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The neural basis of unconditional love

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ABSTRACT

Functional neuroimaging studies have shown that romantic love and maternal love are mediated by regions specific to each, as well as overlapping regions in the brain's reward system. Nothing is known yet regarding the neural underpinnings of unconditional love. The main goal of this functional magnetic resonance imaging study was to identify the brain regions supporting this form of love. Participants were scanned during a control condition and an experimental condition. In the control condition, participants were instructed to simply look at a series of pictures depicting individuals with intellectual disabilities. In the experimental condition, participants were instructed to feel unconditional love towards the individuals depicted in a series of similar pictures. Significant loci of activation were found, in the experimental condition compared with the control condition, in the middle insula, superior parietal lobule, right periaqueductal gray, right globus pallidus (medial), right caudate nucleus (dorsal head), left ventral tegmental area and left rostro-dorsal anterior cingulate cortex. These results suggest that unconditional love is mediated by a distinct neural network relative to that mediating other emotions. This network contains cerebral structures known to be involved in romantic love or maternal love. Some of these structures represent key components of the brain's reward system.

1. Introduction

There is mounting interest in social affective neuroscience regarding the neural mechanisms underlying various forms of attachment and love. To date, a few functional magnetic resonance imaging (fMRI) studies have been conducted to identify the brain regions mediating romantic love and maternal love. In the first of these studies (Bartels and Zeki, 2000), volunteers (11 females, 6 males) deeply in love were scanned while they viewed pictures of their partners (experimental task) and pictures of friends of similar age, sex and duration of friendship as their partners (control task). Blood oxygen level dependent (BOLD) signal increases (partner versus friends contrast) were measured in the middle insula (Brodmann area [BA]—14), rostro-dorsal anterior cingulate cortex (ACC, BA 24), caudate nucleus (dorsal head) and putamen. In addition, BOLD signal decreases (friends versus partner contrast) were observed in the posterior cingulate gyrus and amygdala, and were right-lateralized in the medial prefrontal, parietal and middle temporal cortices. According to Bartels and Zeki (2000), the combination of these brain regions suggests that a unique network of cerebral structures underlies romantic love. Aron et al. (2005) also scanned women ($n = 10$) and men ($n = 7$) who were intensely "in love". Participants were scanned while they viewed a photograph of their beloved (experimental task) and a photograph of a familiar individual (control task). Relative to the control task, in the experimental task BOLD signal increases were noted in the caudate nucleus (right medial and right postero-dorsal, bilaterally in the antero-dorsal portion). A significant locus of activation was also found in the right ventral tegmental area (VTA). Activation in the anteromedial caudate body was correlated with the passionate love scale (PLS) scores of participants. It is noteworthy that the caudate nucleus and the VTA represent major components of the mammalian brain's reward system (Wise, 1996; Schultz, 2000; Martin-Soelch et al., 2001). Interestingly, an fMRI study (Ortigue et al., 2007) has recently shown that the subliminal presentation of a beloved's name (as opposed to a friend's name) recruits brain regions (e.g., caudate nucleus, VTA) also known to be involved in the explicit (conscious) processing of love-related stimuli (Bartels and Zeki, 2000; Aron et al., 2005).

In another study, Bartels and Zeki (2004) used fMRI to measure brain activity in 20 mothers while they viewed pictures of their own (experimental task) and of age-matched child (experimental task) and of an age-matched child with whom they were well acquainted (control task). When mothers viewed their own child compared with when they

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viewed an age-matched child, significant loci of BOLD activation were detected in the middle insula (BA 14), rostro-dorsal ACC (BA 24), caudate nucleus (dorsal head), putamen/globus pallidus, thalamus (subthalamic nucleus, lateral thalamus), lateral orbitofrontal cortex (OFC, BA 47), right substantia nigra and right periaqueductal gray (PAG). The pattern of deactivations was noticeably comparable to that observed with romantic love (Bartels and Zeki, 2000) and involved the middle prefrontal cortex (BA 9, 46, 10), parieto-occipital junction/superior temporal sulcus (BA 39, 40), medial prefrontal/paracingulate cortex (BA 9/32), temporal poles, posterior cingulate gyrus (BA 29, 30), medial cuneus (BA 7, 31) and amygdaloid region. More recently, Noriuchi et al. (2008) investigated maternal brain responses to infant cues. BOLD signal changes were measured while 13 mothers viewed video clips of their own infant and other infants who demonstrated an attachment behavior (smiling at the infant's mother). The lateral OFC (BA 47), PAG, right anterior insula and left putamen were significantly activated when the mothers viewed their own infant versus other infants.

