Affective and Neural Correlates of Conflict Interactions of Romantic Couples

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AFFECTIVE AND NEURAL CORRELATES OF CONFLICT INTERACTIONS OF

ROMANTIC COUPLES

by

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This thesis entitled:
Affective And Neural Correlates Of Conflict Interactions Of Romantic Couples
written by Briana Robustelli
has been approved for the Department of Psychology and Neuroscience

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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Conflict interactions are almost universally experienced by romantic couples, are often emotionally rich, and are associated with many important mental and physical health outcomes. These factors make conflict interactions an excellent topic for investigation in studies of emotion and couples. The current study included 20 heterosexual romantic couples who had been in a relationship for at least 2 years. Each couple completed a video recorded conflict interaction task and both partners in each couple viewed their own interaction and the interaction of another couple in a functional magnetic resonance imaging (fMRI) scanner. Partners then completed an emotion rating task where they watched the videos again and provided a continuous rating of how they remembered feeling during their own interaction, how they thought their partner was feeling during their own interaction, and how they felt watching the other couple’s interaction. These ratings were then used in a whole brain fMRI analysis and results showed that the negative emotion rating for the self-rated condition was associated with activation in the superior temporal sulcus (STS), superior temporal gyrus (STG), and the auditory cortex (false discovery fate corrected $p < .05$); the rating of watching the other couple was also associated with activation in the dorsal medial prefrontal cortex (DMPFC). An additional analyses applied brain activation patterns associated with discrete emotions obtained from two past studies to the data from the current study and found negative emotion ratings were positively associated with patterns representing anger ($\beta = .022, t = 4.12, p < .0005$), amusement ($\beta = .036, t = 4.05, p < .0005$), and sadness ($\beta = .011, t = 2.87, p < .01$) and negatively associated with patterns
representing neutral ($\beta = -.029, t = -4.70, p < .0001$), contentment ($\beta = -.029, t = -5.28, p < .0001$), and empathic distress ($\beta = -.011, t = -2.52, p < .05$). This study used a novel and ecologically valid task to study emotion and conflict interactions and is an important step in understanding the neural representation of the affective experience associated with complex social interactions.
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**Introduction**

In the United States, married partners spend an average of 4.2 waking hours a day in each other’s company (Fein, 2009). Married partners also report that their spouse is present for almost 90% of the time they spend in social situations. Given the significant amount of time partners spend with one another, the types of interactions they have are likely to be important. One type of interaction that has been of particular interest to researchers is conflict. Conflict interactions are fairly common in romantic relationships. More than 90% of couples report engaging in conflict interactions, with an average of about one disagreement per month; however, conflict patterns and frequencies across couples are highly variable (McGonagle, Kessler, & Schilling, 1992). Studies have found that a couple’s frequency and the topics of conflict discussions tend to stay fairly consistent year to year (Lavner, Karney, & Bradbury, 2014), although older couples who have been married for a long time tend to have fewer overt disagreements than newlywed couples (Zietlow & Sillars, 1988). Couples report discussing a wide variety of conflict topics but some of the most common are chores, communication, leisure, money, habits, and relatives (Papp, Cummings, & Goeke-Morey, 2009).

Conflict is important not only because it is frequent, but also because it is associated with poor health outcomes. For example, frequent conflict has been associated with general poor health and specific health conditions such as chronic pain, cardiac disease, and cancer (Schmaling & Sher 1997). Marital conflict has also been associated with the presence of depressive symptoms (Beach et al., 1998), male alcoholism (O’Farrell, Choquette, & Birchler, 1991), and eating disorders (Van den Broucke, Vandereycken, & Norre, 2006).

Studies have proposed that hostile behaviors present during conflict interactions have detrimental effects on cardiovascular, endocrine and immune functioning, which then can lead to
poor health outcomes (for a review, see Fincham, 2003). After a conflict interaction, individuals have been found to have a poorer immune response including reduced cytokine production and slower wound healing (Kiecolt-Glaser et al., 2005). Low levels of positive communication during conflict interactions have been hypothesized to have similar effects on immune functioning, which are mediated by decreases in oxytocin and vasopressin levels (Gouin et al., 2010). High levels of conflict have also been associated with poor marital quality, which has been found to be related to poor physical health and increased risk of mortality (Robles, Slatcher, Trombello, & McGinn, 2014).

