Social Neuroscience

The Speed of Passionate Love, As a Subliminal Prime: A High-Density Electrical Neuroimaging Study

Stephanie Cacioppo*†, Scott T. Grafton‡, Francesco Bianchi-Demicheli§

ABSTRACT
In line with the psychological model of self-expansion, recent neuroimaging evidence shows an overlap between the brain network mediating passionate love and that involved in self-representation. Nevertheless, little remains known about the temporal dynamics of these brain areas. To address this question, we recorded brain activity from 20 healthy participants using high-density electrophysiological recordings while participants were performing a cognitive priming paradigm known to activate the so-called love brain network. Our results show that when a person is feeling high passionate love, the subliminal presentation of their beloved's name evokes specific brain states that are mediated by generators located in the pleasure, reward and cognitive brain pathways. More precisely, visual areas are activated in the first milliseconds after stimulus onset, then higher-order associative brain areas, such as those involved in self-related processes (*e.g.,* the angular gyrus/temporo-parietal junction) are activated, and finally a flow of backward activation seems to occur from these associative brain areas to the primary visual and emotional brain areas. These results reinforce the neuro-functional top-down model of interpersonal relationships, suggesting that associative brain areas may prime more basic brain area sat a pre-conscious stage (i.e., starting at 80ms post-stimulus onset) of information processing. This raises the question of the various states of consciousness in people feeling in passionate love.

Key Words: social neuroscience, love, self-expansion model, electrical neuroimaging, consciousness

NeuroQuantology 2012; 4: 715-724

Abbreviation list
EEG: ElectroEncephaloGram
GFP: Global Field Power
pSTS: posterior Superior Temporal Sulcus
RTs: Reaction Times
SD: Standard Deviation
VEP: Visual Evoked Potentials

Introduction

Over the past twenty years, social neuroscience emerged as a multidisciplinary field dedicated to the study of the complexity of the social brain (Cacioppo and Berntson, 1992, 2005; Cacioppo *et al.,* 2000; Hatfield *et al.,* 1994). Scientists, ranging from physicists to psychologists and philosophers to neurobiologists, have begun working together in interdisciplinary scientific teams combining clinical case reports and animal models with experimental research on healthy individuals to investigate various levels of the biological mechanisms underlying social interactions (Cacioppo and Ortigue, 2011). For instance, using modern neuroimaging techniques, one may look at the brain as a physical system with different dimensions, such as (but not limited to) spatial and temporal dimensions, where every thought, every emotion, every cognitive and associative process may be viewed as a

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Received June 24, 2012. Revised July, 25, 2012.
Accepted August 6, 2012.
*e*ISSN 1303-5150

chemical interaction that is processed at different times and spaces as a function of the types of social bonds (such as love) that are experienced during interpersonal relationships. Although a growing body of functional neuroimaging studies recently provided valuable spatial information about the brain network mediating love, and unraveled the so-called love brain network (see below for further details), little remains known about the temporal dynamics of this complex phenomenon in the human brain. By using high-density electroencephalogram (EEG) recordings and distributed intracranial source estimations in healthy participants passionately in love while they performed a subliminal cognitive task, the present research article sheds light on the spatio-temporal dynamics of passionate love, as a subliminal prime, in the human brain. We begin with the paper's focal point and often a common source of confusion *i.e.,* the definition of love.

Definition of Love

Throughout history, love entailed many definitions. For instance, in the 1960's social psychologists begun to explore the complexity of love (Berscheid and Hatfield, 1969; Hatfield and Rapson, 1996), and defined it more precisely as "*a complex functional whole including appraisals or appreciations, subjective feelings, expressions, patterned physiological processes, action tendencies, and instrumental behaviors*" (Hatfield and Rapson, 2009). During the past 40 years, several studies have reinforced this psychological definition of love, and concluded that "*love is more than a basic emotion. Love is a rewarding emotional state that includes basic emotions and also complex emotions, goal-directed motivations, and cognition*" (Bianchi-Demicheli *et al*., 2006; Cacioppo *et al*., 2012; Ortigue *et al*., 2010). Along these lines, 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*" (Aron *et al*., 2005). In comparison with companionate love, which may be defined as friendship love, passionate love is more intense (Hatfield and Rapson, 1996). Companionate love may be defined as a "*warm feeling of affection and tenderness that people feel for those with whom their lives are deeply connected*". Thus, companionate love is often described as friendship love and involves shared values, deep attachment, long-term commitment, and intimacy (Hatfield and Rapson, 1996). Although passionate love and companionate love may be experienced in concert, they are two different states (Ortigue *et al*., 2010).