In the neuroimaging studies described above, both forms of love (romantic and maternal) were associated with regions specific to each, as well as overlapping regions in the brain's reward system (e.g., caudate, putamen). For Bartels and Zeki (2004), the particular areas in the reward structures activated in their two studies (2000, 2004) suggest the existence of a general, modality-independent network that would be specialized to mediate attachment. These researchers further proposed that maternal and romantic love may share a similar evolutionary origin and a common evolutionary purpose, i.e., the maintenance and perpetuation of the human species. Being rewarding experiences, both maternal and romantic love ensure the formation of firm bonds between individuals. Given this commonality, it would not appear surprising that the neural architectures mediating these two forms of love share a core of common neural mechanisms (Bartels and Zeki, 2004).

Nothing is known yet regarding the neural underpinnings of unconditional love (also called unlimited love or "Agape" love). This kind of love was first studied by sociologist (Sorokin, 1950). Post (2003) has proposed that the essence of unconditional love is to emotionally affirm as well as to unselfishly delight in the well-being of others, and to volitionally engage in acts of care and service on their behalf without expecting anything in return. Unconditional love is extended to all others without exception, in an enduring and constant way. It is considered to be one of the highest expressions of spirituality (Post, 2003). Undoubtedly, this type of love is paramount for the future of our world and humanity.

The unconditional love construct is distinct from the empathy and compassion constructs. Empathy is commonly defined as an affective response that stems from the apprehension of another's emotional state (e.g., sadness, happiness, pain), and which is comparable to what the other person is feeling (Eisenberg, 2000). This affective response is not unconditional and does not involve feelings of love. Compassion refers to an awareness of the suffering of another coupled with the desire to alleviate that suffering (Steffen and Masters, 2005). In contrast to compassion, unconditional love is not specifically associated with suffering.

The main objective of this fMRI study was to identify the brain regions supporting unconditional love. Participants were assistants in two l'Arche communities located in the Montreal area. L'Arche communities (founded by Jean Vanier in 1964) are places where those with intellectual disabilities, called core members, and those who share life with them, called assistants, live together. This special population was selected on the basis that one of the most important criteria to become an assistant is the capacity to love unconditionally.

Given the rewarding aspect of unconditional love, we predicted that it would be associated with activation of the VTA and dorsal striatal regions. In addition, since unconditional love experientially differs to a large extent from romantic love and maternal love, we also predicted that this form of love would be mediated by brain regions not involved in romantic love and maternal love.

2. Methods

2.1. Participants

Participants were eight men and nine women (mean age = 36 ± 14, range: 20–63 years) with no history of psychiatric, neurological or substance use disorders (according to self-reports). They were not taking any psychotropic drug at the time of scanning. The directors of the two l'Arche communities involved in this research project helped us recruit assistants with a very high capacity for unconditional love. We ensured that all recruited individuals understood the meaning of this form of love (based on the construct presented in Section 1) and found their work at l'Arche very gratifying. On average, the participants had been working in l'Arche communities for 2 years. Participants all gave written informed consent, and the study was approved by the ethics committee of the Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal (CRIUGM).

