Review of General Psychology
2014, Vol. 18, No. 4, 313–321

1089-2680/14/$12.00 http://dx.doi.org/10.1037/gpr0000020

The Effects of Romantic Love on Mentalizing Abilities

Rafael Wlodarski and Robin I. M. Dunbar
University of Oxford

The effects of the human pair-bonded state of "romantic love" on cognitive function remain relatively unexplored. Theories on cognitive priming suggest that a state of love may activate love-relevant schemas, such as mentalizing about the beliefs of another individual, and may thus improve mentalizing abilities. On the other hand, recent functional MRI (fMRI) research on individuals who are in love suggests that several brain regions associated with mentalizing may be "deactivated" during the presentation of a love prime, potentially affecting mentalizing cognitions and behaviors. The current study aimed to investigate experimentally the effect of a love prime on a constituent aspect of mentalizing—the attribution of emotional states to others. Ninety-one participants who stated they were "deeply in love" with their romantic partner completed a cognitive task involving the assessment of emotional content of facial stimuli (the Reading the Mind in the Eyes task) immediately after the presentation of either a love prime or a neutral prime. Individuals were significantly better at interpreting the emotional states of others after a love prime than after a neutral prime, particularly males assessing negative emotional stimuli. These results suggest that presentation of a love stimulus can prime love-relevant networks and enhance subsequent performance on conceptually related mentalizing tasks.

Keywords: cognition, mentalizing, pair-bonding, romantic love, theory of mind

The intense emotions associated with human pair-bonding are considered to be a human universal—experienced in some form by every culture and evident in the earliest human oral and written records (Dunbar, 2012; Gottschall & Nordlund, 2006; Jankowiak & Fischer, 1992). The pervasiveness of this form of bonding likely exists because it serves an important function in the context of human mating: namely coordinating parental investments under the auspices of biparental care (Clutton-Brock, 1989; Fraley, Brumbaugh, & Marks, 2005; Kleiman, 1977). Human infants are secondarily altricial, requiring substantial support during rearing because of their relative underdevelopment at birth compared with other mammals and primates (Bogin, 1999), driven in part by the mismatch between our inordinately large brains and the size limitations placed on the female birth-canal by the evolution of bipedal locomotion (Rosenberg & Trevathan, 1995; Ruff, 1995). Such high levels of dependency require intense levels of time and resource investment, with chances of individual offspring survival vastly improved in the active presence of two parents (for a review, see Geary, 2000). Biparental coordination of investment is most commonly maintained through the formation of exclusive pair-bonded mating attachments—commonly referred to in humans as 'romantic love' (Fisher, Aron, & Brown, 2006; Fisher, 1989; Mellen, 1981).

Rafael Wlodarski and Robin I. M. Dunbar, Department of Experimental Psychology, University of Oxford.

The authors acknowledge their colleagues at the Social & Evolutionary Neuroscience Research Group (SENRG) for their valuable input and advice. R.W. and R.D. are both supported by a European Research Council Advanced Grant to R.D.

Correspondence concerning this article should be addressed to Rafael Wlodarski, Department of Experimental Psychology, South Parks Road, Oxford OX1 3UD, United Kingdom. E-mail: rafael.wlodarski@psy.ox.ac.uk

The Neurochemistry of Romantic Love

Because of its importance to offspring survival, the creation of pair-bonds is likely to have been under considerable evolutionary pressure, with the neuroanatomical and neurochemical system of this type of bonding highly conserved among primates and mammals in general. Research examining the biological underpinnings of both human and animal pair-bonds suggests that these attachment behaviors are indeed mediated by several distinct, and sometimes ancient, physiological substrates (Carter, 1998; de Boer, van Buel, & Ter Horst, 2012; Esch & Stefano, 2005; Kendrick, 2004; L. J. Young, Murphy Young, & Hammock, 2005).

One of the first candidate neuroendocrine systems that has been associated with pair-bonding was oxytocin and vasopressin, first examined in monogamous prairie voles. The mating system differences between these voles and the closely related but promiscuously mating montane voles was put down to variation in the expression of brain oxytocin and vasopressin receptor sites (Carter, 1992; Insel, 1992). Monogamous voles have higher densities of oxytocin receptors in regions of the brain associated with the dopamine reward system and in the amygdaloidal region (associated with memory and emotion), as well as higher vasopressin receptor densities in the lateral amygdala (Insel, 1992; Young & Wang, 2004). Further evidence for the role of these peptides in mating system formation was found when the release of oxytocin was blocked in monogamous voles, whereupon they failed to form pair-bonded attachments, whereas when vasopressin was expressed in promiscuous voles they formed monogamous pair-bonds (Lim & Young, 2006). These exact same neuropeptides have also been associated with attachment formation and maintenance in humans (Diamond, 2004).

Because in humans considerable activity of these two neuropeptides takes place in the dopaminergic reward system of the brain, their release has also been associated with the dominant neurochemical of this particular region, dopamine (Young & Wang, 2004). Dopamine is also thought to play a role in pair-bond formation and the mediation of oxytocin and vasopressin effects, perhaps explaining why romantic love behaviors can feel as addictive as other behaviors associated with dopaminergic reward pathways, such as gambling or drug addiction (Edwards & Self, 2006). The neurotransmitter serotonin is yet another substance that has been associated with pair-bonding, with research suggesting that romantic love in its early stages may be associated with depleted levels of serotonin (Zeki, 2007). Similar levels of serotonin depletion are also found in psychiatric conditions such as obsessive–compulsive disorders (Feygin, Swain, & Leckman, 2006; Marazziti, Akiskal, Rossi, & Cassano, 1999), depression (Young & Leyton, 2002), and anxiety (Leonardo & Hen, 2006), suggesting that behaviors associated with intense early stage romantic love might share the same neural substrates as behaviors found in individuals suffering from these disorders. Furthermore, endorphin activity is known to be highly intercorrelated with dopamine activity, with endorphins recently implicated in the formation and maintenance of various forms of social attachment and interpersonal bonding in humans as well as primates (Dunbar, 2010; Machin & Dunbar, 2011). Finally, other neuronal and hormonal changes that have been associated with early stage romantic love include the hypothalamic pituitary adrenal axis (HPA) and cortisol, which are also known to interact with oxytocin and vasopressin, nerve growth factor (NGF), and the hormone testosterone (for an in-depth review see de Boer et al., 2012).

Love Cognitions, Motivations, and Behaviors

It is these biological drivers which are thought to be responsible for influencing various motivations associated with romantic love—directing an individual's interest toward one specific mating partner, reducing interest in the pursuit of other partners, and creating desire and drive for emotional intimacy and closeness with one particular individual (Dunbar, 2012; Fisher, 1992; McIntyre et al., 2006). Such increased levels of intimacy and attachment arising from pair-bond mediated motivations helps individuals to align their respective interests, and coordinate behaviors, so as to successfully rear offspring (Dunbar, 2014). In humans, pair-bonds (in particular the kind of intense bonds associated with early stages of 'passionate love') tend to last an average of about four years, as indexed by divorce/separation patterns in various cultures (Fisher, 1989). This is, coincidentally, also the amount of time that human infants require the heaviest amount of investment to improve their chances of survival (Geary, 2000). The motivations associated with this passionate form of love are also related to various cognitions associated with this state, cognitions which help facilitate long-term relationship maintenance and may include feelings of emotional dependency, security and comfort, commitment, and reduced levels of anxiety (Fisher, 1998). Various affiliative behaviors are further driven by these cognitions so as to reinforce attachment, which include high levels of social interaction, joint coordination of behavior, direct physical contact, and various types of physically and psychologically arousal-inducing activities (Dunbar & Shultz, 2010).

