The Neural Basis of Long-term Romantic Love

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Bianca P. Acevedo

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Bianca P. Acevedo

We, the dissertation committee for the above candidate for the

Doctor of Philosophy degree, hereby recommend acceptance of this dissertation.

Arthur P. Aron - Dissertation Advisor
Professor
Department of Psychology

Daniel K O'Leary
Distinguished Professor
Department of Psychology

Turhan Canli
Professor
Department of Psychology

Helen Fisher
Professor
Department of Anthropology
Rutgers University

This dissertation is accepted by the Graduate School

Lawrence Martin

Dean of the Graduate School

Abstract of the Dissertation

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Is it possible to experience intense romantic love for a long-term partner? If so, how is it like or unlike romantic love in its early stages and other long-term bonds (i.e., friendships or siblings)? This study examined the neural underpinnings of long-term romantic love using functional magnetic resonance imaging (fMRI). One question and main focus was to compare regions found in this study with those found to be associated with early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000). Another question was whether activation in any such regions was due to familiarity or long-term closeness. Finally, predicted regions of activation were correlated with relationship length, self-report measures of love, and marital satisfaction. Procedures used in Aron et al. (2005) were replicated using additional stimuli to control for closeness and familiarity. 10 females and 7 males (mean ages were 51 and 55 years, respectively) who reported being intensely in love with a long-term spouse (married mean of 21.4 years) underwent fMRI scanning while they viewed images of their partner and control images, interspersed with a distraction-attention task. Control images included a highly-familiar, neutral person; a low-familiar, neutral person; and a close, long-time friend or sibling. Group activation specific to the long-term partner occurred in dopamine-rich regions associated with reward and motivation in mammals, replicating results from studies of early stage romantic love. Specifically, significant activations appeared in the ventral tegmental area, and the dorsal and ventral striatum/pallidum. The human drive to establish and maintain long-term pair-bonds, and to continue to experience them as rewarding has significant implications for theory and applications for reproduction, marriages, and families.

Dedication

To my loved ones—thank you for teaching me about love and life, and for providing me with the strength and courage to follow my heart.

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Acknowledgements

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CHAPTER 1: INTRODUCTION

For centuries humans have speculated about the mysteries of romantic love, with some of the earliest documented work in the Western world dating back to Plato. In recent decades, researchers have increasingly explored questions about the nature of romantic love, focusing on its biological underpinnings and its construction as a social phenomenon. Others have focused on the source of romantic love as coming from something outside of the self, and relegated it to the universe outside ourselves (or the gods). A detailed account of these views is beyond the scope of this investigation, however the point being made is to acknowledge the complexity of romantic love as something that pervades all of our being (physical, psychological, and spiritual) and is manifested within us and in the world outside of ourselves. While the topic of this investigation is on the neural basis of long-term romantic love, this is just one facet of the multifaceted gem, a facet that may provide a glimpse of its complexity.

Why Long-term Romantic Love?

The human drive to be united with a particular other, and to continue to experience such a bond as intensely rewarding and deeply connected, plays a pivotal role in family life, marital stability, and individual well-being. Romantic love is associated with a great many factors, including entering a relationship and staying in a marriage (Simpson, Campbell, & Berscheid, 1986), relationship satisfaction (meta-analysis; Masuda, 2003) and general well-being (e.g., Riehl-Emde, Thomas, & Willi, 2003). On the darker side, marital problems may be associated with depression (e.g., Cohen, Klein, & O'Leary; Frech & Williams, 2007) and domestic violence (Anderson, Umberson, Elliott, & Vangelisti, 2004), to name just a few. Recognizing the importance of promoting healthy, strong marital bonds in our society, organizations (such as Strong Bonds and the Association for Couples in Marriage Enrichment) have been established to serve this purpose. As romantic love is one significant factor for entering and maintaining long-term marriages—it is also central to family life and well-being.

However, this may seem like a catch-22 as it is generally assumed that romantic love fades over time in marriages. Indeed, theorists, therapists, and laypeople have puzzled over this question of whether it is possible to experience romantic love for a long-term spouse. A recent review of existing interview and survey research suggests that long-term romantic love (with intensity, sexual interest, and attraction) is a real phenomenon that does not necessarily transform into companionate love (a less intense, warm, friendly type of love) over time (Acevedo & Aron, in press). However, it remains unknown how long-term romantic love is different or similar to love in its early stages. Further, there are reasons to be skeptical of such findings given the possibility of social desirability biases, delusion, self-denial, and sentiment override in self-reports of romantic love.

Definitions of Terms

A widely accepted distinction between two types of love, passionate and companionate, was proposed by Berscheid and Hatfield (1969), pioneers of the scientific exploration of love. Passionate love is defined as "a state of intense longing for union with another" (Hatfield & Rapson, 1993, p. 5); companionate love, as "the affection and tenderness we feel for those with whom our lives are deeply entwined" (Hatfield & Rapson, 1993, p. 9). Companionate love is less intense than passionate love and combines attachment, commitment, and intimacy. Somewhat similar definitions have been proposed for companionate love, referring to deep friendship, easy companionship, and sharing of common interests, but not necessarily involving sexual desire or attraction (e.g., Grote & Frieze, 1994).

Passionate love is also referred to as being in-love (Myers & Berscheid, 1997) or infatuation (Fisher, 1998). This understanding, and a similar understanding for the terms "limerance" (Tennov, 1979) and "Mania" (Lee, 1977), includes an obsessive element, characterized by intrusive thinking, uncertainty, and mood swings. A widely used measure to assess passionate love, the Passionate Love Scale (Hatfield & Sprecher, 1986), contains a few obsessive items consistent with the definition, such as "Sometimes I feel I can't control my thoughts; they are obsessively on ___."

Love theorists have proposed other typologies. For example, Love Styles theory (Lee 1977; Hendrick & Hendrick, 1986) proposes six basic styles: Eros (romantic love), Ludus (game-playing love), Storge (friendship love), Pragma (logical love), Mania (obsessive, dependent love), and Agape (all giving love). Eros is defined as an intense focus, valuing, and desire for union with the beloved, without Mania. The Erotic lover is one that values his or her partner very highly but is not obsessed by him or her (Hendrick & Hendrick, 1992). Mania is defined as an obsessive, insecure, and jealous love that shares many characteristics with Eros, but is distinct from it. The Manic lover is one that "yearns for love, but somehow finds it painful. The lover is jealous, full of doubt about the partner's sincerity and commitment, subject to physical symptoms such as inability to eat and sleep, experiences acute excitement alternating with debilitating depression" (p. 66). Thus, passionate love has a combination of erotic and manic elements associated with it. Storge is similar to companionate love, being defined as a feeling of natural affection; a secure, trusting, friendship that does not involve sexual desire and is often experienced towards siblings or friends. It has much in common with definitions of companionate love.

Passionate love and romantic love (or Eros) clearly differ in respect to the inclusion of obsession. However, the two terms (passionate love and romantic love) are often used interchangeably in research and theory. In the context of long-term relationships, the distinction between romantic love and passionate love may be important. In general, in long-term relationships, romantic love—with very high levels of focus, valuing, sexual interest, and craving for union with the beloved—may not necessarily include an obsessive, manic element. Similar distinctions were proposed early on by several theorists. For example, Tennov (1979) in her descriptive work on passionate love reported that older people in happy marriages replied affirmatively to being "in love," but unlike those in "limerant" relationships, they did not report continuous and unwanted intrusive thinking. However, in the present context it is important to distinguish romantic love from companionate love (as defined by Berscheid & Hatfield), Storge (in Lee's and the Hendricks' model), or friendship-based love (Grote & Frieze, 1994). Most important, compared to companionate love, romantic love is considerably more intense and involves attraction and sexual desire.

Theoretical Perspectives on Long-term Romantic Love

In previous decades, some psychologists assumed that romantic love is transient and that its presence in long-term marriages may be an indication of over-idealization or pathology in the relationship (e.g., Freud, 1921; Fromm, 1956). More recently, theorists (Berscheid & Hatfield, 1969) proposed that passionate love diminishes over time and evolves into companionate love—a less intense, more stable, friendship-type love, not including sexual desire or attraction. Some love theorists have echoed this thinking, proposing that romantic love declines over time in marriages (e.g., Sternberg, 1986) or after the child-rearing years (e.g., Buss, 1989).

Other theorists propose that while love declines generally, there might be mechanisms through which, under specific kinds of circumstances, it may be sustained or increased at all stages of relationships. Berscheid's (1983) interruption theory of emotion predicts that temporary interruptions, such as brief separations and conflicts, may re-ignite passionate love once the conflict or separation is resolved. Hendrick and Hendrick (1992) speculated that people go through a modal development sequence of love styles, with manic love being most characteristic of adolescents, evolving into Eros around early adulthood, then Storge and Pragma in the middle years, and eventually into Agape in the later stages of life. This view is inconsistent with research showing that passionate love affects people of all ages (Tennov, 1979).

In another model, Aron and Aron (1986) proposed that passionate love arises from the intense rapid self-expansion that occurs upon relationship formation as one comes to include another in the self; so that as the other is largely included, the rate of expansion slows down. However, they suggested that continued expansion with one's partner may permit increases in passionate love. More recently they extended this thinking, suggesting that shared participation in novel and challenging activities by married couples, if not overly stressful, can create significant increases in marital quality and passionate love (Aron, et al., 2000) —the idea being that the reward value of the novel and exciting activity becomes associated with the partner. Along the same lines, Baumeister and Bratslavsky (1999) proposed that passion is a function of the rate of change in intimacy over time; such that when intimacy increases rapidly, passion will be high. In contrast, if intimacy is not increasing, (such as when couples reach a point at which they understand and know all there is to know about one another), then passion will drop to zero, even if intimacy remains at a high level.

Researchers have also focused on biological models of romantic love. In the past, evolutionary theories of love focused on its role in the perpetuation of one's genes (e.g., Buss, 1988), suggesting that love evolved to promote pair-bonding and increase the chances of offspring survival. More recently, Buss (2006) proposed an expanded evolutionary perspective on romantic love, noting that (a) it is universal (and not limited to Western cultures); (b) it emerges in the context of long-term mating (and is rare in short-term mating); and (c) it functions to signal long-term commitment to a partner, ensuring that an individual will stay with a partner through time and not just abandon their companion when problems (or other desirable partners) arise.

Taking a somewhat different evolutionary approach, anthropologist Fisher (1998, 2000) proposed that a differentiated three-part brain system evolved for mating, courtship, and parenting: (a) the sex drive, (b) selective attraction (passionate love), and (c) attachment (companionate love). With regard to long-term passionate love, Fisher (2006) proposed that it generally fades over time, being metabolically taxing, particularly to individuals that must redirect energy to rear children. However, she suggested that some couples do sustain romantic love in long-term relationships—helping in "keeping the body toned and the mind alert" (p.106) and providing lovers with companionship, optimism, and energy.

In a recent review of theory and literature, Acevedo and Aron (in press) proposed that one possibility for the widely held assumption that romantic love declines inevitably in long-term relationships is the commingling of romantic love and passionate love. Romantic love, as delineated by Love Styles theory, has clearly distinguished between romantic love without obsession (Eros) and a purely obsessive component (Mania). This thinking dates back thousands of years to ancient Greeks, who distinguished between romantic love (a combination of Eros and sexual passion) and other types of love, such as Agape (a selfless concern for others), Philia (friendship, we-ness, feelings of kinship), and Mania (infatuation). Recently, Walsh (1991) delineated the relationship between romantic love (Eros) and Agape stating that:

> Agape, the generous and unselfish giving of oneself is a noble ideal but it must be augmented by Eros if it is to stand any hope of being realized. In the sacred sense, agape is the love that God pours down upon humanity, while Eros is the vehicle through which humanity ascends to God. In the secular sense, Agape creates value in the object loved by bestowing love upon it. In the act of creating value in the beloved we simultaneously create more joy for ourselves (Eros), and in the act of creating joy for ourselves we create joy for the loved one. The merging of Eros and Agape is the essence of ethical goodness. Few of us ever achieve such a lofty goal, yet no nobler goal has ever been set. Love is goodness, and goodness is love; through it and by it we achieve completeness and unity with the universe outside of ourselves. (p. 30)

Adopting this view of romantic love thus does not constrain it to existing for a finite amount of time in a relationship. Research supports the notion that romantic love may be present among individuals in the later stages of relationships and life (e.g., Cuber & Haroff, 1965; Hatfield et al., 1984; Tennov, 1979). Other studies revealed no significant differences in romantic love across life stages, from single in love youth to married adults with and without children living at home (Montgomery & Sorrell, 1997). Finally, as suggested by extensive indepth interviews (e.g., Cuber & Haroff, 1965) it seems that at least some individuals sustain intensely passionate, deeply connected relationships with their long-term romantic partners.

In sum, many major theories of romantic love have assumed that it generally fades over the course of relationships, and at best may evolve into a warm, calm, attachment bond. Other research and theoretical perspectives suggest that there might be natural mechanisms and adaptive functions that permit romantic love to thrive in long-term marriages. One possibility for the general belief that romantic love fades in long-term marriages may be due to the commingling with infatuation, including intrusive thinking, uncertainty, emotional roller-coasters, pining for another—characteristics often present in early-stages of romantic relationships, unrequited love, or turbulent relationships.

There are reasons to be skeptical of self-reports of romantic love and other methodological drawbacks. Further, while existing research on romantic love is sufficient to answer important questions, key questions remain unanswered. For example, one main issue deals with the ways in which long-term romantic love is like and unlike love in its early stages. More broadly, "What is long-term romantic love like in a long-term relationship?" As a way of getting very directly at these questions, the neural correlates of individuals intensely in-love with a long-term spouse were assessed using functional magnetic resonance imaging (fMRI) and compared with neural correlates of newly in-love individuals from previous studies (Aron, Fisher, Mashek, Strong, Li, & Brown, 2005; Bartels & Zeki, 2000).

Aims and Research Questions

The focus of this study is on reciprocated romantic love in the context of long-term romantic relationships/marriages. Utilizing fMRI to examine the neural systems associated with long-term romantic love, one aim was to determine whether brain regions that are specifically associated with romantic love in its early stages are also significantly activated for individuals in long-term marriages. Thus, procedures from a study of early stage romantic love (Aron et al., 2005) were replicated to directly contrast results with those from the original study. In the first block of the fMRI protocol, participants viewed alternating photographs of their beloved spouse and a highly-familiar, neutral individual to control for familiarity. Based on a previous study of early-stage romantic love (Aron et al., 2005), I predicted that long-term romantic love would involve dopamine-rich subcortical brain regions involved in neural reward circuitry. Such regions include the ventral tegmental area (VTA) and ventral striatum/nucleus accumbens.

Another aim was to control for general closeness. To accomplish this, control conditions not present in the original study (a close, long-time friend and a low-familiar, neutral person) were included in a separate block. Neural activations in response to a close friend versus a low-familiar, neutral person were compared with those from the main contrast (Partner-versus-highly familiar, neutral). Finally, correlations were performed between key measures of interest (e.g., PLS, years married, marital satisfaction, facial attractiveness) and brain responses.

Regions of interest were identified from previous studies of early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000). Question 1 was to compare regions found for high intensity long-term love with those associated with early-stage intense romantic love found in previous studies of romantic love. Thus, Question 2 was whether any such regions could be explained due to familiarity or general closeness. Question 3, and the main focus, was to determine if any regions found in Question 1, not found in Question 2, overlapped with those from studies of early-stage love. Question 4 was whether degree of activation in any of the identified areas correlated with self-report measures of passionate love, marital satisfaction, relationship length, and facial attractiveness.

CHAPTER 2: RELEVANT LITERATURE ON NEURAL PROCESSES

Brain Areas Implicated in Pair-bonding in non-Human Mammals

In recent decades, the neural basis of monogamous pair-bonding has increased and become well-understood in rodents and other mammals. More particularly, studies utilizing monogamous prairie voles have identified key neural circuitry underlying social attachment and pair-bonding (e.g., Carter et al., 1995; Insel & Young, 2001). Such mammals are ideal for the study of pair-bonding as they are easily bred in captivity and are highly social. They display specific preferences for a mate (versus a potential mate) manifested as proximity-seeking, biparental care of pups, sharing of a nest beyond the breeding season, aggression towards strangers, and tendency to travel together (e.g., Curtis, Liu, Aragona, & Wang, 2006; Getz et al., 1981).