2.2. Behavioral protocol

A blocked-design was used to examine brain activity during a passive viewing (PV) condition (control task) and an unconditional love (UL) condition (experimental task). Five blocks of pictures were presented during both conditions. Each block consisted of a series of four pictures. Each picture was presented during 9 s (pre-experimentation revealed that, on average, participants needed that long to feel unconditional love toward the individuals depicted in the pictures). Blocks were separated by periods of 30 s. Pictures depicted individuals (children and adults) with intellectual disabilities. These individuals were unfamiliar to the participants. Instructional cue words ("View", "Unconditional love") printed in white first appeared in the center of a black screen for 2 s. While the picture remained on the screen, participants performed the tasks specified by the prior cue. In the PV blocks, participants were instructed to simply look at the individuals depicted in the pictures. In the UL blocks, participants were instructed to self-generate a feeling of unconditional love toward the individuals depicted in the pictures. Therefore, the UL task involved both a cognitive component (self-generation) and an emotional–experiential component (feeling). Blocks were presented in alternation (PV, UL, PV, UL, etc.). At the end of each block for both experimental conditions, a four-point scale (1 = "No feeling", 2 = "Some feeling", 3 = "Moderate", 4 = "Very intense") for rating the extent to which they currently felt unconditional love was presented for 3 s. A four-button response box was used for rating. To ensure that the participants were able to perform the tasks adequately, they participated in a training session (with comparable but different stimuli) during which they received careful instructions and guidance regarding these tasks 1 h before scanning. Stimulus presentation and response selection were controlled by the program E-Prime (version 1.1, Psychology Software Tools, Inc.) running on an IBM, AMD Opteron Processor 248 (2.19 GHz, 2.00 Go RAM). Stimuli were projected with an EPSON EMP-8300 XGA LCD projector through a collimating lens onto a rear-projection screen that was fastened vertically in the magnet bore at neck level. Participants viewed the stimuli on a tilted mirror mounted on a head coil. Pictures were displayed by computer via back-projection onto a translucent screen of 1024×768 pixels resolution subtending 24×18° visual angle. At the end of the scanning session, participants were interviewed to verify which feelings they experienced besides unconditional love during the control and experimental conditions.

2.3. Image acquisition

Echoplanar images (EPI) was acquired on a 3 Tesla system (Magnetom Trio, Siemens Electric, Erlangen, Germany) located at the fMRI Unit of the CRIUGM. Twenty-eight slices (5 mm thick, voxel size = 3.4×3.5×5 mm) were acquired every 2 s in an inclined axial plane, aligned with the AC–PC axis. These T2* weighted functional images were acquired using an EPI pulse sequence (echo-space time = 0.8 ms, TE = 30 ms, flip angle = 90°, field of view = 215 mm, matrix = 64×64). Following functional scanning, high-resolution data were acquired via a Tl-weighted three-dimensional volume acquisition that was obtained using a gradient echo pulse sequence (TR = 19 ms, TE = 4.9 ms, flip angle = 25° field of view = 250 mm, voxel size = 1×1×1 mm, matrix = 256×256). Earpad foam cushions surrounding the head of the participants and earplugs were used to significantly reduce the perception of the noise generated by the MRI scanner.

2.4. Data analysis

Data were analyzed using Statistical Parametric Mapping software (SPM2, Wellcome Department of Cognitive Neurology, London, UK). Images for all participants were realigned to correct for artifacts due to small head movements and spatially normalized (voxel size: 3 mm×3 mm×3 mm) into an MRI stereotactic space (Talairach and Tournoux, 1988). Images were then convolved in space with a three-dimensional isotropic Gaussian kernel (12 mm FWHM) to improve the signal-to-noise ratio and to accommodate for residual variations in functional neuroanatomy that usually persist between participants after spatial normalization.

For the statistical analysis, the time series of the images were convolved with the delayed box-car function, which approximates the activation patterns. Effects at each

Table 1
UL minus PV contrast.

Brain regions	BA	Talairach coordinates			*P* value	z value	Number of voxels
		x	*y*	*z*			
R PAG		6	−17	−6	0.001	4.00	61
R SPL 7	7	35	−50	45	0.001	4.00	97
L VTA		−1	−13	−10	0.001	3.98	52
L Rostro-dorsal ACC	32	−4	18	37	0.001	3.95	33
R Middle Insula	13	42	1	5	0.001	3.75	105
R Globus pallidus (medial)		11	1	0	0.001	3.68	18
L Middle Insula	13	−38	1	4	0.001	3.58	193
L Rostro-dorsal ACC	24	−11	−15	39	0.001	3.52	13
R IOG	18	30	−86	−12	0.001	3.35	15
L SPL	7	−39	−51	53	0.001	3.34	187
R Caudate (dorsal head)		11	13	13	0.005	3.14	26

Stereotaxic coordinates are derived from the human atlas of Talairach and Tournoux (1988) and refer to medial–lateral position (*x*) relative to midline (positive = right), anterior–posterior position (*y*) relative to the anterior commissure (positive = anterior), and superior–inferior position (*z*) relative to the commissural line (positive = superior). Designations of Brodmann areas (BA) for cortical areas are also based on this atlas. ACC: anterior cingulate cortex; IOG: inferior occipital gyrus; PAG: periaqueductal gray; SPL: superior parietal lobule; VTA: ventral tegmental area; L, left; R, right.

