation within the striatum, with a ventral-to-dorsal pattern from desire-to-love, is an integral link between limbic mechanisms that control emotional responding and cortical mechanisms that bring such responding into conscious and lexical awareness. Indeed, the ventral striatum serves as a terminal for ascending mesolimbic dopamine from the VTA and is activated in animals by variety of natural stimuli that have inherent incentive value [47]. More dorsal aspects of the striatum, such as the caudate and putamen, are innervated by dopamine coming from both the VTA and substantia nigra, track stimuli of conditioned incentive value, and activate stereotyped motor patterns (habits) related to conditioned incentive cues. Recent work in animals has shown that reward states are critical in the development of sexual bonding and conditioned partner preference, both of which involve the activation of opioid and dopamine systems in the brain. Dopamine transmission in mesolimbic terminals such as the nucleus accumbens (NAc) or striatum is stimulated in the presence of both unconditioned and conditioned sexual incentive cues. Thus, stimuli associated with reward activate

dopamine release in the NAc, whereas responses made to conditioned rewards appear to involve more dorsal striatal networks, among which are outputs of the dorsal striatum to cortical regions such as the insula. The insula binds steroid hormones and integrates visceral feedback with emotional and cognitive responses giving rise to the perspective that it may be a critical area of convergence between desire and features associated with reward, translating them into a conscious awareness of love. By providing evidence toward a dual neurobiological model of love and desire, the present findings help advance the field [1–5,13,48–50] and should have interesting implications in sexual medicine as they may explain why some patients have love relationship issues (e.g., the “fortune fool in love”) without having any hypoactive sexual desire disorder, and vice versa.

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*Conflict of Interest:* None.

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### References

- Hatfield E, Rapson RL. Love, sex and intimacy. Their psychology, biology and history. New York: Harper & Collins; 1993.
- Regan PC, Berscheid E. Lust: What we know about human sexual desire. Thousand Oaks, CA: Sage; 1999. Sage series on close relationships.
- Diamond LM. Emerging perspectives on distinctions between romantic love and sexual desire. *Curr Dir Psychol Sci* 2004;13:116–9.
- Levine S. Intrapsychic and individual aspects of sexual desire. In: Lieblum SR, Rosen RCR, eds. Sexual desire disorders. New York: Guilford; 1988:21–44.
- Levine SB. The nature of sexual desire: A clinician’s perspective. *Arch Sex Behav* 2003;32:279–85.
- Costa RM, Brody S. Women’s relationship quality is associated with specifically penile-vaginal intercourse orgasm and frequency. *J Sex Marital Ther* 2007;33:319–27.
- Komisaruk BR, Whipple B. Love as sensory stimulation: Physiological consequences of its deprivation and expression. *Psychoneuroendocrinology* 1998;23:927–44.
- Ortigue S, Bianchi-Demicheli F. Interactions between human sexual arousal and sexual desire: A challenge for social neuroscience. *Rev Med Suisse* 2007;3:809–13.
- Regan P, Levin L, Sprecher S, Christopher FS, Cate R. Partner preferences: What characteristics do men and women desire in their short-term sexual and long-term romantic partners? *J Psychol Human Sex* 2000;12:1–21.
- Bianchi-Demicheli F, Grafton ST, Ortigue S. The power of love on the human brain. *Soc Neurosci* 2006;1:90–103.
- Ortigue S, Bianchi-Demicheli F, Hamilton AF, Grafton ST. The neural basis of love as a subliminal prime: An event-related functional magnetic resonance imaging study. *J Cogn Neurosci* 2007;19:1218–30.
- Ortigue S, Bianchi-Demicheli F, Patel N, Frum C, Lewis JW. Neuroimaging of love: fMRI meta-analysis evidence toward new perspectives in sexual medicine. *J Sex Med* 2010;7:3541–52.
- Bianchi-Demicheli F, Cojan Y, Waber L, Recordon N, Vuilleumier P, Ortigue S. Neural bases of hypoactive sexual desire disorder in women: An event-related fMRI study. *J Sex Med* 2011;8:2546–59.
- Ortigue S, Patel N, Bianchi-Demicheli F. New electroencephalogram (EEG) neuroimaging methods of analyzing brain activity applicable to the study of human sexual response. *J Sex Med* 2009;6:1830–45.

