SOCIAL NEUROSCIENCE OF LOVE

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Abstract

Although philosophers, psychologists, artists, and poets have been interested in the nature and origin of passionate love throughout the ages, only in the 1960s have social psychologists begun to systematically investigate its complexity (Berscheid & Hatfield 1969, Hatfield & Rapson 1993, Hatfield & Rapson 2009). And in the last decade did social neuroscientists begin to contribute to a better understanding of passionate love by unraveling its specific network in the human brain (Ortigue et al. 2010 for review). In the present article, we review what social psychologists and social neuroscientists have learned about the complex phenomenon of passionate love, present the most relevant data on human brain network (as shown by electroencephalogram and/or functional magnetic resonance imaging), which is thought to be involved in the physiology of passionate love, and compare the neuroimaging results with other types of love (such as maternal love). Based on recent neuroimaging findings, passionate love does not only activate subcortical brain areas mediating basic emotions, reward or motivation, but also higher-order cortical brain areas that are involved in social cognition, attention, memory, mental associations, and self-representation.

Key words: passionate love, maternal love, neuroimaging, social cognition, attention, memory, mental associations, and self-representation

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At dawn of its 20th anniversary, social neuroscience is emerging as a strong and essential multidisciplinary field dedicated to the study of the complexity of the social brain and relationships (Cacioppo & Berntson 1992, 2005; Cacioppo et al. 2000; Hatfield et al. 1994). Among the specific questions that social neuroscientists are actively investigating are the effects of social factors on brain and biological functioning; the biological mechanisms underlying social cognition and emotions, social connections, social interactions; the supposed existence of specialized circuits for social functions; and the nature of interdependencies between genes and social environments (Cacioppo & Ortigue 2011). Accordingly, social neuroscience constitutes an astonishing field for the study of complex phenomena such as the nature and origin of love in the human brain (Cacioppo & Ortigue 2011). In the present article, we report what theorists, psychologists, and researchers in social neuroscience have learned about the complex phenomenon of passionate love over the past decades, and compare this view with other types of love (such as maternal love) and other biological drives (such as sexual desire). We begin with the paper's main point and often a common source of confusion i.e., the definition of love.

Definition of passionate love

Love carries many definitions, but the one used here is the existence of an emotional state involving chemical, cognitive, rewarding and goal-directed behavioral components. Passionate love is defined as "a state of intense longing for union with another" (Hatfield & Rapson 1987) that is characterized by a motivated and goal-directed mental state (Hatfield & Sprecher 1986, Hatfield & Rapson 2009)

For years, most social psychologists have agreed that passionate love is an emotion.

In a seminal article, Kurt W. Fischer and his colleagues (1990) characterized emotions this way:

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"*Emotions are complex functional wholes including appraisals or appreciations, patterned physiological processes, action tendencies, subjective feelings, expressions, and instrumental behaviors" (p. 85).*

That said, neuroscientists are still divided as to whether passionate love is an emotion (see Bartels & Zeki 2000, Hatfield & Rapson 2002) or is not an emotion (see Diamond 2004, Diamond 2003). To address this question, scholars have interviewed men and women from a variety of cultures and of different ages using prototype analyses, and taken a social categorical approach (see Hatfield & Rapson 2009 for review of this work). Several cross-cultural studies showed that love is indeed classified as an emotion, among other basic emotions such as joy, anger, sadness, and fear, independently of the languages (e.g., English, Italian, Basque, and Indonesia; see Hatfield & Rapson 2009 for review; Shaver et al. 2001; Shaver et al. 1987).

Yet, recently, another debate appeared in psychology as to whether passionate love should be classified as a basic or a complex emotion (Ekman & Cordaro 2011, Russell et al. 2011). Most scientists accept the idea that all basic emotions share three main characteristics, as they are all: 1) basic, 2) universal, and 3) short-lasting human emotions, debates are raging to define which emotions are basic and which are complex (Ekman 1992, Ekman & Cordaro 2011, Ekman 1999); whereas complex emotions tend to last longer. Darwin differentiated complex emotions from basic emotions, as follows: "Parental love, romantic love, envy, or jealousy last for much longer periods-months, years, a lifetime for love and at least hours or days for envy or jealousy" (Darwin 1872, p. 83). Similarly, Ekman differentiates love from basic emotion based on the fact that there is no facial expression for love (a main criterion of basic emotions) (Sabini & Silver 2005). By demonstrating that love in the brain may be characterized by a specific network involving brain areas that mediate complex cognitive functions (rather than basic emotions only), social neuroscientists provide further evidence towards love as a complex emotion rather than a basic emotion only. Based on the above, one can define passionate love as follows: *"a rewarding emotional state that includes basic emotions and also complex emotions, goal-directed motivations, and cognition*" (Ortigue et al. 2010).

To measure the cognitive, emotional and behavioral indicants of passionate love, Hatfield and Sprecher developed the *Passionate Love Scale* (PLS; Hatfield & Sprecher 1986). The *PLS* has been found to be a useful measure of passionate love for men and women of all ages, in a variety of cultures, and to correlate well with certain well-defined patterns of neural activation (see Hatfield & Rapson 2009, Ortigue et al. 2010 for review).