Several studies using prairie voles have identified some of the neurotransmitters (oxytocin, vasopressin, dopamine) and neural circuitry (e.g., nucleus accumbens, ventral pallidum, mesolimbic projections) involved in monogamous pair-bond formation (e.g., Aragona et al., 2003; Curtis et al., 2006; Gingrich et al., 2000; Lim & Young, 2004; Young et al., 2001). Specifically, it has been established by neuroanatomical and pharmacological studies that concentration of dopamine in the mesocorticolimbic circuitry system is critical in the formation, expression, and maintenance of monogamous pair-bonds in rodents (Curtis et al., 2006). The mesocorticolimbic dopaminergic pathways consist of reciprocal innervation between the ventral tegmental area (VTA) and the medial pre-frontal cortex (mPFC), and projections from each to the nucleus accumbens (NAcc) (e.g., Carr & Sesack, 2000; Swanson, 1982). Excitatory projections from the mPFC exert influences on the VTA and NAcc. This pathway has been implicated in reward processing, mediating motivated behaviors, and processes underlying addiction. This system has been implicated in the formation and maintenance of pair-bonds in prairie voles (e.g., Aragona et al., 2003; Curtis et al., 2006; Gingrich et al., 2000).

Such research has also identified distinctions between monogamous and promiscuous voles with regard to density of D1 receptors in the mPFC and NAcc, oxytocin receptors within the NAcc (Insel & Shapiro, 1992), vasopressin receptors within the ventral pallidum (VP) (Young, et al., 2001), and corticotrophin-releasing factor (CF) binding in the nucleus accumbens, hippocampus, thalamus, amygdala, cingulate cortex, superior colliculus, cerebellum, and dorsal raphe (e.g., DeVries et al., 2002; Lim, Nair, & Young, 2005; Lim & Young, 2006). Moreover, it was found that monogamous voles displayed higher circulating basal levels of corticosterone, compared with promiscuous voles (Hastings et al., 1999).

In one of the few research studies exploring pair-bonding in monogamous nonhuman primates (Bales et al., 2007), pair-bonded and single male Titi monkeys (*Callicebus cupreus*) were assessed for glucose reuptake in the brain using positron emission tomography (PET) and structural MRI. Before pairing with a female, single males differed from bonded males in the reuptake within the nucleus accumbens, ventral pallidum, medial preoptic area, medial amygdala, supraoptic nucleus, lateral septum, and posterior cingulate. After pairing with a female, the right nucleus accumbens and right ventral pallidum showed changes in glucose reuptake (compared to before pairing). These areas have been implicated in studies of pair-bonding and sexual activity in rodents, and are part of the reward circuitry generally speaking. In contrast to human studies (but consistent with rodent studies), no significant differences were found in the caudate (found in humans in Aron et al., 2005, and Bartels &

Zeki, 2000) and the periaqueductal gray (displayed in a study of human maternal love, Bartels & Zeki, 2004).

Brain Areas Implicated in Parental Attachment

Several human studies have investigated the neural basis of early parent-infant attachment. The first studies used general infant cries versus control noise to stimulate maternal brain activity (e.g., Lorerbaum et al., 1999; Lorerbaum et al., 2002). Activated regions included the anterior and posterior cingulate, thalamus, hypothalamus, septal regions, dorsal and ventral striatum, medial prefrontal cortex, right orbitofrontal/insula/temporal polar regions, right lateral temporal cortex, fusiform gyrus, and the amygdale. In one study, mothers responded more than control women to infant cries (Purhonen et al., 2001). Thus, these results suggest that mothers may be more generally alert or attuned to infant cries, even if they are not of their own infant. In an fMRI study using a block-design of 30-second presentations of own infant cries, general cries, and control sounds, Swain et al. (2003) recruited postpartum mothers and fathers. They hypothesized that thalamo-cortico-basal ganglia circuits involved in human obsessive-compulsive thoughts and behaviors (Baxter, 2003; Leckman et al., 2004) would be active as well as emotional alarm and arousal centers in the amygdala (LeDoux, 2003). Findings showed that first-time mothers at around 2-4 weeks post-partum displayed significant activations in the midbrain, basal ganglia, cingulate, amygdala, and insula when hearing their own infant cries versus the general infant cries.

Other human fMRI studies have used infant visual stimuli to elicit parental responses. For example, Bartels and Zeki (2004) compared brain activity of 20 mothers while they viewed pictures of their own infants (about 9 months to 3.5 years of age), familiar, and unfamiliar infants. Results showed significant activations in the midbrain (substantia nigra and periaqueductal gray), middle insula, anterior cingulate, caudate nucleus, putamen, orbitofrontal cortex, thalamus, and lateral fusiform gyrus. Moreover, the researchers compared activations for maternal love with those of a previous study on romantic love (Bartels & Zeki, 2000), finding overlapping and unique activations for each. Overlapping regions included the caudate, putamen, globus pallidus, middle insula, and dorsal part of the anterior cingulate cortex. Areas unique to romantic love included the VTA, dentate gyrus/ hippocampus, and the hypothalamus. Activity specific to maternal love included the lateral orbito-frontal cortex and the periaqueductal gray. Both studies (Bartel & Zeki, 2000, 2004) suggest that regions activated by maternal and romantic love in humans involves reward regions that are known to contain high density receptors for oxytocin and vasopressin.

In another study, using photos of older children (5-12 years), seven mothers viewed images of their own children, their child's friend, unfamiliar children, and unfamiliar adults while being scanned (Leibenluft, Gobbini, Harrison, & Haxby, 2004). Mothers displayed significant activations in the amygdala, insula, anterior paracingulate cortex, and posterior superior temporal sulcus when viewing images of their own child versus a familiar child.

In a third study, Nitschke et al. (2004) scanned six mothers at 2-4 months post-partum. Mothers displayed bilateral activations in the orbitofrontal cortex while they viewed 30-second image blocks of their own infants versus unfamiliar infants. Moreover, activations in the orbitofrontal cortex correlated positively with pleasant mood ratings. However, in contrast to other studies of maternal attachment, other brain regions (i.e., thalamus, insula, striatum, anterior cingulate, etc.) were not significantly activated while viewing images of their own children by mothers.

In a study using a somewhat different procedure, ten mothers were scanned while they viewed 40-second video clips of their own children, an unknown child, and a neutral video (Ranote et al., 2004). There were significant activations in the amygdala and temporal pole for own-infant versus unknown infant viewing. In a yet unpublished study (Strathearn, 2002) described by Swain et al. (2007), eight mothers viewed images of their own infant (3 to 8 months old), a familiar infant, and an unknown infant with varying facial cues (either crying, smiling, or neutral) for 6-seconds each. Results showed areas of activation unique to their own infant included the thalamus and nucleus accumbens, amygdala, hippocampus, the fusiform gyrus, and bilateral hippocampi. Moreover, another study limited to crying infant faces revealed activations in the anterior cingulate and insula bilaterally (Strathearn, Li, & Montague, 2005).

Finally, in a study employing somewhat similar procedures, thirteen mothers viewed video clips with no sound of their own infant (about 16 months old) and other infants either smiling while playing with mom or crying due to a separation from mom. Results showed that recognition of their own infant recruited the orbitofrontal cortex, periaqueducatal gray, anterior insula, dorsal and ventrolateral putamen. Moreover, regions significantly activated while viewing their own infant crying versus playing were the dorsal region of the orbitofrontal cortex, caudate nucleus, right inferior frontal gyrus, dorsomedial prefrontal cortex (PFC), anterior cingulate, posterior cingulate, thalamus, substantia nigra, and posterior superior temporal sulcus. Further, the intensity of the activation in the right OFC was correlated with anxious ratings, and in the left OFC with joyful ratings by the mothers.

In sum, fMRI studies on parental attachment suggest that brain circuits activated by infant stimuli (crying sounds, pictures, or video clips) include the dorsal and ventral striatum, cingulate, periaqueductal gray and thalamus for motivation and reward. Other aspects related to planning, emotional processing, empathy, and behavioral responses may involve the orbitofrontal cortex, anterior cingulate, hippocampus, and the insula. These studies, assessing brain responses, are a good start to delineating neural centers involved in complex set of parental behaviors— such as recognizing one's child, directing attention to the child, empathizing with their needs, and directing behavioral and emotional responses to respond to the child appropriately.

Overlapping regions have been implicated in response to a romantic partner (e.g., Aron et al., 2005), food, drinks, monetary rewards, and addictive substances; suggesting the important role of reward, memory, and emotion in becoming bonded or learning to integrate a loved one in the self. This integration involves attending to and empathizing with partners; approaching them; responding to their needs, emotional, or cognitive states; and deriving a sense of pleasure (or reward) from such interactions. Not only is well-being experienced as a pleasurable state, but research suggests that the formation and maintenance of nurturing maternal bonds (e.g., Harlow, 1958) and satisfying romantic bonds (e.g., Coan, Schaefer, & Davidson, 2006) have measurable benefits for both parties.

Brain Areas Implicated in Romantic Love

In humans, research studies investigating neural activations in response to adult partners for whom subjects reported intense romantic attraction (Aron et al., 2005; Bartels & Zeki, 2000, 2004; Ortigue et al., 2007) all found significant activations in subcortical regions that mediate rewards. In Bartels and Zeki's (2000) study of romantic love, 17 female and male participants viewed images of their beloved (on average 2.4 years in love) and three friends of the same gender, and around the same age and length of relationship as the beloved

(4.3 years on average). Results showed activations specific to viewing the partner in the ventral tegmental area (VTA), head of the caudate nucleus, the putamen, the middle insula, the anterior cingulate cortex (bilateral), posterior hippocampus, and sites in the cerebellum. Deactivations, or activations of viewing friends versus the beloved, were displayed in the right and medial prefrontal cortex, parietal and middle temporal cortex, and the posterior cingulate gyrus.

Bartels and Zeki (2004) reanalyzed data from the early-stage love study and compared it to data of maternal love. Their re-analysis showed activations in the midbrain/VTA region, dorsal caudate nucleus, putamen, globus pallidus, mid-insula, anterior and posterior cingulate, dentate gyrus/hippocampus, and hypothalamus. Brain activity specific to the beloved (versus child) appeared in the VTA, dentate gyrus/hippocampus, and hypothalamus. Activity specific to maternal love included the lateral orbito-frontal cortex and the periaqueductal gray.

In a somewhat similar paradigm, Aron et al. (2005) assessed the brain activity of 17 female and male participants while they viewed images of their beloved (7 months in-love on average) versus a neutral person or countback task. Findings revealed significant activations in dopamine-rich areas, notably the right ventral tegmental area, medial caudate nucleus, and the right posterior cingulate. Length of time in-love correlated significantly with several regions, most notably the mid-insula, the ventral putamen/pallidum, right anterior and posterior cingulate cortex, and right posterior cingulate/retrosplenial cortex. Bartels and Zeki (2000) also found activations in the anterior cingulate, but Aron et al. (2005) showed that activations were time dependent. This was of particular interest in the present study of long-term love as the anterior cingulate is implicated in focused attention related to cognition and emotion (Bush et al., 2000; Rauch et al., 1999; Ursu et al., 2003). Degree of passionate love (measured by the Passionate Love Scale; PLS) correlated significantly with the right antero-medial caudate body and the septum/fornix.

In a third study of romantic love (Ortigue et al., 2007), a different paradigm was used. In an event-related design, female participants viewed subliminal primes related to their beloved (15 months in-love on average), a passion (i.e., a hobby), and a male friend (around the same age as and with a duration of friendship similar to the partner). Results showed activations specific to viewing the partner versus the friend in the VTA, caudate nucleus, insula, bilateral fusiform regions, parahippocampal gyri, angular gyrus, left dorsolateral middle frontal gyrus, left inferior temporal gyrus, and the cerebellum. Correlations with PLS scores revealed significant activations for the love-versus-friend contrast in the VTA, caudate nucleus, right parahippocampal gyrus, angular gyrus, insula, and the left dorsolateral frontal gyrus. For the love-versus-passion contrast, areas correlated with the PLS included the left angular gyrus and the bilateral fusiform region. The angular gyrus is important in abstract representations of the self (e.g., Blanke et al., 2002) and integration of abstract representations of others (Jackson et al., 2006). No correlations were found for length of time in love.

In another study exploring responses to face images of a beloved (Langeslag, Jansma, Franken, & Van Strien, 2007), event-related potentials (instead of fMRI) were used to measure responses of individuals in-love about 12-months on average. Results showed significantly larger responses (late positive potentials; LLP) for a partner versus a familiar control or another unknown beautiful face, suggesting increased motivated attention for the beloved.

Another study, using fMRI, explored the neural activations among 16 women in highly-satisfied marriages, responding to threat cues (shocks) and safety cues while holding their husbands' hand, a stranger's hand, or no hand-holding (Coan, Schaefer, & Davidson, 2006). Results showed that responses to threat cues were significantly attenuated while holding the husband's hand, as evidenced by lower neural activation in the anterior cingulate, left caudate, posterior cingulate, superior colliculis, and post-central gyri. Finally, higher marital satisfaction scores were predictive of less threat (or decreased activation in the right anterior insula, superior frontal gyrus, and the hypothalamus) in response to threat cues while holding a partner's hand.

In sum, all three fMRI studies and the ERP study of human romantic love suggest that the experience is associated with reward neural circuitry in humans and focused attention, respectively. The dopamine-rich, reward regions activated in response to a romantic partner have also been implicated in numerous studies of monetary rewards, drug addiction, food, maternal attachment, and longing for a deceased loved one in humans. These systems are involved in learning associations between stimuli and responses, and motivation to seek out a given reward and work for it, regardless of whether it's affectively pleasant or unpleasant. Research by Berridge and Robinson (1998, 2003) suggests that brain mechanisms involved in "liking or disliking" something (implicit emotion) and "wanting" something (implicit motivation) are distinct, and that "liking" is not necessary for "wanting." Thus, even when lovers experience obstacles, setbacks, or heartbreak, they often keep coming back for more, continuing to crave and work to be united with their beloved.

Areas implicated in learning and memory (e.g., hippocampus and parahippocampal gyrus) were also recruited. The hippocampus is involved in the encoding and retrieval of memories and is linked with motivation, emotion, executive, and sensorimotor functions through connections with other brain regions. Specifically, the intermediate and temporal areas of the hippocampus are linked to the VTA, via projections to the prefrontal cortex and subcortical sites (e.g., Bast, 2007). Finally, the insula (activated in all threes fMRI studies of romantic love and in the fMRI study of the buffering effect of marriage to stress) is involved in processing pain and caress-like touch between individuals (Olausson, et al., 2002) and is thought to be important for social behaviors, emotional and interpersonal interaction and mental illness such as autism (Dapretto et al., 2006). Studies have confirmed the insula as a visceral sensory area, visceral motor area (autonomic), motor association area, vestibular area, and language area. Currently it is thought of as a limbic integration cortex (Augustine, 1996).

Some differences between the three fMRI studies of romantic love include the recruitment of the putamen, reported only in the Bartels and Zeki (2000) study. This difference may be due to the longer relationship length of their sample compared to the other two samples. Another difference among the three studies involves the recruitment of areas related to abstract representations of the self and others by Ortigue et al. (2007). One possibility may be due to the paradigm used by Ortigue et al., as the study implemented names of the beloved as stimuli in comparison to images of faces, thus requiring abstract cognitive processes.

Areas Implicated in Sexual Arousal

Numerous studies on sexual arousal have been conducted. Some have focused on the stages of arousal (for a review, see Maravilla & Yang, 2008), sexual dysfunction (e.g., Yang et al., 2008), differences in neural activations among homosexuals and heterosexuals (e.g., Safron et al., 2007), and differences between pre-menopausal and post-menopausal women (Jeong et al., 2005), among other things. Further, such studies have employed a variety of stimuli to elicit sexual arousal—from video clips, to nude photos, to couples interacting, to scent of an opposite-sex person. Below, I will discuss some studies that are most relevant to the present research—studies of neural activations among heterosexual individuals in good health.

In one study (Karama et al., 2002), 20 females and 20 males (mean age, 24.5 years) were scanned while viewing alternating clips of erotic and neutral films. Results revealed increased activity during the erotic films for females and males in the anterior cingulate, medial prefrontal, orbitofrontal, insular, and occipitotemporal cortices, the amygdala, and ventral striatum. For males only, there was activation in the thalamus and hypothalamus, and activation in the hypothalamus was correlated with self-reported sexual arousal.

In another study (Hamann, Herman, Nolan, & Wallen, 2002), gender differences were found in the amygdala in response to sexually arousing stimuli. In the study, 28 participants (14 females and 14 males) viewed photographs of either sexually arousing stimuli (couples or opposite-sex nude singles) or control stimuli (non-sexual male/female interactions or a fixation). Females and males rated the sexual stimuli as equally arousing and attractive, but males displayed greater response in the amygdala and hypothalamus, bilaterally.

In another study (Feretti et al., 2005), ten healthy males, ages 21 to 25, viewed erotic and sports-related stimuli while penile tumescence was recorded. Results revealed significant activation in the limbic (hypothalamus, hippocampus and amygdala) and paralimbic areas (anterior cingulate gyrus, frontal lobe, and insula), associative cortices (inferior temporal and occipital cortices), and other subcortical and cortical sensory relays (thalamus and SII).

