



Article scientifique

Article

2010

Published version

Open Access

This is the published version of the publication, made available in accordance with the publisher's policy.

---

## Neuroimaging of love: fMRI meta-analysis evidence toward new perspectives in sexual medicine

---

Ortigue, Stéphanie; Bianchi-Demicheli, Francesco; Patel, Nisa; Frum, Chris; Lewis, James W

### How to cite

ORTIGUE, Stéphanie et al. Neuroimaging of love: fMRI meta-analysis evidence toward new perspectives in sexual medicine. In: The journal of sexual medicine, 2010, vol. 7, n° 11, p. 3541–3552. doi: 10.1111/j.1743-6109.2010.01999.x

This publication URL: <https://archive-ouverte.unige.ch/unige:29193>

Publication DOI: [10.1111/j.1743-6109.2010.01999.x](https://doi.org/10.1111/j.1743-6109.2010.01999.x)

# Neuroimaging of Love: fMRI Meta-Analysis Evidence toward New Perspectives in Sexual Medicine

Stephanie Ortigue, PhD,\* Francesco Bianchi-Demicheli, MD,<sup>†</sup> Nisa Patel, MS,\* Chris Frum, MS,<sup>‡</sup> and James W. Lewis, PhD<sup>‡</sup>

\*Department of Psychology, Syracuse University, Syracuse, NY, USA; <sup>†</sup>Department of Psychiatry, University Hospital of Geneva, Geneva, Switzerland; <sup>‡</sup>Department of Physiology & Pharmacology, Center for Neuroscience, West Virginia University, Morgantown, WV, USA

DOI: 10.1111/j.1743-6109.2010.01999.x

## ABSTRACT

**Introduction.** Brain imaging is becoming a powerful tool in the study of human cerebral functions related to close personal relationships. Outside of subcortical structures traditionally thought to be involved in reward-related systems, a wide range of neuroimaging studies in relationship science indicate a prominent role for different cortical networks and cognitive factors. Thus, the field needs a better anatomical/network/whole-brain model to help translate scientific knowledge from lab bench to clinical models and ultimately to the patients suffering from disorders associated with love and couple relationships.

**Aim.** The aim of the present review is to provide a review across wide range of functional magnetic resonance imaging (fMRI) studies to critically identify the cortical networks associated with passionate love, and to compare and contrast it with other types of love (such as maternal love and unconditional love for persons with intellectual disabilities).

**Methods.** Retrospective review of pertinent neuroimaging literature.

**Main Outcome Measures.** Review of published literature on fMRI studies of love illustrating brain regions associated with different forms of love.

**Results.** Although all fMRI studies of love point to the subcortical dopaminergic reward-related brain systems (involving dopamine and oxytocin receptors) for motivating individuals in pair-bonding, the present meta-analysis newly demonstrated that different types of love involve distinct cerebral networks, including those for higher cognitive functions such as social cognition and bodily self-representation.

**Conclusions.** These metaresults provide the first stages of a global neuroanatomical model of cortical networks involved in emotions related to different aspects of love. Developing this model in future studies should be helpful for advancing clinical approaches helpful in sexual medicine and couple therapy. **Ortigue S, Bianchi-Demicheli F, Patel N, Frum C, and Lewis JW. Neuroimaging of love: fMRI meta-analysis evidence toward new perspectives in sexual medicine. J Sex Med \*\*;\*\*.\*\*\*-\*\*.**

**Key Words.** Neuroimaging; fMRI; Love; Sexual Medicine; Self-Expansion Model; Meta-analysis

## Introduction

Although it seems obvious that psychological and emotional factors play a role in the etiology and maintenance of sexual problems [1,2], little is known about the ways in which love, sexual function, and sexual dysfunctions interact [1–3]. Since the 1960s, there is, nevertheless, a growing interest in love in the framework of sexual medi-

cine [4–9]. In the last decade, the development of neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) helped in better understanding the role of the brain, as a central organ in sexual function [4,10–15]. Rare, however, are the fMRI studies on love [4,16–21]. A review of these fMRI studies could critically be helpful in improving one's knowledge on the neural bases of love (in comparison with the neural bases of sexual

**Table 1** Functional MRI studies of love

Authors	Year	Love	Number of participants	Stimuli
Aron et al.	2005	Passionate	7 men, 10 women	Faces
Bartels and Zeki	2000	Passionate	6 men, 11 women	Faces
Ortigue et al.	2007	Passionate	36 women	Names
Bartels and Zeki	2004	Maternal	20 women	Pictures
Noriuchi et al.	2008	Maternal	13 women	Video clips
Beauregard et al.	2009	Unconditional	8 men, 9 women	Pictures

function) by extending one's knowledge of the psychology of love in the context of close relationships, and comparing this knowledge with previous fMRI studies on different phases of human sexual response. In the present article, we will review these fMRI studies of love.

### *What Does fMRI Measure?*

fMRI measures the change in blood flow and oxygenation (hemodynamic response) that is produced in the brain in response to the presentation of a broad variety of stimuli (e.g., faces, name of sexual partner). Functional neuroimaging studies of love present changes in blood flow and metabolism associated with the presentation of partner-related stimuli (e.g., face of a beloved partner; or name of the beloved partner). These stimuli can be visual, auditory, or tactile. To date, however, mostly visual partner-related stimuli (i.e., faces, names, pictures, video-clips; Table 1) have been used in fMRI studies of love. In fMRI studies of love, changes in blood flow and oxygenation in the brain are always analyzed in comparison with another (neutral) stimulus. For instance, a psychologist or a physician, who is interested in discovering the brain activity that is generated in response to faces of a significant/beloved partner, will analyze the brain responses that are generated in responses to the visual presentation of the face of that significant/beloved partner minus the brain responses that are generated in response to the visual presentation of neutral faces (e.g., faces of neutral strangers). By comparing/subtracting these two types of brain responses, the investigator is able to unravel the brain responses that are specific to the face of a beloved partner.

### *What Does fMRI Bring to Sexual Medicine?*

In recent years, researchers have devoted increasing attention to neurobiological substrates and neurological processes of sexual function and close relationships [4,15]. For instance, a growing body

of fMRI studies enables the visualization of brain networks that are recruited during human sexual response, such as sexual arousal, sexual desire, and orgasm [14,22–36]. Combining knowledge from fMRI studies with standard approach in sexual medicine may be helpful to better understand the psychological mechanisms that occur in couple relationships. This approach fits well with a new trend in medicine called translational neuroscience. Translational neuroscience aims to translate scientific knowledge from the lab bench to the clinical practice. The understanding and the integration of fMRI knowledge into daily clinical practice might help better target drug therapies on the brain networks that may be affected [14]. In sexual medicine, translational neuroscience is important in order to better help patients with sexual disorders, and couple relationship issues. Because several reviews about the brain networks involved during human sexual responses have been done recently [13,14,37], we are not going to review them in the present article. Rather, the present article will focus on an important topic that is often neglected in sexual medicine, i.e., love.