Spatial Dimension of Love in the Human Brain

In the past decade, the development of neuroimaging techniques in social neuroscience, such as functional magnetic resonance imaging (fMRI), helped in better understanding the role of the brain, as a central organ, in love. For instance, a recent fMRI multilevel kernel analysis of the fMRI studies of love showed that love activates a specific brain network including a set of twelve main brain areas (*i.e.,* caudate nucleus/putamen; thalamus; ventral tegmental area; anterior insula; anterior cingulate cortex; posterior hippocampus; occipital cortex; occipito-temporal/fusiform region, angular gyrus/temporo-parietal junction, dorsolateral middle frontal gyrus, superior temporal gyrus, and precentral gyrus; Cacioppo *et al*., 2012; Ortigue *et al*., 2010). Interestingly these twelve areas are not located only in the subcortical reward and/or emotional regions of the brain, but also in brain regions that mediate more complex, and associative cognitive functions, such as angular gyrus/temporo-parietal junction (Ortigue *et al*., 2007). These brain regions are known to mediate (among other functions) higher-order cognitive functions such as body image, self-representation, metaphors, and abstract representations. Together these findings highlight the fact that love recruits brain areas that are not only involved in basic instincts or dopaminergic-like rewarding experiences or basic emotions (Aron, 2005; Bianchi-Demicheli *et al*., 2006; Fisher *et al*., 2002; Hatfield and Rapson, 1996; Najib *et al*., 2004; Ortigue *et al*., 2007; 2010). Rather love also call for complex emotions and complex goal-directed motivations and cognition (Bianchi-Demicheli *et al*., 2006; Ortigue *et al*., 2010). For instance, the activation of brain regions that are spatially located in brain networks mediating both love and self-representation is in line with the cognitive and social psychological model of self-expansion of love, which suggests that people fall in love with another individual when they (consciously and/or unconsciously) see a cognitive opportunity to expand their own self (Aron and Aron, 1996; Aron *et al.*, 1995), and include their significant other in their cognitive sphere to represent themselves as possessing their significant other's characteristics/qualities (Aron and Aron, 1996; Aron *et al.*, 1991). This concept is not new. For centuries, philosophers (like Plato) have described love as a way for individuals to complete their selves and bring back together two parts of the same element that was split in twain. More recently psychologists, such as William James and then Aron and Aron elaborated on this model of love. In 1996, Aron and Aron re-actualized this concept (Aron and Aron, 1986; James, 1950) by suggesting that individuals, who feel in love, seek to enhance their potential self-efficacy by "*increasing the physical and social and cognitive resources, perspectives, and identities that facilitate achievement of any goal that might arise*" (Aron and Aron, 1996; Aron *et al.*, 1991).

This self-expansion model of love is also in line with a universal and key evolutionary purpose of love, which manifests itself in the maintenance and upholding of a species by ensuring the formation of firm bonds between individuals (Beauregard, Courtemanche, Paquette, St-Pierre, 2009; Fisher, Aron, Brown, 2005). By highlighting the spatial dimension of love in the human brain, the brain imaging techniques used in social neuroscience allow a better understanding of the brain mechanisms that mediate this complex phenomenon as a motivation to attain the resources to be able to achieve goals (Aron and Aron, 1996; Aron *et al.*, 1991).