- 15 Ortigue S, Bianchi-Demicheli F. The chronoarchitecture of human sexual desire: A high-density electrical mapping study. *Neuroimage* 2008;43:337–45.
- 16 Basson R. Rethinking low sexual desire in women. *BJOG* 2002;109:357–63.
- 17 Ortigue S, Grafton ST, Bianchi-Demicheli F. Correlation between insula activation and self-reported quality of orgasm in women. *Neuroimage* 2007;37:551–60.
- 18 Pfau JG. Neurobiology of sexual behavior. *Curr Opin Neurobiol* 1999;9:751–8.
- 19 Pfau JG. Pathways of sexual desire. *J Sex Med* 2009;6:1506–33.
- 20 Lewis JW. Cortical networks related to human use of tools. *Neuroscientist* 2006;12:211–31.
- 21 Cox RW. AFNI: Software for the analysis and visualization of functional magnetic resonance images. *Comput Biomed Res* 1996;29:162–73.
- 22 Van Essen DC. A population-average, landmark- and surface-based (PALS) atlas of human cerebral cortex. *Neuroimage* 2005;28:635–62.
- 23 Wager TD, Lindquist MA, Nichols TE, Kober H, Van Snellenberg JX. Evaluating the consistency and specificity of neuroimaging data using meta-analysis. *Neuroimage* 2009;45(1 suppl):S210–21.
- 24 Aron A, Fisher H, Mashek DJ, Strong G, Li H, Brown LL. Reward, motivation, and emotion systems associated with early-stage intense romantic love. *J Neurophysiol* 2005;94:327–37.
- 25 Bartels A, Zeki S. The neural basis of romantic love. *Neuroreport* 2000;11:3829–34.
- 26 Bartels A, Zeki S. The chronoarchitecture of the human brain—natural viewing conditions reveal a time-based anatomy of the brain. *Neuroimage* 2004;22:419–33.
- 27 Beaugregard M, Courtemanche J, Paquette V, St-Pierre EL. The neural basis of unconditional love. *Psychiatry Res* 2009;172:93–8.
- 28 Noriuchi M, Kikuchi Y, Senoo A. The functional neuroanatomy of maternal love: Mother's response to infant's attachment behaviors. *Biol Psychiatry* 2008;63:415–23.
- 29 Arnow BA, Millheiser L, Garrett A, Lake Polan M, Glover GH, Hill KR, Lightbody A, Watson C, Banner L, Smart T, Buchanan T, Desmond JE. Women with hypoactive sexual desire disorder compared to normal females: A functional magnetic resonance imaging study. *Neuroscience* 2008;158:484–502.
- 30 Beaugregard M, Levesque J, Bourguoin P. Neural correlates of conscious self-regulation of emotion. *J Neurosci* 2001;21:RC165.
- 31 Buhler M, Vollstadt-Klein S, Klemen J, Smolka MN. Does erotic stimulus presentation design affect brain activation patterns? Event-related vs. blocked fMRI designs. *Behav Brain Funct* 2008;4:30.
- 32 Ferretti A, Caulo M, Delgratta C, Dimatteo R, Merla A, Montorsi F, Pizzella V, Pompa P, Rigatti P, Rossini P. Dynamics of male sexual arousal: Distinct components of brain activation revealed by fMRI. *Neuroimage* 2005;26:1086–96.
- 33 Gizewski ER, Krause E, Karama S, Baars A, Senf W, Forsting M. There are differences in cerebral activation between females in distinct menstrual phases during viewing of erotic stimuli: A fMRI study. *Exp Brain Res* 2006;174:101–8.