However, only some of these areas were activated through full penile erection—the anterior cingulate, insula, amygdala, hypothalamus, and secondary somatosensory cortices.

Yet another study (Kim et al., 2006), using healthy middle-aged males (mean age 52 years, range 46–55) who viewed erotic and non-erotic films, revealed that sexual stimuli were associated with activations in the occipitotemporal area, anterior cingulate gyrus, insula, orbitofrontal cortex, and caudate nucleus. However, in contrast to the other studies, the hypothalamus, thalamus, and amygdala were not activated. The researchers concluded that the hypothalamus and thalamus were not activated due to decreased physiological arousal in response to erotic visual stimuli, as the sample was composed of older males (compared to previous studies). Thus, it may be that age is a factor to consider in such studies.

Finally, in a recent study (Walter et al., 2008), researchers investigated neural activations specific to sexual arousal in 21 participants (10 females) ages 21 to 26 (mean age around 26), controlling for general emotional arousal and pleasure. Participants were shown sexually intense pictures (opposite sex nudes or couples) of either positive or negative valence, non-bodily emotional pictures of people in sports or other social interactions, and non-human motives in a positive or negative context. Findings showed that stimulus-specific sexual intensity was correlated with activity in the ventral striatum and hypothalamus. Further, activations in the anterior cingulate were correlated with an interaction of sexual intensity and emotional valence. Activations in the dorsomedial prefrontal cortex, the mediodorsal thalamus, and the amygdala were associated only with a general emotional component. Finally, in contrast to previous studies, no differences were found when comparing females and males.

CHAPTER 3: METHOD

Overview

The current study sought to examine the neural systems associated with long-term romantic love and more generally long-term pair-bonding among individuals intensely in-love with their spouse. Utilizing fMRI, procedures used in Aron et al.'s (2005) study of early-stage intense romantic love were replicated, but with three key modifications: (a) all stimuli were presented for 30 second blocks (in Aron et al., most blocks were 30 seconds, but the distraction blocks were either 20 or 40 seconds), (b) an additional session was added to permit analyses to control for closeness and familiarity, and (c) at the end of each session, participants provided emotion ratings for each stimuli (e.g., how intensely they felt). (The design details are elaborated below.)

In the present study, participants in long-term relationships and who reported being intensely in-love with their partner were recruited. Potential participants completed a pre-experimental interview to assess their eligibility (Appendix A). Those who were eligible were asked to complete several relationship and personality questionnaires (Appendix B) prior to scanning. Participants were also asked to provide four pictures to serve as the stimuli for the study: (a) one of their partner (P); (b) one of a highly familiar, neutral individual (HFN); (c) one of a close, long-time friend (CF); and (d) one of a low-familiar, neutral individual (LFN). The scanning portion of the study consisted of two, 12-minute sessions with stimulus ratings at the end of each, and a 2-minute rest period between sessions. In Session 1 (which replicates the Aron et al., 2005 study except for lengths of the distraction blocks) participants viewed alternating images for 30 seconds each of Partner and HFN, with a countback task between each image. Session 2 followed the same design, but participants viewed images of the CF and the LFN, also interspersed with the countback task. Order of stimulus presentation was counterbalanced within sessions, with equal numbers of males and females in each order. All participants viewed alternating images of a Partner and HFN in Session 1, to closely replicate studies of early-stage romantic love. During the scanning sessions, when viewing each image, participants were instructed to think about something relevant to the relationship with that stimulus person (such as something they did with the person, not sexual in nature). After each session, participants were asked to provide ratings of each stimulus they viewed during the session (Appendix D). After scanning session 2, participants completed a post-experiment interview and debriefing (Appendix C).

Participants

Participants were 10 healthy females (*M* age = 51.3 yrs; median = 49.0 yrs) and 7 healthy males (*M* age = 55.07 yrs; median = 50.0 yrs), all in a romantic/sexual long-term marriage (of 10 years or more) and who self-reported feeling intense romantic love for their spouse. Participants were married a mean of 21.4 years (females 19.25 yrs, males 24.57 yrs); median of 22.0 years, with an average of 1.9 children (either biological, adopted, or step-children), ranging from 0 to 4 children (3 participants had no children). Seven participants had an empty nest (no children living at home) and 10 had children living with them at present (six with 1 child, two with 2 children, one with 3 children, and one with 4 children). Seven participants were in a first marriage (for both partners), 5 had been previously divorced (as well as their spouse), 4 were in a first marriage with a spouse that had been divorced previously, and one was previously divorced and married to a spouse that had never been divorced.

All participants were right-handed, heterosexual adults with few health problems, and none were taking antidepressant medications. Ethnic composition of the sample was 2 (12%) Asian-American, 2 (12%) Latino, and 12 (76%) Caucasian. Regarding the highest education degree obtained, 1 subject completed up to high-school; 4, an associates (2-year college) degree; 6, a bachelor's degree; 4 a master's degree, and 2 a PhD or M.D.

Sample size was based on extrapolation from previous studies (e.g., Aron et al., 2005; Bartels & Zeki, 2000) using similar methods with individuals newly "in love." Those studies found significant results with sample sizes of 17. The present study used brain areas found to be significant in these previous studies as a priori hypothesized regions of interest, thus increasing statistical power.

Procedure

Pre-experimental interviews. Participants were recruited by word-of-mouth, flyers, and newspaper ads. Flyers read, "Are you still madly in-love with your long-term partner? Help scientists study intense long-term romantic love!!" Interested participants completed two pre-experimental interviews to assess their eligibility. The pre-experimental interview (Appendix A) assessed demographics, handedness, length of relationship, and fMRI contraindications. Standard MRI-contra-indications included metal fragments in their bodies, implanted electrical devices such as a cardiac pacemaker, severe heart disease including susceptibility to arrhythmia, pregnancy, self-reported severe head trauma, and self-reported substance abuse in the past 6 months or intake of psychiatric medications. To assess the strength of the bond, several global-item questions were asked: percent of an average day spent thinking about the spouse, intensity of love, attraction, closeness, sexual intimacy, and annoyance for the spouse. To assess the quality of the relationship and validity of claims of being intensely in love, participants were asked several open-ended questions regarding infatuation with another person, sexual activity, adjectives to describe the relationship, and to recount the story of how they met and fell in-love. Participants were excluded if they reported being infatuated with someone other than their partner, were not sexually active, could not provide details or substantiate accounts of the relationship, or if accounts were more than slightly negative. To assess degree of long-term romantic love, participants were asked several questions relating to their cognitions, behaviors, and emotions in the relationship. The mean intensity of "being in-love" with the partner on a one-item, 7-point scale was 6.99 (SD = 0.02) and the mean time spent thinking about the spouse was 35.47% (SD = 21.90, range 10-90%) of an average day. Records were not kept, but as best as can be reconstructed, approximately five potential participants were excluded because they did not meet eligibility criteria for being in-love. Participants were also asked to rate their partners on 10-point scales for attractiveness (see Figure 3), closeness, and extent of annoyance/upset (see Table 1). They also were asked for their sexual intimacy per week (M = 2.20, SD = 1.85).

The second part of the pre-experimental interview (Appendix A) determined experimental stimuli images: P, HFN, CF, and LFN. All targets were the same gender and about the same age as the long-term spouse, and someone for whom they had never had feelings of romantic attraction or sexual desire. The targets varied in familiarity and closeness. The LFN was someone known less than 6 months; the HFN and CF were known about as long as the spouse. The HFN and LFN were neutral; the CF was someone with whom the participant had a close, positive, interactive bond—like a friend, in-law, or sibling. The interview also established attractiveness, any romantic attraction/sexual desire, closeness, frequency of interaction, and annoyance for each target person. If the participant reported any romantic attraction/sexual desire or a high degree of annoyance for any of the nonpartner targets, they were asked to select another target person for the category. In addition, participants were asked to think of recent interactions with the target person that they could call to mind during the experiment.

Stimuli. Table 1 describes the mean characteristics of each of the target stimuli (Partner, HFN, CF, and LFN) in relation to study participants. Targets were around the same mean age. On average, participants knew their partners (M = 21.44 yrs) about as long as their long-time close friend (M = 25.59 yrs.) and the high-familiar, neutral person (M = 19.97 yrs); and the low-familiar person was barely known (0.83 yrs). For Partner versus HFN, repeated measures *t*-tests found no significant difference in degree of familiarity (measured by number of years known), t (16), = 0.66, *ns*; but there were significant difference in closeness measured by a global question (t [16] = 12.17, $p < .001$) and the Inclusion of Other in the Self (IOS) Scale (t [16] = 11.26, $p < .001$). For CF versus LFN, there was a significant difference in familiarity (number of years known), t (16), = 7.14, $p < .001$; and there were also significant differences in closeness measured by the global question (t [16] = 15.22, $p < .001$) and the IOS Scale (t [16] = 4.88, $p < .001$). Regarding the relationship of the CFs to participants, 3 were siblings, 1 was a cousin, 2 were in-laws, 9 were friends, and 2 were co-workers. Annoyance ratings were generally low (means between 1.00 and 2.20 on a 10-point scale) across targets. If participants reported in the screening process that one of the targets annoyed or upset them greatly (rating 2 or greater) they were asked to select another target.

Stimuli attractiveness and photo quality. All photos were rated for attractiveness and image quality by independent raters, and correlated with results from various contrasts. Figure 3 displays means for independent-coder-rated and participant-rated attractiveness across target stimuli (Partner, HFN, CF, and LFN). Independent coder-rated attractiveness of images did not differ significantly across target stimuli, F (3, 64) = 0.94, *ns*. Similarly, there was no significant difference among independent rated image quality, Partner (M = 5.94), CF (M = 5.63), HFN (M = 6.22), and LFN (M = 5.41), F (3, 11) = 0.63, *ns*.

To assess correlations between BOLD responses and independent coder-rated attractiveness, first difference scores were created for the coder ratings of Partner-minus-HFN images and for CF-minus-LFN images. Next, brain activity for the Partner-versus-HFN contrast was correlated with facial attractiveness difference scores. No significant correlations were found between BOLD responses and coder-rated attractiveness difference scores.

Stimulus presentation. Several days prior to the scanning session, participants were asked to provide good quality photos for each target person (including the partner). The photos were standardized and sharpened using photo-editing software, such that headshots appeared against a neutral gray background.

The length of presentation of each stimulus was partially based on a previous study of early-stage romantic love (Aron et al., 2005). That study employed an alternating block design in which participants viewed images of the partner or a familiar, neutral person for 30 second blocks, with countback tasks of 40 seconds (following the partner) and 20 seconds (following the neutral person). In the countback task, the participant is shown a high number (e.g., 2,081) and asked to count back by 7s. A different starting number is given each time.

The countback task was used because it is difficult to subdue intense feelings of romantic love once they have been elicited. Therefore, performing a distraction task between picture viewings decreases carryover effects. In the present study, all image stimuli and countback tasks were 30 seconds long.

There were several reasons for modifying the countback tasks to be 30 seconds. In previous piloting work, it was found that intensity of feelings generally diminished after viewing photographs of a beloved after about 30 seconds and that 40 second countback tasks were sufficient to erase feelings associated with viewing a new beloved's photo (Mashek, Aron, & Fisher, 2000). However, having different lengths of countback tasks is a possible confound. Thus, having both countback tasks set to 30 seconds eliminates this confound. Further, the piloting for the original study was conducted with participants that had recently fallen in love, thus obsession was probably quite high. The present study was on long-term romantic love, where mania is low (Acevedo & Aron, 2008), thus participants may not need as much time to erase feelings after viewing their partner.

The rationale for including the additional targets (LFN and CF) was to control for closeness and familiarity. To keep the study design as maximally similar to the early-stage love study, while including additional targets, the experiment was conducted in two sessions (separated by a rating task and a 2-minute rest period). The first session was a close replication to the Aron et al. (2005) study. The second session consisted of the LFN and CF (the new control targets).

The rationale for inclusion of the CF > LFN contrast was to determine overlaps with the Partner > HFN contrast. If an area found for the Partner > HFN contrast was also found for the CF > LFN contrast, it suggests that the effect found could be due to closeness or familiarity, and not solely romantic love per se. However, areas found for the Partner > HFN contrast, but *not* found for the CF > LFN contrast are likely to be uniquely due to love and not to familiarity or closeness. Any areas found for the CF > LFN contrast but *not* for the Partner > HFN contrast are possibly due to familiarity or closeness. However, since the difference in familiarity of the CF > LFN is especially dramatic (with the LFN known only very minimally), some effects are likely due to familiarity.

Post-scan emotion ratings. Immediately after each of the two sessions, participants were asked to provide emotion ratings of each target while still in the scanner. Participants rated how intensely they experienced a series of emotion words on a scale from 1 to 4 (1=not at all and 4 = a great deal) by making a button box response (Appendix D). Ratings were done after each session to interfere minimally with the experiment and to maintain the procedure of the first session to be as similar to Aron et al. (2005). The results of the post-scan emotion intensity ratings are displayed in Figure 4.

Instructions to participants and exit interviews. Several days prior to scanning, participants were provided with detailed instructions about the experiment, scanning, site, and procedures. About 1 to 2 days prior to scanning, the experimenter phoned participants to remind them about the appointment and procedures, as well as to assess if any changes in the relationships with the spouse or the other targets had occurred. Upon arrival to the scanner site, participants were asked to read and sign a consent form and an MRI safety form, and then to complete a short questionnaire assessing romantic love and closeness with their spouse and closeness with other targets (CF, HFN, and LFN). They were reminded of the experimental protocol, not to think of sexual thoughts, and the importance of remaining still during scans prior to being led to the scanner.

Once on the scanner bed, participants were given earplugs to dampen the scanning noise and their heads were placed in a special foam holder with additional padding to keep the head still. Participants were asked about their comfort and were allowed a few minutes to get adjusted to the scanner bed prior to starting any scanning. Researchers operating the system were able to see the participant, and through an intercom, participants could talk with the operators while in the scanner. The experimenter periodically verbally verified that the participant was comfortable and ready to proceed. Each session started with the following instructions:

> In the next few minutes you will view pictures of 2 people interspersed with a countback task. While viewing pictures of each person think of experiences you have had with them. For the countback task, count backwards by 7's starting at the number displayed on the screen.

During the exit interviews (Appendix C), participants were asked to describe the events they called to mind and how they felt while viewing images of their spouse and each target. In regards to the countback task, they were asked if they did as instructed and how comfortable it was for them to do it. More generally, participants were asked about their discomfort while in the scanner and whether they moved a lot during scanning.

Experimental design and procedures. Scanning started with high-resolution 3-d and in-plane anatomical images. After that, functional images were recorded while participants performed their given tasks. The experimental protocol consisted of two 12-minute sessions, each consisting of four tasks in an alternating block design; with stimulus ratings following each session. After the Session 1 ratings, participants were allowed an optional 2-minute rest period.

During Session 1 (which replicated the Aron et al., 2005 paradigm except for countback lengths), participants viewed alternating images of their partner and the HFN (order counterbalanced), interspersed with the countback task. Stimuli images and countback numbers were presented for 30-seconds each, with 6 repetitions, totaling 12-minutes (the same as the Aron et al., 2005 study). Session 2 followed the same design, but participants viewed images of the LFN and CF (order counterbalanced). After scanning, participants were led to the waiting room where they completed an exit interview (Appendix C) and questionnaires (Appendix B). Finally, participants were paid $75 for the fMRI scanning session and if feasible, were given a printout image of their brain.

Questionnaires. A sample of questionnaires received by participants is provided in Appendix B. Below are descriptions of questionnaires assessing major study variables.

Passionate Love Scale (PLS; Hatfield and Sprecher, 1986). The PLS is a 15-item scale, consisting of both positive and negative cognitive, emotional, and behavioral statements related to passionate love for one's partner. The items are scored on a Likert scale (1 = *definitely true*, 6 = *not at all true*). The scale contains items such as "Knowing that __ cares about me makes me feel complete," "I would rather be with ___ than anyone else," "Sometimes I feel I can't control my thoughts; they are obsessively on ___." This measure includes some obsessive aspects of passionate love.

Inclusion of Other in the Self Scale (IOS; Aron, Aron, & Smollan, 1992). The IOS Scale is a pictorial measure intended to directly tap people's sense of interpersonal interconnectedness. In the scale, participants select one of seven items that best describes their relationship with their partner from a set of Venn diagrams each representing different degrees of overlap of two circles.