Love and Mentalizing

One potential cognitive ability that may be instrumental in aligning interests within dyadic pairs is the ability to reason about another individual's mental states, an ability known as mentalizing (or Theory of Mind; Frith, Morton, & Leslie, 1991; Premack & Woodruff, 1978). Theorizing about the intentions, emotions, desires, and beliefs of another individual is arguably a uniquely human trait (though see also Povinelli & Bering, 2002), one which is thought to be fully developed in children around the age of four to five years (Wellman, Cross, & Watson, 2001), but may possibly be present at an earlier stage in some form in infants (Kovács, Téglás, & Endress, 2010). In the context of pair-bonded relationships, mentalizing would be necessary to assist in facilitating biparental care, coordinating behaviors and resource investments, and mediating attachment bonds. One component mechanism of mentalizing is the ability to assess and reason about the emotional states of others. This ability can involve attributing an emotional state to another individual based on an external cue, and although this does not necessarily allow for inferring the detailed content of a particular mental state, it is nonetheless an important prerequisite stage in the mentalizing process (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001).

An ability to reason about others' minds and intentions would be of vital importance to coordinating behaviors within pair-bonded relationships, as well as to ascertaining the beliefs and intentions of the other individual so as to ensure the continued survival of a pair-bond attachment. As such, it is possible that individuals in a pair-bonded relationship may be utilizing such processes to a greater extent with their romantic partners than with other individuals with whom they have nonsexually bonded relationships. Interestingly, past research has found that females typically out-perform males on various mentalizing tasks as well as on tasks involving the attribution of emotional states to others (Baron-Cohen et al., 2001; Stiller & Dunbar, 2007). These differences may reflect greater female focus on relationship formation and maintenance, both in terms of pair-bonded and nonsexual relationships (Ellis & Symons, 1990; Low, 1978; Shackelford, Schmitt, & Buss, 2005).

If this is the case, then models of conceptual priming would predict that being primed by a love stimulus would activate schema and memories relevant to that stimulus, which in the case of a love prime are likely to include mentalizing about the beliefs of another individual, in this case the romantic partner (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991; Tulving, Schacter, & Stark, 1982). Such priming is thought to enhance the accessibility of these schemas and is likely to result in improved performance on tasks requiring their use. Because it is known that individuals in love expend considerably more energy thinking about the object of their love than about others (Fisher, 1998; Hatfield & Sprecher, 1986; O'Leary, Acevedo, Aron, Huddy, & Mashek, 2012), to the point of bordering on obsessive–compulsive behavior (Feygin et al., 2006), it seems plausible that a love stimulus may act as a particularly effective conceptual prime for mentalizing cognitions. As has been previously noted, such increased mentalizing cognitions might only be directed to the romantic partner in question, and thus it remains uncertain whether such mentalizing would be transferrable to other, non-partner individuals. However, previous research on conceptual priming implies that the activated schema can be rather broad and indeed 'conceptual' in nature, suggesting that mentalizing cognitions directed at one individual may activate broad mentalizing schema which might then be applied to other individuals.

Neural Activity Associated With Romantic Love

However, recent fMRI research on individuals who are deeply in love with their partner have predicted, based on blood oxygen level–dependent (BOLD) signal changes, that individuals who are presented with a love stimulus might suffer from poorer mentalizing skills. These studies have revealed unique patterns of brain activation in individuals who are 'in love,' showing that when presented with a picture of a loved one (a love prime) activity increases in dopaminergic areas that form the brain's reward system, while activity may actually be decreasing in regions related to mentalizing and Theory of Mind (e.g., Acevedo, Aron, Fisher, & Brown, 2012; Aron et al., 2005; Bartels & Zeki, 2000; Ortigue, Bianchi-Demicheli, Hamilton, & Grafton, 2007; Xu et al., 2011; Younger, Aron, Parke, Chatterjee, & Mackey, 2010; Zeki & Romaya, 2010). Methodology in such studies typically involves recruiting participants who self-identify as being in love with their romantic partner, assessing the 'intensity' of their love using either interviews or questionnaires, and examining the patters of brain responses within these individuals when they are presented with a stimulus of their loved one (either pictures, names or video of their love interest) as compared with activations to a baseline/neutral stimulus condition.

The first neuroimaging study to look at this phenomenon selectively recruited 17 participants (six male) who self-identified as being 'truly, deeply, and madly in love' with their partner, assessed their levels of love using the Passionate Love Scale (PLS, Hatfield & Sprecher, 1986), and compared fMRI responses when looking at a color picture of their loved one to when looking at pictures of control-matched friends (Bartels & Zeki, 2000). This study found that when looking at pictures of a loved one as compared to a friend, activity was greater in the dopaminergic regions of the brain such as the caudate nucleus and putamen, as well as in regions related to reward processing, emotion regulation, and sensory integration, areas which included the insula and anterior cingulate cortex. Follow-up studies have found similar activations in subcortical dopaminergic brain regions, particularly the ventral tegmental area (VTA), dorsal caudate body, and caudate tail (Aron et al., 2005; Fisher et al., 2006). This later research additionally utilized participants' scores on the Passionate Love Scale to show that some of these activations (such as in the caudate) correlated with the self-reported answers on this scale—suggesting a dose-response relationship between 'intensity' of love and love-induced activations in some brain regions. Other research has found similar activations using implicit love stimuli (the subliminal presentation of the partner's name; Ortigue et al., 2007), also finding that implicit passionate love stimuli uniquely activated regions associated with social cognition, self-representation, and implicit mental representations. Meanwhile, follow-up research to the original Bartels and Zeki (2000) imaging study looking at differences in brain activation between heterosexual and homosexual participants who were in love found the same love-typical activations patterns as before, with no significant differences between individuals of different sexual orientations or between the two sexes (Zeki & Romaya, 2010).

In an attempt to look at temporal changes in love-related brain activations over the duration of a pair-bonded relationship, researchers have looked at how fMRI activations and self-report ratings of love intensity (again using a PLS scale) changed over the course of six months within participants who had initially been in love for less than three months (Kim et al., 2009). It was found that while self-ratings of love had decreased only slightly over a 6-month period, initial brain activations in the caudate were significantly reduced over this time and activations in cortical regions, such as the cingulate gyrus, increased—suggesting that the nature of romantic pair-bonds might change over time as relationships develop. Similarly, another experiment comparing activations at initial stages of romantic love (Xu et al., 2011) to activations 40 months later (Xu et al., 2012) in a Chinese sample again found the typical pattern of reward-center activations in early stages of love, but also showed that reduced levels of initial activations in certain forebrain reward areas were predictive of both lower initial relationship satisfaction and higher likelihood of relationship dissolution at the 40-month follow-up. Research looking exclusively into the relationships of individuals who have been in very long-term romantic love pair-bonds (average marriage length 21.4 years) found similar activations as those of early stage romantic love in the dopamine-rich reward areas and the basal ganglia system, as well as in areas previously associated with maternal love (Acevedo et al., 2012).