The brain network of passionate love

Central and peripheral electrophysiological indices of love in the human brain

To our knowledge, the first modern-day neuroscientists to study passionate love were Niels Birbaumer and his Tübingen colleagues (1993), who performed a series of electroencephalogram (EEG) recordings (from 15 different brain locations on the surface of the scalp) in healthy participants during love-related imaging tasks (imagining a time in their past in which they had been joyously in love [without sexual imagery] and imagining the same scene [with sexual imagery]) compared to sensory tasks - such as determining which of two pieces of sandpaper was the smoothest (Birbaumer et al. 1993). The authors suggested (on the basis of their EEG assessments) that the frontal and posterior groupings showed similar dimensions on the romantic imagery tasks, whereas smaller dimensions were found in the frontal as compared to the posterior electrode sites on the four sensory tasks. The authors then concluded that passionate imagery involves a significantly higher brain complexity than does sensory stimulation at all brain sites, but particularly at frontal regions (Birbaumer et al. 1993).

In another experiment, Birbaumer and his group compared electrophysiological responses from students passionately in love (as assessed by the *Passionate Love Scale* described earlier) with a matched group of 10 people, who were not emotionally involved with anyone. In this experiment, participants were asked to imagine a joyous scene with a beloved partner, a scene of intense jealousy, and a neutral scene (an empty living room), while their electric brain activity was recorded from the midline (Fz, Cz, Pz) and its fractal dimensions were estimated (using the method described by Graf & Elbert 1988). No meaningful between group or content differences resulted from these specific analyses. Overall, nevertheless, the fractal dimensionality of the EEG indicated that passionate imagery employed anatomically more widespread ("less localized", (Birbaumer et al. 1993, p. 133) activity and more complex brain processes than sensory tasks. Frontal lobe mechanisms, in particular, seemed to add to imagery-related chaos compared to tactile or visual stimulation. Images, they note, may be "more than just pictures in the head" (Birbaumer et al. 1993, p. 134).

A decade later, other experiments are reported in social neuroscience of love. For instance, in 2008, Başar et al. investigated the oscillatory brain dynamics of love using facial stimuli of a "loved person" in 20 women (Başar et al. 2008). Their main results showed that a specific frequency band generated by the brain (i.e., the delta band here) may be evoked by the photo of a "loved person", and showed significantly higher amplitude values in comparison with an "unknown person", and also with the picture of the "appreciated person" (Başar et al. 2008). More recently, in 2010, Vico and colleagues also investigated central and peripheral electrophysiological indices associated with the perception of loved faces. In Vico et al.'s experiment, 30 female undergraduate students (ranging in age between 20 and 27 years), viewed black-and-white photographs of faces that belonged to one of five categories: loved ones, famous people (pre-selected by the participants), unknown people, babies from the IAPS, and neutral faces from the Ekman and Friesen system. Subcategories of loved faces included romantic partner, parents, siblings, second-degree relatives, and friends. Participants were informed that the purpose of the study was to examine physiological responses to familiar faces (Vico et al. 2010). One of the selection criteria was that participants were required to have a current romantic relationship and to reside in close proximity to five loved ones, including the partner, so as to be able to take their photograph. Pictures were presented in two separate blocks, differing in viewing time (0.5 s vs. 4 s), inter-stimulus interval (1.2 s vs. 18s), and number of face presentations (200 vs. 50). Heart rate, skin conductance, electromyography of the zygomatic muscle, and event-related potentials (ERPs) were obtained while participants passively viewed the pictures. Subjective picture ratings of valence, arousal, and dominance were obtained at the end of the experiment. Both central and peripheral electrophysiological measures differentiated faces of loved ones from all other categories by eliciting higher heart rate, skin conductance, and zygomatic activity, as well