*Love Attitudes Scale (*LAS; Hendrick & Hendrick, 1986). The LAS is a 24-item scale, composed of six, 4-item subscales: Eros, Ludus, Storge, Pragma, Mania, and Agape, each meant to assess different styles of loving. Sample Eros items include: "My partner and I have the right physical chemistry between us," "I feel that my partner and I were meant for each other," and "My partner and I were attracted to each other immediately after we first met." Sample Mania items include: "When my lover doesn't pay attention to me, I feel sick all over" and "When I am in love, I have trouble concentrating on anything else." A major difference between the various ways of conceptualizing love is that passionate love captures "manic," "obsessive" elements and misses some of the secure, ego-based elements expressed in the Eros (romantic love) subscale.

*Friendship-Based Love scale (*FBLS; Grote, & Frieze, 1994). The FBLS is a measure of a comfortable, affectionate, trusting love for a likable partner, based on a deep sense of friendship and involving companionship and the enjoyment of common activities, mutual interests, and shared laughter.

Relationship Assessment Scale (RAS; Hendrick, 1988). The RAS is a 7-item unifactorial measure of generic relationship satisfaction. Sample items include: "How well does your partner meet your needs?" and "To what extent has your relationship met your original expectations?"

Self-expansion Questionnaire (SEQ; Lewandowski & Aron, 2004) is a measure of perceived self-expansion within a relationship. Example items include: "How much does your partner help to expand your sense of the kind of person you are?", "How much has knowing your partner made you a better person?", and "How much do you see your partner as a way to expand your own capabilities?"

Satisfaction with Life Scale (Diener, Emmons, Larsen, & Griffin, 1985) assesses the cognitive component of subjective well-being with 5 items. Sample items include "In most ways my life is close to ideal," "I am satisfied with my life," and "If I could live my life over, I would change almost nothing." Subjects are asked the extent to which they agree or disagree with each of the statements.

Affective Intensity Measure (AIM*;* Larsen & Diener, 1987) is a 40-item scale to assess the general tendency to experience emotions intensely. Sample items include "When something good happens, I am usually much more jubilant than others" and "When I do feel anxiety it is normally very strong".

Means and Correlations. Table 2 displays the means and standard deviations and Table 3 describes the correlations of major study variables assessed by the questionnaires described above. The mean PLS score was 5.51 (6 being the highest rating), indicating high scores on passionate love for the sample. Of major interest were correlations with PLS. Results did not reveal significant correlations among PLS scores with AIM scores, years married, frequency of sex per week, friendship-based love, Storge (companionate love), Ludus (game-playing love), or Pragma (pragmatic love). Passionate love (PLS) was significantly correlated with Eros (romantic love), Mania (infatuation), Agape (selfless love), relationship satisfaction, SEQ (self-expansion with the partner), inclusion of partner in the self (IOS), and life-satisfaction.

Another particularly important variable was Eros (romantic love without obsession), also displaying a high mean for the sample (5.76 out of 6). Eros was significantly correlated with the PLS, SEQ, IOS, and life-satisfaction. In the context of the present study, it is important to distinguish romantic love and passionate love from general affective intensity, companionate love, and friendship-based love. In fact, both the PLS and Eros were negatively correlated with companionate love (measured as Storge), Eros was negatively correlated with friendship-based love, and PLS was negatively correlated with the AIM. Results from correlations suggest these constructs are distinct.

Image Acquisition

Data were acquired utilizing a 3T Siemens magnetic resonance imaging system with a NOVA head coil at the Center for Brain Imaging at New York University. Three-hundred and sixty functional images were collected per block, in volumes of thirty; 3mm axial slices (0 mm gap) covering the whole brain. A repetition time (TR) of 2,000-ms was used, with a TE of 30-ms, a 90˚ flip, resulting in a voxel size of functional images of 3X3X3mm. Before functional scanning, a circle localizer was applied to aid in localization.

CHAPTER 4: DATA ANALYSIS

Functional Image Processing

All analyses were carried out with Statistical Parametric Mapping software (SPM2; http://www.fil.ion.ucl.ac.uk/spm). First, functional images were realigned to correct for motion; no participants had greater than 3 mm (half voxel) motion. Next, data were co-registered and normalized to the SPM2 EPI template. Then, normalized images (warped) were smoothed 6 mm.

Statistical Regions of Interest (ROIs)

Changes in blood oxygen level dependent (BOLD) signal were used as the dependent variable. There were a large number of potential contrasts. However, analyses were focused on those contrasts of direct theoretical interest. Several contrast images were created for each participant and after careful inspection it was determined that only within-session contrasts were reliable. The two main contrasts created for each participant and reported in group analyses below were: (1) Partner-versus-HFN (from Session 1), and (2) CF-versus-LFN (from Session 2); as well as the reverse.

Multisubject regions of interest (ROIs) were identified from previous fMRI studies of early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000). For planned comparisons (hypothesis-driven analyses), small volume corrections (SVC) for false discovery rate (FDR) (Genovese et al., 2002) with a threshold of $p \leq .05$ (corrected) were used. The small volume consisted of a 3-mm radius, centered on the most significant voxel of clusters from previous studies of early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000). To investigate unpredicted regions of activation extracted from whole brain analyses, a threshold of $p \leq .001$

(uncorrected) was applied, with a minimum of 5 voxels. (All of these contrasts, whether ROIs or whole-brain were done using standard random effects procedures.)

To investigate correlations between brain responses and important variables (i.e., the PLS, relationship length, marital satisfaction, and attractiveness ratings), a between-subject random effects analysis was conducted, with a threshold of $p \leq .001$ and 5 voxels. As noted earlier, all images were rated for attractiveness and image quality by independent female and male coders around the same age as participants. The coder-rated attractiveness difference scores (partner-minus-HFN) were correlated with the neural response for the partner-versus-HFN contrast. For relationship length and PLS scores an analogous approach was used.

Anatomical localization

To display data, the SPM 2 Single Subject T1 Template was used as in Aron et al. (2005) because major landmarks are more visible than in other templates.

CHAPTER 5: RESULTS

A. Regional Brain Activations Measured by the BOLD Response to a Long-term Romantic Partner versus a High-familiar, Neutral Person

Table 4 displays all significant areas of activation for the partner-versus-HFN contrast. Responses to a long-term spouse recruited dopamine-rich reward regions in the basal ganglia (e.g., VTA, accumbens, caudate, putamen, SN, and subthalamic nucleus); cortical regions associated with sensory processing (e.g., insula), focused attention (e.g., anterior cingulate), memory (e.g., posterior cingulate and posterior hippocampus); and subcortical regions associated with pain suppression and feelings of calmness (e.g., PAG), processing emotional and socially salient stimuli (amygdala), learning stimulus-reward associations and decision-making (medial orbitofrontal cortex), synthesizing and secreting hormones, sexual arousal (hypothalamus), and regulating arousal level of awareness and activity (thalamus). The present results recruited neural regions overlapping with studies of early-stage romantic love using a similar paradigm (Aron et al., 2005; Bartels & Zeki, 2005) plus several more areas of the brain. These results are discussed in more detail below.

Comparison of Long-term versus Early-stage Romantic Love

Overlapping regions

Replicating results from Aron et al.'s (2005) study of early-stage intense romantic love, small volume measurements displayed significant activations in the right ventral tegmental area (Figure 1) at (2,-14,-14), an area associated with wanting or working for a reward (e.g., Aharon et al., 2001). Inspection of the time course plots showed the effects displayed in the VTA were due to more activation in response to the partner, not less activation in response to the HFN. Time course plots also suggest that effects for the partner peak during the first 20 seconds of each trial. Other results overlapping with those from a study of early-stage love (Aron et al., 2005) were found in antero-dorsal and postero-dorsal areas of the caudate nucleus body.

Overlapping regions with another study of early-stage love in humans (Bartels & Zeki, 2000) were displayed in the dorsal head of the caudate nucleus, left putamen, bilateral globus pallidus, bilateral middle insula, left anterior cingulate, bilateral posterior hippocampus, and the hypothalamus (Bartels & Zeki, 2004). The globus pallidus is of particular interest, as it has been implicated in both early-stage romantic love (Bartels & Zeki, 2000) and maternal love (Bartels & Zeki, 2004). This suggests that the effects may be due to processes related to attachment bonds in general. Activation of the anterior cingulate was notable as it has appeared in studies of social pain, witnessing pain of another, social rejection, viewing one's own child, and viewing a beloved romantic partner. It plays a crucial role in visual attention (Woldorff et al., 1999) and thinking about a range of stimuli to focus attention (Swain et al, 2007). It has also been implicated in numerous studies related to obsessive thinking (e.g., Rauch et al., 2001) and maternal responses to infant cries (Swain et al., 2007).

Activation in the hypothalamus is notable as it plays an important role in synthesizing and secreting hormones, arousal, and reproductive behaviors. Activation of the hypothalamus in the present sample is consistent with participants' self-reports expressing high levels of sexual desire (from post-scan emotion ratings) and physical attraction (from participant-rated attraction scores) for their long-term spouse, compared to controls (HFN, CF, and LFN).

Activations specific to early-stage romantic love

Regions unique to studies of early-stage romantic love (in comparison with long-term love) were displayed in the right anterior cingulate (Bartels & Zeki, 2000), medial caudate body, and posterior cingulate/retrosplenial cortex (Aron et al., 2005). The anterior cingulate (BA 24), the first of the areas found for early stage romantic love but not displayed in the present study, has been associated with obsessive compulsive disorder (OCD) (e.g., Ursu et al., 2003) and this specific site was shown to be responsive to anti-depressant medication for OCD (Fontenelle, 2006). Aron et al. (2005) suggested activation of the anterior cingulate (BA 24) was evidence of intense focus and obsession with a beloved, characteristic in the early-stages of romantic love.

The second region found for early stage love but not found here was the medial body of the caudate nucleus, which is associated with visual and attentional aspects of romantic love (Aron et al., 2005), reward, motivation, and planning. The third major region apparently unique to early stage romantic love was the posterior cingulate/ retrosplenial cortex (BA 30), which is associated with spatial memory (Vogt et al., 1992). Aron et al. (2005) showed that greater activation in the posterior cingulate/retrosplenial cortex was associated with *shorter* relationship length. This is consistent with lack of significant activation in the present sample. However, research investigating monogamous male prairie voles found that low levels of vasopressin 1a receptor expression in the retrosplenial cortex was associated with sexual infidelity and wandering (cohabitiation with many male and female voles) (Ophir, Wolff, & Phelps, 2008). These findings are not easy to interpret in light of the present study.

Activations specific to a long-term romantic partner

Long-term romantic love in comparison with early-stage romantic love specifically activated predicted regions in the basal ganglia including the nucleus accumbens, regions of the VTA including the raphe nuclei, ventral putamen/pallidum, subthalamic nucleus, and substantia nigra. (These areas were "predicted" regions because they had been predicted in previous studies of romantic love, maternal love, or animal studies on pair-bonding, but they were not found in the early stage love studies.) The nucleus accumbens is a major component of the human neural reward circuitry (Knuston et al., 2001). It is associated with negative reward prediction errors (expecting a reward but not receiving it) (D'Ardenne, McClure, Nystrom, & Cohen, 2008), craving a deceased loved one (O'Connor et al., 2008), and feeling high upon self-administered cocaine injection (Risinger et al., 2005). The accumbens has been implicated in studies of monogamous pair-bonding in prairie voles (Young et al., 2001) and primates (Bales et al., 2007). It was predicted by Aron et al. (2005), but did not reach significance in either study of early-stage romantic love. This distinction suggests that the nucleus accumbens may require conditioning and learning in response to the partner over time. Another possibility is that a long-term beloved, whether or not as intensely beloved, may be more reliably rewarding than a newly loved partner for whom one can not know for sure what to expect as time goes by.

VTA activation specific to long-term love also appeared bilaterally, in a posterior, dorsal area (compared to results from Aron et al., 2005), extending into regions of raphe nuclei. The raphe nuclei send serotonergic projections to the striatum, amygdala, hippocampal formation, and areas of the cortex. Drugs that block serotonin reuptake are effective in treating anxiety and obsessive-compulsive disorder. This may be indicative of one distinction between early-stage and long-term romantic love—with the latter being associated with decreased anxiety and obsession.

Activation of the ventral pallidum was notable (Figure 2) as it has been also been implicated in numerous studies of monogamous pair-bonding in prairie voles (e.g., Lim & Young, 2004; 2006) and among nonhuman primates (Bales et al., 2007) through the neuropeptide vasopressin (Pitkow et al., 2001). In one study, it was found that monogamous prairie voles had higher densities of vasopressin in the ventral pallidum (Young et al., 1997). Among humans in the early stages of romantic love, the ventral pallidum was positively correlated with relationship length (Aron et al., 2005). The ventral pallidum, in conjunction with the ventrolateral putamen and nucleus accumbens, has also been implicated in human fMRI studies of reward learning that may occur without explicit training in the presence of goal-specific cues (e.g., Bray et al., 2008; McClure et al., 2003; O'Doherty et al., 2003).

Cortical regions unique to long-term romantic love included the insular cortex and posterior cingulate. The insular cortex is important in processing pain, representations of taste, viscerosensations, and vestibular functions. The posterior cingulate seems to play a role during autobiographical memory retrieval. Paradigms included hearing names of familiar individuals (such as a spouse, parent, child, sibling, or close friend) versus non-familiar persons (Maddock, Garrett, & Buonocore, 2001); viewing images of faces belonging to familiar children versus unfamiliar children (Leibenluft et al., 2004); and listening to familiar voices and viewing familiar faces versus unfamiliar ones (Shah et al., 2001). Aron et al. (2005) found activation in the posterior cingulate was correlated with relationship length. The posterior cingulate seems to respond differentially with increased familiarity of a stimulus. In the present study, the partner and highly-familiar neutral person were about equally familiar (at least in the sense of being known for the same length of time), suggesting the effect may due to increased closeness/attachment with the partner over time. This is substantiated by evidence showing that the posterior cingulate shows a large variation of oxytocin and vasopressin receptors in prairie voles (e.g., Phelps & Young, 2003).

Subcortical regions of interest specifically activated in response to a long-term partner compared to newly-in-love individuals included the periaqueductal gray (PAG), medial orbitofrontal cortex, thalamus, and amygdala. The PAG is an oxytocin-rich area that plays an important role in the body's response to stress and feelings of acquiescence. It projects to the raphe nuclei, whose neurons use serotonin as their neurotransmitter, suppressing the transmission of pain to the spinal cord. PAG has direct connections with the orbitofrontal cortex (Cavada, 2000) and receives inputs from limbic areas that contain high-density oxytocin and vasopressin receptors (Jenkins, 1984). It has been implicated in numerous studies of maternal attachment (Swain et al., 2007) and was found to be specific to maternal love in comparison with romantic love (Bartels & Zeki, 2004). Consistent with previous research, recruitment of the PAG in the present study suggests the effect be due to stronger attachment to a long-term partner in comparison with a new love.

Deactivations (Partner-versus-HFN)

For deactivations, no predicted regions of change met thresholds for small volume measurements. However, whole brain analyses yielded several significant deactivations. The most notable appeared in an area of the right ventral striatum, which has been associated with receiving rewards at unpredictable versus predictable intervals (Berns et al., 2001). Other deactivations appeared in the temporal gyri (associated with visual and emotional information processing), frontal gyri (associated with planning and the production of body and eye movements, speech, cognition, and emotions), lingual gyrus, and the parietal fissure/precuneus.

B. Correlations of BOLD Responses with Key Variables: Partner vs. HFN Contrast

Years Married

Focusing on the Partner-versus-HFN contrast, a between-subjects random effect analysis correlating BOLD responses and participants' years married to the partner showed significant activations in the nucleus accumbens, subcolossal area, periaqueductal gray (PAG) region, red nucleus, and the medial temporal gyrus (see Table 5). Participants married a greater number of years showed stronger activation in the right nucleus accumbens core, an area associated with expecting and receiving rewards (D'Ardenne, McClure, Nystrom, & Cohen, 2008; Knuston et al., 2000). Nearby coordinates were reported in a study of cocaine-addiction for feeling high and craving a dose of cocaine (Risinger et al., 2005) and in a study of grief when yearning for a deceased loved one (O'Connor et al., 2008). Similarly, activation in the red nucleus (involved in the motor coordination of shoulders and upper arms) was positively correlated with years married and was also associated with feeling high upon cocaine injection (Risinger et al., 2005). Another notable activation positively correlated with years married was displayed in the PAG. The PAG is associated with feelings of acquiescence and pain suppression, attachment, and reproductive behaviors.

Areas correlated with relationship length and brain activity in the present study did not overlap with respective analyses in a sample of newly in-love individuals (Aron et al., 2005), suggesting that differences between the two samples were not merely due to time, but perhaps time-related/relationship-factors that change as the attachment bond between the couple grows and strengthens. In regards to deactivations, there were very few significant areas that would have been predicted. However, deactivations appeared in the right insular cortex, suggesting a decrease in anxiety associated with the response to the partner over time.