Many of the regions found to be active in studies on love lie in dopaminergic areas that form the brain's reward system, particularly the ventral tegmentum (VTA), dorsal caudate body, and caudate tail. The actions of the neurotransmitter dopamine in these regions have been linked to the motivational state of 'wanting,' with these brain areas further associated with the expectation of rewards, desire, addiction, euphoria and goal-directed behaviors (McClure, York, & Montague, 2004; O'Doherty, 2004; Schultz, 2002). This research suggests that, rather than being a distinct 'emotional' trait, romantic love is in fact based on neural systems associated with motivation to pursue a rewarding experience, which in this case may be the company and physical intimacy of a romantic partner. Areas such as the VTA also happen to be rich in both oxytocin and vasopressin receptors, neuropeptides that have been linked to monogamous mating behavior in prairie voles and are thought to mediate both mother-infant and romantic pair-bonds (see above).

Most interestingly, BOLD signal "deactivations" have also been observed in regions including the amygdala, medial prefrontal cortex, the temporal pole, and temporoparietal junction when viewing pictures of a loved one (Acevedo et al., 2012; Aron et al., 2005; Bartels & Zeki, 2000; Xu et al., 2012; Zeki & Romaya, 2010). The amygdala is typically more active during recognition of faces, in response to novel stimuli, in social judgments, and when mediating a variety of emotions—particularly negative emotions such as fear and anxiety (Gobbini & Haxby, 2007; Kosaka et al., 2003; Leibenluft, Gobbini, Harrison, & Haxby, 2004; Morris et al., 1996; Shin & Liberzon, 2010; Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). Meanwhile, the set of regions comprising the temporal pole, temporoparietal junction, and the medial prefrontal cortex has been associated with cognitive processes involved in mentalizing and Theory of Mind (Apperly, 2012;

Critchley et al., 2000; Frith & Frith, 2003; Gallagher & Frith, 2003; Saxe, 2006). It has been hypothesized that if deactivation of these regions represents an actual decrease in neuronal activity, then cognitions relying on these same regions may be adversely affected (Bartels & Zeki, 2000; Esch & Stefano, 2005; Zeki & Romaya, 2010; Zeki, 2007). It has even been suggested that some love-typical behaviors, such as reduced ability to critically assess a lover's intentions or character (i.e., the perception that 'love is blind') and reduced levels of fear when in love, might actually be the result of such brain deactivations (ibid.). As no sex differences in love prime activations/deactivations have been found in previous research (i.e., Zeki & Romaya, 2010), this hypothesis would not suggest that any behavioral differences would exist between the sexes.

A Test Between Hypotheses

We tested between the two competing hypotheses regarding the effects of romantic love on theory of mind cognitions, and in particular empathizing, using an experimental design. The aim was to examine the behavioral consequences of the presentation of a love prime to individuals who are 'in love.' The specific behavior examined was the attribution of emotional states to others (a component mechanism of mentalizing), including the attribution of negative emotional states. If a love prime activates target-relevant cognitive schema (such as mentalizing) through conceptual priming, then performance should improve on schema-related cognitive tasks like mentalizing following a love prime. However, if previously observed deactivations among individuals who are in love in regions associated with mentalizing have a detrimental effect on such cognitions, then individuals would likely perform worse on these tasks following a love prime than following a neutral prime.

Method

Participants

Participants were recruited from students and staff of the University of Oxford using posters and e-mails. The recruitment materials advertised for participants who considered themselves "truly, madly, deeply in love" with their current romantic partner (as per Bartels & Zeki, 2000) for an experiment on love and cognition, for which they were remunerated U.K.£10 for their time. The research was approved by the University of Oxford Ethics Committee (CUREC), with all participants providing informed consent to participate in the research. All data provided was completely confidential and results were anonymized.

In total, 102 participants completed the study; however, 11 participants were excluded from the analysis because their self-appraised English skill level and understanding was below "very good."[1] Of the remaining 91 participants, 23 were male and 63 were female, ages ranged from 18 to 51 ($M = 23.4$, $SD = 4.5$), with 49.5% being U.K. Nationals, 17.6% North American, 9.9% Western European, and 8.8% Eastern European. Seven participants identified themselves as primarily homosexual and provided pictures of their same-sex partners for the love prime condition.

Procedure

Before arriving at the laboratory participants provided a digital photograph of their partner, and of a friend who was the same sex and age as their partner whom they have known for roughly the same amount of time.

During the experiment, all instructions and materials were presented on a PC. The measure of cognitive function assessed was the Reading the Mind in the Eyes task (RTM, Baron-Cohen et al., 2001), which involved participants looking at a series of 36 black and white photographs of cropped male and female eyes displaying a wide variety of emotions and being asked to state which emotion is being felt by each target set of eyes (from among four possible options). A subscore of the RTM was also calculated when attributing emotions to 'negative' stimulus faces. This task was chosen partly for its association with brain regions previously found to be deactivated in love research, but also because it could be completed quickly following a prime (i.e., within 60 seconds), thus falling in the relatively small 45- to 60-second post-prime window within which a love prime is thought to affect brain activity (Mashek, Aron, & Fisher, 2000).

Participants were provided with a list of definitions of all the emotion words that were to be presented during the RTM task and were asked to familiarize themselves with the words. Upon arrival at the laboratory, participants were given a short practice run of the tasks to ensure understanding.

The love prime condition involved presenting participants with the picture and the name of their loved one for 45 seconds, and asking them to "think about one of the very first times you met" for 45 seconds. Participants were then asked to write a couple of brief sentences about these memories. The neutral prime condition was the same as the love prime, except that the picture and name presented was that of the participant's friend.

Each experimental session consisted of a love prime, immediately followed by half of the RTM task, and a neutral prime, immediately followed by the second half of the RTM task. In between the two primes, participants were asked to complete a 2- to 3-minute cognitive distractor task consisting of a visual and auditory 2-back *n*-back task (Owen, McMillan, Laird, & Bullmore, 2005). The order of love and neutral priming conditions was counterbalanced between participants.

The RTM task was scored for the proportion of emotions attributed correctly to all sets of eyes. Correct attribution of negative emotion words (i.e., despondent, distrustful) was used to create a separate negative emotion RTM subscore. To confirm that participant feelings toward their partner and their friend differed significantly, participants rated each relationship on the Passionate Love Scale (PLS, Hatfield & Sprecher, 1986) and on the Other in Self scale (OIS, Aron, Aron, & Smollan, 1992).