### *Why Does Love Matter in Sexual Medicine?*

Even if it is, of course, clear that being in love is not a prerequisite to have a sexual intercourse, to desire someone else, or to have a satisfactory sexual life [4,36], studies show a positive relationship between love, desire, and orgasm [7,9,38]. This is in line with a recent growing body of studies in the field that investigated not only the potential risks associated with sexual activities, but examined also the potential physical and mental health benefits [5–7]. This fascinating field of research allows the integration of the scientifically essential differentiation of specific sexual behaviors, notably penile–vaginal intercourse (PVI [6]). As highlighted by Komisaruk and Whipple, “love and sexual activity, while different from each other, share a common element in that they both involve giving and receiving intimate stimulation” [9]. In line with this growing field of research, a large number of

studies reveals associations between love, sexual arousal, sexual desire, and sexual motivation [19,36,40,44–47], and also commitment, and sexual satisfaction [1,3,8,9,39–46]. For instance, recent studies show that women aged 18–45 years have sex primarily for pleasure, commitment, and love [40]. Also, love has been found to be associated positively with sexual satisfaction [43,48–52]. Reciprocated love (union with the other) is associated with fulfillment and ecstasy [8]. In addition, several studies reveal that love may be a predictor of satisfaction, happiness, positive emotions, and well-being in a couple relationship [40,42,44–46,53].

However, it is important to note that all forms of intimate stimulation are not so similar [6]. For instance, to test whether sexual behaviors differ in their associations with both sexual satisfaction and satisfaction with other aspects of life, in a recent article, Brody and Costa reviewed a representative sample of 2,810 Swedes who reported frequency (during the past 30 days) of PVI, noncoital sex, and masturbation as well as their degree of satisfaction (on a 6-point Likert-type scales anchored with 1 = very unsatisfying and 6 = very satisfying) with their sex life, their life in general, their relationship with their partner, and their mental health. For both sexes, multivariate analyses revealed that PVI frequency significantly predicted the satisfaction indices with a large effect size for sexual satisfaction and a medium effect size for relationship quality. By contrast, masturbation frequency was independently inversely associated with almost all satisfaction measures (small to medium effect sizes), and noncoital sex frequencies independently inversely associated (small to very small effect sizes) with some satisfaction measures (and uncorrelated with the rest) [6]. Age did not confound the results. These results reinforce the evidence that, specifically, PVI frequency, rather than other sexual activities, is associated with sexual satisfaction, health, and well-being. The authors concluded that inverse associations between satisfaction and masturbation are not due simply to insufficient PVI [6]. In another study including 30 Portuguese women, Costa and Brody also showed that frequency of PVI positively correlated with various dimensions of the Perceived Relationship Quality Components Inventory, such as satisfaction, intimacy, trust, and love (all  $r \geq 0.40$ ) and global relationship quality ( $r = 0.55$ ) [7]. By contrast, masturbation frequency was inversely associated with love ( $r = -0.38$ ) [7].

When love does not go well in couple relationships, it may be one of the major causes of conflicts, sexual difficulties, emotional distress, anxiety, depression, and, eventually, divorce and/or suicide [8,41,42,54–58]. For instance, studies show that 40% of the persons who are rejected in love experienced depression [47]. Love deprivation, unrequited love, and loneliness may also have negative consequences in a couple relationship [8,56,59,60]. This is in line with Komisaruk and Whipple's model suggesting that deprivation of love may generate endogenous and compensatory mechanisms that manifest as psychosomatic illness [9]. According to Komisaruk and Whipple, compensatory mechanisms occur with deprivation of yearned-for stimulation (e.g., unrequited love) [9]. These compensatory mechanisms represent the body's effort to provide "substitute sensory stimulation to replace (or compensate) for the stimulation that is lost or denied, and craved. If the stimulation remains unrequited, this effort may become frozen into a psychosomatic symptom, as in conversion reaction, which is the bodily expression of a psychological conflict" [9].

The ways in which love is expressed within a couple relationship may therefore play a critical role in sexual health and dysfunction [1]. Along these lines, the study of love and its dysfunctions in couple relationships is important in sexual medicine and clinical practice.

Furthermore, love may be characterized by a broad variety of changes of neurohormones and neuropeptides (e.g., oxytocin) that mediate attachment between individuals, social memory, and reward [17,19]. For instance, individuals in passionate love show increased levels of neurotrophins (relative to individuals neither romantically involved nor in long-term established romantic relationships [61,62]). Interestingly, upregulation of neurotrophins can induce activation of the hypothalamic–pituitary–adrenocortical axis of the endocrine system [62]. This means that some of neurobiological changes that occur in love may potentially also interact (inhibit or facilitate) with the neurobiological substrates that mediate sexual responses, such as arousal and sexual desire [62,63].

Accordingly, the understanding of the brain networks that are activated during love may help clinicians to better apprehend issues in the couple relationship, their emotional relationships and/or their sexual behaviors [64]. Understanding the functional brain network of love might provide physicians, psychologists, and/or couple therapists

with new key paths of therapy for couples that suffer from love addiction, love deprivation, or rejection in love [9,65]. As described by Komisaruk and Whipple: “the better is our understanding of love, the greater is our respect for the significance and potency of its role in mental and physical health” [9]. For all these reasons, love and its underlying mechanisms need to be taken more systematically into consideration in couple therapy and sexual medicine.

### **Definition of the Different Types of Love**

Love carries many definitions, but the one used here is the existence of a complex rewarding emotional state involving chemical, cognitive, and goal-directed behavioral components [66]. Although many emotion theories have included love as a basic emotion, love is more than a basic emotion [17,21,66]. Love includes basic emotions and also complex emotions, goal-directed motivations, and cognition. This knowledge applies to many different types of love, such as passionate love, companionate love, maternal love, and unconditional love. However, it is important to note that differences may exist between these different types of love. In fact, every type of love embraces its own brain complexity.