Even though conflict interactions have important implications for health outcomes and have been highly studied at the affective and physiological levels, no published study to date has used neuroimaging techniques to examine conflict interactions between romantic partners. The current study aims to evaluate what neural regions are associated with a couple’s emotional experience during a conflict interaction. The study has two primary goals: to use conflict interactions as a naturalistic emotion elicitation task to examine neural activation in the context of couple interactions, and more generally, to increase understanding of how complex emotional responses are represented in the brain. Specifically, romantic couples engaged in a videotaped conflict interaction, and then both partners watched their own and another couple’s interaction in a functional magnetic resonance imaging (fMRI) scanner. Partners then made continuous emotion ratings while watching the interactions outside the scanner of how they recalled feeling, how they thought their partner was feeling during their own interaction, and how they felt watching the interaction of the other couple. The study has three broad aims: (a) to use continuous emotion ratings to evaluate neural activation patterns at the level of the individual and the couple that are associated with completing an emotion elicitation task of viewing one’s
own conflict interaction; (b) to use continuous emotion ratings to evaluate neural activation patterns that are associated with viewing another couple’s conflict interaction; and (c) to apply whole brain voxel level patterns representing specific emotion states from past studies to neural activation patterns associated with completing the emotional elicitation task of viewing one’s own conflict interaction.

In the sections that follow, I provide a selective review of the research that forms the basis for the current focus on neural activation associated with conflict in intimate relationships. First, I review the research on several outcomes associated with conflict in intimate relationships, including the association between conflict and relationship satisfaction and stability, emotional response and regulation, and recovery, empathy, and physiology. I then review some of the research on neuroimaging studies examining topics related to social interactions such as romantic love, empathy, criticism, and social rejection, and how most studies of emotion do not use such naturalistic stimuli. This section is followed by a discussion of machine learning techniques used to create brain activation pattern maps from specific stimuli that then can be applied to other datasets. Finally, I conclude with a summary of the aims and hypotheses of the current study.

**Conflict in Intimate Relationships**

**Conflict and Relationship Satisfaction and Stability.** Even though the topic of love and marriage has been of great interest to theorists and researchers for centuries, the scientific and systematic study of conflict interactions mostly began in the late 1970’s. Beginning around this time, John Gottman and colleagues conducted studies of conflict interactions and their association with relationship satisfaction and stability. These studies generally involved bringing couples into the laboratory and having them engage in a conflict and neutral discussions while being video recorded; some of these studies also included monitoring of the subjects’
physiological responses. The researchers would then follow the couples over time to gather data on relationship satisfaction and stability. Gottman and colleagues created the Specific Affect Coding System (Shapiro & Gottman, 2004), which was then used to provide observational data on the interactions. Coders categorized the behaviors of the partners and created positive, negative, and positive-negative affect composites. Coders also recorded the number of instances of more specific affect displays such as interest, affection, joy, disgust, anger, defensiveness, whining, and stonewalling. Among the many findings generated from these methods, the researchers observed that couples who divorced displayed more negative and less positive affect than couples who stayed together (Carrère & Gottman, 1999).

Other studies in the laboratory found that compared to nondistressed couples, distressed couples were more likely to use summary statements during discussions that summarized the self rather than the partner, to deliver mindreading statements with negative affect, and to reciprocate negative affect (Gottman, Markman, & Notarius, 1977). They also found that marital satisfaction was likely to decline over the next three years when wives reciprocated their husband’s negative affect and when husbands did not reciprocate their wives negative affect during conflict interaction (Levenson & Gottman, 1985). In addition, when husbands turned away from their wives’ attempts to engage them in conversation during everyday situations, the wives were more likely to use the attack-defend mode (place blame on the partner and become defensive) during conflict interactions, which lead to reductions in marital satisfaction (Gottman, Driver, & Tabares, 2015).

The Gottman laboratory also examined physiological reactivity during conflict interactions. The more physiologically aroused a couple was during an interaction, the more likely they were to report a decline in marital satisfaction three years later (Levenson & Gottman,
Compared to nondistressed couples, distressed couples also showed a higher level of “linkage,” or physiological similarity during a conflict interaction. In one study, 60% of the variance in marital satisfaction was explained by physiological linkage (Levenson & Gottman, 1983).

Over time, Gottman identified a recurrent set of negative behavioral processes that occur during conflict discussions that he named “The Four Horsemen of the Apocalypse” (Gottman, 1994). They include criticism, contempt, defensiveness, and withdrawal or stonewalling. Whenever these behaviors were present in a conflict discussion, the couple had a higher chance of divorcing. He also found that the conflict discussions of couples that divorced early (around 7 years) versus late (around 14 years) were consistently different. Couples who showed high levels of negative affect during conflict interactions were likely to divorce early and couples with low levels of positive affect were likely to divorce late (Gottman & Levenson, 2000).