Results

PLS & OIS Scores

Two separate 2×2 mixed-design ANOVAs were carried out, each ANOVA treating partner/friend PLS or OIS scores as within-subject factors and sex as between-subjects factors. All participants had significantly higher PLS score for partners ($M = 105.8$, $SD = 12.9$) than for friends ($M = 31.1$, $SD = 10.1$), $F(1, 88) =$

[1] It was observed that many of these participants had to consult the emotion word definition list throughout the RTM task.

1951.12, $p < .001$, partial $\eta^2 = 0.957$, with no sex effects, $F(1, 88) = 0.01$, $p = .947$, partial $\eta^2 < 0.001$, or interactions, $F(1, 88) = 0.02$, $p = .896$, partial $\eta^2 < 0.001$. Similarly, participants had significantly higher OIS scores for partners ($M = 5.3$, $SD = 1.3$) than for friends ($M = 2.1$, $SD = 1.3$), $F(1, 89) = 374.64$, $p < .001$, partial $\eta^2 = 0.808$, with no sex, $F(1, 89) = 0.01$, $p = .949$, partial $\eta^2 < 0.001$, or interaction effects, $F(1, 89) = 0.14$, $p = .714$, partial $\eta^2 = 0.002$.

Reading the Mind in the Eyes Task Scores Following a Neutral and Love Prime

To determine whether performance on the Reading the Mind in the Eyes task differed following a love prime versus a neutral prime, a 2 × 2 mixed design ANOVA was carried out with RTM score as the dependent variable, love/neutral prime condition as a within-subject factor, and sex as a between-subjects factor. Overall, RTM scores were higher after a love prime than after a neutral prime, $F(1, 89) = 4.46$, $p = .037$, partial $\eta^2 = 0.048$, and although there were no sex differences in RTM scores, $F(1, 89) = 6027.24$, $p = .769$, partial $\eta^2 = 0.001$, there was a significant interaction between sex and condition, $F(1, 89) = 5.43$, $p = .022$, partial $\eta^2 = 0.057$. The interaction suggests that whereas female participants' RTM scores did not change between the love ($M = 0.81$, $SD = 0.10$) and the neutral ($M = 0.81$, $SD = 0.11$) prime conditions, male participants' RTM scores were significantly higher after a love prime ($M = 0.83$, $SD = 0.09$) than after a neutral prime ($M = 0.77$, $SD = 0.11$; see Figure 1).

Reading the Mind in the Eyes Task Scores for Negative Emotions Following a Neutral and Love Prime

Analyses were also carried out on the subset of participants' RTM score which involved attributing emotion to faces displaying negative emotions only. A similar 2 × 2 mixed design ANOVA, with negative RTM subscore as the dependent measure, love/neutral prime condition as a within-subject factor, and sex a between-subjects factor. A significant main effect of prime, $F(1, 89) = 5.19$, $p = .025$, partial $\eta^2 = 0.055$, suggested that negative emotion RTM scores were higher after a love prime ($M = 0.82$, $SD = 0.17$) than after a neutral prime ($M = 0.77$, $SD = 0.19$), and a significant main effect for sex, $F(1, 89) = 4.24$, $p = .042$, partial $\eta^2 = 0.045$, suggests that female participants ($M = 0.81$, $SD = 0.13$) had higher overall negative emotion RTM scores than male participants ($M = 0.75$, $SD = 0.13$), with no significant interaction effect present, $F(1, 89) = 0.77$, $p = .383$, partial $\eta^2 = 0.009$ (see Figure 2).

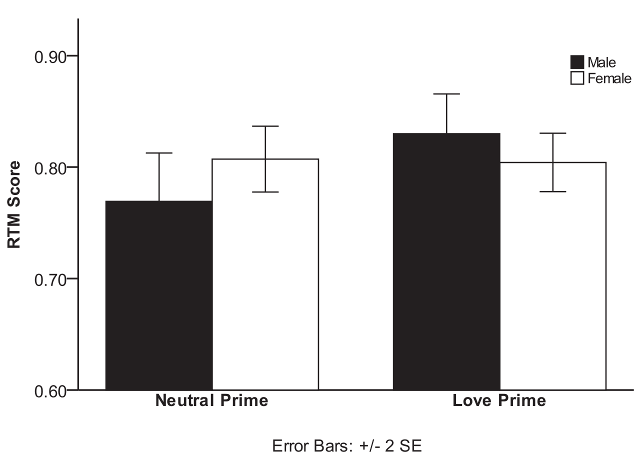

Figure 1. Mean RTM scores for male & female participants after neutral and love prime. Percentage correct scored on the "Reading the Mind in the Eyes Task" following the presentation of either a Love Prime (featuring the love interest of the participant) or a Neutral Prime (featuring a matched control), for male and female participants.

Reading the Mind in the Eyes Task Scores for Positive/Neutral Emotions Following a Neutral and Love Prime

Analyses on the subset of participants' RTM scores involving attributing emotion to positive/neutral emotion faces were run again using a 2 × 2 mixed design ANOVA, with positive/neutral RTM subscore as the dependent measure, love/neutral prime condition as a within-subject factor, and sex a between-subjects factor. No significant main effect was found for either prime, $F(1, 89) = 0.63$, $p = .429$, partial $\eta^2 = 0.007$, or sex, $F(1, 89) = 0.56$, $p = .455$, partial $\eta^2 = 0.006$. Although the interaction effect approached significance, it did not meet the traditional criterion $F(1, 89) = 3.20$, $p = .077$, partial $\eta^2 = 0.035$; nonetheless, the data suggest that whereas female scores on positive/neutral RTM task did not differ after a neutral prime ($M = 0.81$, $SD = 0.14$) or a love prime ($M = 0.80$, $SD = 0.13$), male scores may have been somewhat improved after a love prime ($M = 0.84$, $SD = 0.10$) compared with a neutral prime ($M = 0.80$, $SD = 0.13$; see Figure 3).

Discussion

This study found that when individuals who are 'in love' with a romantic partner were primed with a picture of their loved one, performance on a subsequent mentalizing (RTM) task was improved. Results showed that male participants were particularly better at interpreting the emotions of others after a love prime than after a neutral prime when it came to assessing negative emotions.