In a couple relationship, two kinds of love may be distinguished: passionate love (i.e., being in love) and companionate love (i.e., loving) [54,55]. Of particular importance for sexual medicine and couple therapy, these two typologies have been accepted as a valid conceptualization of love regardless of age, gender, and culture in a wide array of research [67]. Passionate love is defined as “a state of intense longing for union with another” that is characterized by a motivated and goal-directed mental state [17]. In comparison with passionate love, companionate love is less intense [67]. This typology of love (i.e., companionate love) is often described as friendship love [67]. Although passionate love and companionate love may be experienced in concert (at least at the beginning of a couple relationship), they are different. Yet little is known about the brain pathways that differentiate passionate love from the other types of love. The similarities (as well as the differences) between these two different types of love may lead one to hypothesize similar (and also different) neural architectures between these different types of love. By comparing the brain networks that are recruited for passionate love in comparison with companionate love, researchers recently provided interesting facts on the specific-

ity of passionate love. In order to better understand the specificity of the neural bases of passionate love, it is important to compare these results with fMRI neuroimaging results from other types of love, such as maternal love (i.e., a tender intimacy and selflessness of a mother’s love for her child/children) and the so-called unconditional love (e.g., love for people with intellectual disabilities [16]). In the present review, we present the fMRI findings from these different types of love.

### **Aims**

The main aim of the present article is to unravel the neural network that is specific to passionate love (in comparison with companionate love), i.e., two types of love that play an important role in couple relationships. To do so, we provide readers with a review on the fMRI studies on passionate love. Then, to discover what brain network is specific to passionate love, we compare its brain network with other types of love, such as maternal love and unconditional love [16–21].

Critically, three issues are considered here: (i) What are the neural underpinnings of passionate love?; (ii) Do the neural substrates of passionate love differ from the neural substrates of other types of love?; (iii) What is the relationship between passionate love and cognition? With this review, the ultimate goal of the present article is to offer clinicians another non-invasive option to approach theoretical complexities of love, close relationships, couples, human sexual health, and behaviors during daily practice.

### **Main Outcome Measures**

fMRI analyses of human brain activation were reviewed.

### **Methods**

#### **Search Procedures**

We performed a systematic review of functional neuroimaging studies of love, evaluating brain responses evoked in response to partner-related stimuli (e.g., face of a beloved partner). All papers and books in the literature published through March 2010 (inclusive) were considered for this review, subject to two general limitations: the 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

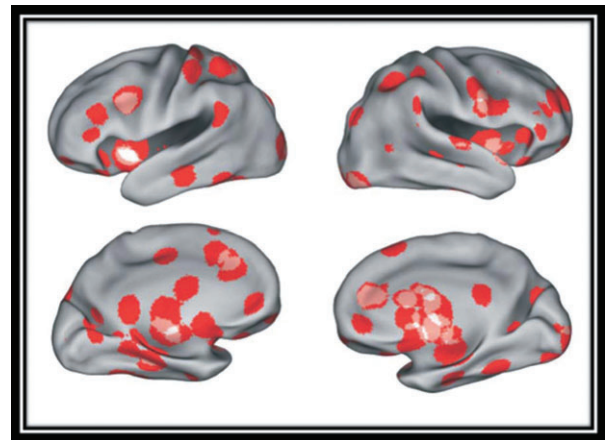
A systematic computer-based search of the literature was performed using the local university electronic database. The wide search for fMRI studies on love had no restrictions on the date of the study. We searched the Cochrane Library, EMBASE, and MEDLINE through OVID and PubMed. We used the key words “human,” “love,” “fMRI,” “sexual medicine,” “sexual,” and “couple.” We mainly selected publications in the past 10 years, but did not exclude commonly referenced and highly regarded older publications. 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) participants of the paper had to be identified as having “love” for a partner; (ii) the studies had to be reported with a neuroimaging exam; (iii) no participant had any history of schizophrenia, neurological disease, drug abuse, or alcohol abuse; and (iv) all studies concerning love have been conducted in accordance with ethical standards and under the supervision of the responsible human subject’s committees. Only studies on love and fMRI were included. Articles concerning broader issues, such as psychological dimensions of developmental and psychoanalytic aspects of love, are generally essential for humans’ physical and mental health. Since these issues have been addressed in depth previously, they will not be reviewed in the present article. Here, we focus on a review of neuroimaging data.

### Combined Analysis of the fMRI Results

To provide readers with a synthesized view of the fMRI results on love, we then created a figure (see Figure 1) derived from the fMRI neuroimaging results of love that have been published to date [16–21]. More precisely, Figure 1 represents a combined analysis illustrating composite maps derived from six fMRI studies related to love (i.e., fMRI of passionate love, maternal love, and unconditional love;  $N = 120$  subjects (see Table 1). For conducting the combined analysis, the reported group-averaged data from each study were all converted to a common Talairach coordinate brain space (AFNI-Talairach). Using techniques reported previously [68], activation

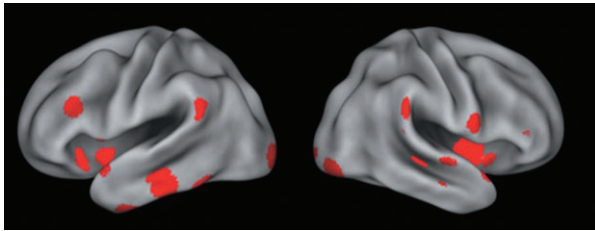


**Figure 1** Combined analysis of fMRI studies of love. Composite meta-analysis map of fMRI paradigms related to love (i.e., fMRI of passionate love, maternal love and unconditional love;  $N = 120$  subjects including 99 women, and 21 men). Results are superimposed on lateral (top panels) and medial views (lower panels) of an average human cortical surface model—an inflated rendition of the PALS surface model.

volumes were approximated by spheres and then projected into a brain volume space using AFNI software [69]. These volumetric data were then projected onto the so-called PALS atlas (Population-Average, Landmark- and Surface-based), which is an atlas of cortical surface models (left and right hemispheres; <http://brainmap.wustl.edu>). The PALS surface models represent averaged cortical surfaces of 12 individuals [70]. Most activation foci appear roughly as circular disks on the cortical surface maps, depending on how they intersected with the underlying three-dimensional spherical volumes. The color hues in the “heat maps” depict an increasing number of paradigms that activated a given portion of cortex. This combined-analysis approach serves to highlight the major cortical regions reported to be involved during specific fMRI studies on love. This approach also allows us to compare the brain network of passionate love (Figure 2) with other types of love (e.g., maternal love and unconditional love).