Other researchers investigating conflict interactions and relationship satisfaction and stability have identified a variety of specific behaviors present during conflict that are related to these outcomes. Couples report low relationship satisfaction if conflicts are frequently unresolved, even when controlling for frequency of conflicts and negative conflict style (Cramer, 2000). Other studies have found that the use of defensive denial, by either males or females, can lead to conflict escalation and relationship instability over time (Lannin, Bittner, & Lorenz, 2013). In addition, avoidant partners are more likely to respond to negative perceptions of their partner’s emotions with hostile and defensive behaviors both during conflict and daily life (Overall, Fletcher, Simpson, & Fillo, 2015). Demandingness and withdrawal have also been associated with relationship satisfaction over time; this pattern is especially problematic when men withdraw and women engage in demandingness during discussion of topics chosen by
women (Heavey, Christensen, & Malamuth, 1995). Contempt and affection, expressed during conflict and positive interactions, have also been found to be predictive of relationship quality and stability (Graber, Laurenceau, Miga, Chango, & Coan, 2011). Specifically, higher levels of contempt during a conflict interaction are predictive for wives and higher levels of contempt during a positive interaction are predictive of the husbands’ reduction in commitment to the relationship at follow-up.

**Emotional Response and Regulation During Conflict.** Several studies have investigated the emotional experiences of couples during conflict and have reported several important findings. For example, researchers have examined the use of hard emotions (such as anger or blame) compared to soft emotions (such as sadness) during conflict interactions. For example, Sanford (2012) found that when hard emotions were expressed, this reduced the likelihood that soft emotions would be expressed. In contrast, soft emotions did not influence the expression of hard emotions. Anger, once expressed, was likely to be expressed by both partners and to stay in the interaction, whereas sadness was more likely to be ignored by the other partner.

Depression has been associated with increased levels of negative conflict expression and the absence of positive strategies (Du Rocher Schudlich, Papp, & Cummings, 2004). Impairment in conflict strategies is especially apparent for couples where the husband is experiencing high levels of depressive symptoms and this results in difficulty resolving even minor disagreements.

Men and women may also show different patterns in emotional synchrony. When engaged in cooperation, an interaction involving a back-and-forth exchange of feelings and thoughts, men were more likely to have their emotions change in unison with their partner whereas women were more likely to have their emotions change in the opposite direction of their partners (Randall, Post, Reed, & Butler, 2013). Women have also been found to be more
emotionally aware in response to situations within the relationship (Croyle & Waltz, 2002).

Higher levels of emotional awareness, particularly awareness of hard emotions, were associated with lower levels of relationship satisfaction for women. Also, discrepancies in both partners’ emotional awareness were associated with lower relationship satisfaction. Another study found that couples with high emotional intelligence tended to report higher levels of relationship satisfaction (Malouff, Schutte, & Thorsteinsson, 2014).

Emotion regulation also seems to play an important role in conflict discussions. For example, researchers have found that the use of suppression during conflict interactions is problematic. Specifically, Velotti et al. (2015) found that a husband’s habitual use of suppression significantly predicted reduced marital quality two years later. For wives, similarity in use of suppression was positively associated with marital quality irrespective of overall suppression levels. In another study, when one partner was instructed to use suppression and refrain from expressing emotions during a conflict interaction, both partners showed increased cardiovascular arousal and negative affect (Ben-Naim, Hirschberger, Ein-Dor, & Mikulincer, 2013).

Suppression has also been found to be problematic during positive interactions. In one study, one partner was instructed to describe to the other partner a sacrifice they had made for the relationship. Listening partners thought that speaking partners were less authentic the more they seemed to be suppressing their emotions. Perceived partner inauthenticity was also associated with poorer personal well-being and relationship quality three months later (Impett, Le, Kogan, Oveis, & Keltner, 2014). The use of suppression or reappraisal also appears to influence memory. Richards, Butler, and Gross (2003) asked couples to use reappraisal or suppression during a conflict interaction and found that the accuracy of each partner’s memory of what was said increased with the use of reappraisal and decreased with the use of suppression. Similarly,
when suppression was used, partners tended to remember a higher level of emotional reactivity during the discussion. Depending on what emotion regulation strategy is used, partners could have very different memories of conflict interactions. Also trying to control emotion (likely by using suppression) during a discussion is associated with greater dissatisfaction in the relationship (Waldinger & Schulz, 2006).