Passionate Love Scores

For the Partner-versus-HFN contrast, correlations of BOLD signal changes and scores on the PLS showed significant differences in several regions predicted from previous studies correlating PLS with neural activity (see Table 6). For example, degree of activation in the right antero-medial caudate body and the left septum/fornix region replicated findings reported by Aron et al. (2005). Strength of activation in the left angular gyrus replicated findings reported by Ortigue et al. (2007), presenting beloved versus neutral acquaintance names to newly in-love subjects (about 16 months on average). The left angular gyrus is an associative brain area associated with episodic memory retrieval, conceptual knowledge, and abstract representations of self and others.

Other regions showing activation for the contrast itself were also significant, including the caudate, putamen, globus pallidus, subthalamic nucleus, insular cortex, anterior cingulate, posterior cingulate, posterior hippocampus, thalamus, hypothalamus, and the amygdala.

A between-subjects random effect analysis correlating the BOLD responses and participants' PLS scores yielded significant activations in the right postero-dorsal caudate nucleus body, lateral prefrontal cortex, and middle occipital gyrus. Activation of the postero-dorsal caudate replicated that yielded by a contrast of beloved versus neutral in Aron et al., (2005).

Marital Satisfaction Scores

A similar analysis was conducted correlating degree of activation with participants' marital satisfaction scores (measured by the RAS), again for the Partner-versus-HFN contrast. As shown in Table 7, several regions of interest displayed stronger activations with greater marital satisfaction scores in dopamine-rich reward regions (VTA, substantia nigra, caudate, putamen) oxytocin and vasopressin-rich regions involved in the regulation of hormones (hypothalamus and thalamus) and the amygdala (involved in processing emotional and social information). Activation in the right VTA appeared at a location nearly identical to that reported by Aron et al. (2005) for early-stage love and with the main contrast (Partner vs. HFN) for long-term love. This area is associated with wanting or working for rewards (e.g., Aharon et al., 2001). Activation in the hypothalamus appeared in the periventricular nucleus, a region involved in the synthesis and release of oxytocin and vasopressin, and reproductive behaviors. This is supported by sexual liveliness reported by the sample of intensely in-love long-term married individuals.

The whole brain analysis correlating the Partner-versus-HFN contrast with marital satisfaction scores yielded a striking number of activations that met threshold criteria of .001 and >= 5 voxels (see Table 7). The most prominent activation appeared in right striatum, particularly the substantia nigra and putamen. The substantia nigra is a dopamine-rich reward area that responds to salient stimuli (receiving inputs from the amygdala and the reticular formation, which is involved in arousal). Activation of the right putamen has been implicated in studies of social fairness (e.g., Rilling et al., 2002; Singer et al., 2004) where faces associated with cooperative vs. uncooperative players recruited reward-related neural activity. Consistent with a study of social cooperation (Singer et al., 2004), strength of activation in a large portion of the left amygdala was positively correlated with marital satisfaction. Beyond emotion and reward, the amygdala is also seems to be involved in processing fairness in social judgment. Thus, being satisfied with one's marriage, like social fairness and cooperation, is experienced as rewarding.

Another notable activation appeared in the anterior cingulate cortex. This region is associated with a broad range of functions including reward anticipation and reward-related decision-making (e.g., Bush et al., 2002; Hampton & O'Doherty, 2007; Marsh et al., 2007). More specifically, the anterior cingulate cortex seems to anticipate and detect targets, encode reward values, and signal errors, and influence motor responses (Bush et al., 2000; 2002).

Activation of the prefrontal cortex (anterior, lateral, and medial-orbito) was consistent with research showing that it is associated with differentiating among conflicting thoughts, social judgments, expectation and future consequences based on current actions, and working toward a specific goal. The prefrontal cortex is believed to have evolved in close relationship with the limbic system (MacLean, 1973) and it displays associations with empathy, self-reflection, and perspective-taking. The right prefrontal cortex has been implicated in studies of social norm compliance (the ability to suppress urges that, if not suppressed, could result in socially-unacceptable outcomes), (e.g., Spitzer et al., 2007), and self-conscious emotions (such as embarrassment and guilt) related to inhibition of behavior (e.g., Takahashi et al., 2004).

In sum, the correlation between BOLD responses and marital satisfaction scores revealed a constellation of neural activations. The strongest activations appeared in neural areas associated with reward processing and decision-making; hormone and reproductive behavior regulation, emotions (like empathy, embarrassment, guilt) and evaluating social fairness, and social norm compliance. These findings highlight the connections between experiencing a long-term marriage as rewarding, and perceived and mutual cooperation, empathy, emotions, and the regulation of hormones—all of which serve to guide behavior. Such behaviors may in turn promote the happily long-time married individual to behave in ways that protect and further enhance their relationship.

Facial Attractiveness

Focusing on the partner versus HFN contrast, BOLD responses were correlated with independent-rated facial attractiveness scores. Findings showed that facial attractiveness difference scores (partner-minus-HFN) did not correlate with any predicted region of change (e.g., left VTA), basic reward regions displayed for the main contrast (Partner > HFN), or unpredicted regions of change (from whole-brain exploratory analyses).

C. Regional Brain Activations Measured by the BOLD Response to a Close Friend versus a Low-familiar, Neutral Person: General Closeness and Familiarity Effects

Table 8 displays all significant areas of activation for a close friend versus a low-familiar, neutral individual (CF > LFN), for all predicted regions (that is, regions predicted for the Partner-versus-HFN contrast) and for whole brain exploratory results. The rationale for inclusion of the CF > LFN contrast was to determine overlaps with the Partner > HFN contrast. If an area found for the Partner > HFN contrast was also found for the CF > LFN contrast, it suggests that the effect found could be due to closeness or familiarity, and romantic love per se. However, areas found for the Partner > HFN contrast, but *not* found for the CF > LFN contrast are likely to be uniquely due to love and not to familiarity or closeness. Any areas found for the CF > LFN contrast but *not* for the Partner > HFN contrast are possibly due to familiarity or closeness. However, since the difference in familiarity of the CF > LFN is especially dramatic (with the LFN known only very minimally), some effects are likely due to familiarity .

Results for the predicted ROI areas included significant effects in dopamine-rich reward regions in the basal ganglia (ventral striatum, caudate, putamen, and globus pallidus); cortical regions, such as the posterior cingulate and the posterior cingulate/retrosplenial cortex; and subcortical regions (such as the PAG, medial orbitofrontal cortex, thalamus, hypothalamus, and amygdala). As noted, the main reason for the CF > LFN contrast was to control for general closeness and familiarity of the main contrast (Partner > HFN). In the following subsections, I will discuss regions that overlapped between the two contrasts, regions unique to each of the contrasts, and deactivations for the CF > LFN contrast.

Comparison of Close Friend Effects and Long-term Partner Effects

Activations specific to a long-term romantic partner

Long-term romantic love (that is, the Partner-versus-HFN contrast) specifically (that is, in comparison to the CF vs LFN contrast) activated the VTA, substantia nigra, left antero-dorsal caudate nucleus, bilateral ventral pallidum, left globus pallidus, and subthalamic nucleus, middle insula, insular cortex, posterior hippocampus, anterior cingulate, right amygdala, and left thalamus.

Recall that the Partner-versus-HFN contrast yielded activations similar to studies of early-stage romantic love plus several more. Areas that were uniquely displayed in response to a long-term romantic partner (comparing with a close friend) also found in previous studies of early-stage romantic love included the VTA, caudate nucleus, globus pallidus, middle insula, anterior cingulate, and posterior hippocampus.

Bartels and Zeki (2004) compared activations for romantic love with maternal love and found overlap in the caudate nucleus, globus pallidus, middle insula, and part of the anterior cingulate. This suggests that activation of these regions may be due to love/attachment bonding generally speaking, and not general closeness or familiarity, but also not specifically romantic love.

Evidence suggests that activations in the VTA and part of the anterior cingulate are specific to romantic love. For example, in the present study, significant activations appeared specifically in these areas in response to a long-term romantic partner. In previous studies of early-stage romantic love, activations in the VTA and anterior cingulate were displayed in response to a beloved's image versus a neutral person (Aron et al., 2005), friends (Bartels & Zeki, 2000). Collectively, this would seem to be strong evidence that effects in the VTA and parts of the anterior cingulate are due to romantic love, not attachment bonding, general closeness, or familiarity. Activation of the VTA is particularly interesting as it is associated with working for a reward (e.g., Elliot et al., 2000; 2004), expecting a reward and receiving it (D'Ardenne et al., 2008) and in the present study it was shown to be correlated with marital satisfaction.

The posterior hippocampus has been suggested in processing information that have response related familiarity (Strange et al., 1999) and is related with recall of past experiences. The hippocampus (specifically the temporal region) has strong direct connections to subcortical regions such as the nucleus accumbens, amygdala, septum and hypothalamus (Bast, 2007). The temporal and intermediate hippocampus is also linked, via projections to the prefrontal cortex and subcortical sites, to the VTA, which releases dopamine and plays a critical role in motivation, emotion, and behavior. It has been shown that stimulation of the temporal hippocampus modulates activity in the VTA and increases dopamine release in the nucleus accumbens (e.g., Legault et al., 2000). Thus, suggesting an important link in this area of the hippocampus with activity in the VTA, important to the experience of romantic love.

Overlapping Regions

Overlapping regions between the two contrasts (Partner > HFN and CF > LFN) included the right ventral striatum, right caudate body (antero and postero-dorsal), bilateral putamen, right globus pallidus, PAG, right posterior cingulate, right medial orbitofrontal cortex, right thalamus, right hypothalamus, and left amygdala.

Several regions overlapping between the two contrasts in the present study also overlapped with findings from previous studies of romantic love. Such regions included the postero-dorsal and antero-dorsal caudate body, posterior cingulate (Aron et al., 2005), bilateral putamen, globus pallidus (Bartels & Zeki, 2000), and the PAG (Bartels & Zeki, 2004). Activation of these regions in the present context (response to a close, long-term friend versus an unfamiliar person) suggests that these particular effects found in previous studies of romantic love, maternal love, and presently for a long-term romantic partner may be due to general closeness or intensity of interaction history, and not specifically to romantic love.

Activation of the right ventral striatum was displayed in the present study but not in studies of early-stage romantic love or maternal love. Recall that activation of the nucleus accumbens was found for the correlation of neural responses to the long-term partner with number of years married and in a study of yearning for a deceased mother or sister (O'Connor et al., 2008). Thus, activation of the ventral striatum by a long-term romantic partner and by a close, long-term friend suggests these effects may be due to time-dependent changes as attachment bonds between individuals solidify and strengthen or perhaps increased familiarity.

Activations in the caudate body and posterior cingulate replicate those reported by Aron et al. (2005). More specifically, in the early-stage romantic love study, the posterior cingulate was found to be correlated with relationship length. The posterior cingulate has been implicated in autobiographical memory retrieval such as when listening to familiar names (such as a spouse, parent, child, sibling, or close friend) versus a non-familiar person (Maddock, et al., 2001), or when viewing images of a familiar child versus an unfamiliar child (Leibenluft, Harrison, & Haxby, 2004). This all suggests that across-studies of early and long-term romantic love, its activation is likely due to effects of familiarity.

Activations in the putamen, globus pallidus, and PAG replicate results of overlapping regions between early-stage romantic love and maternal love (Bartels & Zeki, 2004), thus indicating that activations of the putamen, globus pallidus, and PAG in the present context (Partner > HFN and CF > LFN) likely reflect general attachment or closeness effects.

Activations specific to a close friend

The contrast of a close friend versus a low-familiar neutral person (in comparison to the partner-versus-HFN contrast) specifically recruited the posterior cingulate/retrosplenial cortex and left medial orbitofrontal cortex. Recall that Aron et al. (2005) found activation in the posterior cingulate/retrosplenial cortex was associated with shorter relationship length. In the present context this result is not easily interpretable.

The medial orbitofrontal cortex receives dopamine projections from the VTA (O'Doherty, Kringelbach, Rolls, Homak, & Andrews, 2001; Schoenbaum, Chiba, &

Gallagher, 1998). It is important for evaluating and learning stimulus-reward associations (Rolls, 2000), face expression identification (e.g., Kringelbach et al., 2003; Rolls, 2004), affective processes such as decision-making (e.g, Bechara, 2001; Bechara et al., 2000), and classifying rewards based on preference (O'Doherty et al., 2002).

Deactivations (CF > LFN)

Whole-brain analyses displayed significant deactivations in several regions, mainly the insula, anterior cingulate, dorsolateral prefrontal cortex. Other significant deactivations appeared in areas of the frontal gyri, occipital lobe, parietal lobe, temporal gyri, and precentral gyri. These effects may be due to novelty, as the LFN was someone novel, barely known to participants.

CHAPTER 6: DISCUSSION

It has been widely assumed that romantic love cannot last in long-term relationships. Many major theories of romantic love propose that it fades with time and if things go well, may evolve into companionate love (a warm, calm love that does not include sexual passion, intensity, or attraction) (e.g., Berscheid & Hatfield, 1969) or commitment (e.g., Sternberg, 1986). However, some theories (e.g., Aron et al., 2000; Buss, 2006; Fisher, 2006) suggest there may be mechanisms and adaptive reasons which allow romantic love to prosper in long-term relationships. Further, numerous research studies suggest that long-term romantic love is real, but is generally believed to fade out due to its commingling with obsession (for review see Acevedo & Aron, 2008).

One aim of the present study was to get directly at the comparability of early-stage and long-term romantic love to determine if romantic love can last, as has been suggested by research. Thus, a previous study of early-stage romantic love (Aron et al., 20005), was replicated closely, but sampling participants intensely in-love with a long-term spouse. A second aim of the present study was to describe what romantic love is like in long-term relationships in light of brain response data, but guided by questionnaires and interviews with participants. Finally, to get even more directly at the experience of romantic love, participants viewed images of close friends and a high-familiar, neutral person. Thus, it was possible to determine if effects found for the long-term partner (as well as in studies of early-stage romantic love and maternal) were due to general closeness or familiarity.

Results from the present study largely replicated those from studies of early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000), activating dopamine-rich subcortical reward regions (such as the VTA, caudate, and putamen). Even in comparison to responses to a long-term friend (versus an unfamiliar person), and a comparable study of maternal love (Bartels & Zeki, 2004), neural activity specific to a long-term beloved appeared in the right VTA. The VTA is particularly interesting, being part of the mesolimbic dopamine system and where dopamine projections originate. It has been shown to be critical in the formation and maintenance of pair-bonds in prairie voles (e.g., Gingrich et al., 2000) and in early-stage romantic love in humans (Aron et al., 2005; Bartels & Zeki, 2004). More generally, the VTA has been associated with numerous studies of reward value (e.g., Montague & Berns, 2002), anticipating rewards and punishments (e.g, Knuston et al., 2000), tracking positive reward prediction errors (reward expected and received) (D'Ardenne, et al., 2008), and working for rewards (e.g., Elliott et al., 2000). Thus, the long-term beloved is associated with reward and motivation—a key characteristic found in early-stage romantic love.

Responses to a long-term partner recruited some brain regions not found in studies of early-stage romantic love. Mostly such activations appeared in oxytocin and vasopressin-rich areas of the nucleus accumbens, ventral pallidum, and PAG. These areas were predicted from studies of monogamous pair-bonding in non-human mammals but not found in studies of early-stage romantic love. For example, the ventral pallidum is a vasopressin-rich region implicated in monogamous pair-bonding in prairie voles (Young, Lim, Gingrich, & Insel, 2001) and non-human primates (Bales et al., 2007). It was also unique to the long-term partner in comparison to the close friend in the present study. Activation of the ventral pallidum was found to have a positive correlation with relationship length in a study of early-stage romantic love (Aron et al., 2005), suggesting its role in the formation and maintenance of pair-bonds.

The nucleus accumbens is rich in oxytocin receptors and has also been implicated in pair-bonding (Insel & Shapiro, 1992). It has also been implicated in feeling craving for a deceased loved one and (O'Connor et al., 2008) as well as for cocaine in addicts (e.g., Risinger et al., 2005). The PAG receives direct connections from limbic areas that contain high density oxytocin and vasopressin receptors (Jenkins, 1984). It has been implicated in maternal attachment (Bartels & Zeki, 2004) and pain modulation (e.g., Fairhurst Wiech, Dunckley, & Tracey, 2007).

In the present study, the PAG appeared to be unique to long-term love (in comparison with new love from previous studies) but was also evoked in response to a close friend. Thus, suggesting effects found for the PAG were due to attachment bonding more generally, rather than romantic or maternal love specifically (as reported by Bartels & Zeki, 2004). Activations of the ventral pallidum and nucleus accumbens were specific to romantic love (and not found for close friendship). These results are consistent with animal research implicating the ventral pallidum and nucleus accumbens as critical regions involved in monogamous pair-bonding formation (e.g., Lim & Young, 2004) and maintenance (Bales et al., 2007).