### Results

We found a total of six fMRI studies [16–21]. The number of participants included in each study ranged from 13 to 36 (Table 1). Accordingly, a total of 120 participants were analyzed in the



**Figure 2** Passionate love network. Cortical networks reported in fMRI paradigms specifically related to passionate love (N = 70 subjects including 57 women, and 13 men). Results are superimposed on lateral views of an average human cortical surface model—an inflated rendition of the PALS surface model.

present review. Results are described below according to different types of love.

#### *Romantic/Passionate Love*

The first neuroscientists to study romantic/passionate love with fMRI were Bartels and Zeki, who identified the brain regions associated with romantic/passionate love in comparison with companionate love [19]. They recruited volunteers who were “truly, deeply, and madly in love” with their partner. A total of 17 participants (six men, 11 women) participated into their fMRI study (Table 1). All participants scored high on the Passionate Love Scale (7.55 out of 9 points) [71]. During the fMRI scans, participants were instructed to gaze at pictures of their partner or at pictures of their friends. Participants’ instruction was to look at the pictures and to think of the person whom they were viewing, and to relax. Pictures were presented for 17.36 seconds. Although many different thoughts and brain mechanisms may occur during those 17.36 seconds (duration of picture presentation), Bartels and Zeki concluded from their fMRI study that pictures of a beloved partner involves increased activity in the dopaminergic-related brain areas (e.g., caudate nucleus and putamen) associated with euphoria and reward. They found brain activations within the dopaminergic subcortical system in the same brain regions that have previously been shown to be active while people were under the influence of euphoria-inducing drugs, such as cocaine. With a lowered threshold of significance ( $P < 0.005$ ), a broader activity was also seen in a brain area involved in memory and mental associations (i.e., the posterior hippocampus). In addition, the authors found that viewing pictures of a beloved partner (as opposed to friends of the same sex as their beloved partner) is associated with activation

in other parts of the brain, notably in brain areas mediating emotion, somatosensorial integration, and reward processes (e.g., insula and anterior cingulate cortex) [19]. Interestingly, some of these brain areas (i.e., insula and the anterior cingulate cortex) have also been shown to become active when people view sexually arousing material [72].

In addition, the authors found decreased levels of activity in brain areas associated with anxiety and fear [19]. Notably, deactivations were observed in the posterior cingulate gyrus and amygdala, i.e., two brain areas that have been shown to be activated in lovers who were actively grieving over a recent romantic/passionate breakup, romantic rejection, or loss [73,74]. The role of the posterior cingulate cortex in grief has been reinforced by a recent fMRI study evaluating grief in eight bereaved women with photographs of a deceased partner vs. photographs of a stranger [73,74]. Together, these results suggest that the anterior part of the cingulate cortex is activated in passionate love and sexual arousal, while the posterior part of the cingulate cortex is rather involved in grief of love [73,74]. No gender differences were observed [19].

In a subsequent fMRI study on passionate love, Aron et al. found similar and different brain activations. In their study, Aron et al. recorded brain activity of 17 participants (7 men and 10 women), who were in early stages of passionate love, while they were viewing pictures of their beloved partner and were thinking about pleasurable (but not sexual) events that occurred with their partner [17]. In this study, pictures were presented for 30 seconds, which is again quite a long time in terms of cognitive processes. The reason for such a long stimulus presentation was based on previous studies in which participants reported that “in addition to a photo, thinking about specific events relating to their beloved partner was the best circumstance to elicit intense romantic love during a 30-second time period” [75]. To analyze their fMRI results, Aron et al. used a technique focused on a subset of 12 brain regions of interest (ROI; i.e., the ventral tegmental area, caudate, putamen, nucleus accumbens, striatum, amygdala, posterior hippocampus, anterior cingulate, posterior cingulate, insula, medial and lateral orbitofrontal cortex), rather than an analysis on the whole brain. ROI technique has the advantage of focusing the analysis on a subset of brain areas of interest. It has, however, the disadvantage of limiting the findings to a subset number of brain areas (rather than the whole brain).

Results from Aron et al.'s study reinforced Bartels and Zeki's findings by showing brain activations in dopamine-rich subcortical brain areas (i.e., ventral tegmental area and caudate nucleus) in response to passionate love-related stimuli (in comparison with companionate love-related stimuli). Also, deactivation was observed in a brain area (the amygdala), which is well known for mediating a broad variety of emotions, notably anxiety, fear, and grieving [17,76–78]. Finally, the authors tested for differences between men and women; however, none met the criterion of  $P < 0.001$ . Together, these results reinforce Bartels and Zeki's.

In another study, Ortigue et al. [21] investigated another aspect of passionate love: the implicit mental representation of a partner's name in a woman's brain. To do so, the authors recorded the brain activity of 36 women while they were viewing implicitly (i.e., below the threshold of visual awareness) the name of their beloved partner on a video screen (in comparison with the name of their friends or strangers). Results reinforced the role of reward-related brain areas in passionate love, even at the implicit level. Results in response to passionate-love stimuli (compared to friend-related stimuli) showed activation in subcortical brain areas involved in dopaminergic reward, emotion, and mental associations (i.e., caudate nucleus, insula, midbrain/ventral tegmental area, and thalamus). Also, as in previous study, activation was observed in anterior cingulate gyrus. Interestingly, the analysis of brain activations collected in response to passionate love (in comparison with companionate love; and in comparison with passion for a hobby/sport) revealed brain activations in higher-order cortical brain areas (i.e., occipitotemporal/fusiform region, angular gyrus, dorsolateral middle frontal gyrus, superior temporal gyrus, occipital cortex, and precentral gyrus). These cortical activations suggest a role of brain areas involved in social cognition, attention, and self-representation in the implicit mental representation of a beloved partner.

The fact that some of these areas were not specifically found in previous fMRI studies of love might be due to the difference between subliminal designs and non-subliminal designs. Differences of findings between the three studies might be due to difference in terms of, fMRI analysis, duration of stimulus presentation, and/or duration of the love relationships of the participants (i.e., a longer-term love relationship was observed in Bartels and Zeki's [19] study than in Aron et al.'s). Further

studies need to be done to control for these variables and better understand the brain network of passionate love per se.

### Summary on Passionate Love

Figure 2 displays the brain clusters activated during passionate love. Based on fMRI studies, passionate love recruits brain areas mediating emotion, motivation, reward, social cognition, attention, and self-representation.