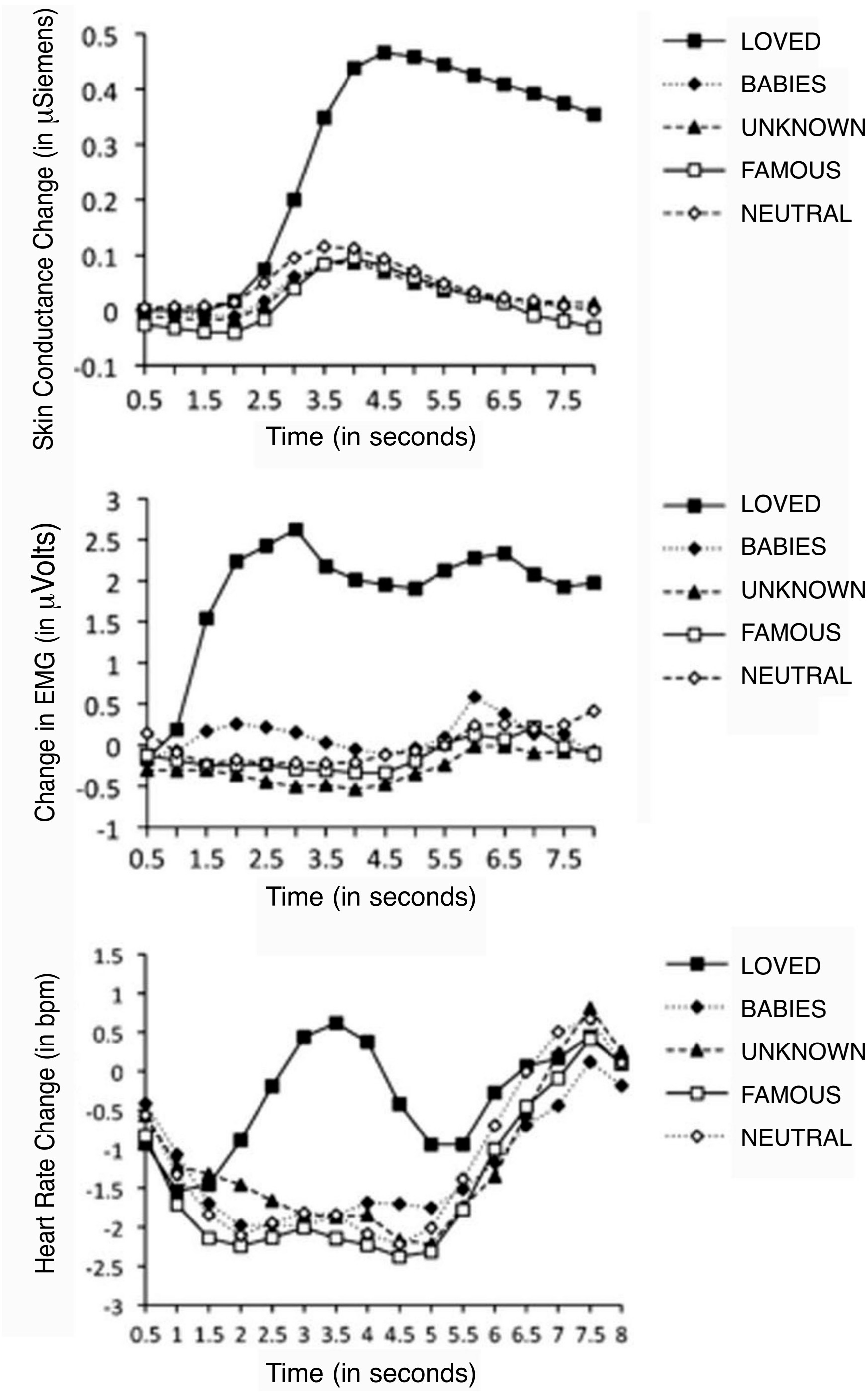

Figure 1. *Skin conductance (top), zygomatic activity (middle), and heart rate (bottom) as a function of face category (loved, babies, neutral, famous, and unknown; Vico et al. 2010)*

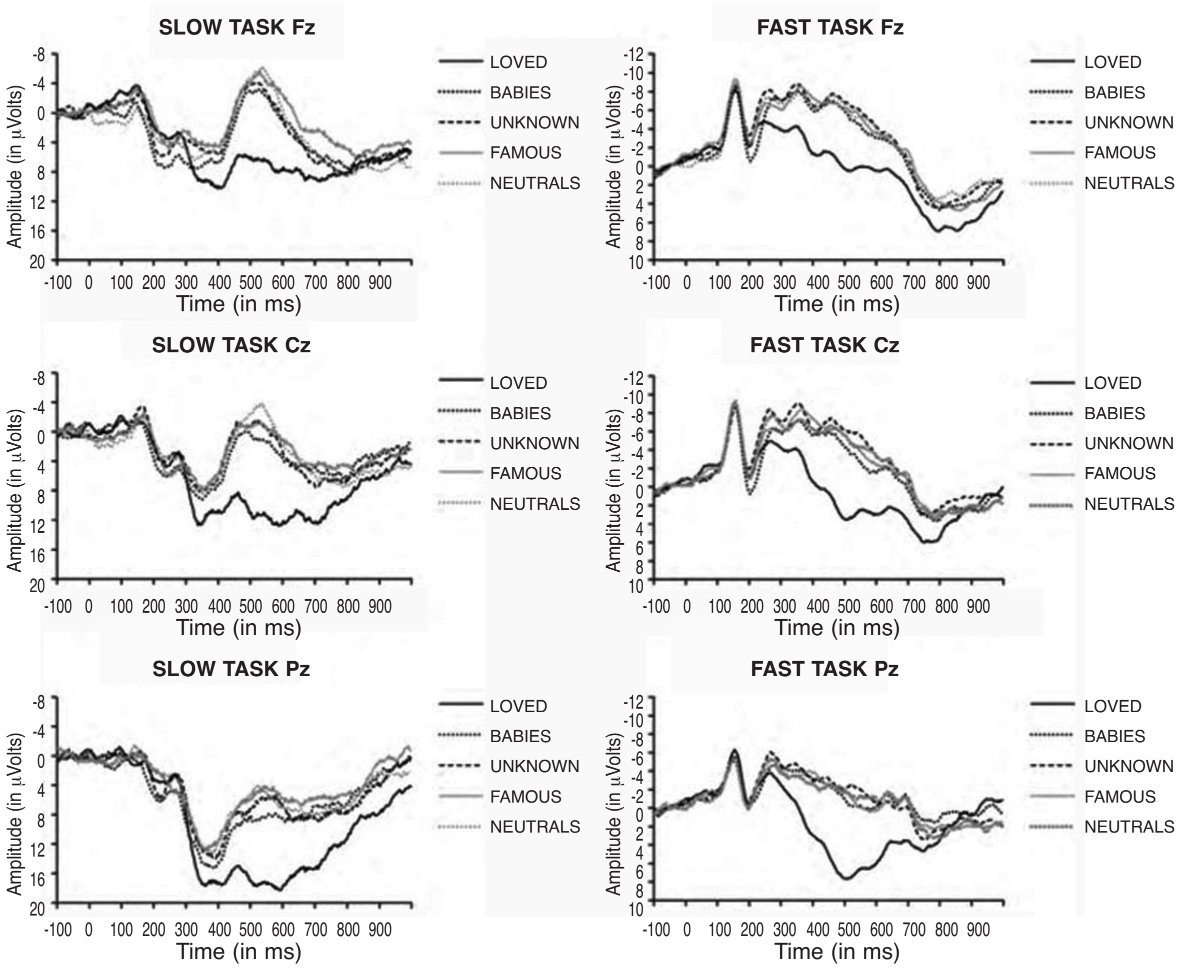

Figure 2. *Event-related potentials (ERPs) for the Slow (left column) and Fast (right column) Blocks as a function of Face Category and Electrode Location: Fz (top), Cz (middle), and Pz (bottom); Vico et al. 2010*