and every voxel were estimated using the general linear model. Voxel values for the contrasts of interest yielded a statistical parametric map of the *t* statistic (SPM *t*), subsequently transformed to the unit normal distribution, (SPM Z). The brain activity in the PV condition was contrasted from that associated with the UL condition (UL minus PV contrast). The reverse contrast (PV minus UL) was also examined. A "random-effects model" was used to perform these contrasts, i.e., the difference images from all participants for these contrasts were submitted to a one-sample *t* test. In this procedure, the significance values assigned to each voxel indicate the likelihood of its being activated in the whole population from which the sample has been drawn (Friston et al., 1999). An *a priori* search strategy was used and a small volume correction was performed in the brain regions (ROIs) defined *a priori*. These regions, which belong to the brain's reward system and have been shown to be implicated in various forms of love, included the caudate nucleus, putamen, globus pallidus and VTA. The search volume corresponding to the ROIs was defined *a priori* by tracing the neuroanatomical boundaries of these regions on the MR reference image (MNI template), using SVC and box volume function in SPM2. For this *a priori* search, a corrected probability threshold for multiple comparisons of $P<0.05$ corrected was used. The small volume was centered on the midpoint of an anatomically defined structure. A whole-brain *post hoc* analysis was also carried out. For this analysis, a corrected probability threshold of $P<0.005$ was utilized. Only clusters showing a spatial extent of at least 10 contiguous voxels were kept for image analysis.

3. Results

3.1. Self-report data

All participants reported feeling unconditional love in both the UL condition and the PV condition. The mean level of reported unconditional love was significantly higher in the UL condition (mean = 3.75; SD = 0.45; range: 3–4) than in the PV condition (mean = 2.69; SD = 0.70; range: 2–4) ($P<0.0001$, Student's *t* test). During the interview conducted at the end of the scanning session, participants did not report feelings other than unconditional love during the control and experimental conditions. At the end of the experiment, several participants told the experimenters that the UL task was relatively easy to do.