**Positive Emotions and Recovery During Conflict.** Researchers have also examined factors that can attenuate the impact of conflict interactions. One of these factors is positive emotion. Individuals with high trait positive emotion have been found to be more likely to be in relationships and to have high quality relationships (Berry & Willingham, 1997). They are also less likely to engage in conflict interactions. The authors propose that individuals with high trait positive emotion are less willing to engage in active destructive responses and are more likely to engage in active, constructive responses to conflict. Having a constructive communication style has also been found to be beneficial for both the individuals’ well-being and the relationship. Positive emotions have been found to reduce physiological activity and emotional behaviors when they are experienced during a conflict interaction (Yuan, McCarthy, Holley, & Levenson, 2010). Greater down-regulation of negative experience during conflict has been concurrently and longitudinally associated with greater marital satisfaction (Bloch, Haase, & Levenson, 2013). These results suggest that positive emotions can have an undoing effect even in the midst of a stressful conflict discussion.

Purposefully trying to repair an interaction has also been shown to be helpful during conflict interactions (Gottman et al., 2015). Preemptive repairs, which occurred in the first 3 minutes of a conflict, were the most effective. Repairs were deemed effective if they resulted in reduced negative affect and increased positive affect. Affective repairs used shared humor,
affection, empathy, taking responsibility, self-disclosure, and expressing understanding. Most repairs were effective in the middle of the discussion (between 4 and 12 minutes) but few were successful in the last 3 minutes.

Ogolsky and Gray (2015) found that having a constructive communication style buffers the influence of conflict on commitment to a relationship and relationship maintenance by reducing the experience of negative emotions on days of high conflict, which would normally reduce relationship commitment. Feeling understood has also been found to be associated with conflict resolution and relationship satisfaction (Gordon & Chen, 2016). Similarly, high levels of empathy (Perrone-McGovern et al., 2014), autonomy (Knee, Lonsbary, Canavello, & Patrick, 2005), and optimism (Srivastava, McGonigal, Richards, Butler, & Gross, 2006) are beneficial. Partners with high levels of empathy reported high relationship satisfaction and more frequent use of positive problem solving during conflict interactions (Perrone-McGovern et al., 2014). Trait autonomy was associated with relationship autonomy and in turn relationship satisfaction after a conflict. Autonomy was also associated with decreased defensiveness and increased understanding during a conflict (Knee et al., 2005). Optimists have higher relationship satisfaction as a result of perceiving more support (Srivastava et al., 2006). Optimists also engage more constructively in conflict interactions, which can lead both partners to feel that the conflict was better resolved. The same study found that men’s optimism level was positively associated with relationship stability up to one year later. During conflict interactions, individuals who are more satisfied with their relationship use more positive humor, in contrast to avoiding humor (Butzer & Kuiper, 2008). Aune and Wong (2002) found that having high self-esteem and humor orientation increases playfulness in a relationship, which influences positive emotions and relationship satisfaction.
Conflict Interactions and Empathy. A sizable literature has examined the role of empathy and empathic accuracy during conflict interactions. Most studies show that perceived and expressed empathy is beneficial for relationships and studies testing empathy training have found increased relationship satisfaction as a result of the training (Long, Angera, Carter, Nakamoto, & Kalso, 1999). Specifically, perceived empathy is positively associated with relationship satisfaction and negatively associated with conflict and depression (Cramer & Jowett, 2010). In addition, perceived self-disclosure and perspective taking skills are associated with relationship satisfaction (Meeks & Murrell, 2015). Partners with more education and those who have been married for shorter periods of time tend to show superior empathic accuracy during conflict discussions (Thomas, Fletcher, & Lange, 1997). Female partners have also been found to be more accurate at describing the thoughts and feelings of their male partners during conflict interactions than males are of females and that higher levels of empathic accuracy is associated with not only higher relationship satisfaction but also closeness and higher levels of prior disclosure about the problems discussed (Thomas & Fletcher, 2003).