The Temporal Dimension of Love in the Human Brain

Although the past two decades have witnessed a growing body of studies unraveling the spatial dimension of love in the human brain (e.g., Acevedo *et al.*, 2011; Aron, 2005; Fisher *et al.*, 2002; Ortigue *et al.*, 2010), little remains known about its temporal dimension. Rare are the studies that investigated the chrono-architecture of love in the human brain. To our knowledge, the first neuroscientists to study the temporal dynamics of passionate love were Niels Birbaumer and colleagues. In 1993, the scientists performed different tasks on the imagery of love and analyses electric brain activity from specific electrode sites (such as midline electrodes Fz, Cz, Pz). In brief, the authors first concluded that passionate love can be characterized as a "mental chaos", and then they described it in more specific terms by explaining that the frontal and posterior electrodes showed similar dimensions on the passionate love imagery tasks, whereas smaller dimensions were found in the frontal as compared to the posterior electrode sites during other sensory tasks (Hatfield and Rapson, 2009). In other words, Birbaumer and colleagues concluded that "passionate imagery involves a significantly higher brain complexity than does (Hatfield and Rapson, 2009). More recently, in 2008, Başar *et al.* also 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) is evoked by the photo of a "loved person", and shows significantly higher amplitude values in comparison with an "unknown person", and also with the picture of the "appreciated person" (Başar *et al.*, 2008). Although all these electrophysiological findings shed light on the temporal mechanisms of love, they don't provide enough high spatio-temporal resolution. To address this question, here we recorded high-density EEG neuroimaging from twenty women. The materials, methods and results are described here after.

Aim

The main aim of the present study was to investigate the spatio-temporal dynamics of love as a subliminal prime in participants in high vs. low passionate love.

Materials and methods

Participants

A total of twenty healthy heterosexual women (age between 18 and 26 years old), college students from Dartmouth College in the United States received extra credit for completing this electrophysiological study regarding love relationships. Participants were recruited from the Dartmouth College experiment scheduling system. All participants provided written informed consent to participate in the experiment, which was approved by the local Committee for

Protection of Human Subjects at Dartmouth College. All participants were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971), English speakers with normal or corrected-to-normal vision, and were not taking antidepressant medication. None of the participants had prior or current neurological symptoms or psychiatric disorders, as ascertained by a detailed anamnesis and a structured clinical interview (including the Brief Psychiatric Rating Scale, BPRS 24, (Ventura *et al.*, 1993); and the Hospital Anxiety and Depression scale, Zigmond and Snaith, 1983). Moreover, a detailed anamnesis did not reveal any history of psychiatric disorders, traumatic brain injury with loss of consciousness, epilepsy, neurological impairment or degenerative neurological illness. As in previous studies (e.g., Bianchi-Demicheli, *et al.*, 2006; Ortigue *et al.*, 2007), just prior to the EEG scanning session, each participant performed a semi-structured interview providing general personal information (such as date of birth; feelings of passionate love).This semi-structured interview provided insights into the women's feelings about their beloved, the duration and the intensity of their love relationship, and the percentage of time they think about their beloved during their waking hours, as well as the standard self-report questionnaire titled the passionate love scale (Hatfield and Sprecher, 1986).

Experimental Procedure

We used a similar procedure than that we used previously (Bianchi-Demicheli, *et al.*, 2006; Ortigue *et al.*, 2007). During the high-density electroencephalogram (EEG) recordings, participants were instructed to perform a lexical decision task each time that they saw a visual stimulus flash onto the screen. As in previous studies (Bianchi-Demicheli, *et al.*, 2006; Ortigue *et al.*, 2007), participants were asked to indicate as rapidly and as accurately as possible whether or not an English word was presented on that trial. Responses were made by pressing one of two response buttons on a keyboard with fingers of the right hand (response "yes" with the index and response "no" with the middle). Participants were not informed of the presence of the prime. To check that participants were not aware of the type of prime stimuli, we used an extensive debriefing procedure in which participants were asked increasingly specific questions about the study. This procedure revealed that all participants reported that they had seen the flash of the mask. However, no participant could report on the specific emotional or semantic contents of the flashes. This experiment was carried out using Matlab 7.0.1 and Cogent 2000 developed at the Laboratory of Neurobiology and the Wellcome Department of Imaging Neuroscience, University College London.