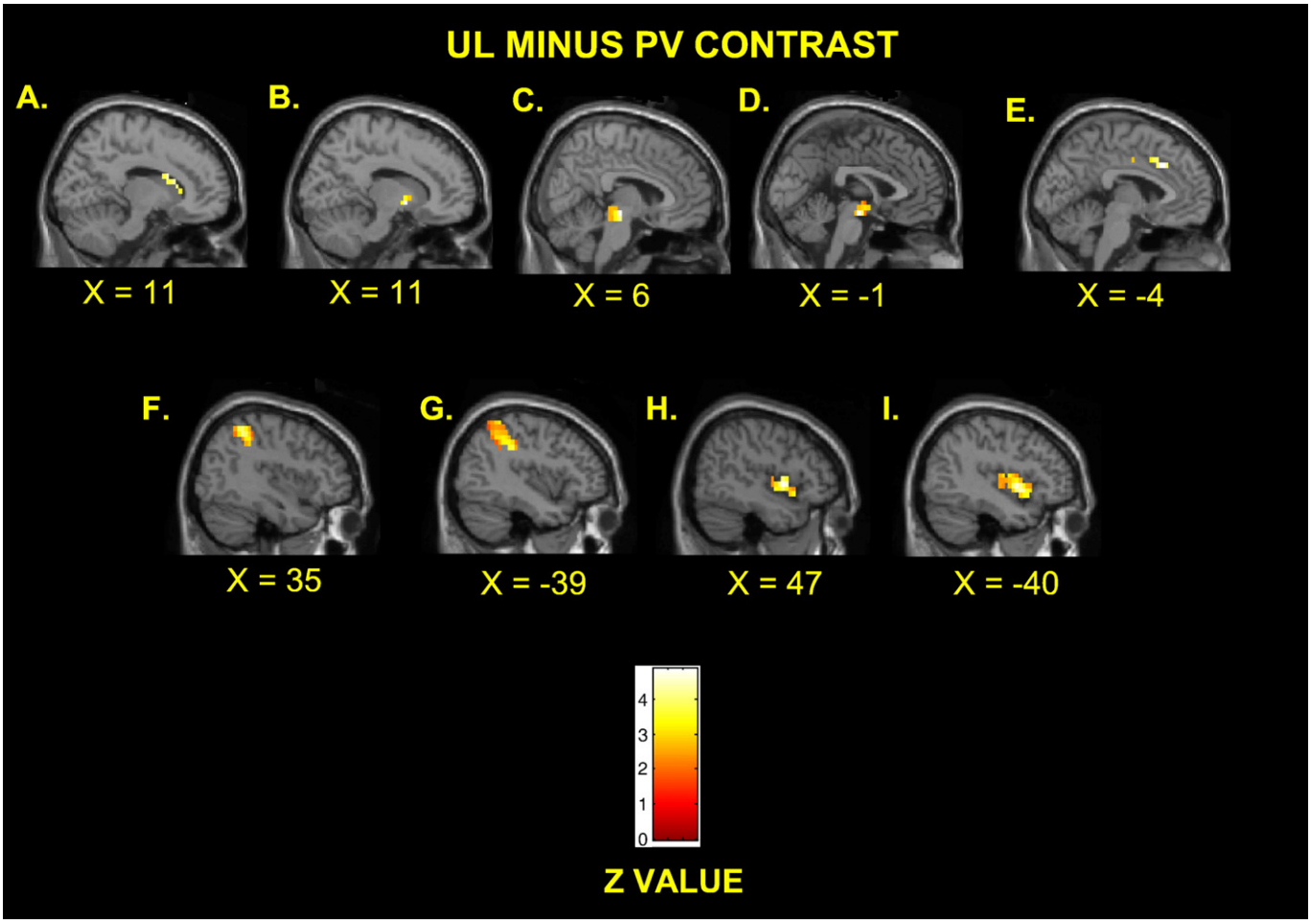

Fig. 1. Statistical activation maps for the UL minus PV contrast. Images are sagittal sections for the data averaged across participants. Significant loci of activation were noted in the right caudate nucleus (dorsal head) (A.), right globus pallidus (medial) (B.), right PAG (C.), left VTA (D.), left rostro-dorsal ACC (E.), right SPL (F.), left SPL (G.), right insula (H.) and left insula (I.). PV: passive viewing; UL: unconditional love.

Table 2
A posteriori correlational analyses between self-report ratings of unconditional love and magnitude of BOLD signal increases.

Brain regions	BA	Talairach coordinates			*P* value	*R* value	Number of voxels
		x	*y*	*z*			
L Middle Insula	13	−45	−15	16	0.017	0.61	55
L Rostro-dorsal ACC	24	−13	7	36	0.021	0.59	34
R Lingual gyrus	18	15	−89	−13	0.021	0.59	23
R IPL	40	45	−38	42	0.03	0.56	29
R Middle Insula	13	45	−5	9	0.035	0.55	37

As in Table 1. ACC: anterior cingulate cortex; BA: Brodmann areas; BOLD: blood oxygen level dependent; IPL: inferior parietal lobule; L, left; R, right.

3.2. FMRI data

3.2.1. UL minus PV contrast

For this *a priori* search, significant BOLD signal increases were found in the right globus pallidus (medial), right caudate nucleus (dorsal head) and left VTA. For the whole-brain *post hoc* analysis, significant loci of activation were noted in the middle insula (BA 13), superior parietal lobule (SPL, BA 7), right PAG, right inferior occipital gyrus (IOG, BA 18), and left rostro-dorsal ACC (BA 24, 32) (Table 1, Fig. 1).

3.2.2. PV minus UL contrast

The PV minus UL contrast did not reveal any significant BOLD signal change.

3.2.3. A posteriori correlational analyses

A posteriori correlational analyses were conducted between self-report ratings of unconditional love in the UL condition and the magnitude of regional BOLD signal increases found in the UL minus PV contrast (corrected probability threshold for multiple comparisons: $P<0.05$). These analyses revealed the existence of positive correlations in the left middle insula (BA 13, $P=0.017$, $R=0.61$), left rostro-dorsal ACC (BA 24, $P=0.021$, $R=0.59$), right IPL (BA 40, $P=0.030$, $R=0.56$), right middle insula (BA 13, $P=0.035$, $R=0.55$) and right lingual gyrus (BA 18, $P=0.021$, $R=0.59$) (Table 2).

4. Discussion

The feelings of unconditional love during the UL condition were associated with significant BOLD signal increases in the middle insula (BA 13), SPL (BA 7), right caudate nucleus (dorsal head), right PAG, right globus pallidus, right IOG (BA 18), left VTA and left rostro-dorsal ACC (BA 24, 32). In addition, positive correlations were found between the intensity of unconditional love feelings in the UL condition and the magnitude of regional BOLD signal increases in the middle insula (BA 13), left rostro-dorsal ACC (BA 24), right IPL (BA 40) and right lingual gyrus (BA 18).