The finding that a love prime improved the ability of participants to attribute emotions to others may be explained by the phenomenon of conceptual priming (Fazio et al., 1986; Keane et al., 1991; Tulving et al., 1982). By activating implicit memories and motivations associated with the priming love stimulus, including memories revolving around the attribution of mental states to another individual, the priming condition may have acted to improve successive performance on a mentalizing task, which also utilizes similar concepts. Because participants in love have been shown to devote more cognitive resources to thinking about a love interest than about other individuals (Fisher, 1998; Hatfield & Sprecher, 1986; O'Leary et al., 2012; Zeki, 2007), it is possible that a love stimulus would be more effective as a prime for concepts related to mentalizing than a neutral stimulus. Previous research has similarly found that participants are faster to identify the intentions of a romantic partner than of a friend or a stranger (particularly if they were "passionately in love" with that partner; Ortigue, Patel, Bianchi-Demicheli, & Grafton, 2010), and that

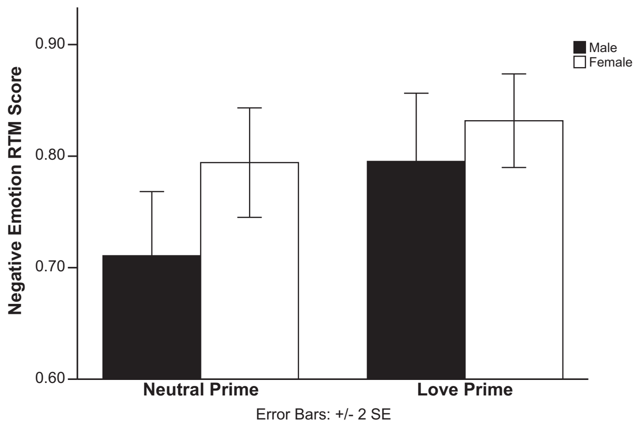

Figure 2. Mean negative emotion RTM scores for male & female participants after neutral and love prime. Percentage correct scored on the "Reading the Mind in the Eyes Task" for 'negative' words only, following the presentation of either a Love Prime (featuring the love interest of the participant) or a Neutral Prime (featuring a matched control), for male and female participants.

even the subliminal presentation of a romantic partner's name can facilitate cognitive performance (on a lexical-decision task; Bianchi-Demicheli, Grafton, & Ortigue, 2006).

When examining the effect of sex on our results, it appears that whereas a love prime had little effect on overall female RTM scores, it mostly acted to improve the RTM scores of males. While past research suggests that females typically display superior mentalizing abilities in general (Stiller & Dunbar, 2007) and outperform men on the RTM task (Baron-Cohen et al., 2001), our results showed that this sex difference in mentalizing ability appears to be greatly reduced following a love prime. This suggests that whereas a mentalizing prime has a limited effect on females, perhaps because females are already near an upper limit of mentalizing ability to begin with, such a prime can significantly improve the mentalizing abilities of males, who typically show poorer baseline mentalizing performance. This improvement in mentalizing ability was found to vary with the valence of the emotions being assessed, with male participants' poor performance in discerning negative emotions showing the greatest improvement following a love prime. Previous research has found that females are particularly adept at encoding emotionally negative stimuli and assessing negative emotions (Canli, Desmond, Zhao, & Gabrieli, 2002; Rotter & Rotter, 1988), especially during the follicular phase of their menstrual cycle (Derntl et al., 2008), which may explain the large sex discrepancy in baseline (i.e., neutral prime) assessment of negative emotions observed in our study—with women generally better at this task than males.

The finding that a love stimulus improves ability to infer emotional states in others, particularly for males when it comes to negative emotions, has some interesting implications and might bear further investigation in future research. We speculate that this phenomenon may be serving a useful function in the process of pair-bonding—allowing individuals to improve their understanding of the emotions and intentions of a mating partner, and thus assisting in the coordination of mating efforts and investments. This improvement would be particularly beneficial for males, who are typically less inclined to pursue the formation of long-term mating bonds than females (as a result of evolved differences in minimal parental investment) (Ellis & Symons, 1990; Low, 1978; Trivers, 1972). Males may also be hampered in their ability to form long-term bonds by the fact that they typically fare worse than females on various mentalizing and empathy tasks, which may be an essential faculty for understanding the cognitions and motivations of other individuals so as to create and maintaining intimate attachments (Baron-Cohen et al., 2001; Stiller & Dunbar, 2007). Although males may be typically less inclined to pursue long-term bonds, the chances of offspring survival are greatly increased by the presence of the kind of biparental care afforded by the forming of pair-bonded relationships (Geary, 2000). The fact that mentalizing abilities in males are improved after a love prime suggests that the initiation of a pair-bond may further help males facilitate the maintenance of that bond, thus increasing the chances of offspring survival. Being more adept at recognizing negative feelings and emotions in a pair-bonded partner could assist males in addressing these negative feelings and safeguarding the health of their pair-bond.

This observed effect may also be beneficial to males in protecting an established relationship and its associated opportunity costs, as males must oftentimes sacrifice potentially beneficial alternate mating opportunities when they engage in long-term relationships (Buss & Schmitt, 1993). An improved ability to detect negative/threatening emotion in non-pair others, for example, may improve a male's ability to carry out certain male-typical 'mate guarding' behaviors, which are sometimes used to assess and rebuff either physical threats from others or mate-poaching attempts (Buss, 1988; Hughes, Harrison, & Gallup, 2004). Past research suggests that males have a suite of such behavioral proclivities that serve to protect the kinds of intense parental investments necessitated by long-term pair-bonds. The ability to detect negative emotions in

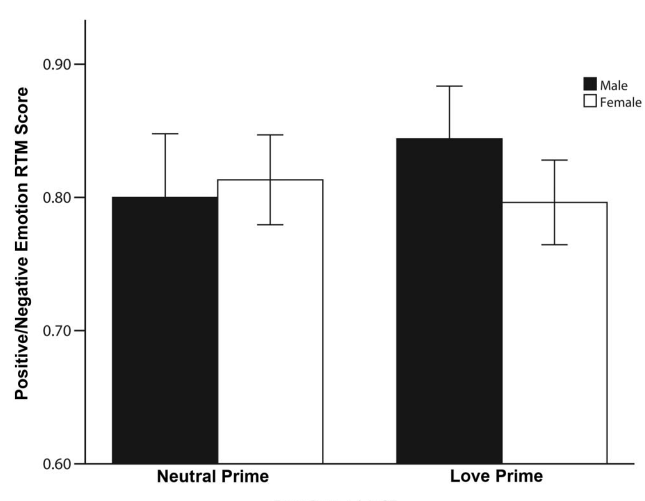

Figure 3. Mean positive/neutral emotion RTM scores for male & female participants after neutral and love prime. Percentage correct scored on the "Reading the Mind in the Eyes Task" for 'positive' and 'neutral' words only, following the presentation of either a Love Prime (featuring the love interest of the participant) or a Neutral Prime (featuring a matched control), for male and female participants.

potential mating rivals may be helpful in directing mate guarding behaviors toward suitably threatening others.

It must be noted here that it is assumed that although the mentalizing schema activated by a love prime in this study would be likely initially directed at the object of love interest (i.e., the romantic partner), this schema would be equally relevant to mentalizing about the thoughts and cognitions of other, non-partner individuals. Although the 'conceptual' and indirect nature of priming may indeed allow for such mentalizing abilities to be directed to other individuals, it would be useful to test this assumption to examine whether emotional sensitivity toward a loved one is greater than toward a non-loved one after a love prime. We would hypothesize that this may indeed be the case, as the prime would be more direct and relevant—although it appears that individuals may already be much better at mentalizing about the thoughts of romantic partners than non-partners (Ortigue et al., 2010), and thus may be hampered by ceiling effects.