Stimulus sequence

The visual stimulus on each trial was composed of a sequence of three frames. First, a prime word was presented for 13 ms, followed by a mask of ########## symbols for 160 ms and then the target word for 150 ms. Each trial began with central presentations of a 150 ms-fixation cross and ended with a random 1500–2500 inter-stimulus interval (Fig. 1).

Stimuli

Visual evoked potentials (VEPs) were recorded while participants were presented with strings of letters from three different targets (positive emotional words i.e., love; or neutral words i.e., line, or blanks) that were preceded by a prime (which was either the name of their beloved, e.g., Romeo; a friend, e.g., Albert; and a passion, e.g., biking). For each participant, three unique words (3 to 11 characters long) were used as prime stimuli (see Ortigue *et al.*, 2007) for further information about the stimuli). Stimuli were randomly presented during six experimental blocks. Stimuli were randomly presented during six experimental blocks. Each trial was composed of one of three primes together with one of 40 words, or one of 40 non-words, or one of 40 "blank" trials, giving a total of 360 possible trials. As in our previous fMRI study (Ortigue *et al.*, 2007) trial order within a block was pseudo-randomized with the constraint of no more than three consecutive trials with the same target type. Each participant performed six blocks with 60 trials in each block, for a total of 360 trials, which took up to 40 min including breaks between each block.

Electrophysiological recordings

Continuous EEG was recorded from 128 AgCl carbon-fiber coated electrodes using an Electric Geodesic Sensor Net® (GSN300;

Electrical Geodesic Inc., Oregon; http://www.egi.com/), where EEG electrodes are arrayed in a dense and regular distribution across the head surface with an inter-sensor distance of approximately 3 cm. The EEG was digitized at 500 Hz (corresponding to a sample bin of 2 ms), band-width at 0.01–200 Hz, with the vertex electrode (Cz) serving as an on-line recording reference; and impedances were kept below 50 kΩ. Participants were seated in a comfortable chair 150 cm away from a PC computer screen in which stimuli were presented centrally. Participants were instructed to gaze at the center of the screen and to refrain from blinking or moving their eyes except during the interval between trials (Ortigue and Bianchi-Demicheli, 2008).

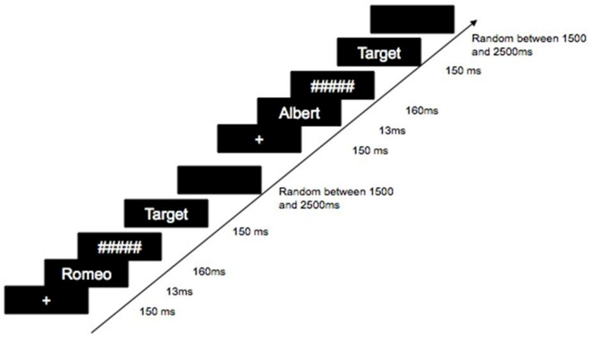

Figure 1. Experimental design and stimulus sequence. The visual stimulus on each trial was composed of a sequence of three frames. First, a prime word was presented for 13 ms, followed by a mask of ########## symbols for 160 ms and then the target word for 150 ms. Subjects were not informed of the presence of the prime. The type of target letter strings (positive emotional words, non-words, or blanks) and the type of the primes (beloved, e.g., Romeo; friend, e.g., Albert; and passion, e.g., biking) were randomly presented according to a Latin square calculated over the six experimental blocks. This means a target stimulus was not presented twice in the same block in order to avoid any effects of familiarization. In addition, the order of experimental trials was random, with the constraint of no more than three consecutive trials with the same target type. This procedure is a modified procedure from (Bianchi-Demicheli, *et al.*, 2006; Ortigue *et al.*, 2007; 2010).