The dorsal head portion of the caudate nucleus and the VTA have previously been shown to be associated with romantic love (Bartels and Zeki, 2000; Aron et al., 2005). In addition, the globus pallidus appears to be implicated in maternal love (Bartels and Zeki, 2004). In keeping with one of our hypotheses, the present findings suggest that these cerebral structures are also involved in unconditional love. In a meta-analytic review of several positron emission tomography (PET) and fMRI emotion studies, activation of dorsal striatal structures (caudate nucleus, globus pallidus, putamen) was noted in nearly 70% of studies involving the induction of positive emotional states (Phan et al., 2002). Electrophysiological, pharmacological, neuroimaging and clinical studies have demonstrated that the caudate nucleus plays a pivotal role in the representation of goals, reward detection and expectation, and the preparation for action (Wise, 1996; Kawagoe et al., 1998; Salinas and White, 1998; White and Hiroi, 1998; Schultz, 2000; Martin-Soelch et al., 2001; Lauwereyns et al., 2002; O'Doherty et al., 2002; Delgado et al., 2003; Phillips et al., 2003). The caudate nucleus can be selectively activated by monetary reward stimuli (Knutson et al., 2001; Elliott et al., 2003), cocaine (Breiter et al., 1997; Breiter and Rosen, 1999), and during sexual arousal (Rauch et al., 1999; Stoleru et al., 1999; Karama et al., 2002). Here, we propose that the activations noted in the dorsal striatum are related to the rewarding aspect of unconditional love. More specifically, we submit that the activation of the caudate nucleus (dorsal head) was related to the detection of the reward associated with the feelings of unconditional love. As for the globus pallidus, there is some evidence that deep brain stimulation of this dorsal striatal structure can significantly improve mood in patients suffering from a treatment-refractory major depressive episode with comorbid neuroleptic-induced tardive dyskinesia (Kosel et al., 2007). In this context, it is possible that the globus pallidus activation reflected the positive emotional state experienced by the participants during the UL condition. With regard to the VTA, fMRI studies have shown that this mesencephalic structure can be activated by pleasant music (Menon and Levitin, 2005), cocaine (Breiter et al., 1997), alcohol (Filbey et al., 2008), chocolate (Small et al., 2001) and money (Delgado et al., 2000; Breiter et al., 2001; Knutson et al., 2001; Elliott et al., 2000, 2003, 2004). Activation of the VTA has also been reported during human male ejaculation (Holstege et al., 2003). It seems conceivable that the VTA activation noted here was linked with the pleasurable feelings produced by unconditional love, and that the VTA is associated with the experiential aspect of positive emotional states. Since many lines of evidence indicate that dopaminergic projections from the midbrain tegmentum to the basal ganglia play an important role in mediating the behavioral effects of natural and artificial rewards (Hernandez et al., 2006), we propose that dopamine is implicated in unconditional love. This neurotransmitter/neuromodulator is also known to be associated with desire, euphoric states and addiction (Zeki, 2007).

This study also suggests that the periaqueductal gray matter of the midbrain (PAG) may be involved in unconditional love. Previous fMRI studies (Bartels and Zeki, 2004; Noriuchi et al., 2008) support the view that the PAG is involved in human maternal behavior. This cerebral structure, which is heavily connected with various limbic regions, contains a high density of oxytocin receptors (Jenkins et al., 1984). Oxytocin is a hypothalamic neuropeptide that has been widely implicated in the regulation of positive social interactions, social bonding, and maternal responsiveness in several mammalian species, including humans (Olazábal and Young, 2006). It is thus possible that oxytocin activity in the PAG promotes unconditional love.

Two areas of the rostro-dorsal ACC, BA 24 and BA 32, were significantly activated in the UL condition. Interestingly, BA 24 of this prefrontal cortical area was also activated in the two fMRI studies previously conducted by Bartels and Zeki (2000, 2004). The rostro-dorsal ACC (BA 24) thus seems to be implicated in several forms of attachment and love. There is some evidence that the rostro-dorsal portion of the ACC (BA 24 and BA 32) is involved in that aspect of emotional awareness related to the interoceptive and exteroceptive detection of emotional signals (Lane et al., 1997, 1998). Therefore, the rostro-dorsal ACC (BA 24 and BA 32) activation noted during the UL condition might reflect self-awareness of unconditional love feelings. The positive correlation found between self-report ratings of unconditional love and the magnitude of regional BOLD signal increases in the left rostro-dorsal ACC (BA 24) is consistent with such a view. It is noteworthy that the rostro-dorsal subdivision of the ACC has previously been shown to be involved in empathy for pain (Singer et al., 2004, 2006).