Sheehausen and colleagues showed that demonstrating cognitive empathy through reflective paraphrasing can be beneficial for individuals experiencing distress (Seehausen, Kazzer, Bajbouj, & Prehn, 2012). Specifically, they found that after participants described a conflict situation and an experimenter used paraphrasing, participants reported reduced negative affect, lowered their voice, and showed reductions in skin conductance and heart rate. Other studies have found that empathic effort (or a partner trying to understand the other’s perspective) is more important for relationship satisfaction than actual empathic accuracy (Cohen, Schulz, Weiss, & Waldinger, 2012).
Attachment style also may influence individuals’ ability to have high empathic accuracy. Specifically, partners who were highly avoidant were less empathically accurate when discussing a severe relationship issue involving intimacy or jealousy and a general relationship conflict. Individuals who were highly anxious were more accurate when discussing the intimacy issue that posed a threat to the relationship (Simpson et al., 2011). Not all studies have found empathic accuracy to be beneficial at all times. Simpson, Orina, and Ickes (2003) found that lower empathic accuracy during certain topic discussions was associated with closeness and satisfaction. For example, in their study when one member of a married couple was having relationship threatening thoughts and the other partner was able to detect those thoughts and feelings accurately, it led to decreases in closeness, whereas the opposite was true for nonthreatening thoughts and feelings. In those situations, high empathic accuracy was associated with feelings of closeness.

**Conflict and Physiology.** Studies have found that problematic behaviors during conflict influence physiology and immune functioning. Specifically, high levels of cynical hostility (a set of negative attitudes and beliefs about others that are frequent sources of frustration and provocation) has been associated with increases in blood pressure, heart rate, natural killer cell numbers, and cortisol levels during conflict interactions (Miller, Dopp, Myers, Stevens, & Fahey, 1999). Greater separateness or less use of “we” has been associated with greater cardiovascular arousal, lower marital satisfaction, and less positive and more negative behaviors (Seider, Hirschberger, Nelson, & Levenson, 2009). Gunlicks-Stoessel and Powers (2009) found that men who generally cope with relationship stress by seeking social support showed higher cortisol levels during and after a conflict interaction. In another study, husbands were found to have a greater display of skin conductance in response to wives’ negative affect than wives had to their
husbands’ negative affect (Notarius & Johnson, 1982). The authors also found that compared to husbands, wives’ speech tended to be characterized by more negative and less neutral affect during conflict interactions on average. Wives also were more likely than husbands to reciprocate their partner’s positive and negative speech.

**Social Interaction and MRI Methodology**

Although no published study to date has specifically examined the neural underpinnings of conflict interactions between romantic partners, studies have investigated a few related topics at the neural level.

**Romantic Love.** Several researchers have attempted to map the neural signature of romantic love. A review of several articles reported that romantic love (compared to companionate love) is associated with activation in the ventral tegmental area and caudate nucleus, which are dopamine rich subcortical brain areas that have been implicated in reward processing (Ortigue, Bianchi-Demicheli, Patel, Frum, & Lewis, 2010). The review also reported agreement across several studies that priming romantic love in the scanner results in activation in the occipitotemporal/fusiform region, angular gyrus, dorsolateral middle frontal gyrus, superior temporal gyrus, occipital cortex, and precentral gyrus and deactivation in the posterior cingulate gyrus and amygdala, which the authors suggest may be indicative of reductions in fear and anxiety.

**Empathy.** Several researchers have investigated the neural correlates of empathy. A review found that studies of empathy most often reported activation in the anterior insula and midcingulate cortex across a variety of stimuli, such as social exclusion, disgust, taste, and anxiety (Bernhardt & Singer, 2012). One study showed participants images of patients with life threatening diseases and asked participants to imagine the feelings of the patient (other) and how
they would feel if they were the patient (self) (Lamm, Batson, & Decety, 2007). The contrast between the other versus the self showed differences in activation in the middle insula, anterior medial cingulate cortex, left supramarginal gyrus, left middle frontal gyrus, putamen, caudate nucleus, and medial and lateral premotor areas. Another study provided empathic responses to participants in an fMRI scanner after being interviewed about a social conflict (Seehausen et al., 2014). Results suggest that when participants listened to the empathic responses there was activation in a fronto-parietal network including the right precentral gyrus, left middle frontal gyrus, left inferior parietal gyrus, and right postcentral gyrus.