Electrophysiological data processing

Electrophysiological data were imported and analyzed in Cartool.[2] Epochs of analysis were visually inspected for oculomotor (saccades, and blinks), muscles, and other artifacts in addition to an automated threshold rejection criterion of 100 microvolts. After off-line artifact rejections, VEPs were computed covering 600 ms after the onset of the visual stimuli. Visual evoked potential (VEP) data were then band-pass filtered between 1and 30 Hz. VEP data were then recalculated off-line against the average reference, and normalized to their mean global field power (i.e., GFP; Lehmann and Skrandies, 1980)before group-averaging. The GFP is computed as the spatial standard deviation of the scalp electric field, yields larger values for stronger electric fields, and is calculated as the square root of the mean of the squared value recorded at each electrode (vs. the average reference). Channels with corrupted signal sand channels showing substantial artifacts and noise throughout the recordings were interpolated to a standard 111-channel electrode array (Perrin *et al.*, 1987).

Second level electrical data analysis

Topographical analyses

Then, VEP data were analyzed with space-oriented brain electric field analysis using Cartool (Ortigue *et al.*, 2004; Ortigue and Bianchi-Demicheli, 2008). Because this electrophysiological method has been extensively detailed previously (Michel *et al.*, 2001; Murray *et al.*, 2004; 2008; Ortigue *et al.*, 2009), here we provide only the essentials details. This space-oriented brain electric field approach is based on the empirical observation that the brain electric field configuration changes step-wise overtime. Epochs of quasi-stable field configurations ('microstates') are concatenated by abrupt transitions in the brain electric field configurations (Ortigue*et al.*, 2009). Microstates thus are assumed to implement specific brain functions. To identify start and end of each optimal microstate, a standard cluster analysis previously described was employed using the grand-mean ERPs of each condition. This cluster analysis uses a hierarchical agglomerative cluster-algorithm to identify the predominant topographies (i.e., maps) and their sequence within a data set (these methods are implemented in Cartool). The optimal number of maps (i.e., the minimal number of maps that accounts for the greatest variance of the data set) is determined based on a modified Krzanowski–Lai criterion (Krzanowski and Lai, 1985). Importantly, this pattern analysis is reference-free, and insensitive to amplitude modulation of the same scalp potential field across conditions,

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[2] Version 3.32; Denis Brunet; http://brainmapping.unige.ch/Cartool.htm

since normalized maps are compared (Lehmann, 1987). We also applied the constraint that a given scalp topography must be observed for at least five consecutive data points (i.e., 10 ms at a 500-Hz digitization rate) in the group-averaged data. This criterion is effectively similar to that frequently applied in the analysis of VEP waveform modulations (Picton *et al*., 2000). This pattern analysis was performed across time and experimental conditions in order to determine whether and when different experimental conditions recruited different configurations of intracranial generators (Pascual-Marqui *et al*., 1995). This conservative approach allowed us to analyze the VEPs responses for love primes vs. friend primes in participants in high passionate love and low passionate love. Then, the pattern of maps observed in the group-averaged data was statistically tested by comparing each of these maps with the moment-by-moment scalp topography of individual subjects' VEP from each condition (e.g., love primes for participants in high passionate love vs. love primes for participants in low passionate love). To do so, each time point of each VEP from each subject was labeled according to the map with which it best correlated spatially. In other words, the optimal number of maps was fitted into the original data for each individual subject, using a competitive fitting procedure (Ortigue *et al*., 2004). This “fitting” procedure determines whether a given experimental condition is more often described by one map versus another. From this “fitting” procedure a large amount of information can be extracted and analyzed for a given condition across subjects, such as the total amount of time a given stable configuration. This latter value represents the frequency with which a given microstate was observed within a given time period for each experimental condition. This is the information we used here. Then, the extracted values of interest were subjected to a repeated-measure ANOVA. Results were accepted as significant at $p< 0.05$.