as larger amplitudes of the late ERP components P3 and LPP - see **figure 1**; Vico et al. 2010).

In Vico et al.'s experiment, additional differences were found among subcategories of loved faces. For instance, faces of romantic partners elicited higher physiological (skin conductance and zygomatic activity) and higher subjective (emotional arousal) responses than parents, siblings, or friends, suggesting that looking at the image of someone we love evokes strong positive affect and emotional/cognitive arousal that go beyond a feeling of familiarity or simple recognition. Accordingly, the electroencephalogram (EEG) recordings done at the Fz, Cz, and Pz electrode sites of the 10-20system showed that faces of love evoked larger positive responses than the other four types of faces (**figure 2**). For instance, the authors noted that approximately 300 ms after the onset of a face:

"*A component (named P3)'s amplitude was affected by Face Categories($F(4, 96)=13.18$, $p < .001$), being largest when evoked by the faces of loved ones than by all other face categories (all p-values < .001). No significant differences were found between babies and neutral faces, or between famous and unknown faces. The largest amplitudes of the P3 were found at Pz and Cz ($F(2, 48)=70.49$, $p < .0001$), with both electrodes sites differing significantly from the Fz location ($p < .001$). Similar differences, that we don't describe here) were also observed at later stages of information processing (after 400 ms) as a function of face categories. In the past two years, Vico and colleagues performed a series of three other experiments attempting to tease apart the role of familiarity, arousal, and valence during the facial processing of loved ones (Vico et al. 2010, Guerra et al. 2011). Their results all support the conclusion that "viewing the faces of familiar loved ones elicits an intense positive emotional reaction that cannot be explained either by familiarity or arousal alone*" (Guerra et al. 2011).

Although these studies provide interesting results about the speed of love at the central and peripheral level, the poor spatial resolution of standard EEG when recorded from only a few locations on the surface of the scalp does not allow researcher to know exactly where love is mediated in the brain.

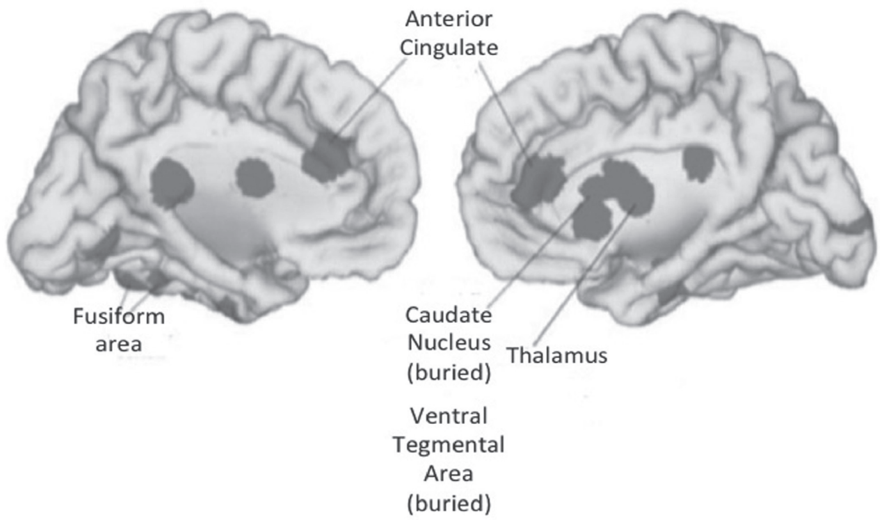

Figure 3. *Subcortical brain network of passionate love*

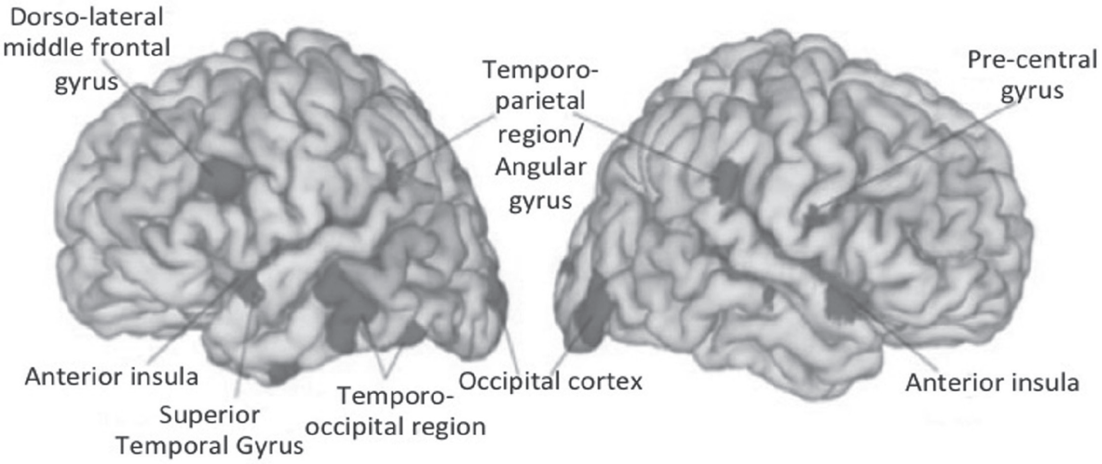

Figure 4. *Cortical brain network of passionate love*

Where does love happen in the human brain? fMRI (*functional magnetic resonance imagery*) evidence