### Maternal Love

In 2004, Bartels and Zeki conducted another fMRI study in order to compare the passionate love brain network with the maternal love brain network. To investigate maternal love, the authors asked a total of 20 mothers to participate in this fMRI study. The general procedures and methods used in this study were similar to those used in their previous study on passionate love [18,19]. The consistency between the paradigms used in 2000 and 2004 allowed a direct data comparison. While the authors were scanning the brain activity of the participants, they gave each participant photographs of "their own child, of another child of the same age with whom they were acquainted with, their best friend, and photographs of another person they were acquainted with." Participants' instruction was to view the pictures and relax. Results showed activity in the insula, and in the anterior cingulate cortex, i.e., brain areas overlapping with activity observed with passionate love.

Results from this study also revealed activation cortical brain regions mediating higher cognitive or emotive processing (lateral fusiform gyrus, lateral orbitofrontal cortex, and in the lateral prefrontal cortex), and also dopaminergic-rich subcortical brain areas (caudate nucleus, putamen, subthalamic nucleus, periaqueductal gray, substantia nigra, and lateral thalamus). The fact that the activation of the periaqueductal (central) gray matter (PAG) was observed in maternal (but not passionate) love suggests that PAG might be specific to maternal love (in comparison with passionate love). This would make sense since PAG receives direct connections from the limbic emotional system, and contains a high density of vasopressin receptors that are important in maternal bonding. As pointed out by Bartels and Zeki [18], the role of PAG in maternal love is important because PAG is also known to be involved in endogenous pain suppression during experience of intense emotional experiences, such as childbirth.

In another study, Noriuchi et al. reinforced the role of PAG in maternal love by investigating the



neural bases of maternal love in 13 mothers while they were viewing “video clips of their own infant and four unknown infants in two different situations (situation #1: playing situation; and situation #2: separation situation)” [20]. When the mothers viewed their own infant vs. other infants, results showed significant activation in the PAG [20]. Also, as in previous studies, the authors found activation in emotion-related brain areas, and also dopaminergic brain areas (i.e., right anterior insula, putamen, thalamus, hypothalamus, and the orbitofrontal cortices). As in the previous study on maternal love, the authors also noticed activity in cortical brain regions that were associated with higher-order cognitive or emotive processing (i.e., inferior frontal gyrus, dorsomedial prefrontal cortex, middle frontal gyrus, middle temporal gyrus, superior temporal gyrus, postcentral gyrus, and the inferior parietal lobule).

#### Summary on Maternal Love

Together, these findings suggest that maternal love is mediated by a PAG-centered reward system, and also by higher-order cognitive or emotional cortical brain areas.

#### Unconditional Love

In 2009, Beauregard et al. investigated the neural bases of unconditional love in an experimental setting. Although unconditional love is commonly defined as “a love that extends to all others without exception, in an enduring, unselfish and constant way,” here, Beauregard et al. investigated unconditional love as “the ability to self-generate love for individuals with intellectual disabilities” [16]. According to Beauregard et al., unconditional love is different from empathy (affective mechanisms that one feels when they apprehend others’ emotional states [16]). Rather, unconditional love is to “act with care on behalf of others without expecting anything in return” [16].

In their experiment, Beauregard et al. ([16]) investigated the neural bases of unconditional love from 17 participants (8 men and 9 women) in an experimental setting including two main conditions: a “passive view” condition, and a so-called “unconditional love viewing” condition. In the “passive view” condition, participants’ instruction was to passively view pictures depicting individuals (children and adults) with intellectual disabilities. In the “unconditional love” condition, participants’ instruction was to self-generate feelings of unconditional love toward the same pictures depicting individuals with intellectual disabilities.

By asking their participants to self-generate love, the authors aimed to test both a cognitive component (self-generation) and an emotional-experiential component (feeling), as compared to a passive viewing [16]. This is an interesting experimental design. However, the specificity of this type of self-generated unconditional love might limit the generalization of the results. Further studies thus need to test other aspects of unconditional love in order to better grasp this general construct and its neural bases.

In comparison with the “passive” condition, Beauregard et al.’s results for the “unconditional love” condition revealed significant brain activation in the reward and dopaminergic system (i.e., insula, globus pallidus, caudate nucleus, and ventral tegmental area). Interestingly, activation was also observed in PAG. Thus, this finding suggests that PAG is not specifically activated during maternal love. Rather, PAG is activated for both maternal love and unconditional love, which makes sense given that mothers often feel unconditional love for their child/children. As in previous fMRI studies of love, activation was also observed in anterior cingulate cortex, superior parietal lobule, and the inferior occipital gyrus.

#### Summary on Unconditional Love

According to this first experimental study on unconditional love, these results indicate that unconditional love for persons with intellectual disabilities, like maternal love and passionate love, involves the reward system. Also, like maternal love, unconditional love recruits PAG and higher-order cognitive brain areas. Further studies on unconditional love need to be done to confirm these results.

#### Discussion

Although the present fMRI findings may be seen as preliminary [4] and considerably more research, including the different components of love (e.g., lust, trust [56]) and the direct comparisons of passionate love stimuli with other types of stimuli, is needed before we can make more conclusive theories about the nature of passionate love, the present fMRI findings show some consistency that might provide a new avenue of knowledge in couple therapy, daily practice, and sexual medicine [4]. Below, we describe two important axes: (i) love as a dopaminergic goal-directed motivation for pair-bonding; and (ii) love and cognition.

### *Love as A Dopaminergic Goal-Directed Motivation for Pair-Bonding*

Together, the present fMRI studies of love point to a common subcortical dopaminergic reward-related brain system (involving dopamine and oxytocin receptors), independently of the types of love. The dopaminergic system mediates functions that are important for goal-directed motivation, reward, and pair-bonding. As it has been found previously for other partner-related responses (such as sexual desire, sexual arousal), love-related stimuli induce the activation of dopamine-rich brain areas that mediate motivational drive states and rewards [17,19,21,62,79]. By demonstrating a specific activation of the subcortical dopaminergic system in love, as it has been found for different phases of sexual response, these findings fit well with the long-lasting theories of love, defining love as a central motivation for pair-bonding in human beings [80–83]. Although different stimuli (faces or names of beloved) were presented in the present fMRI studies on love, similar brain networks were found. Indeed, despite the fact that differences were observed at the cortical level in brain areas mediating the intrinsic nature of stimuli (e.g., the visual word form area for word processing [84,85]; the fusiform face area for face processing [86–88]), the common fMRI studies on love showed common brain activation (independently of the nature of the stimuli), notably in the subcortical brain areas. In addition, the present analysis newly demonstrated that different types of love involve distinct cerebral networks inside and outside the dopaminergic-rich brain network. For instance, passionate love specifically recruits the ventral tegmental area and the caudate nucleus, although maternal love and unconditional love for persons with intellectual disabilities rather recruits PAG. Despite the close spatial proximity of these three brain regions, they may mediate different functions. More precisely, the ventral tegmental area (a brain area coinciding with brain areas rich in dopamine, oxytocin, and vasopressin receptors) is considered as a central platform for pleasurable feelings and pair-bonding. Another notable activation is observed in the caudate nucleus, associated with representation of goals, reward detection, expectation, and the preparation for action. These fMRI results suggest that passionate love is more than a basic emotion. Passionate love is a complex positive emotion and also a reward-based goal-directed motivation toward a specific partner. The systematic study of the modulation of these specific dopaminergic passionate love-related brain