- 34 Karama S, Lecours AR, Leroux J-M, Bourgouin P, Beaudoin G, Joubert S, Beaugregard M. Areas of brain activation in males and females during viewing of erotic film excerpts. *Hum Brain Mapp* 2002;16:1–13.
- 35 Kawabata H, Zeki S. The neural correlates of desire. *PLoS ONE* 2008;3:e3027.
- 36 Kim SW, Sohn DW, Cho Y-H, Yang WS, Lee K-U, Juh R, Ahn K-J, Chung Y-A, Han S-I, Lee KH, Lee CU, Chae J-H. Brain activation by visual erotic stimuli in healthy middle aged males. *Int J Impot Res* 2006;18:452–7.
- 37 Mouras H. Brain processing of visual sexual stimuli in healthy men: A functional magnetic resonance imaging study. *Neuroimage* 2003;20:855–69.
- 38 Mouras H, Stoleru S, Moulrier V, Pelegrini-Issac M, Rouxel R, Grandjean B, Glutron D, Bittoun J. Activation of mirror-neuron system by erotic video clips predicts degree of induced erection: An fMRI study. *Neuroimage* 2008;42:1142–50.
- 39 Monseti J, Bosinski HA, Wolff S, Peller M, Jansen O, Mehdorn HM, Buchel C, Siebner HR. A functional endophenotype for sexual orientation in humans. *Neuroimage* 2006;33:825–33.
- 40 Stark R, Schienle A, Girod C, Walter B, Kirsch P, Blecker C, Ott U, Schafer A, Sammer G, Zimmermann M, Vaitl D. Erotic and disgust-inducing pictures—differences in the hemodynamic responses of the brain. *Biol Psychol* 2005;70:19–29.
- 41 Stoleru S, Redoute J, Costes N, Lavenne F, Bars DL, Dechaud H, Forest MG, Pugeat M, Cinotti L, Pujol JF. Brain processing of visual sexual stimuli in men with hypoactive sexual desire disorder. *Psychiatry Res* 2003;124:67–86.
- 42 Walter M, Bermppohl F, Mouras H, Schiltz K, Tempelmann C, Rotte M, Heinze HJ, Bogerts B, Northoff G. Distinguishing specific sexual and general emotional effects in fMRI-subcortical and cortical arousal during erotic picture viewing. *Neuroimage* 2008;40:1482–94.
- 43 Rizzolatti G, Sinigaglia C. Further reflections on how we interpret the actions of others. *Nature* 2008;455:589.
- 44 Craig AD. How do you feel? Interoception: The sense of the physiological condition of the body. *Nat Rev Neurosci* 2002;3:655–66.
- 45 Helmuth L. Society for Neuroscience meeting. Caudate-overheals in love. *Science* 2003;302:1320.
- 46 Postuma RB, Dagher A. Basal ganglia functional connectivity based on a meta-analysis of 126 positron emission tomography and functional magnetic resonance imaging publications. *Cereb Cortex* 2006;16:1508–21.
- 47 Kagerer S, Klucken T, Wehrum S, Zimmermann M, Schienle A, Walter B, Vaitl D, Stark R. Neural activation toward erotic stimuli in homosexual and heterosexual males. *J Sex Med* 2011;8:3132–43.
- 48 Komisaruk BR, Wise N, Frangos E, Liu WC, Allen K, Brody S. Women's clitoris, vagina, and cervix mapped on the sensory cortex: fMRI evidence. *J Sex Med* 2011;8:2822–30.
- 49 Kühn S, Gallinat J. A quantitative meta-analysis on cue-induced male sexual arousal. *J Sex Med* 2011;8:2269–75.
- 50 Ortigue S, Bianchi-Demicheli F. Why is your spouse so predictable? Connecting mirror neuron system and self-expansion model of love. *Med Hypotheses* 2008;71:941–4.