In sum, results suggest that responses to a long-term partner evoke activations in key regions associated with reward and motivation replicating previous studies of early-stage romantic love (Aron et al., 2005; Bartels & Zeki, 2000) and supporting self-report evidence of the possibility of romantic love in long-term marriages. Activations unique to a long-term partner (versus a new beloved) appeared in oxytocin and vasopressin-rich regions (namely the nucleus accumbens and ventral pallidum) found to be critical in the formation and maintenance of monogamous pair-bonds in mammals. It is likely that activations in these areas were not apparent in studies of early-stage romantic love due to time-dependent changes that occur as bonds develop.

Romantic Love, Attachment, Obsession, and Anxiety

Several results from previous studies (for review see Acevedo & Aron, 2008) and the present study suggest that an important distinction between romantic love in its early versus later stages is the diminished obsession and anxiety, and greater sense of calmness and well-being associated with long-term romantic love. For example, activations specific to the long-term spouse were displayed in areas of the VTA extending into the raphe nuclei; which are serotonin-rich, implicated in feelings of calmness, and centers for treating anxiety and obsessive-compulsive disorder. Similarly, activation of the PAG (an oxytocin-rich area associated with stress responses, pain suppression, and feelings of acquiescence) was specifically activated for long-term romantic love, maternal love, and the close friend—but not in studies of early-stage romantic love.

Results specific to early-stage romantic love, in comparison to a long-term partner, appeared in areas generally associated with obsessive thinking. For example, activation of the anterior cingulate, medial caudate body, and posterior cingulate/ retrosplenial cortex among newly in-love humans is consistent with evidence that obsessive thinking, intense focus, and infatuation are characteristic of early stage romantic love (Tennov, 1979), but not generally in the later stages of romantic love (Acevedo & Aron, 2008). Finally, a correlation with relationship length and brain responses displayed a deactivation in region associated with anxiety, suggesting a decrease in anxiety with number of years married. Evidence from the present study and another study (Tennov, 1979) suggest that many older individuals in happy marriages when interviewed, report being in-love, but do not necessarily report continuous and unwanted thinking about the partner. In conclusion, one distinction between early-stage and long-term romantic love, is the presence of obsessive, intrusive thinking among newly in-love individuals. In contrast, long-term romantic love seems to be lower obsession and anxiety, and greater feelings of calmness, well-being, and attachment over time.

What is Romantic Love Like in Long-term Relationships?

Interesting results were revealed by a correlation of marital satisfaction scores and brain activity, showing a large constellation of significantly active regions. The strongest activations appeared in neural regions associated with reward processing (e.g., VTA) and decision-making (anterior cingulate cortex); hormone regulation and reproductive behaviors (periventricular nucleus); empathy, perspective-taking, and self-reflection (prefrontal cortex), social fairness (e.g., right putamen and left amygdala), and social norm compliance (right prefrontal cortex). Taken together these results emphasize the links between experiencing a long-term marriage as rewarding, and perceived and mutual cooperation, empathy, emotions, hormones and reproductive behaviors.

A correlation of degree of neural activation with years married (for Partner-versus HFN contrast) showed greater activation in regions associated with reward processing and craving (nucleus accumbens), feeling high and motor coordination (red nucleus); and pain suppression, attachment and reproductive behaviors (PAG). Thus, suggesting that individuals married for many years continue to crave their beloved and derive feelings of arousal as well as calmness and acquiescence even after many years.

Limitations and Future Directions

Overall, this project aimed to clarify the distinct and overlapping neural systems associated with long-term and early-stage romantic love. Another aim was to describe and speculate on what romantic love is like (or associated with) in long-term marriages. Finally, with additional controls (specifically a close-friend) it was possible to determine if any regions found in the present study for a long-term spouse and in present studies of early-stage romantic love were due to familiarity or general closeness. Such findings may have significant implications for both theory and practice. For example, knowing some of the possibilities associated with long-term marriages people (as well as therapists, clergy, instructors counseling them) may set realistic expectations. However, the possibility of intense long-term romantic love presented here may create some distress for those in satisfying, but not intensely romantic marriages. Undeniably, relationships, even those of extremely connected and in-love couples, go through ups and downs, and perhaps even longer cycles where the spark may just be latent. That intensely high feelings, those associated with rushes of energy, are sustained constantly is not the case made here. Rather in long-term relationships, romantic love— with attention, attraction, sexual interest, and craving for union with the beloved—seems to be related to reward as well as feelings of tranquility, harmony, and connectedness. It is also associated with high-arousal states, such as intense passion, joy, and sexual desire, but unlike love in its early stages it's not full of anxiety, pining, and obsession with the beloved. Thus, like the ocean currents that run below the surface of the water, long-term romantic love does not move as quickly, but it runs deep.

The sample selected for the present study consisted of individuals reporting they were not just happy, but intensely in-love. The design of the present study does not permit a definitive conclusion that this sample is different from individuals who are very happy, but not intensely in love. Future studies may aim to recruit individuals in long-term marriages that are happy, but not necessarily extremely in-love to further sort out effects due to marital satisfaction, sexual liveliness, and so forth, from romantic love effects. However, this limitation (of not having a control of very happy, but not intensely in-love group) was substantially controlled for by not finding the same areas in the close-friend contrast. The close friend is not an all-inclusive control as happily married individuals may share qualities with in-love married individuals that are not characteristic of close friends (e.g., sexual activity and desire, shared investments, children together, interdependence). It may also be worthwhile to conduct a similar study but comparing the partner directly (in the same session) with the various control target persons to permit more differentiated comparisons, so as to sort out issues of closeness, attachment, and familiarity, for example. In general with fMRI research one tries to implement optimal controls, but it’s not always practical ore feasible to define control conditions that rule out every potential confound that could undermine unambiguous interpretation. Finally, in order to directly examine time-course changes as bonds develop, grow, or deteriorate over time, it may be useful to conduct a large scale longitudinal study tracking participants at the formation phase of their relationship.

It’s important to note while these results are provocative, there are limitations to fMRI research in general. First, there are several inferences involved in fMRI research that constrain interpretation of the data. For example, the labeling of some brain regions as “attachment centers” and others as “romantic centers” is somewhat preliminary. Further, it’s best to err on the conservative side when drawing conclusions about brain regions from studies using different paradigms. Thus, some of the result interpretations highlighted above should be taken as preliminary. Finally, fMRI experiments in general, do not demonstrate that any such region is the cause of an experience. Thus, in the present context, it cannot be concluded that the VTA is the cause of experiencing romantic love. However, future research studies using dopamine antagonists may be able to do so.

Conclusions

Collectively results from the present study suggest that long-term romantic love includes intensity, reward, craving, sexual desire, and motivation to be with the beloved—characteristics also present in the early-stages of romantic love. However, in the later stages it is generally associated with lower obsession and anxiety, and increased calmness and attachment. Individuals in such relationships continue to crave union with their beloved and this craving (motivation) may manifest in behaviors (working) that maintain, enhance, and protect the relationship. The relationship with the long-term spouse continues to be experienced as a source of reward and well-being, and this supercedes time, life challenges, and even the energy and attentional demands of rearing children, having careers, and so forth. In sum, that romantic love exists at all, and may even conquer the human demands of life, is a sheer miracle and without doubt a "gift from the gods."

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Table 1. Characteristics of target stimuli in relation to study participants

	Age	Years Known	Closeness	Annoyance	Frequency of Interaction	Inclusion of Other in Self*
Partner	54.82 (7.98)	24.18 (6.42)	9.81 (0.54)	2.20 (2.14)	-	5.82 (1.59)
CF	54.06 (13.05)	25.59 (14.31)	8.16 (1.26)	1.00 (1.58)	7.38 (1.91)	3.06 (1.60)
HFN	55.25 (10.96)	19.97 (8.66)	4.06 (1.91)	1.00 (1.46)	4.45 (2.10)	1.53 (0.62)
LFN	48.63 (13.23)	0.83 (0.78)	1.78 (1.35)	1.29 (2.38)	3.16 (2.05)	1.12 (0.33)

Note: Ratings were on a 10-point scale, with 1 being not at all, 5 being neutral, and 10 being the greatest degree. Variable marked with an asterisk (*) on a 7-point scale, with 1 indicated the lowest score and 7 being the highest score. Standard deviations are in parentheses.

Table 2. Means and standard deviations of major study variables

	Mean	Standard Deviation
PLS*	5.51	0.36
Eros*	5.76	0.26
Ludus	2.11	1.21
Storge	4.16	2.16
Pragma	3.19	1.82
Mania	2.36	1.37
Agape	4.94	1.58
FBL	6.48	0.77
RAS	6.75	0.26
SEQ	5.57	0.59
IOS	5.82	1.59
Life-Satisfaction	6.51	0.60
AIM	4.47	0.54

Note: Ratings were on a 7-point scale, with 1 being strongly disagree, 4 being neutral, and 7 being strongly agree. Ratings marked with an asteriks (*) were on a 6-point scale, with 1 being untrue and 6 being true.
Note: FBL = Friendship-based Love Scale, RAS = Relationship Assessment Scale, SEQ = Self-expansion Questionnaire, IOS = Inclusion of Other in the Self Scale, AIM = Affective Intensity Measure

Table 3. Correlations among major study variables

	Eros	Ludus	Storge	Pragma	Mania	Agape	FBL	RAS	SEQ	IOS	Sex/week	Life-satisfaction	AIM	Yrs Married
PLS	0.54*	0.07	-0.10	-0.04	0.51*	0.56*	0.23	0.49*	0.60*	0.54*	0.20	0.50*	-0.11	0.29
Eros	--	-0.07	-0.38	0.09	0.21	0.39	-0.20	0.12	0.52*	0.58*	-0.13	0.55*	0.22	0.26
Ludus		--	0.23	0.23	-0.02	-0.02	-0.07	-0.16	0.00	-0.14	-0.33	-0.55	-0.01	-0.01
Storge			--	0.17	-0.31	-0.01	0.32	-0.33	0.22	-0.33	0.21	-0.44	0.15	-0.16
Pragma				--	-0.27	-0.66	-0.59	-0.14	-0.21	0.27	-0.17	-0.12	0.57*	-0.33
Mania					--	0.43	0.12	0.09	0.19	0.10	0.44	0.43	-0.17	0.40
Agape						--	0.64**	0.17	0.60*	0.10	0.73	0.30	-0.33	0.39
FBL							--	0.18	0.25	-0.22	0.76	-0.04	-0.45	-0.09
RAS								--	0.11	0.54	-0.16	0.18	-0.36	-0.25
SEQ									--	0.82	0.13	0.31	0.04	0.30
IOS										--	0.15	0.62**	0.12	0.42
Sex/week											--	0.34	-0.25	0.36
Life-satisfaction												--	-0.04	0.48
AIM													--	0.06
Yrs Married														--

Note: * $p \leq .05$; ** $p \leq .01$. Note: FBL = Friendship-based Love Scale, RAS = Relationship Assessment Scale, SEQ = Self-expansion Questionnaire, IOS = Inclusion of Other in the Self Scale, AIM = Affective Intensity Measure.

Table 4. Regional activations specific to viewing images of the partner versus the high, familiar neutral acquaintance

Region	MNI coordinates x	y	z	*p* (FDR)	*T*	*Z*
Basal Ganglia						
VTA	2	-12	-8	0.04	2.83	2.51
	2	-14	-14	0.012	2.23	2.06
	2	-22	-18	0.008	2.71	2.43
	-2	-22	-18	0.01	3.12	2.72
VTA/SN	4	-14	-16	0.039	2.82	2.5
Accumbens	10	4	-4	0.05	2.56	2.31
Caudate, dorsal head	-20	0	28	0.013	3.33	2.86
	18	4	26	0.045	3.09	2.7
Caudate body, postero-dorsal	16	-14	20	0.04	2.64	2.37
Caudate body, antero-dorsal	-20	2	18	0.04	2.7	2.42
	16	-6	14	0.006	3.5	2.97
Ventral Putamen/	24	-8	-8	0.025	3.14	2.73
Pallidum	-32	6	-8	0.025	2.76	2.46
Putamen	-20	2	16	0.02	2.79	2.49
	24	0	-2	0.03	2.61	2.35
	10	2	-2	0.05	2.34	2.14
Putamen/Globus Pallidus	-32	6	-8	0.028	2.76	2.46
	24	0	-2	0.032	2.61	2.35
SN	16	-20	-12	0.036	2.88	2.55
Subthalamic nucleus	18	-20	-10	0.035	2.77	2.47
Cortical						
Mid-Insula	-44	4	-2	0.05	2.19	2.02
	38	10	-6	0.04	2.49	2.25
Insular Cortex	-38	8	-14	0.021	3.23	2.79
Anterior Cingulate	-6	24	38	0.05	2.05	1.91
Posterior Cingulate	10	-52	16	0.03	3.01	2.64
Posterior Hippocampus	36	-34	0	0.002	6.11	4.33
	-36	-32	-8	0.04	2.88	2.55

Subcortical						
PAG	2	-26	-22	0.005	4.05	3.31
Mediaorbitofrontal cortex	2	58	-10	0.04	2.77	2.47
Thalamus	-2	-14	12	0.024	3.28	2.83
	2	-16	14	0.018	4.33	3.47
Hypothalamus	2	-4	-6	0.006	5.45	4.04
	0	-8	-14	0.05	2.71	2.42
Amygdala	-20	-2	-12	0.012	3.24	2.8
	10	-16	-18	0.015	3.23	2.79
	18	-4	10	0.015	3.02	2.65

Deactivations	x	y	z	P (unc)	T	Z	cluster k
R. Nucleus Accumbens	6	6	-12	0.001	4.01	3.29	47
	6	14	-10	0.008	2.69	2.41	47
Supramarginal gyrus	56	-66	32	0	5.56	4.49	1318
	58	-58	30	0	4.38	3.5	1318
Inferior temporal gyrus	44	52	4	0	4.81	3.73	1999
Mid Temporal gyrus	-54	4	-22	0	4.72	3.68	92
	64	-46	-12	0	4.4	3.51	373
	70	-30	-4	0.001	3.56	3.01	373
Superior temporal gyrus	-46	-6	-8	0.001	3.96	3.26	37
Inferior frontal gyrus	-60	12	20	0.001	3.67	3.08	16
Superior frontal gyrus, prefrontal	20	66	10	0	4.11	3.34	1999
Lingual gyrus	-14	-62	-6	0	4.29	3.45	94
Parietal fissure/precuneus	-6	-82	42	0.001	3.54	3	348

Table 5. Regional changes in brain activity that were correlated with number of years married for the partner minus high-familiar, neutral contrast

	MNI coordinates						
	x	y	z	*p* (unc)	*T*	*Z*	cluster k
Nucleus accumbens	14	18	0	0.001	3.67	3.05	515
Subcolossal area	14	28	-6	0	4.93	3.74	listed above
Periaqeductal region	2	-28	-20	0.001	3.67	3.05	71
L. red nucleus	8	-24	-12	0.001	3.6	3.01	listed above
Medial temporal gyrus	-54	-8	-32	0.001	4.01	3.26	386

Table 6. Regional changes in brain activity that were correlated with scores on the PLS for the partner minus high-familiar, neutral contrast

	MNI coordinates					
Region	x	y	z	*p* (FDR)	*T*	*Z*
Caudate body, postero-medial	12	0	16	0.039	2.63	2.35
Septum/fornix	-2	0	16	0.05	2.35	2.14
L. angular gyrus	-56	-56	40	0.007	3.55	2.98
Caudate, dorsal head	-24	-4	30	0.029	3.02	2.63
	16	4	20	0.016	3.52	2.96
Caudate body, medial	12	16	10	0.035	2.89	2.54
Putamen, medial dorsal	-20	0	12	0.002	4.82	3.69
	24	2	2	0.047	3.04	2.64
Putamen/Globus pallidus	-32	2	-8	0.029	3.36	2.85
Subthalamic nucleus	18	-20	-8	0.026	3.09	2.67
Insular cortex	30	10	-8	0.034	2.98	2.6
Anterior cingulate	-2	30	26	0.028	3.21	2.76
Posterior cingulate	6	-52	16	0.025	3.12	2.7
Posterior hippocampus	-36	-28	-12	0.013	3.89	3.19
	36	-34	0	0.003	4.69	3.62
Thalamus	0	-14	-8	0.033	3.05	2.65
Hypothalamus	-2	-4	-8	0.001	5.11	3.83
Amygdala	16	-2	10	0	6.14	4.28
	12	-16	-20	0.005	4.32	3.43

Table 7. Regional changes in brain activity that were correlated with marital satisfaction for the partner versus the high-familiar, neutral contrast