areas (i.e., ventral tegmental area and caudate nucleus) might be helpful to better grasp the motivational modulations (increases/decreases) that may occur in couple relationships over life span. A focus on the specificity of these three brain regions and their functions would facilitate the development of new pharmaceutical approaches that would target drug therapies on the dysfunction of a specific brain network. Based on the present findings, we hypothesize that modulations of activity in these dopaminergic brain areas could modify the motivational dynamics within a couple. For instance, the excess (or deprivation) of dopaminergic-related inputs may have detrimental consequences in couple relationships.

### *Love and Cognition*

Interestingly, the present fMRI results demonstrate that love not only recruits subcortical dopaminergic brain areas, but also activates higher-order cortical brain areas. This reinforces the fact that love is more than a basic emotion. Love also involves cognition.

Passionate love activates specific cortical areas with respect to the other types of love. Notably, passionate love recruits brain areas mediating complex cognitive functions, such as body image, self-representation, attention, and social cognition. Interestingly, the presentation of explicit stimuli vs. implicit stimuli led to different cortical activation, notably in the angular gyrus (i.e., a brain area that mediates cognitive functions related to the perception/representation of one's self, which is a critical function with respect to the psychological model of self-expansion of love [80,89]). This suggests that this activation of this brain area might occur mostly at an implicit level. Further studies need to be done to better understand the temporal dynamics of the differential brain mechanisms that take place during the visual presentation of real beloved stimuli in comparison with the visual presentation of conditioned beloved stimuli. The understanding of each of these complex functions might help to better understand the complexity of love.

### **Conclusion**

Together, these results show that love is more than a basic emotion. Love is also a complex function including appraisals, goal-directed motivation, reward, self-representation, and body-image [21,62,90]. Interestingly different types of love call for different brain networks that carry a broad

variety of basic and complex mechanisms that are also implicated in sexual response, such as: emotional processing, reward, autonomic regulation, motivation, and also self-representation, and body image. This knowledge provides a novel anatomical and functional foundation for developing a cortical network-level perspective for advancing research in sexual medicine and couple therapy. This approach is in line with a growing field in sexual medicine, which highlights that medical and psychological therapies for sexual dysfunctions should address not only the biopsychosocial influences of the patient but also of the couple [1].

### Acknowledgments

This work was supported by the NCRR NIH COBRE grant E15524 to JWJL (to the Sensory Neuroscience Research Center of West Virginia University), and by the University Funds Maurice Chalmers to SO and FBD.

**Corresponding Author:** Stephanie Ortigue, PhD, Department of Psychology, Syracuse University, 506 Huntington Hall, Syracuse, NY 13210, USA. Tel: (315)-443-2705; Fax: (315)-443-4085; E-mail: sortigue@syr.edu

*Conflict of Interest:* None.

### Statement of Authorship

#### Category 1

##### (a) Conception and Design

Stephanie Ortigue; Francesco Bianchi-Demicheli; Nisa Patel

##### (b) Acquisition of Data

Stephanie Ortigue

##### (c) Analysis and Interpretation of Data

Stephanie Ortigue; Francesco Bianchi-Demicheli; Chris Frum; James W. Lewis

#### Category 2

##### (a) Drafting the Article

Stephanie Ortigue; Francesco Bianchi-Demicheli; Nisa Patel; Chris Frum; James W. Lewis

##### (b) Revising It for Intellectual Content

Stephanie Ortigue; Francesco Bianchi-Demicheli

#### Category 3

##### (a) Final Approval of the Completed Article

Stephanie Ortigue; Francesco Bianchi-Demicheli; Nisa Patel; Chris Frum; James W. Lewis

### References

- McCabe M, Althof SE, Assalian P, Chevret-Measson M, Leblum SR, Simonelli C, Wylie K. Psychological and interpersonal dimensions of sexual function and dysfunction. *J Sex Med* 2010;7:327–36.
- Diamond LM. Emerging perspectives on distinctions between romantic love and sexual desire. *Curr Dir Psychol Sci* 2004;13:116–9.
- Sprecher S. Sexual satisfaction in premarital relationships: Associations with satisfaction, love, commitment, and stability. *J Sex Res* 2002;39:190–6.
- Bancroft J. Human sexuality and its problems. New York: Elsevier; 2009.
- Brody S. The relative health benefits of different sexual activities. *J Sex Med* 2010;7:1336–61.
- Brody S, Costa RM. Satisfaction (sexual, life, relationship, and mental health) is associated directly with penile–vaginal intercourse, but inversely with other sexual behavior frequencies. *J Sex Med* 2009;6:1947–54.
- 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.
- Hatfield E, Rapson RL. Love, sex and intimacy. Their psychology, biology and history. New York: Harper & Collins; 1993.
- Komisaruk BR, Whipple B. Love as sensory stimulation: Physiological consequences of its deprivation and expression. *Psychoneuroendocrinology* 1998;23:927–44.
- McKenna KE. The brain is the master organ in sexual function: Central nervous system control of male and female sexual function. *Int J Impot Res* 1999;11:S48–55.
- Meston CM, Frohlich PF. The neurobiology of sexual function. *Arch Gen Psychiatry* 2000;57:1012–30.
- Meston CM, Hull E, Levin RJ, Sipski M. Women's orgasm. In: Lue TF, Basson R, Rosen R, Giuliano F, Khoury S, Montorsi F, eds. Sexual medicine: sexual dysfunctions in men and women. Paris: Health Publications; 2004:783–850.
- 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.
- Maravilla KR, Yang CC. Magnetic resonance imaging and the female sexual response: Overview of techniques, results, and future directions. *J Sex Med* 2008;5:1559–71.
- Bancroft J. Sexual desire and the brain. *Sex Relat Ther* 1988;3:11–27.
- Beauregard M, Courtemanche J, Paquette VS, St-Pierre EL. The neural basis of unconditional love. *Psychiatry Res* 2009;172:93–8.
- 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.
- Bartels A, Zeki S. The neural correlates of maternal and romantic love. *Neuroimage* 2004;21:1155–66.
- Bartels A, Zeki S. The neural basis of romantic love. *Neuroreport* 2000;11:3829–34.
- 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.
- 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.
- Waldinger MD, van Gils AP, Ottervanger HP, Vandenbroucke WV, Tavy DL. Persistent genital arousal disorder in 18 Dutch women: Part I. MRI, EEG, and transvaginal ultrasonography investigations. *J Sex Med* 2009;6:474–81.
- Klucken T, Schweckendiek J, Merz CJ, Tabbert K, Walter B, Kagerer S, Vaitl D, Stark R. Neural activations of the acquisition of conditioned sexual arousal: Effects of contingency awareness and sex. *J Sex Med* 2009;6:3071–85.
- Gizewski ER, Krause E, Schlamann M, Happich F, Ladd ME, Forsting M, Senf W. Specific cerebral activation due to visual