In agreement with our second hypothesis, unconditional love was mediated by brain regions not known to be implicated in romantic love or maternal love, such as BA 13 of the middle insula. There is increasing evidence that the insula is implicated in the representation of bodily states that colour conscious experiences (or "background feelings"—Damasio, 1999). This cerebral structure contains a topographical representation of inputs from visceral, olfactory, gustatory,

visual, auditory and somatosensory areas, and it is proposed to integrate representations of external sensory experience and internal somatic state (Mesulam and Mufson, 1982; Augustine, 1996). The middle insula has been found to be activated in several neuroimaging studies of emotion (Phillips et al., 1997), and appears to support a representation of somatic and visceral responses accessible to consciousness (Critchley et al., 2004). Given this, it is plausible that the middle insular activation noted during the UL condition was associated with the somatic and visceral responses elicited by the presented pictures. The positive correlation between self-report ratings of unconditional love and BOLD signal increases in this cortical region is supportive of such an interpretation. In other respects, it was previously demonstrated (Lutz et al., 2008) that the strength of activation in the anterior insula during a compassion meditation state was associated with self-reported intensity of compassion meditation (for both novice and expert meditation practitioners). It has also been demonstrated that the anterior insula plays a crucial role for empathic experience related to pain (Singer et al., 2004, 2006). It thus seems that the middle subdivision of the insula is involved in various forms of love (romantic, maternal, unconditional) but not in compassion or empathy.

In a recent fMRI study (Ruby and Decety, 2004), healthy participants were required to take a first or third person perspective in response to situations involving various social emotions. Adopting a third person stance was associated with increased BOLD signal in IPL (BA 40). In line with this, it has been proposed that the IPL (BA 40) is implicated in the distinction between self and other (Decety and Jackson, 2004). The positive correlation found between self-report ratings of unconditional love in the UL condition and the magnitude of regional BOLD signal increase in the IPL (BA 40) is consistent with this hypothesis since a self-other distinction was associated with the unconditional love feelings experienced in the UL condition. As for the SPL (BA 7) activations noted here, functional neuroimaging studies have associated activity in this area of the parietal cortex—a component of the posterior attentional system—with shifts of visual spatial attention (Corbetta et al., 1993; Vandenberghe et al., 2001). The superior parietal lobule activations detected in the UL condition may be related to visual spatial attention to the emotional stimuli presented.

A significant activation of the right IOG (BA 18) and a positive correlation between self-report ratings of unconditional love and BOLD signal increases in the right lingual gyrus (BA 18) were found in this study. Given that the pictures presented were similar in both experimental conditions, these findings point to the possibility that the self-induced unconditional love feeling state of the participants, during the UL task, up-regulated the neural activity in the extrastriate visual cortex related to the processing of these pictures.

Some limitations of this study have to be acknowledged. First, it is possible that self-reports were driven to a certain extent by demand characteristics. Indeed, it seems unlikely that subjects did not experience any other feelings than the unconditional love. However, to circumvent this potentially confounding variable, we recruited only individuals who have a very high capacity for unconditional love and who clearly understand the meaning of this form of love. Second, it is conceivable that some of the regional activations reflected effortful attempts to perform a novel task. Still, participants were pre-trained on the control and activation tasks to prevent this potential problem.

In conclusion, the results of the present fMRI study suggest that unconditional love is mediated by a distinct neural network relative to other forms of love and attachment. This network includes brain regions not implicated in romantic and maternal love, such as BA 13 of the middle insula and the rostro-dorsal ACC (BA 32). Nevertheless, this network also contains cerebral structures implicated in romantic love or maternal love, such as the dorsal head portion of the caudate nucleus, the globus pallidus and the VTA. These structures represent key components of the brain's reward system. As in the case of romantic love and maternal love, the rewarding nature of unconditional love facilitates the creation of strong emotional links between humans. Such robust emotional bonds may critically contribute to the preservation of the human species.

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