Region	MNI coordinates			*p* (FDR)	*T*	*Z*	cluster k
	x	y	z				
VTA	2	-14	-10	0.027	3.28	2.8	5
VTA/SN	6	-12	-16	0	6.88	4.55	13
	8	-12	-16	0	8.03	4.93	14
Cudate body, antero-dorsal	-14	0	18	0.015	3.28	2.81	19
	16	-4	12	0.016	3.33	2.83	8
Putamen	-24	2	6	0.016	3.45	2.92	4
	24	2	-4	0.009	3.98	3.24	6
Thalamus (dorsomedial)	-2	-12	10	0.004	4.11	3.31	12
Hypothalamus, posterior, periventricular	-2	-4	-4	0.017	3.57	2.99	5

Table 8. Regional activations specific to viewing images of the close friend compared to the low-familiar, neutral acquaintance

Region	MNI coordinates x	y	z	*p* (FDR)	*T*	*Z*
Basal Ganglia						
Ventral striatum	2	0	-6	0.01	3.87	3.21
	8	6	0	0.03	2.34	2.14
Caudate body, postero dorsal	20	-20	22	0.04	2.61	2.35
Caudate body, antero dorsal	-14	0	24	0.04	2.86	2.54
Putamen	-18	6	8	0.04	2.72	2.43
	24	-4	6	0.03	2.91	2.57
Putamen/globus pallidus	26	0	-4	0.03	2.99	2.63
Cortical						
Posterior cingulate	6	-56	14	0.02	3.32	2.85
Posterior cingulate/retrosplenial cortex	30	-54	8	0.04	2.61	2.35
Subcortical						
PAG	2	-32	-20	0.00	4.58	3.61
Medial orbitofrontal cortex	-4	52	-6	0.04	3.39	2.9
	2	56	-12	0.01	3.29	2.83
Hypothalamus	4	0	-6	0.04	2.86	2.54
Amygdala	-24	-2	-28	0.00	7.03	4.68

Deactivations	x	y	z	*p*(unc)	T	Z	cluster k
Posterior ventral Insula	42	-12	-6	0	5.31	3.97	1184
Insula	-28	-26	10	0.001	4	3.28	48
Anterior cingulate	8	8	48	0	4.17	3.38	284
Frontal gyrus	38	56	14	0.001	3.55	3	523
Occipital lobe	16	-84	26	0	4.57	3.6	2834
Superior parietal lobe	12	-66	64	0	5.45	4.04	2834
	24	-58	58	0	4.89	3.77	2834
Parietal operculum	-52	-28	12	0	4.7	3.67	784

	52	-32	30	0.001	3.86	3.2	1236
Superior temporal gyrus	60	-16	2	0	4.91	3.78	1184
	64	-30	16	0.001	3.5	2.97	1236
	-30	4	-24	0.001	3.54	2.99	55
Lingual gyrus	22	-54	-6	0	5.08	3.87	101
L. Supramarginal gyrus	-62	-42	34	0	4.41	3.51	784
	-64	-34	36	0.001	3.93	3.24	784
Precentral sulcus	-62	-8	36	0	4.24	3.42	27
R. Precentral gyrus	58	4	38	0.001	3.68	3.09	52

Figure 1. Sagittal view of single subject showing localized activation in the right VTA

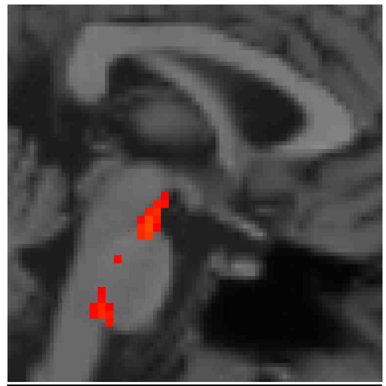


Figure 2. Coronal view of ventral pallidum in the same subject as Figure 1

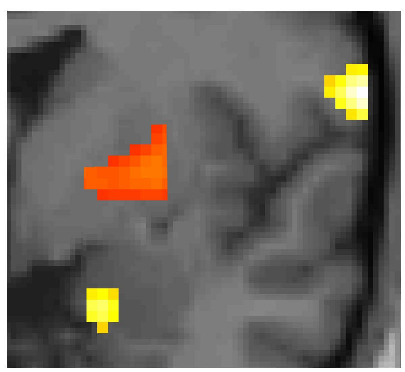


Figure 3. Mean target attractiveness ratings by participants and independent coders

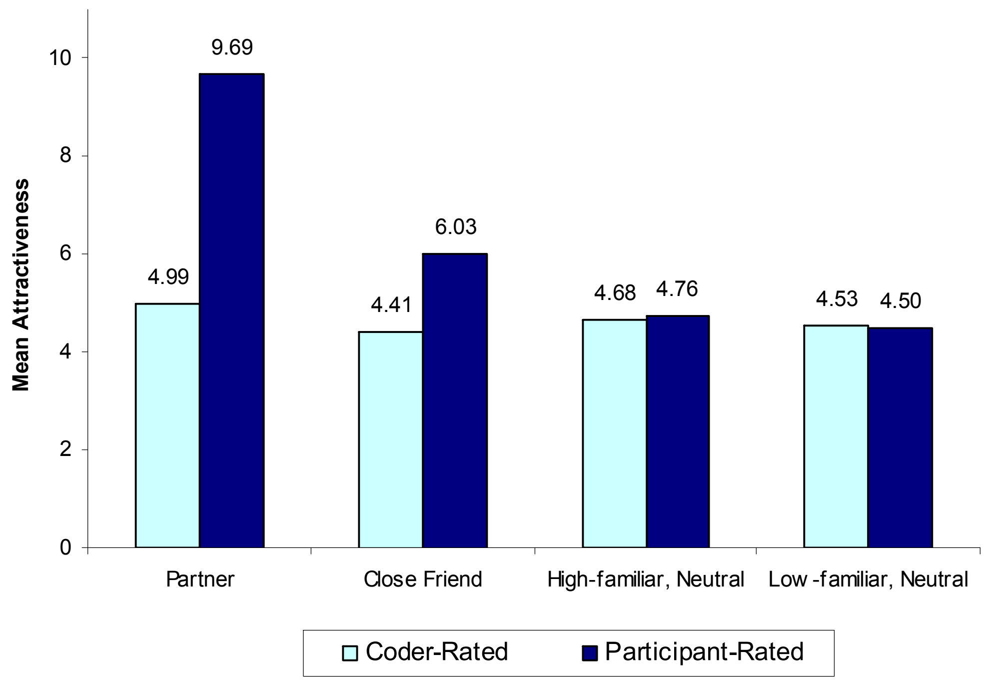
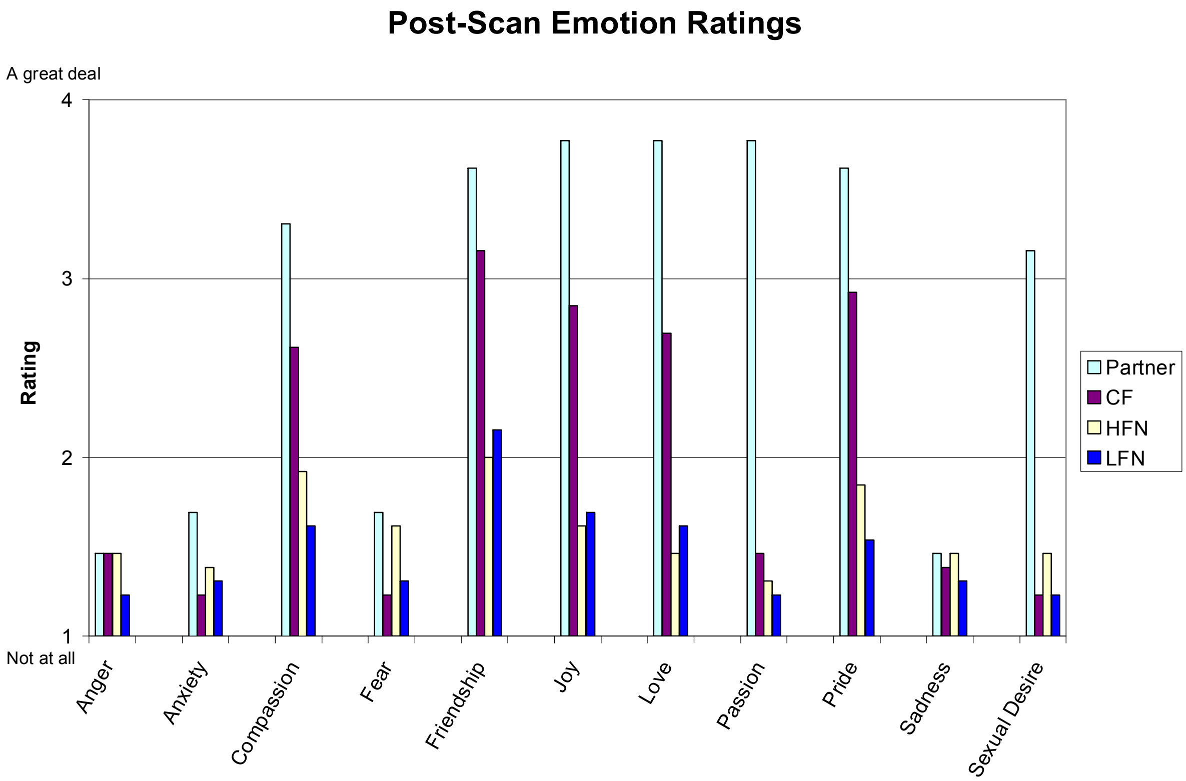


Figure 4. Mean Post-Scan Emotion Ratings



APPENDIX A:

PRE-EXPERIMENTAL INTERVIEW

General Instructions

The following questionnaires are about yourself, your long-term romantic partner, and some people that you know.

Not answering questions: You may find that some questions do not apply to your situation, so that you cannot answer them. Pease don't feel that you have to answer those questions. Also, of course, you are not required to answer any question that makes you uncomfortable or that you simply choose not to answer for any reason. However, it will make the study maximally scientifically valuable if you can try hard to answer all questions. That is, please try not to skip questions unless you have personal reasons for doing so.

Confidentiality and Honesty*:* Finally, rest assured that all your responses are absolutely confidential. Please try to answer as honestly and accurately as possible.

1) Age: __________ (*40-65 years old?*)

2) Sex: ____ Male _____Female

3) Are you right handed, left handed, or both? _____ Right _____ Left _____ Both
(Only right-handed)

4) Partner Name: __________________ Partner Sex: _____ Male ____ Female

Partner Age: _________

5) How long have you and your partner been married or living together? _______ yrs.
(*10 yrs or >?)*

6) Are you currently infatuated with anyone other than your partner? ____ Yes _____No

7) Do you and your partner engage in sexual activities regularly? ____ Yes _____No

If no, please explain: ____

8) On a scale from 1 to 7, how in love are you with your partner? ________

With 1 being not at all in love, 4 being in love, and 7 being very intensely in love

8b) How in love would you say that your partner is with you? _________

9) When you are not with your partner, about what percent of an average day do you think about your partner?

I think about my partner about ____________% of an average day

10) Are you currently taking any prescription or over-the-counter medications?
____ Yes _____No If so, what medications are you taking?
____
____
______

(*Exclude if taking anti-depressants)*

11) What is your medical history?
____
____
______

12) What is height? _________ What is your weight? _____

13) Are you pregnant or suspect that you are pregnant? ____ Yes _____No

14) Are you post-menopausal? ____ Yes _____No Date of your last period?

15) Are you claustrophobic? ____ Yes _____No
Have you ever had an MRI done? ____ Yes _____No (If yes, how many? _____)
Have you ever suffered severe head trauma? ____ Yes _____No
Do you have any metal in or on your body? ____ Yes _____No
Any surgical clips__, pacemakers __, stents__, implants__,
Metal Rods__, Plates__, Screws__, Hearing Aid__, Braces__

1) How did you and <> meet? How did you fall in love?

2) Can you provide me with 3 adjectives that describe your relationship with <>? Can you tell me about a specific scenario/event that describes each of the adjectives you mentioned?

3) How attractive do you find your partner? _____________
(On a scale from 1 to 10, with 1 being "not at all attractive", 5 neutral, and 10 being "extremely attractive")

4) Relative to all your other relationships, both same and opposite sex, how close _______
would you characterize your relationship with your partner?
(On a scale from 1 to 10, with 1 being "not at all close" , 5 neutral, and 10 being " extremely close")
(Interviewer: If less than 7 enquire about it)

5) Does your partner annoy or upset you or seem bothersome to you in any way? _________

(On a scale from 1 to 10, with 0 = does not upset me in any way at all to 10, 1=upsets me slightly; and so on, up to 10=upsets me a great deal.)

Ok, now please think about your partner and answer the questions below using the following responses: Never, Almost Never, Some of the time, Most of the time, All of the time

Interviewer: Log responses as follows

1	2	3	4	5
Never	Almost never	Some of the time	Most of the time	All of the time

______1) After a brief separation (like after work), do you get very excited when you see your partner?

______ 2) Do you have more energy when you are with your partner?

______ 3) Do you love everything about your partner?

______ 4) Could you see yourself spending your life with someone other than your partner?

______ 5) When you are not with your partner, do you think about your partner constantly?

______ 6) Are you extremely satisfied with your sexual life with your partner?

______ 7) Do you very much want to know all about your partner – like about your partner's experiences, their thoughts, and feelings?

______ 8) Would you rather be with your partner than with anyone else?

______ 9) Do you like to think about tiny moments that you have spent with your partner?

______ 10) When you are away from your partner for extended periods of time, do you yearn to be reunited with your partner?

______ 11) Do you feel that your relationship with your partner is becoming stagnant?

______ 12) Do you very much enjoy doing things that you think will make your partner happy?

______ 13) Do other people who know you consider you and your partner to be passionately in love?

______ 14) Do you and your partner engage in public displays of affection?

HIGHLY FAMILIAR NEUTRAL (HFN)

For this part of the interview I would like for you to think of a neutral acquaintance that: you have known at least 10 years and around as long as you have known your partner, and that is of the same sex and about the same age as your long-term partner.

This person should be someone you feel pretty neutral about. That is, someone you have no particular feelings for--either positive or negative. For example, this might be someone at work, who has been there a long time, but you have no special relationship with; a long-term neighbor that you have no special relationship with; an in-law or friend of your partner's that you have no special feelings about; or a relative like a cousin that you see often but have no special feelings about one way or the other.

Go ahead and take a few moments to think of a neutral person that is the same sex as your partner, about the same age as your partner, and that you have known about as many years as you have known your partner. This also should be someone for whom you have or could easily obtain a photo.

This person cannot be: a) an adult child b) your sibling c) anyone with whom you have ever had a romantic relationship or felt romantic feelings or sexual desire for.

1. What is your familiar neutral person's first name? ____________________________
2. Who is <>? ____
3. What is <>'s sex? __________________
4. About how old is <>?______________
5. How long have you known <>? ____________ months/years (circle one)
6. How do you know <>? ____
7. What is the nature of your relationship to <>?
   ____
8. How do you feel about <>?

9. Could you please describe to me various interactions you have had with <>?

10. Have you ever had even slight feelings of romantic attraction or sexual desire for <>?____

11. Did <> ever express even slight feelings of romantic attraction or sexual desire for you?

____
_

12. How attractive do you find <>? _____________
(On a scale from 1 to 10, with 1 being "not at all attractive", 5 neutral, and 10 being "extremely attractive")

13. Over the years, how much have you interacted with <> ? _____________
(On a scale from 1 to 10, with 1 = "not at all", 5 = somewhat, and 10 = " a great deal")

14. Relative to all your other relationships, both same and opposite sex, how _______ would you characterize your relationship with <>?
(On a scale from 1 to 10, with 1 being "not at all close" , 5 neutral, and 10 being " extremely close")

15. Does <> annoy or upset you or seem bothersome to you in any way? _________
(On a scale from 1 to 10, with 0 = does not upset me in any way at all to 10, 1=upsets me slightly; and so on, up to 10=upsets me a great deal.)

LOW FAMILIAR NEUTRAL (LFN)

For this part of the interview I would like you to think of someone that you barely know, but would recognize. That is, someone you have known for only a short time short time (say between 1 and 6 months) and that is the same sex and about same age as your partner, but for whom you have no particular feelings—either positive or negative.

Some examples: New person at work, new neighbor, grocer or bank teller, or anyone else you interact with now and then and would recognize, but with whom you have no special feelings and have not known for more than about 6 months.

Go ahead and take a few moments to think of a neutral person that is the same sex, about the same age, and that you have not known very long. This should be someone you have no feelings for and for whom you have or could easily obtain a photo.