Distributed intracranial source estimations

The intracranial generators for each condition were estimated using a distributed linear inverse solution based on a Local Auto-Regressive Average (LAURA) model of the unknown current density in the brain (Grave de Peralta Menendez *et al*., 2001; Grave *et al*., 2004). LAURA deals with multiple simultaneously active sources of a priori unknown locations and makes no assumptions regarding the number or location of active sources. LAURA selects the source configuration that better mimics the biophysical behavior of electric vector fields and produces a unique estimator of the current source density vector inside the human brain. That is, the estimated activity at one point depends on the activity at neighboring points as described by electromagnetic laws (Grave de Peralta Menendez *et al*., 2001; Grave *et al*., 2004). Here, LAURA was used with a lead field (solution space) that was calculated on a realistic head model that included 3005 solution points, selected from a 6 x 6 x 6 mm grid equally distributed within the gray matter. Source estimations were rendered on the MNI/McGill average standard brain as supplied by Cartool. Accuracy of anatomical labeling was ascertained with a visual inspection of the standard Duvernois (1991) atlas. The LAURA inverse solution for these data was estimated for each of the 3005 nodes in the solution space.

Participants

Women in high passionate love

Ten out of the twenty participants were healthy women, aged 18-22 years (mean 19.1 years), who subjectively felt passionate love for their partner for ranges of 2 to 42 months. Each participant completed the standard Passionate Love Scale (PLS, Hatfield and Sprecher, 1986; Hatfield and Rapson, 2009), a 9-point Likert scale self-report questionnaire, which confirmed for their partner (PLS mean scores = 8, SD = .73).

Women in low passionate love (control group)

The remaining ten participants were healthy women, aged 18-26 years (mean 20.4 years), who were with their partner for ranges of 2 to 36 months. These ten women were aware of not being in a high passionate state with their partner, but rather in a state of low passionate state. PLS scores confirmed their subjective feeling (PLS mean scores = 7.27, SD = .45). A t-test for independent samples showed significant different PLS scores between the two groups of participants (p = .02).

Behavioral results

Participants performed differently with respect to the speed of decision making for target words with love primes compared to friend primes or passion primes. For participants in high passionate love, reaction times (RTs) were faster for target words with a love prime (mean 623.4 ± SD 40.8 ms) than with a friend primes (697.7 ±92.73 ms, p = .017) or with a passion prime (mean 692.9± SD117.4 ms, p = .04). No significant difference was observed between friend prime and passion prime (p > .05). For participants in low passionate love, reaction times (RTs) were not significantly different for target words with a love prime (mean 707 ± SD 91.27 ms) than with a friend primes (683.3 ± 45.51 ms) or with a passion prime (mean 683.1± 90.57 ms). Compared to participants in low passionate love, participants with high passionate were faster at detecting target words with a love prime (p= .03). No significant difference was observed between the two groups of participants for friend prime (p = .68) or passion prime (p = .84).

Electrophysiological results

Electrophysiological results showed archetypal VEP components (e.g., P100 and N200) for each condition. In addition, our topographical analysis combined with distributed intracranial source estimations extended our behavioral results by demonstrating specific brain microstates for target words associated with love primes compared to friend primes in participants with high passionate love (compared to participants with low passionate love). Similar brain topographies were observed in both groups of participants for target words associated with a friend prime (not shown here). More specifically, the topographical analysis revealed seven time periods of stable topography across the collective 600 ms post-stimulus period for participants in high passionate love (Fig. 2A), while only six time period of stable topography (brain microstate) appeared in participants with low passionate love in response to target words associated with love primes (Fig. 2B). The additional microstate observed in participants with high passionate love in response to love primes appeared in the early stages of visual information processing i.e., between 80ms and 220 ms after stimulus onset. During this time window, two distinct brain microstates appeared in participants with high passionate love (one between 80 ms and 120 ms, and another one between 120 ms and 220ms), instead of one brain microstate in participants with low passionate love. Distributed intracranial source estimations over the entire 600ms-time period revealed brain generators located in the visual, pleasure, reward and cognitive brain pathways (Fig. 2AB). More precisely, visual areas were activated in the first milliseconds after the stimulus onset, then higher-order associative brain areas, such as those involved in self-related processes (e.g., the angular gyrus/temporo-parietal junction) are activated, and finally a flow of backward activation from these associative brain areas to the primary visual and emotional brain areas occurred (Fig. 2AB). Distributed intracranial source estimations of the two brain microstates that are specific to love primes in participants in high passionate love(Fig. 2A)revealed specific brain generators (compared to participants in low passionate love, Fig. 2B) that were localized bilaterally in the posterior superior temporal sulcus (pSTS) region extending to the left temporo-parietal region (TPJ) with a maximal peak in the left pSTS (i.e., a brain area known to be involved in self-representation and social cognition) for the brain microstate appearing between 80 ms and 120 ms, and in the left pSTS with a maximal peak in the anterior cingulate cortex (i.e., a brain region known to be involved in emotional processing) for the brain microstate appearing between 120 and 220 ms.