Using high-spatial resolution neuroimaging techniques, such as fMRI, researchers have devoted increasing attention to neurobiological substrates and neurological processes of close relationships and love during the past decade. In brief, fMRI studies of love present changes in blood flow and metabolism associated with the presentation of partner-related stimuli fMRI measures, changes in blood flow and oxygenation (hemodynamic response) that are produced in the brain in response to the presentation of a broad variety of stimuli. These stimuli can theoretically be visual, auditory, olfactory, or tactile. To date, however, mostly visual stimuli (i.e., faces, names, pictures, video-clips) have been used in fMRI studies of love. The first neuroscientists to use an fMRI approach to attempt to identify the brain regions associated with passionate love were Andreas Bartels and Semir Zeki (2000). The scientists put up posters around London, advertising for men and women who were "truly, deeply, and madly in love". They also recruited participants via the internet. Seventy young men and women from 11 countries and several ethnic groups responded. Respondents were asked to write about their feelings of love and to complete the *Passionate Love Scale (PLS)*. Seventeen men and women, ranging in age from 21-37, were selected for the study. Participants were then placed in an fMRI scanner (Bartels & Zeki 2000). Bartels and Zeki (2000) gave each participant a color photograph of their beloved to gaze at, alternating the beloved's picture with pictures of a trio of casual friends. They then digitally compared the scans taken while the participants viewed their beloved's picture with those taken while they viewed a friend's picture, creating images that represented the brain regions that became more (or less) active in both conditions. These images, the researchers argued, revealed for the first time the brain regions involved when a person experiences passionate love. Not surprisingly, the Bartels and Zeki (2000, 2004) research sparked a cascade of fMRI research. Since 2000, a growing body of fMRI studies of passionate love has been performed in social neuroscience. To provide readers with a synthetized view of the specific brain network of love found from these studies, we recently performed a multilevel kernel density analysis (Cacioppo et al. 2012, Ortigue et al. 2010). Results are summarized here below.

Subcortical brain network of passionate love

Overall, fMRI studies on passionate love show that passion sparked increased activity in the subcortical brain areas that are associated with euphoria, reward, and motivation (**figure 3**).

Notably, subcortical activity is reported in the ventral tegmental area, caudate nucleus, and the putamen, all bilaterally (**figure 3**). The activation of these subcortical dopaminergic-rich areas during experiences of passionate love is in line with psychological studies defining love as a rewarding, positive and motivating experience. Most of these regions were those that are active when people are under the influence of euphoria-inducing drugs such as opiates or cocaine. Apparently, both passionate love and those drugs activate a "blissed-out" circuit in the brain.

> Blink (2007) observes:
> "You see someone, you click, and you're euphoric. And in response, your ventral tegmental area uses chemical messengers such as dopamine, serotonin, and oxytocin to send signals racing to a part of the brain called the nucleus accumbens with the good news, telling it to start craving. [Certain regions] are deactivated—areas as within the amygdala, associated with fear (p. 3; cited in Hatfield & Rapson 2009)".

Activity was also noted in other parts of the brain, notably in brain areas mediating emotion, somatosensorial integration, and reward processes (e.g., insula and anterior cingulate cortex). Interestingly, insula and the anterior cingulate cortex have also been shown to become active when people view sexually arousing material. This makes sense since passionate love and arousal are generally assumed to be tightly linked constructs.

The cortical brain network of passionate love

Interestingly, research shows that love does not only activate subcortical brain areas. fMRI studies on love also reveal 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; **figure 4**). These cortical activations suggest a role of brain areas involved in social cognition, attention, memory, mental associations, and self-representation.

Together, these fMRI findings suggest that passionate love recruits not only areas mediating basic emotions, reward or motivation, but also recruits brain regions involved in complex cognitive processing, such as social cognition, body image, self representation and attention. Among these cognitive brain areas, one can cite the angular gyrus, a brain region involved in integration of self-related abstract representations (Arzy et al. 2006, Blanke et al. 2002), which showed a positive correlation between BOLD responses in these brain areas and the measures of passionate love (as measured by the PLS). On the other hand, the absence of correlation between brain activation in these brain areas and the length of being in love underlines that the angular gyrus does not seem to be directly ''love time dependent". This is coherent with a previous study that assessed this question (Aron et al. 2005) and showed changes in several regions as the relationship changes, but not in the angular gyrus and the fusiform regions. Instead, activity related to the length of the relationship was found in the right insula, the right cingulate cortex, and the right posterior cingulated/retrospenial cortex (Aron et al. 2005). In a recent fMRI study investigating the neural correlates of long-term intense passionate love performed by Acevedo, Aron and colleagues with 10 women and seven men married an average of 21.4 years, effects specific to the intensely loved, long-term partner were found in: (i) areas of the dopamine-rich reward and basal ganglia system, such as the ventral tegmental area (VTA), dorsal striatum, insula, consistent with results from other passionate love studies; and (ii) several regions implicated in maternal attachment, such as the globus pallidus (GP), substantia nigra, Raphe nucleus, thalamus, anterior cingulate and posterior cingulate (Acevedo et al. 2011).