- erotic stimuli in male-to-female transsexuals compared with male and female controls: An fMRI study. *J Sex Med* 2009;6:440–8.
- 25 Huh J, Park K, Hwang IS, Jung SI, Kim HJ, Chung TW, Jeong GW. Brain activation areas of sexual arousal with olfactory stimulation in men: A preliminary study using functional MRI. *J Sex Med* 2008;5:619–25.
  - 26 Jeong GW, Park K, Youn G, Kang HK, Kim HJ, Seo JJ, Ryu SB. Assessment of cerebrocortical regions associated with sexual arousal in premenopausal and menopausal women by using BOLD-based functional MRI. *J Sex Med* 2005;2:645–51.
  - 27 Schoning S, Engelien A, Bauer C, Kugel H, Kersting A, Roestel C, Zwitserlood P, Pyka M, Dannowski U, Lehmann W, Heindel W, Arolt V, Konrad C. Neuroimaging differences in spatial cognition between men and male-to-female transsexuals before and during hormone therapy. *J Sex Med* 2009;7:1858–67.
  - 28 Ponseti J, Granert O, Jansen O, Wolff S, Mehdorn H, Bosinski H, Siebner H. Assessment of sexual orientation using the hemodynamic brain response to visual sexual stimuli. *J Sex Med* 2009;6:1628–34.
  - 29 Pfaus JG. Pathways of sexual desire. *J Sex Med* 2009;6:1506–33.
  - 30 Yang JC, Park K, Eun SJ, Lee MS, Yoon JS, Shin IS, Kim YK, Chung TW, Kang HK, Jeong GW. Assessment of cerebrocortical areas associated with sexual arousal in depressive women using functional MR imaging. *J Sex Med* 2008;5:602–9.
  - 31 Komisaruk BR, Whipple B. Functional MRI of the brain during orgasm in women. *Annu Rev Sex Res* 2005;16:62–86.
  - 32 Komisaruk BR, Whipple B, Crawford A, Liu WC, Kalnin A, Mosier K. Brain activation during vaginocervical self-stimulation and orgasm in women with complete spinal cord injury: fMRI evidence of mediation by the vagus nerves. *Brain Res* 2004;1024:77–88.
  - 33 Whipple B, Komisaruk BR. Brain (PET) responses to vaginal-cervical self-stimulation in women with complete spinal cord injury: Preliminary findings. *J Sex Marital Ther* 2002;28:79–86.
  - 34 Whipple B, Ogden G, Komisaruk BR. Physiological correlates of imagery-induced orgasm in women. *Arch Sex Behav* 1992;21:121–33.
  - 35 Ortigue S, Bianchi-Demicheli F. [The neurophysiology of the female orgasm]. *Rev Med Suisse* 2006;2:784–6.
  - 36 Ortigue S, Grafton S, Bianchi-Demicheli F. Correlation between insula activation and self-reported quality of orgasm in women. *Neuroimage* 2007;37:551–60.
  - 37 Maravilla KR, Yang CC. Sex and the brain: The role of fMRI for assessment of sexual function and response. *Int J Impot Res* 2007;19:25–9.
  - 38 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.
  - 39 Mulhall J, King R, Glina S, Hvidsten K. Importance of satisfaction with sex among men and women worldwide: Results of the global better sex survey. *J Sex Med* 2008;5:788–95.
  - 40 Meston CM, Hamilton LD, Harte CB. Sexual motivation in women as a function of age. *J Sex Med* 2009;6:3305–19.
  - 41 Hatfield E, Rapson RL. Passionate love/sexual desire: Can the same paradigm explain both? *Arch Sex Behav* 1987;16:259–78.
  - 42 Kim J, Hatfield E. Love types and subjective well being. *Soc Behav Pers* 2004;32:173–82.
  - 43 Sprecher S, Metts S, Burleson B, Hatfield E, Thompson A. Domains of expressive interaction in intimate relationships: Associations with satisfaction and commitment. *Fam Relat* 1995;44:203–10.
  - 44 Colson MH, Lemaire A, Pinton P, Hamidi K, Klein P. Sexual behaviors and mental perception, satisfaction and expectations of sex life in men and women in France. *J Sex Med* 2005;3:121–31.
  - 45 McCall K, Meston C. Cues resulting in desire for sexual activity in women. *J Sex Med* 2006;3:838–52.
  - 46 McCall K, Meston C. Differences between pre- and post-menopausal women in cues for sexual desire. *J Sex Med* 2007;4:364–71.
  - 47 Fisher H. *Why we love?* New York: Henry Holt and Company; 2004.
  - 48 Aron A, Henkemeyer L. Marital satisfaction and passionate love. *J Soc Pers Relat* 1995;12:139–46.
  - 49 Sprecher S, Regan PC. Passionate and companionate love in courting and young married couples. *Sociol Inq* 1998;68:163–85.
  - 50 Yela C. Predictors of and factors related to loving and sexual satisfaction for men and women. *Eur Rev Appl Psychol* 2000;50:235–43.
  - 51 Christopher FS, Sprecher S. Sexuality in marriage, dating, and other relationships: A decade review. *J Marriage Fam* 2000;62:999–1017.
  - 52 Sprecher S, Regan PC. Sexuality in a relational context. In: Hendrick CHSS, ed. *Close relationships: A sourcebook*. Thousand Oaks, CA: Sage. Veroff, J.; 2000:217–27.
  - 53 Myers DG. *The pursuit of happiness: Who is happy and why?* New York: William Morrow & Company; 1992.
  - 54 Hatfield E, Rapson RL. Passionate love and sexual desire. Cross-cultural and historical perspectives. In: Vangelisti A, Reis HT, Fitzpatrick MA, eds. *Stability and changes in relationships*. Cambridge, England: Cambridge University Press; 2002:306–24.
  - 55 Hatfield E, Rapson RL. Love. In: Craighead WE, Nemeroff CB, eds. *The concise Corsini encyclopedia of psychology and behavioral science*. New York: John Wiley & Sons; 2000:898–901.
  - 56 Hatfield E, Cacioppo JT, Rapson RL. *Emotional contagion*. New York: Cambridge University Press; 1994.
  - 57 Tenenov D. *Love and limence: The experience of being in love*. New York: Stein and Day; 1979.
  - 58 Mongrain M, Lubbers R, Struthers W. The power of love: Mediation of rejection in roommate relationships of dependents and self-critics. *Pers Soc Psychol Bull* 2004;30:94–105.
  - 59 Hawkey LC, Thisted RA, Cacioppo JT. Loneliness predicts reduced physical activity: Cross-sectional and longitudinal analyses. *Health Psychol* 2009;28:354–63.
  - 60 Cacioppo JT, Loneliness HLC. Loneliness. In: Leary MR, Hoyle RH, eds. *Handbook of individual differences in social behavior*. New York: Guilford; 2010.
  - 61 Emanuele E, Politi P, Bianchi M, Minoretti P, Bertona M, Geroldi D. Raised plasma nerve growth factor levels associated with early-stage romantic love. *Psychoneuroendocrinology* 2005;20:1–7.
  - 62 Loving TJ, Crockett EE, Paxson AA. Passionate love and relationship thinkers: Experimental evidence for acute cortisol elevations in women. *Psychoneuroendocrinology* 2009;34:939–46.
  - 63 Fisher H. Lust, attraction, attachment: Biology and evolution of the three primary emotion systems for mating, reproduction, and parenting. *J Sex Educ Ther* 2000;25:96–104.
  - 64 Bianchi-Demicheli F, Rollini C, Lovblad K, Ortigue S. “Sleeping Beauty paraphilia”: Deviant desire in the context of bodily self-image disturbance in a patient with a fronto-parietal traumatic brain injury. *Med Sci Monit* 2010;16:CS15–7.
  - 65 Fisher HE, Brown LL, Aron A, Strong G, Mashek D. Reward, addiction and emotion regulation systems associated with rejection in love. *J Neurophysiol* 2010;104:51–60.
  - 66 Bianchi-Demicheli F, Grafton S, Ortigue S. The power of love on the human brain. *Soc Neurosci* 2006;1:90–103.
  - 67 Hatfield E, Rapson RL. *Love and sex. Cross-cultural perspectives*. Boston: Allyn and Bacon; 1996.