Discussion and Conclusion

Together our results show that when a person is feeling high passionate love, the subliminal presentation of their beloved’s name evokes faster reaction times on decision making and also specific brain states that are mediated by generators located in the pleasure, reward, cognitive brain and motor planning pathways. More specifically, participants in high passionate love are faster in detecting target stimuli when primed by a beloved’s name, as compared to a friend’s name. This facilitation love priming effect is in agreement with a large body of research on affective priming suggesting that positive emotional target words are faster detected when primed with a word from the same category (e.g., positive emotional word; Bianchi-Demicheli *et al.*, 2006; Ortigue *et al.*, 2009), based on the automatic spreading of activation in a semantic [affective-associations] conceptual network from the prime to affectively congruent targets (Bargh *et al.*, 1996).

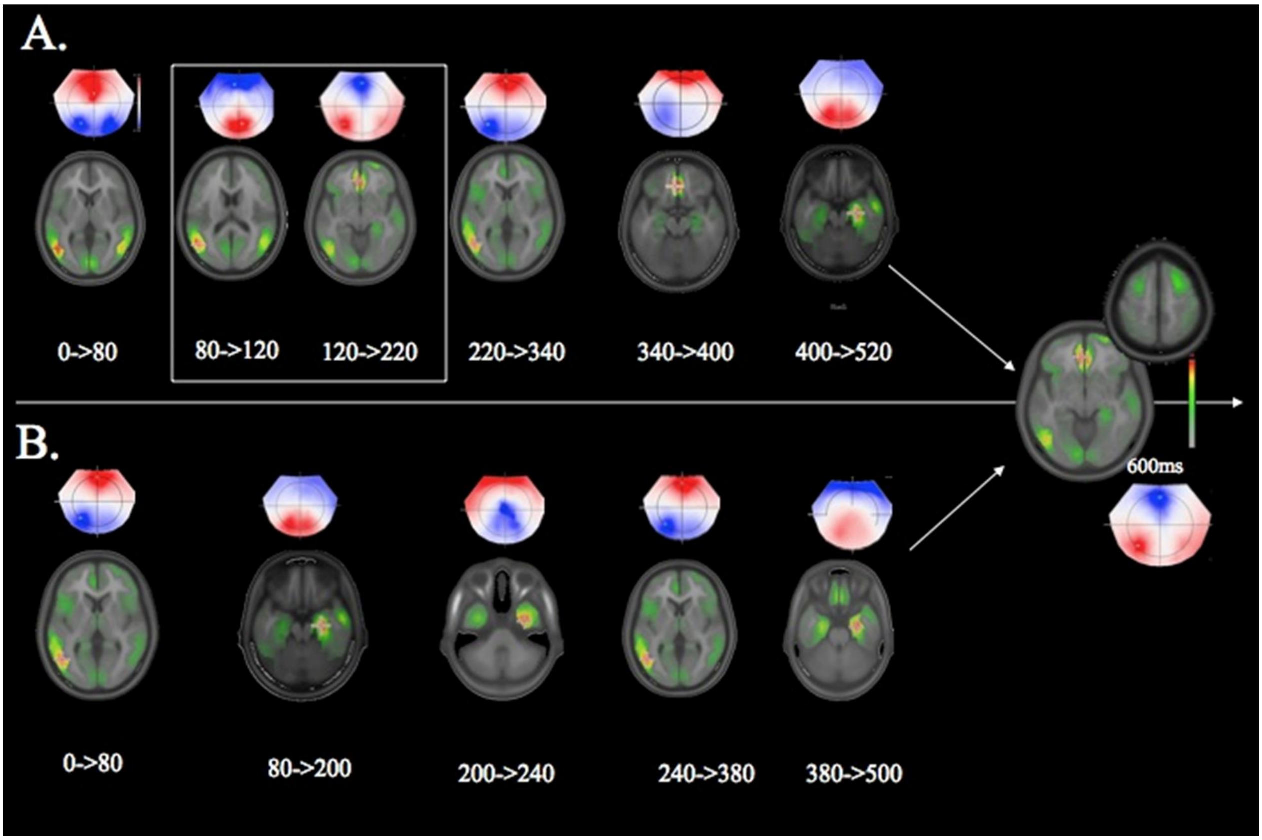

Figure 2. Localization of the intracranial brain generators as estimated with LAURA inverse solution.

By emphasizing this model of automatic spreading of activation, which is one of the most fundamental precepts of several modern cognitive-representational theories of emotion and general appraisal models of emotion generation (Bargh *et al.*, 1996; Bianchi-Demicheli, *et al.*, 2006; Hermans *et al.*, 2005; 2001), the present results also reinforce the hypothesis suggesting that intense passionate love activates mental representations that are parts of that particular emotional state and thus, implicitly modulates motor behavior, planning and decision making, as previously suggested for other emotions. This is in agreement with recent modeling of cortical language representation that applied Hebbian principles to posit that words' representations may be segregated throughout cerebral hemispheres by their conceptual structures (Hermans *et al.*, 2001). Interestingly this facilitation love priming effect was only present in participants in high passionate love and not in participants in low passionate love. This reinforces previous findings suggesting that love priming occurs at an associative level rather than a perceptual level (Pulvermuller, 1996), and indicating that love priming effects activate mental representations from "top-down" mechanisms coming from the love-dedicated neural network that is modulated as a function of the intensity of passionate brain state of the participants (Bianchi-Demicheli *et al.*, 2006).