> Furthermore, the authors report:
> "*Correlations of neural activity in regions of interest with widely used questionnaires showed: (i) VTA and caudate responses correlated with romantic love scores and inclusion of other in the self; (ii) GP responses correlated with friendship-based love scores; (iii) hypothalamus and posterior hippocampus responses correlated with sexual frequency; and (iv) caudate, septum/fornix, posterior cingulate and posterior hippocampus responses correlated with obsession*".

Together all the results reported above emphasize the fact that passionate love is characterized by a subcortical AND a cortical brain network, in which each brain region might have a specific function. Further studies need to be done to better understand what these functions are exactly. 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 (Ortigue et al. 2010).

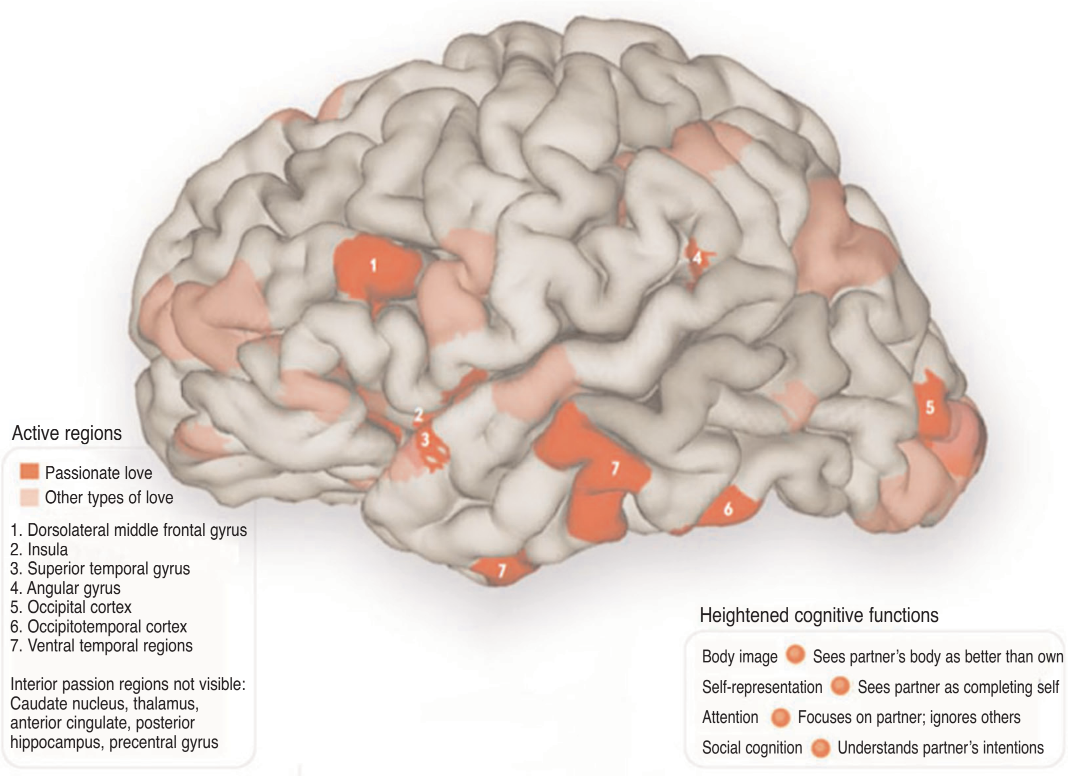

Figure 5. *Passionate love vs. other types of love in the human brain (view of the left hemisphere; Scientific American Mind)*

The different types of love in the human brain

In order to better understand the specificity of the neural bases of passionate love, it is important to compare the above fMRI results with fMRI neuroimaging results from other types of love, such as companionate love (i.e., friendship love); 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; see **figure 5**).

Companionate love

In comparison with passionate love, companionate love is defined as being less intense (Hatfield & Rapson 1996). Companionate love is comprised of feelings of calm, social comfort, emotional union, and the security felt in the presence of a long-term mate. It sparks affiliative behaviors, the maintenance of close proximity, separation anxiety when closeness disappears, and a willingness to participate in shared parental chores. Animal studies suggest that this brain system is primarily associated with oxytocin and vasopressin in the nucleus accumbens and ventral pallidum. Little is known, however, about companionate love in the human brain, as fMRI studies on love often use this condition as a control condition to better understand passionate love. This means that while the fMRI results regarding the comparison passionate love minus companionate love are often reported, the reverse comparison (companionate love minus passionate love) is less frequent. Further studies need to be done to better understand the brain network of companionate love.