1. What is your neutral acquaintance's first name? ______________________________
2. Who is <>? ____
3. What is <>'s sex? ___________________
4. About how old is <>?_______________
5. How long have you known <>? _____________ months/years (circle one)
6. How do you know <>? ____
7. What is the nature of your relationship to <>?
   ____
8. How do you feel about <>?
9. Could you please describe to me various interactions you have had with <>?

10. Have you ever had even slight feelings of romantic attraction or sexual desire for <>?____

11. Did <> ever express even slight feelings of romantic attraction or sexual desire for you?
____

12. How attractive do you find <>? _____________
(On a scale from 1 to 10, with 1 being "not at all attractive", 5 neutral, and 10 being "extremely attractive")

13. How much have you interacted with <> ? _____________
(On a scale from 1 to 10, with 1 = "not at all", 5 = somewhat, and 10 = " a great deal")

14. Relative to all your other relationships, both same and opposite sex, how _________ would you characterize your relationship with <>?
(On a scale from 1 to 10, with 1 being "not at all close" , 5 neutral, and 10 being " extremely close")

15. Does <> annoy or upset you or seem bothersome to you in any way? _________
(On a scale from 1 to 10, with 0 = does not upset me in any way at all to 10, 1=upsets me slightly; and so on, up to 10=upsets me a great deal.)

CLOSE, LONG-TERM FRIEND (CF)

Ok now, I would like you to think of someone that you have a close bond with, have known at least 10 years, and that is of the same sex and about the same age as your partner. This person should be someone that you currently have a very good relationship with and that you interact with a lot.

This person cannot be anyone that you have ever had sexual desire or romantic feelings for.

A best example would be a sibling that you have a very good relationship with and talk to often. This person could also be a close friend, relative, or in-law that you see or talk to often and are very attached and connected to, or it could be a work colleague that you have worked with very closely for a long time and from whom you feel a very strong connection. Sometimes this is a close friend that is the opposite sex partner of a couple with whom you and your partner are extremely close and have known a long time. But it cannot be your parent or child (they would not be the same age in any case). Go ahead and take a few moments to think of someone like this that you have a deep connection and close bond with, but no romantic or sexual feelings. This should be someone for whom you have or could easily obtain a photo.

1. What is this person's name? ______________________________
2. Who is <>? ____
3. What is <>'s sex? ___________________
4. About how old is <>?_______________
5. How long have you known <>? _____________ months/years (circle one)
6. How do you know <>? ____
7. What is the nature of your relationship to <>?
   ____
8. How do you feel about <>?
9. Could you please describe to me various interactions you have had with <>?

10. Have you ever had even slight feelings of romantic attraction or sexual desire for <>?____

11. Did <> ever express even slight feelings of romantic attraction or sexual desire for you?

    ____

12. How attractive do you find <>? _____________
    (On a scale from 1 to 10, with 1 being "not at all attractive", 5 neutral, and 10 being "extremely attractive")

13. Over the years, how much have you interacted with <> ? _____________
    (On a scale from 1 to 10, with 1 = "not at all", 5 = somewhat, and 10 = " a great deal")

14. Relative to all your other relationships, both same and opposite sex, _________ how would you characterize your relationship with <>?
    (On a scale from 1 to 10, with 1 being "not at all close" , 5 neutral, and 10 being " extremely close")

15. Does <> annoy or upset you or seem bothersome to you in any way? _________
    (On a scale from 1 to 10, with 0 = does not upset me in any way at all to 10, 1=upsets me slightly; and so on, up to 10=upsets me a great deal.)

APPENDIX B:

QUESTIONNAIRES

Participant Number:________ **Today's Date: ______________**
Time: _____________

General Instructions

This questionnaire is about yourself, your long-term romantic partner, and your relationship with one another. There are also a few questions about the other people whose photographs you will be looking at.

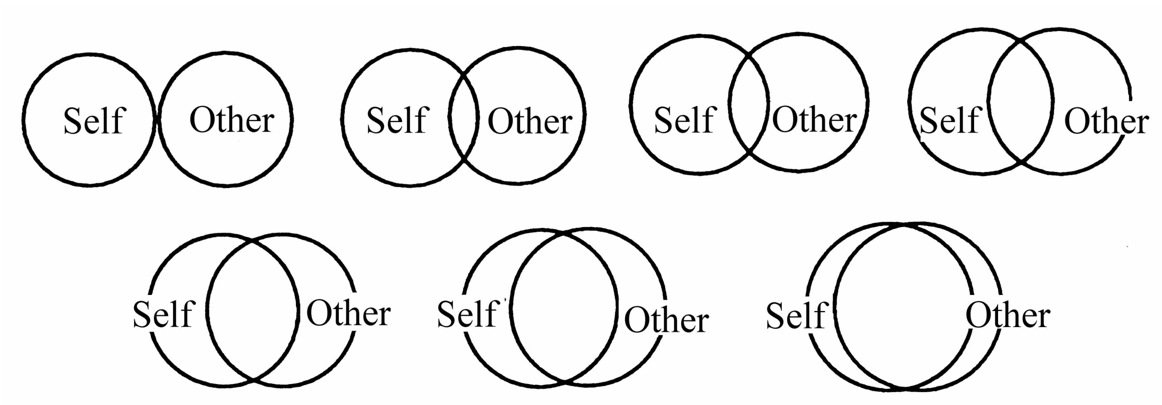
Please try hard to answer all questions as listed in the questionnaire. That is, please try not to skip questions.

Rest assured that all your responses are absolutely confidential and will never be seen by your partner or anyone else, but only our research team. Please try to answer as honestly and accurately as possible.

A) How I Feel About My Partner

1. Passionate Love Scale (Hatfield & Sprecher, 1986)

2) Please select the picture below that best describes your current relationship with your partner (Circle one):



3) How often do you communicate with your partner (either by phone, e-mail, or in person)? Please circle your response below. (Circle one):

Never	Less than once a month	About once a month	About once a week	A few times a week	Every day	Several times a day

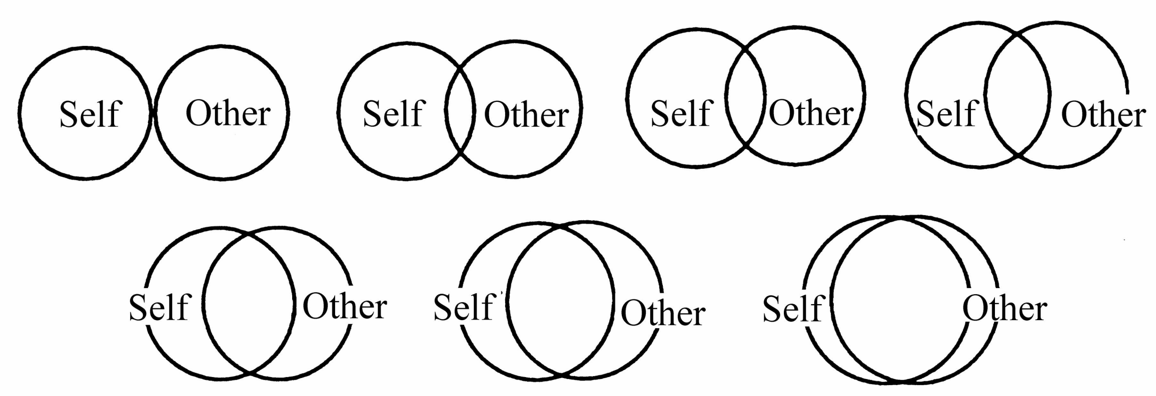
4) What percent of the average day do you think about your partner?

I think about my partner about ____________% of an average day

B) Questions Regarding the Other People

1) Ok, now please think about the highly, familiar neutral person we discussed, ____________________ . Please keep them in mind for the next two questions.

a) Please select the picture below that best describes your current relationship with him or her. (Circle one):

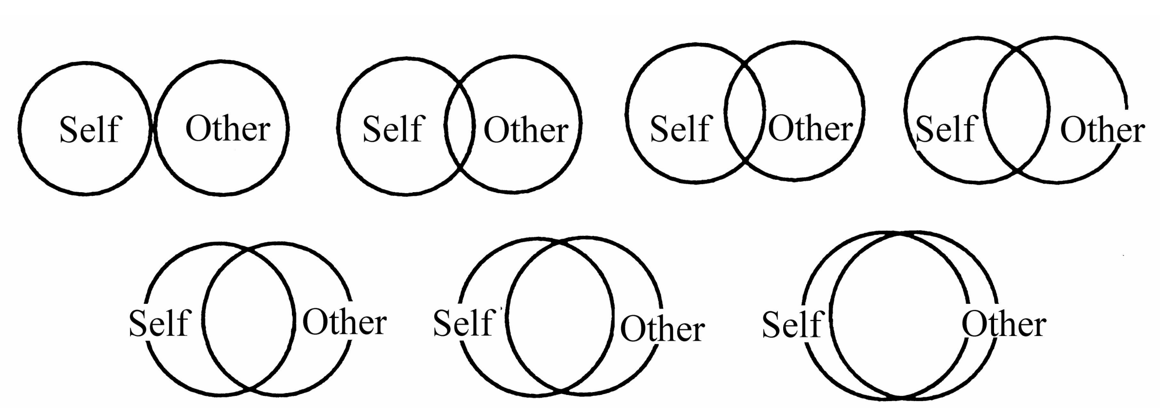


b) How often do you communicate with him or her (either by phone, e-mail, or in person)? Please circle your response below. (Circle one):

Never	Less than once a month	About once a month	About once a week	A few times a week	Every day	Several times a day

2) Ok, now please think about the neutral person that you barely know that we discussed, _________________. Please keep them in mind for the next two questions.

a) Please select the picture below that best describes your current relationship with him or her (Circle one):

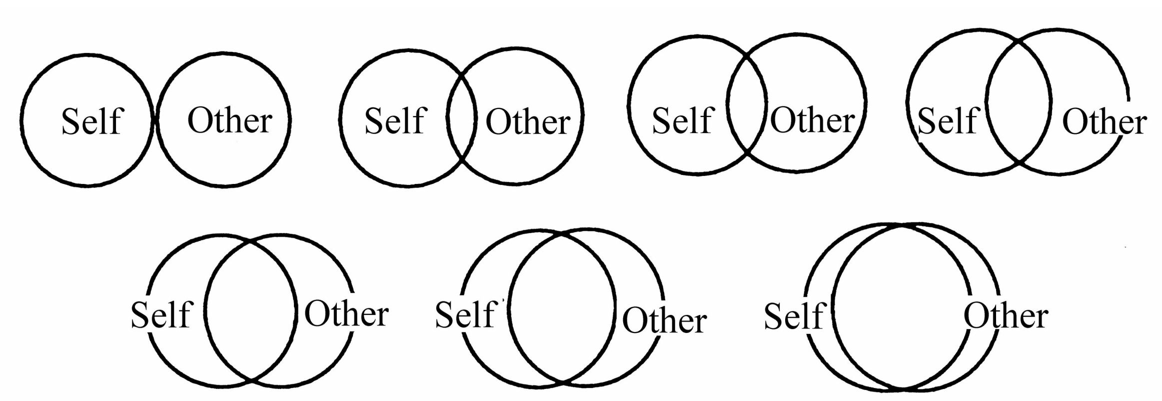


b) How often do you communicate with him or her (either by phone, e-mail, or in person)? Please circle your response below. (Circle one):

Never	Less than once a month	About once a month	About once a week	A few times a week	Every day	Several times a day

3) Ok, now please think about your non-romantic, very close and friend that we discussed, _________________. Please keep them in mind for the next two questions.

a) Please select the picture below that best describes your current relationship with him or her (Circle one):



b) How often do you communicate with him or her (either by phone, e-mail, or in person)? Please circle your response below. (Circle one):

Never	Less than once a month	About once a month	About once a week	A few times a week	Every day	Several times a day

C. My Relationship with my Partner

1. Relationship Satisfaction Measure (Hendrick, 1988)

2. Self-Expansion Questionnaire (Lewandowski & Aron, 2004)

3. Love Attitudes Scale (Hendrick & Hendrick, 1986)

4. Friendship Based Love Scale (Grote, 1994)

D. About Myself

1. Life Satisfaction Scale (Diener, Emmons, Larsen, & Griffin, 1985)

2. Affective Intensity Measure (Larsen & Diener, 1987)

APPENDIX C:

POST-EXPERIMENT INTERVIEW

MY PARTNER:

For this part of the study please think about how you felt and what you thought while viewing pictures of your **long-term partner** during the experiment.

1) What event(s) did you call to mind when viewing pictures of your partner?

2) Please describe any thoughts you had while viewing pictures of your partner during the experiment.

3) Please describe any feelings you had while viewing pictures of your partner during the experiment. How intensely did you experience each of these feelings?
(1= not at all; 4 = somewhat; 7=great deal)

4) How easy was it to recall experiences with your partner? Did you recall many (on a scale from 1 to 10)

HIGHLY FAMILIAR NEUTRAL (HFN)

Now I would like you think about how you felt and what you thought while viewing pictures of your familiar, neutral acquaintance during the experiment. (This is the neutral person whose picture you saw in the first part of the experiment when it was alternated with your partner.)

What is this person's name? _______________________________

1) What event(s) did you call to mind when viewing pictures of <>?

2) Please describe any thoughts you had while viewing pictures of <> during the experiment.

3) Please describe any feelings you had while viewing pictures of <> during the experiment. How intensely did you experience each of these feelings? (1= not at all; 4 = somewhat; 7=great deal)

4) How easy was it to recall experiences with <> ? Did you recall many (on a scale from 1 to 10)

LOW FAMILIAR NEUTRAL (LFN)

Now I would like for you to think about how you felt and what you thought while viewing pictures of the neutral person you barely know during the experiment.

What is this person's name? ___________________________________

1) What event(s) did you call to mind when viewing pictures of <> ?

2) Please describe any thoughts you had while viewing pictures of <> during the experiment.

3) Please describe any feelings you had while viewing pictures of <> during the experiment. How intensely did you experience each of these feelings?
(1= not at all; 4 = somewhat; 7=great deal)

4) How easy was it to recall experiences with <> ? Did you recall many
(on a scale from 1 to 10)

<u>CLOSE, LONG-TERM FRIEND (CF)</u>

Now I would like for you to think about how you felt and what you thought while viewing pictures of your highly close and familiar nonromantic person. The following questions refer to your reactions *while viewing pictures of this person.*

What is this person's name? ________________________________

1) What event(s) did you call to mind while viewing pictures of <> ?

2) Please describe any thoughts you had while viewing pictures of <> during the experiment.

3) Please describe any feelings you had while viewing pictures of <> during the experiment. How intensely did you experience each of these feelings?
(1 = not at all; 4 = somewhat; 7 = great deal)

4) How easy was it to recall experiences with <> ? Did you recall many?
(on a scale from 1 to 10)

THE SCANNING

1) How did you feel while in the scanner?

2) Did any aspects of the experiences or tasks make you feel uncomfortable?

3) Did you move a lot during the scanning?

4) When you were asked to countdown the numbers, did you do as instructed? Was it very difficult for you to focus on the countback task?

5) Anything else you would like us to know?

APPENDIX D:

POST-SESSION STIMULI RATINGS

[Please Note: The actual display of the post-session stimuli ratings were different—each emotion word was displayed individually. Responses by participants were made using a button box with four buttons. Along with each question item, an image was displayed indicating which of the four buttons (with a schematic hand) corresponds with each response on a scale from 1 to 4.]

Post Session 1

1) Overall, please rate the INTENSITY of each of the feelings that you felt while viewing pictures of your partner.

Response Scale:

1	2	3	4
Not at all	Slightly	Somewhat	A Great Deal

____ Anger	____Anxiety	____Compassion
____Fear	____Friendship	____Joy
____Love	____Passion	____Pride
____Sadness	____Sexual Desire	

2) Overall, please rate the INTENSITY of each of the feelings that you felt while viewing pictures of your familiar acquaintance.

Response Scale:

1	2	3	4
Not at all	Slightly	Somewhat	A Great Deal

____ Anger	____Anxiety	____Compassion
____Fear	____Friendship	____Joy
____Love	____Passion	____Pride
____Sadness	____Sexual Desire	

Post Session 2

1) Overall, please rate the INTENSITY of each of the feelings that you felt while viewing pictures of your minimally familiar acquaintance.

Response Scale:

1	2	3	4
Not at all	Slightly	Somewhat	A Great Deal

____ Anger ____Anxiety ____Compassion

____Fear ____Friendship ____Joy

____Love ____Passion ____Pride

____Sadness ____Sexual Desire

2) Overall, please rate the INTENSITY of each of the feelings that you felt while viewing pictures of your familiar acquaintance.

Response Scale:

1	2	3	4
Not at all	Slightly	Somewhat	A Great Deal

____ Anger ____Anxiety ____Compassion

____Fear ____Friendship ____Joy

____Love ____Passion ____Pride

____Sadness ____Sexual Desire