From an electrical neuroimaging viewpoint, the fast (within 220 ms) recruitment of higher-order associative brain areas, such as those involved in self-related processes (e.g., the angular gyrus/temporo-parietal junction) reinforces the neuro-functional top-down model of interpersonal relationships (Ortigue and Bianchi-Demicheli, 2008), suggesting that associative brain areas may be activated at pre-conscious stages of information processing (i.e., starting at 80ms post-stimulus onset) and then prime more basic brain areas. This stresses that the functional organization of the human brain can be modulated not only by elementary emotional states, but also by one of the most complex and conceptual emotional and cognitive state of human endeavors i.e., intense passionate love. The fast recruitment of brain microstate specific to love in participants in high passionate love (compared to participants in low passionate love) highlights the non-conscious and automatically component of passionate love. Furthermore, by demonstrating the recruitment of self-related brain areas for love primes in participants in high passionate love only (compared to participants in low passionate love), the present findings reinforce the self-expansion model hypothesis of love, and suggest that exposure to intense love calls for self-related mechanisms at a pre-conscious level. By providing information about the fast (pre-conscious) brain spatio-temporal dynamics of some of the components of passionate love, as a subliminal prime, the present findings might provide a neuro-functional rationale, and open new avenues of research for some of the irrational components of the passionate mind in love.

Acknowledgements

The authors thank Professor Elaine Hatfield. The authors thank also Megan M. Vucovich for her technical assistance.

Funding

This study was supported by the Swiss National Science Foundation: grant #1223/PASMA 111563/1 and grant #FNS_PP00_1_128599/1 to SC.

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