Unconditional love

To our knowledge, only one fMRI has been performed on unconditional love (Beauregard et al. 2009). In their experiment, the authors asked 17 participants (8 men and 9 women) to perform two different tasks while they were in the fMRI scanner: one task was to passively view pictures depicting individuals (children and adults) with intellectual disabilities; another task was to perform what the authors called an "unconditional love viewing" and self-generate feelings of unconditional love toward the same pictures. In comparison with the "passive" condition, Beauregard et al.'s results showed that the "unconditional love" condition revealed significant brain activation in the love-related reward and dopaminergic system (i.e., insula, globus pallidus, caudate nucleus, and ventral tegmental area), as well as the periaqueductal (central) gray matter (PAG). As in previous fMRI studies of love, additional brain activations were also observed in anterior cingulate cortex, superior parietal lobule, and inferior occipital gyrus. According to this specific experimental study, these results indicate that unconditional love for persons with intellectual disabilities, like maternal love and passionate love, involves the subcortical and cortical brain regions involved in reward, emotion and social

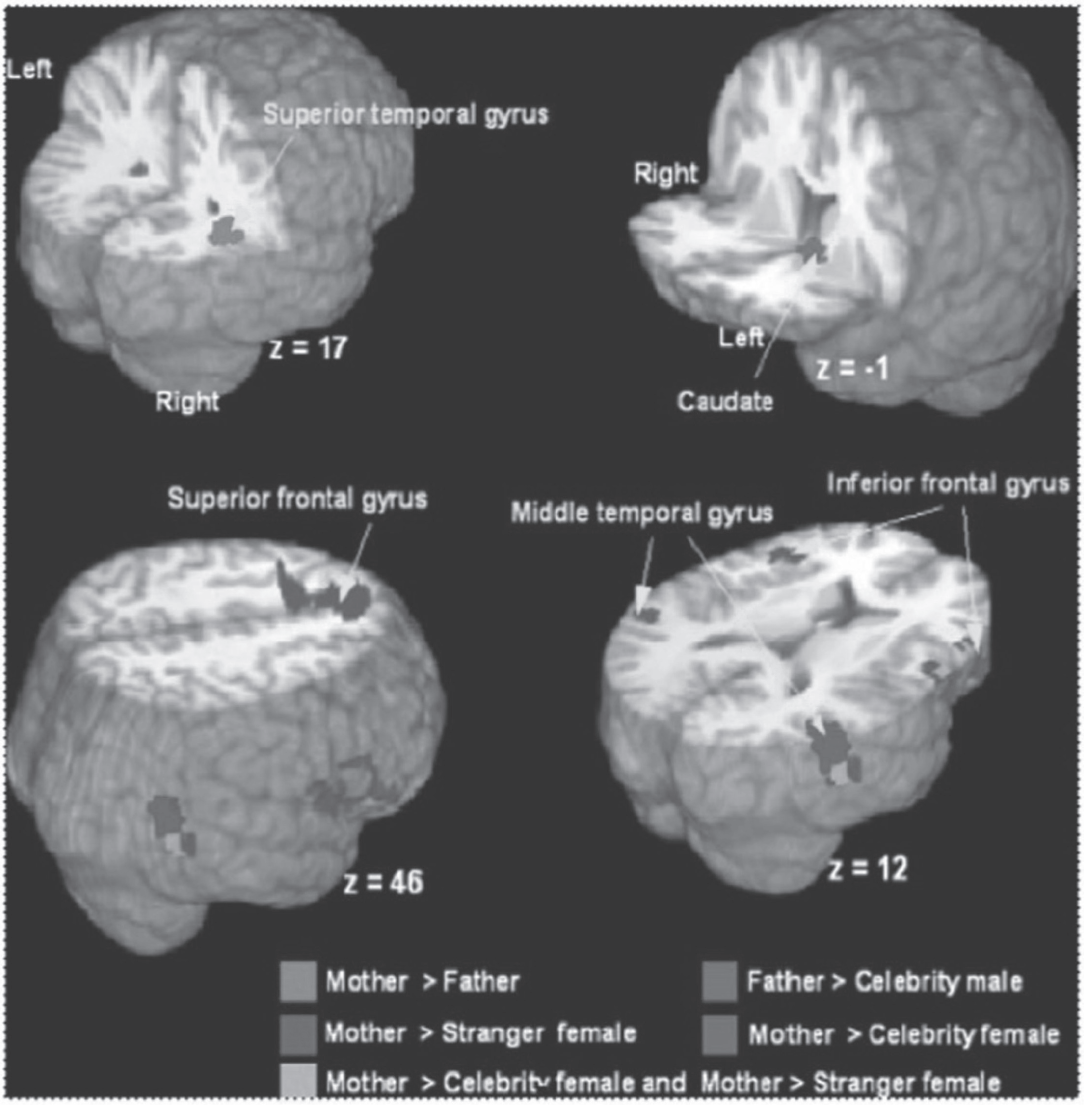

Figure 6. *Rendered group activation maps of brain regions more active during processing of mother and father faces (Arsalidou et al. 2010)*

cognition (Ortigue et al. 2010). Although the present experiment uses an interesting experimental design, its specificity and subjective condition requiring to self-generate 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.