These findings also suggest that deactivations observed during previous fMRI research on love-stimuli-induced brain activity, in the temporal poles, temporoparietal junction, medial prefrontal cortex, and amygdala, might not have as detrimental an effect as previously assumed on subsequent cognitions related to those areas, such as assessing emotional states in others. This finding could imply that such deactivations merely indicate a hemodynamic response to activity in adjacent areas, with cerebral blood flow immediately redirected back to deactivated areas as soon as their neuronal resources are required again (Shmuel et al., 2002; Tomasi, Ernst, Caparelli, & Chang, 2006). Although the possibility of such a hemodynamic response suggests that cognitive abilities might not be reduced after a love prime, it does not preclude the possibility that such abilities might be improved if the situation warrants it (such as with conceptual priming). Alternatively, if love-induced deactivations do represent direct inhibition of neuronal activity in selected areas, these inhibitions may only affect cognitions as they relate to the original love-stimulus, and may not generalize other non–love-related stimuli (such as emotional assessment of strangers) (Zeki, 2007).

This study found that the presentation of a love prime to individuals in love improved performance on a subsequent mentalizing task, particularly for men. It appears that a love stimulus conceptually primes mentalizing concepts and motivations and acts to enhance subsequent performance on assessing the emotional states of others. This improvement is particularly obvious in males, who are otherwise typically worse than females at assessing negative emotions in others. The possibility remains that previously observed brain deactivations may only affect concurrent behaviors which rely on deactivated areas, in which case it may be useful to conduct future studies which look at fMRI activations concurrently with cognitive task performance.

References

Acevedo, B. P., Aron, A., Fisher, H. E., & Brown, L. L. (2012). Neural correlates of long-term intense romantic love. *Social Cognitive and Affective Neuroscience, 7,* 145–159. http://dx.doi.org/10.1093/scan/nsq092

Apperly, I. A. (2012). What is "theory of mind"? Concepts, cognitive processes and individual differences. *The Quarterly Journal of Experimental Psychology, 65,* 825–839. http://dx.doi.org/10.1080/17470218.2012.676055

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology, 63,* 596–612. http://dx.doi.org/10.1037/0022-3514.63.4.596

Aron, A., Fisher, H., Mashek, D. J., Strong, G., Li, H., & Brown, L. L. (2005). Reward, motivation, and emotion systems associated with early-stage intense romantic love. *Journal of Neurophysiology, 94,* 327–337. http://dx.doi.org/10.1152/jn.00838.2004

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" Test revised version: A study with normal adults, and adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry, 42,* 241–251. http://dx.doi.org/10.1111/1469-7610.00715

Bartels, A., & Zeki, S. (2000). The neural basis of romantic love. *Neuroreport, 11,* 3829–3834. http://dx.doi.org/10.1097/00001756-200011270-00046

Bianchi-Demicheli, F., Grafton, S. T., & Ortigue, S. (2006). The power of love on the human brain. *Social Neuroscience, 1,* 90–103. http://dx.doi.org/10.1080/17470910600976547

Bogin, B. (1999). *Patterns of human growth* (2nd ed., p. 455). New York, NY: Cambridge University Press.

Buss, D. M. (1988). From vigilance to violence: Tactics of mate retention in American undergraduates. *Ethology & Sociobiology, 9,* 291–317. http://dx.doi.org/10.1016/0162-3095(88)90010-6

Buss, D. M., & Schmitt, D. P. (1993). Sexual strategies theory: An evolutionary perspective on human mating. *Psychological Review, 100,* 204–232. http://dx.doi.org/10.1037/0033-295X.100.2.204

Canli, T., Desmond, J. E., Zhao, Z., & Gabrieli, J. D. E. (2002). Sex differences in the neural basis of emotional memories. *PNAS Proceedings of the National Academy of Sciences of the United States of America, 99,* 10789–10794. http://dx.doi.org/10.1073/pnas.162356599

Carter, C. S. (1992). Oxytocin and sexual behavior. *Neuroscience and Biobehavioral Reviews, 16,* 131–144. http://dx.doi.org/10.1016/S0149-7634(05)80176-9

Carter, C. S. (1998). Neuroendocrine perspectives on social attachment and love. *Psychoneuroendocrinology, 23,* 779–818. http://dx.doi.org/10.1016/S0306-4530(98)00055-9

Clutton-Brock, T. H. (1989). Review lecture: Mammalian mating systems. *Proceedings of the Royal Society of London, Series B: Biological Sciences, 236,* 339–372. http://dx.doi.org/10.1098/rspb.1989.0027

Critchley, H., Daly, E., Phillips, M., Brammer, M., Bullmore, E., Williams, S., . . . Murphy, D. (2000). Explicit and implicit neural mechanisms for processing of social information from facial expressions: A functional magnetic resonance imaging study. *Human Brain Mapping, 9,* 93–105. http://dx.doi.org/10.1002/(SICI)1097-0193(200002)9:2<93::AID-HBM4>3.0.CO;2-Z

de Boer, A., van Buel, E. M., & Ter Horst, G. J. (2012). Love is more than just a kiss: A neurobiological perspective on love and affection. *Neuroscience, 201,* 114–124. http://dx.doi.org/10.1016/j.neuroscience.2011.11.017

Derntl, B., Windischberger, C., Robinson, S., Lamplmayr, E., Kryspin-Exner, I., Gur, R. C., . . . Habel, U. (2008). Facial emotion recognition and amygdala activation are associated with menstrual cycle phase. *Psychoneuroendocrinology, 33,* 1031–1040. http://dx.doi.org/10.1016/j.psyneuen.2008.04.014

Diamond, L. M. (2004). Emerging perspectives on distinctions between romantic love and sexual desire. *Current Directions in Psychological Science, 13,* 116–119.

Dunbar, R. I. M. (2010). The social role of touch in humans and primates: Behavioural function and neurobiological mechanisms. *Neuroscience and Biobehavioral Reviews, 34,* 260–268. http://dx.doi.org/10.1016/j.neubiorev.2008.07.001

Dunbar, R. I. M. (2012). *The science of love & betrayal*. London, UK: Fabel & Faber.

Dunbar, R. I. M. (2014). Deacon's dilemma: The problem of pair-bonding in human evolution. In R. I. M. Dunbar, C. Gamble, & J. A. J. Gowlett (Eds.), *Lucy to language: The benchmark papers* (pp. 153–176). New York, NY: Oxford University Press.

Dunbar, R. I. M., & Shultz, S. (2010). Bondedness and sociality. *Behaviour, 147,* 775–803. http://dx.doi.org/10.1163/000579510X501151

Edwards, S., & Self, D. W. (2006). Monogamy: Dopamine ties the knot. *Nature Neuroscience, 9,* 7–8. http://dx.doi.org/10.1038/nn0106-7

Ellis, B. J., & Symons, D. (1990). Sex differences in sexual fantasy: An evolutionary psychological approach. *Journal of Sex Research, 27,* 527–555. http://dx.doi.org/10.1080/00224499009551579

Esch, T., & Stefano, G. B. (2005). The neurobiology of love. *Neuroendocrinology Letters, 26,* 175–192.

Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology, 50,* 229–238. http://dx.doi.org/10.1037/0022-3514.50.2.229

Feygin, D. L., Swain, J. E., & Leckman, J. F. (2006). The normalcy of neurosis: Evolutionary origins of obsessive-compulsive disorder and related behaviors. *Progress in Neuro-Psychopharmacology & Biological Psychiatry, 30,* 854–864. http://dx.doi.org/10.1016/j.pnpbp.2006.01.009

Fisher, H. E. (1989). Evolution of human serial pairbonding. *American Journal of Physical Anthropology, 78,* 331–354. http://dx.doi.org/10.1002/ajpa.1330780303

Fisher, H. E. (1992). *Anatomy of love: A natural history of mating, marriage, and why we stray*. London, UK: Simon & Schuster.

Fisher, H. E. (1998). Lust, attraction, and attachment in mammalian reproduction. *Human Nature, 9,* 23–52. http://dx.doi.org/10.1007/s12110-998-1010-5

Fisher, H. E., Aron, A., & Brown, L. L. (2006). Romantic love: A mammalian brain system for mate choice. *Philosophical Transactions of the Royal Society: Biological Sciences, 361,* 2173–2186. http://dx.doi.org/10.1098/rstb.2006.1938

Fraley, R. C., Brumbaugh, C. C., & Marks, M. J. (2005). The evolution and function of adult attachment: A comparative and phylogenetic analysis. *Journal of Personality and Social Psychology, 89,* 731–746. http://dx.doi.org/10.1037/0022-3514.89.5.751

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society: Biological Sciences, 358,* 459–473. http://dx.doi.org/10.1098/rstb.2002.1218

Frith, U., Morton, J., & Leslie, A. M. (1991). The cognitive basis of a biological disorder: Autism. *Trends in Neurosciences, 14,* 433–438. http://dx.doi.org/10.1016/0166-2236(91)90041-R

Gallagher, H. L., & Frith, C. D. (2003). Functional imaging of 'theory of mind'. *Trends in Cognitive Sciences, 7,* 77–83. http://dx.doi.org/10.1016/S1364-6613(02)00025-6

Geary, D. C. (2000). Evolution and proximate expression of human paternal investment. *Psychological Bulletin, 126,* 55–77. http://dx.doi.org/10.1037/0033-2909.126.1.55

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia, 45,* 32–41. http://dx.doi.org/10.1016/j.neuropsychologia.2006.04.015

Gottschall, J., & Nordlund, M. (2006). Romantic love: A literary universal? *Philosophy and Literature, 30,* 450–470. http://dx.doi.org/10.1353/phl.2006.0030

Hatfield, E., & Sprecher, S. (1986). Measuring passionate love in intimate relationships. *Journal of Adolescence, 9,* 383–410. http://dx.doi.org/10.1016/S0140-1971(86)80043-4

Hughes, S. M., Harrison, M. A., & Gallup, G. G. J. (2004). Sex differences in mating strategies: Mate guarding, infidelity and multiple concurrent sex partners. *Sexualities, Evolution & Gender, 6,* 3–13.

Insel, T. R. (1992). Oxytocin—A neuropeptide for affiliation: Evidence from behavioral, receptor autoradiographic, and comparative studies. *Psychoneuroendocrinology, 17,* 3–35. Retrieved from http://dx.doi.org/10.1016/0306-4530(92)90073-G

Jankowiak, W. R., & Fischer, E. F. (1992). A cross-cultural perspective on romantic love. *Ethnology, 31,* 149–155. Retrieved from http://www.jstor.org/stable/3773618. http://dx.doi.org/10.2307/3773618

Keane, M. M., Gabrieli, J. D. E., Fennema, A. C., Growdon, J. H., & Corkin, S. (1991). Evidence for a dissociation between perceptual and conceptual priming in Alzheimer's disease. *Behavioral Neuroscience, 105,* 326–342. http://dx.doi.org/10.1037/0735-7044.105.2.326

Kendrick, K. M. (2004). The neurobiology of social bonds. *Journal of Neuroendocrinology, 16,* 1007–1008. http://dx.doi.org/10.1111/j.1365-2826.2004.01262.x

Kim, W., Kim, S., Jeong, J., Lee, K.-U., Ahn, K.-J., Chung, Y.-A., . . . Chae, J.-H. (2009). Temporal changes in functional magnetic resonance imaging activation of heterosexual couples for visual stimuli of loved partners. *Psychiatry Investigation, 6*(1), 19–25. http://dx.doi.org/10.4306/pi.2009.6.1.19

Kleiman, D. G. (1977). Monogamy in mammals. *The Quarterly Review of Biology, 52,* 39–69. Retrieved from http://www.jstor.org/stable/10.2307/2824293. http://dx.doi.org/10.1086/409721

Kosaka, H., Omori, M., Iidaka, T., Murata, T., Shimoyama, T., Okada, T., . . . Wada, Y. (2003). Neural substrates participating in acquisition of facial familiarity: An fMRI study. *NeuroImage, 20,* 1734–1742. http://dx.doi.org/10.1016/S1053-8119(03)00447-6

Kovács, Á. M., Téglás, E., & Endress, A. D. (2010). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science, 330,* 1830–1834. http://dx.doi.org/10.1126/science.1190792

Leibenluft, E., Gobbini, M. I., Harrison, T., & Haxby, J. V. (2004). Mothers' neural activation in response to pictures of their children and other children. *Biological Psychiatry, 56,* 225–232. http://dx.doi.org/10.1016/j.biopsych.2004.05.017

Leonardo, E. D., & Hen, R. (2006). Genetics of affective and anxiety disorders. *Annual Review of Psychology, 57,* 117–137. http://dx.doi.org/10.1146/annurev.psych.57.102904.190118

Lim, M. M., & Young, L. J. (2006). Neuropeptidergic regulation of affiliative behavior and social bonding in animals. *Hormones and Behavior, 50*(4), 506–517. http://dx.doi.org/10.1016/j.yhbeh.2006.06.028

Low, B. S. (1978). Environmental uncertainty and the parental strategies of marsupials and placentals. *American Naturalist, 112,* 197–213. http://dx.doi.org/10.1086/283260

Machin, A., & Dunbar, R. I. M. (2011). The brain opioid theory of social attachment and human social relationships: A review of the evidence. *Behaviour, 9,* 1–63.

Marazziti, D., Akiskal, H. S., Rossi, A., & Cassano, G. B. (1999). Alteration of the platelet serotonin transporter in romantic love. *Psychological Medicine, 29,* 741–745. http://dx.doi.org/10.1017/S0033291798007946

Mashek, D. J., Aron, A., & Fisher, H. E. (2000). Identifying, evoking, and measuring intense feelings of romantic love. *Representative Research in Social Psychology, 24,* 48–55.

McClure, S. M., York, M. K., & Montague, P. R. (2004). The neural substrates of reward processing in humans: The modern role of FMRI. *The Neuroscientist, 10*(3), 260–268. http://dx.doi.org/10.1177/1073858404263526

McIntyre, M., Gangestad, S. W., Gray, P. B., Chapman, J. F., Burnham, T. C., O'Rourke, M. T., & Thornhill, R. (2006). Romantic involvement often reduces men's testosterone levels—but not always: The moderating role of extrapair sexual interest. *Journal of Personality and Social Psychology, 91,* 642–651. http://dx.doi.org/10.1037/0022-3514.91.4.642

Mellen, S. L. (1981). *The evolution of love* (p. 312). Oxford, UK: Freeman.