- 68 Lewis JW. Cortical networks related to human use of tools. *Neuroscientist* 2006;12:211–31.
- 69 Cox RW. AFNI: Software for the analysis and visualization of functional magnetic resonance images. *Comput Biomed Res* 1996;29:162–73.
- 70 Van Essen DC. A population-average, landmark- and surface-based (PALS) atlas of human cerebral cortex. *Neuroimage* 2005;28:635–62.
- 71 Hatfield E, Sprecher S. Measuring passionate love in intimate relationships. *J Adolesc* 1986;9:383–410.
- 72 Ortigue S, Bianchi-Demicheli F. A socio-cognitive approach of human sexual desire. *Rev Med Suisse* 2008;26:768–71.
- 73 Najib A, Lorberbaum JP, Kose S, Bohning DE, George MS. Regional brain activity in women grieving a romantic relationship breakup. *Am J Psychiatry* 2004;161:2245–56.
- 74 Gundel H, O'Connor MF, Littrell L, Fort C, Lane RD. Functional neuroanatomy of grief: An fMRI study. *Am J Psychiatry* 2003;160:1946–53.
- 75 Mashek D, Aron A, Fisher H. Identifying, evoking, and measuring intense feelings of romantic love. *Represent Res Soc Psychol* 2000;24:48–55.
- 76 Ledoux JE. *The emotional brain*. New York: Simon and Schuster; 1996.
- 77 LeDoux JE. Emotion circuits in the brain. *Annu Rev Neurosci* 2000;23:155–84.
- 78 LeDoux JE. The amygdala. *Curr Biol* 2007;17:R868–74.
- 79 Fisher H, Aron A, Brown LL. Romantic love: An fMRI study of a neural mechanism for mate choice. *J Comp Neurol* 2005;493:58–62.
- 80 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.
- 81 Aron A, Aron E, Smollan D. Inclusion of other in the self scale and the structure of interpersonal closeness. *J Pers Soc Psychol* 1992;63:596–612.
- 82 Aron A, Aron EN. Love and sexuality. In: McKinney K, Sprecher S, eds. *Sexuality in close relationships*. Hillsdale, NJ: Lawrence Erlbaum; 1991:25–48.
- 83 Aron A, Aron EN, Tudor M. Close relationships as including other in the self. In: a. C. E. R. Harry T. Reis, ed. *Close relationships* (pp. 365–380). New York: Taylor & Francis Group; 2004.
- 84 Dehaene S, Cohen L, Sigman M, Vinckier F. The neural code for written words: A proposal. *Trends Cogn Sci* 2005;9:335–41.
- 85 Dehaene S, Naccache L, Le Clec HG, Koechlin E, Mueller M, Dehaene-Lambertz G, van de Moortele PF, Le Bihan D. Imaging unconscious semantic priming. *Nature* 1998;395:597–600.
- 86 Downing PE, Chan AW, Peelen MV, Dodds CM, Kanwisher N. Domain specificity in visual cortex. *Cereb Cortex* 2006;16:1453–61.
- 87 Kanwisher N, Yovel G. The fusiform face area: A cortical region specialized for the perception of faces. *Philos Trans R Soc Lond B Biol Sci* 2006;361:2109–28.
- 88 Schwarzlose RF, Baker CI, Kanwisher N. Separate face and body selectivity on the fusiform gyrus. *J Neurosci* 2005;25:11055–9.
- 89 Aron A, Aron EN. *Love and the expansion of self: Understanding attraction and satisfaction*. New York: Hemisphere Publish Corporation; 1986.
- 90 Aron A, Paris M, Aron EN. Falling in love: Prosepective studies of self-concept change. *J Pers Soc Psychol* 1995;69:1102–12.