Maternal love

In 2004, Bartels and Zeki conducted an fMRI study on maternal love and compared the results with those they obtained previously on passionate love (Bartels & Zeki 2004). In this fMRI experiment, the authors asked 20 mothers to passively view photographs of their own child, photographs of another child of the same age with whom they were acquainted, and photographs of another person they were acquainted with. Results showed activity in the insula, and in the anterior cingulate cortex, i.e., brain areas overlapping with activity observed with passionate love. As for passionate love, results for maternal love revealed brain activation in subcortical dopaminergic-rich areas (more precisely, here activations were observed in caudate nucleus, putamen, subthalamic nucleus, periaqueductal gray, substantia nigra, and lateral thalamus), as well as activation in cortical brain regions mediating higher-order cognitive or emotive processing, such as the lateral fusiform gyrus, lateral orbitofrontal cortex, and in the lateral prefrontal cortex). A specific activation of PAG was observed in maternal (but not passionate) love only. The role of PAG in maternal love was reinforced in another fMRI study that investigated 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)" (Noriuchi et al. 2008). When the mothers viewed their own infant vs. other infants, results showed significant activation in the PAG. This suggests that PAG might be specific to maternal love (in comparison with passionate love), which makes sense since PAG contains a high density of vasopressin receptors that are important in maternal bonding. On the other hand, these findings also suggest that PAG is not specifically activated during maternal love only. 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. Also, as in previous studies, additional brain activations were also found for maternal love in emotion-related brain areas (i.e., right anterior insula, putamen, thalamus, hypothalamus, and the orbitofrontal cortices), and 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).

Reciprocally, fMRI studies investigating the neural correlates of face recognition using paradigms where participants are being asked to recognize familiar faces (e.g., one's own face, partner's and parents' faces) vs. famous faces show similar brain activations as well as activations in brain areas known to mediate semantic, salient, and social information known about a person. For instance, in a recent fMRI study performed in 10 participants, Taylor and colleagues reported that:

"*All familiar faces (compared with baseline) activate the fusiform gyrus* [a key area in face processing that can be also activated for color, shape]*; own faces also activate occipital regions and the precuneus; partner faces activate similar areas, but in addition, the parahippocampal gyrus, middle superior temporal gyri and middle frontal gyrus. Compared with unfamiliar faces, only personally familiar faces activated the cingulate gyrus and the extent of activation varied with face category. Partner faces also activated the insula, amygdala and thalamus. Regions of interest analyses and laterality indices showed anatomical distinctions of processing the personally familiar faces within the fusiform and cingulate gyri. Famous faces were right lateralized whereas personally familiar faces, particularly partner and own faces, elicited bilateral activations. Regression analyses show experiential predictors modulated with neural activity related to own and partner faces. Thus, personally familiar faces activated the core visual areas and extended frontal regions, related to semantic and person knowledge and the extent and areas of activation varied with face type"* (Taylor et al. 2009).

In a subsequent fMRI study (Arsalidou et al. 2010), Taylor and colleagues examined brain activity in 10 adult participants (4 men, mean age 35.4 ± 7.7 years; eight right handed) in response to faces of their mothers and fathers compared to faces of celebrities and strangers. The authors report their results as follows:

"Whole-brain contrasts were also performed among the different faces. The right superior temporal gyrus was more active to mothers' faces than fathers' faces. Mothers' faces also elicited more activity compared to unknown females in left supramarginal gyrus, left insula, and left middle frontal gyrus, right middle temporal gyrus and right superior and inferior frontal gyri. Bilateral middle temporal gyri, right inferior frontal gyrus and left cingulate gyrus activity was observed for mother faces compared to celebrity females.

Fathers' faces elicited more activity in the left caudate than celebrity males (Arsalidou et al. 2010; p. 48).

Overall, these findings show a differential processing for mother's faces and father's faces in core and extended brain regions associated with face and familiarity processing for mother's face processing (compared to father's, celebrity's or stranger's faces), and in the caudate nucleus for father's faces (when compared to celebrity males, whereas no significant difference in activity was found between father's faces and faces of unknown males; **figure 6**). The activation of the dorsal striatum (caudate nucleus) here is in line with previous studies showing the key role of this subcortical dopaminergic-rich area love as well as in the emotional aspects of faces. The restricted activation of this brain area in the processing of fathers' faces might be due to a limitation in the method and threshold. At a lower threshold, the authors report the following results:

"*Activity in the caudate was present for the comparisons fathers' versus unknown male faces (p = 0.07), mothers' versus celebrity female faces (p = 0.08), and mothers' versus unknown female faces (p = 0.03). It may be the case that while viewing mothers' faces activity in the caudate is obscured by activity in other cortical areas and thus only appears at a more lenient threshold. Together with the distinct caudate activity associated with fathers' faces, these findings support the idea that this region is associated with a global sensation of love or reward which mothers' and fathers' faces engender*" (Arsalidou et al. 2010).

Overall, the current data complement the standard models of face proposing that suggest that faces are processed by a specific distributed network of brain areas, that may vary as a function of the emotional valence, or salience of the person. The present studies shed light on the specific brain circuits that are involved in response to stimuli that evoke love (in contrast to baseline or other affective states, such as desire; Cacioppo et al. 2012). Although passionate love and other types of love may be experienced in concert, they are different emotional and cognitive states that are characterized by specific and different networks in the human brain (**figure 5**; Ortigue et al. 2010).

Conclusion

Social neuroscience of love is a growing field of research, which only recently has become the topic of intensive and rigorous scientific empirical investigations. By identifying the specific cortico-subcortical neural network as well as the central and peripheral electrophysiological indices of love, we hope to provide an interdisciplinary approach to better understand the complexity of love and its disorders. Although combining knowledge from neuroimaging (fMRI and EEG) studies with standard approach in relationship science still doesn't solve the hard problem of love regarding its nature and origin, an integrative approach combining neuroimaging techniques with other disciplines such as social psychology, animal studies, and genetics has the potential to answer age-old questions as to the function of love, which can have useful applications in mental health and couple therapies.

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