Morris, J. S., Frith, C. D., Perrett, D. I., Rowland, D., Young, A. W., Calder, A. J., & Dolan, R. J. (1996). A differential neural response in the human amygdala to fearful and happy facial expressions. *Nature, 383,* 812–815. http://dx.doi.org/10.1038/383812a0

O'Doherty, J. P. (2004). Reward representations and reward-related learning in the human brain: Insights from neuroimaging. *Current Opinion in Neurobiology*, *14*(6), 769–776. http://dx.doi.org/10.1016/j.conb.2004.10.016

O'Leary, K. D., Acevedo, B. P., Aron, A., Huddy, L., & Mashek, D. J. (2012). Is long-term love more than a rare phenomenon? If so, what are its correlates? *Social Psychological and Personality Science, 3,* 241–249. http://dx.doi.org/10.1177/1948550611417015

Ortigue, S., Bianchi-Demicheli, F., Hamilton, A. F. de C., & Grafton, S. T. (2007). The neural basis of love as a subliminal prime: An event-related functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience, 19,* 1218–1230. http://dx.doi.org/10.1162/jocn.2007.19.7.1218

Ortigue, S., Patel, N., Bianchi-Demicheli, F., & Grafton, S. T. (2010). Implicit priming of embodied cognition on human motor intention understanding in dyads in love. *Journal of Social and Personal Relationships, 27,* 1001–1015. http://dx.doi.org/10.1177/0265407510378861

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping, 25,* 46–59. http://dx.doi.org/10.1002/hbm.20131

Povinelli, D. J., & Bering, J. M. (2002). The mentality of apes revisited. *Current Directions in Psychological Science, 11,* 115–119. http://dx.doi.org/10.1111/1467-8721.00181

Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences, 1,* 515–526. http://dx.doi.org/10.1017/S0140525X00076512

Rosenberg, K., & Trevathan, W. (1995). Bipedalism and human birth: The obstetrical dilemma revisited. *Evolutionary Anthropology, 4,* 161–168. http://dx.doi.org/10.1002/evan.1360040506

Rotter, N. G., & Rotter, G. S. (1988). Sex differences in the encoding and decoding of negative facial emotions. *Journal of Nonverbal Behavior, 12,* 139–148. http://dx.doi.org/10.1007/BF00986931

Ruff, C. B. (1995). Biomechanics of the hip and birth in early Homo. *American Journal of Physical Anthropology, 98,* 527–574. http://dx.doi.org/10.1002/ajpa.1330980412

Saxe, R. (2006). Uniquely human social cognition. *Current Opinion in Neurobiology, 16,* 235–239. http://dx.doi.org/10.1016/j.conb.2006.03.001

Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron, 36*(2), 241–263. http://dx.doi.org/10.1016/S0896-6273(02)00967-4

Shackelford, T. K., Schmitt, D. P., & Buss, D. M. (2005). Universal dimensions of human mate preferences. *Personality and Individual Differences, 39,* 447–458. http://dx.doi.org/10.1016/j.paid.2005.01.023

Shin, L. M., & Liberzon, I. (2010). The neurocircuitry of fear, stress, and anxiety disorders. *Neuropsychopharmacology, 35,* 169–191. http://dx.doi.org/10.1038/npp.2009.83

Shmuel, A., Yacoub, E., Pfeuffer, J., Van de Moortele, P. F., Adriany, G., Hu, X., & Ugurbil, K. (2002). Sustained negative BOLD, blood flow and oxygen consumption response and its coupling to the positive response in the human brain. *Neuron, 36,* 1195–1210. http://dx.doi.org/10.1016/S0896-6273(02)01061-9

Stiller, J., & Dunbar, R. I. M. (2007). Perspective-taking and memory capacity predict social network size. *Social Networks, 29,* 93–104. http://dx.doi.org/10.1016/j.socnet.2006.04.001

Tomasi, D., Ernst, T., Caparelli, E. C., & Chang, L. (2006). Common deactivation patterns during working memory and visual attention tasks: An intra-subject fMRI study at 4 Tesla. *Human Brain Mapping, 27,* 694–705. http://dx.doi.org/10.1002/hbm.20211

Trivers, R. L. (1972). Parental investment and sexual selection. In B. Campbell (Ed.), *Sexual selection and the descent of man* (pp. 136–179). New Brunswick, NJ: Aldine.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 336–342. http://dx.doi.org/10.1037/0278-7393.8.4.336

Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., & Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron, 59,* 1037–1050. http://dx.doi.org/10.1016/j.neuron.2008.09.006

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development, 72,* 655–684. Retrieved from http://www.jstor.org/stable/1132444. http://dx.doi.org/10.1111/1467-8624.00304

Xu, X., Aron, A., Brown, L., Cao, G., Feng, T., & Weng, X. (2011). Reward and motivation systems: A brain mapping study of early-stage intense romantic love in Chinese participants. *Human Brain Mapping, 32,* 249–257. http://dx.doi.org/10.1002/hbm.21017

Xu, X., Brown, L., Aron, A., Cao, G., Feng, T., Acevedo, B., & Weng, X. (2012). Regional brain activity during early-stage intense romantic love predicted relationship outcomes after 40 months: An fMRI assessment. *Neuroscience Letters, 526,* 33–38. http://dx.doi.org/10.1016/j.neulet.2012.08.004

Young, L. J., Murphy Young, A. Z., & Hammock, E. A. D. (2005). Anatomy and neurochemistry of the pair bond. *The Journal of Comparative Neurology, 493,* 51–57. http://dx.doi.org/10.1002/cne.20771

Young, L. J., & Wang, Z. (2004). The neurobiology of pair bonding. *Nature Neuroscience, 7,* 1048–1054. http://dx.doi.org/10.1038/nn1327

Young, S. N., & Leyton, M. (2002). The role of serotonin in human mood and social interaction: Insight from altered tryptophan levels. *Pharmacology, Biochemistry, and Behavior, 71,* 857–865. http://dx.doi.org/10.1016/S0091-3057(01)00670-0

Younger, J., Aron, A., Parke, S., Chatterjee, N., & Mackey, S. (2010). Viewing pictures of a romantic partner reduces experimental pain: Involvement of neural reward systems. *PLoS ONE, 5,* e13309. http://dx.doi.org/10.1371/journal.pone.0013309

Zeki, S. (2007). The neurobiology of love. *FEBS Letters, 581,* 2575–2579. http://dx.doi.org/10.1016/j.febslet.2007.03.094

Zeki, S., & Romaya, J. P. (2010). The brain reaction to viewing faces of opposite- and same-sex romantic partners. *PLoS ONE, 5,* e15802. http://dx.doi.org/10.1371/journal.pone.0015802

Received June 3, 2014
Revision received November 3, 2014
Accepted November 5, 2014 ■