A significant literature also exists focused on the question of whether neural responses associated with the experience of pain are similar or distinct from those associated with vicarious pain (imaging the suffering of someone else). Meta-analyses have found consistent activation in the anterior insula and anterior cingulate cortex both during physical pain tasks and vicarious pain tasks (Singer & Klimecki, 2014). In addition, the strength of the activation in these areas was correlated with reported negative affect in response to the vicarious pain trials. Other studies have found that perceived fairness of the situation and in-group membership (such as being on the same football team) are also correlated with both how empathic the participant feels and the strength of activation in the anterior insula and anterior cingulate cortex. Even more interesting, the “empathy related” signal in these brain regions was predictive of later altruistic behaviors and were responsive to empathy training (leading to increased neural activation) and compassion training (leading to decreased neural activation). Other studies, have found similar shared networks for experienced and vicarious taste, touch, disgust, and social rewards (for a review, see Singer & Klimecki, 2014).
Some researchers propose that to understand the neural underpinnings of empathy, studies need to ask more nuanced questions about the neural representations of experienced and vicarious pain because they may be represented by separable neural patterns even within the same regions (Zaki, Wager, Singer, Keysers, & Gazzola, 2016). Krishnan et al. (2016) found distinct and dissociable neural activation patterns for physical pain and vicarious pain by using multivariate pattern analyses: vicarious pain was associated with activation in a variety of multisensory areas associated with mentalizing, such as the dorsal medial prefrontal cortex, amygdala, posterior cingulate cortex, and temporal parietal junction.

**Criticism.** In addition to studying empathy, several researchers have examined the neural correlates of another feature of social interaction, criticism. In one study, children and adolescents (aged 9 to 17) listened to recordings of their mothers providing criticism, praise, and neutral statements in the scanner (Lee, Siegle, Dahl, Hooley, & Silk, 2014). Results showed that in response to criticism, the youth showed increased activation in several limbic regions such as the lentiform nucleus and posterior insula and decreased activity in cognitive control networks and social cognitive networks. In another study, differences were found in neural activation between formerly depressed and healthy young adult woman listening to criticism from their mothers (Hooley et al., 2009). Specifically, women with a history of depression showed increased activation in the amygdala and decreased activation in the dorsolateral prefrontal cortex and anterior cingulate cortex compared to controls. Although the results of this study are interesting, the contrasts were not very strong so results may need to be interpreted with caution. In a similar study, Hooley, Siegle, and Gruber (2012) found that women with higher levels of perceived criticism showed increased amygdala activation and decreased activation in prefrontal regulatory regions while listening to criticism from their mothers.
Social Rejection. Social rejection has also been investigated in the MRI scanner. One method used in several studies of social rejection is the cyberball task, which was developed by Kip Williams and colleagues (Eisenberger, Lieberman, & Williams 2003). In this task, participants interact on a computer screen and toss a “ball” back and forth with two virtual players who eventually stop passing the ball to the participant, which is proposed to result in the participant feeling left out and rejected. This method has resulted in many interesting results such as the association between brain activation in specific areas with varying levels of distress during the task, rejection sensitivity, and interpersonal competence in general (Masten et al., 2009).

Studies have also investigated the similarities between social rejection (viewing the picture of an ex-partner) and physical pain. Kross, Berman, Mischel, Smith, and Wager (2011) found similar patterns of neural activation for emotional and physical pain in the secondary somatosensory cortex and dorsal posterior insula. In contrast, Woo et al., (2014) identified unique patterns of neural activity that differentiated the distress of physical pain from the emotional pain of thinking about being rejected.

Machine Learning

The analysis used in the current study included both traditional regression and contrast methods for analyzing brain activation and also the application of patterns created using machine learning techniques. Traditional fMRI analyses attempts to predict activity in a single voxel using a model of the psychological variable. In comparison, machine learning techniques or MVPA (Multivoxel Pattern Analysis) use powerful pattern-classification algorithms to find the most informative pattern of activation across many voxels to predict a psychological state. In this framework, voxels are treated as features or independent variables in the regression model. Voxels are the smallest unit of measurement used in fMRI and are created by dividing each
subject’s neural data into 3-D blocks that are usually around 3 x 3 x 3 mm. Even though past studies have proposed that certain brain regions are responsible for specific cognitions and behaviors (e.g., activation in the amygdala is the cause of the emotional experience of fear), studies suggest that a more accurate description is that cognitions and behaviors are a result of many areas of the brain working together in networks. Machine learning techniques allow researchers to examine the independent contribution of each voxel to a psychological state, which can result in higher resolution results and more specific explanations of neural activation. Machine learning techniques have been used to identify classifiers for a variety of neural processes, including decoding of vision regions to identify what a subject is viewing (Cox & Savoy, 2003), stages of sleep (Altmann et al., 2016), working memory (Lewis-Peacock & Postle, 2008), and physical pain (Wager et al., 2013).

Machine learning techniques have also been used to investigate the neural signature of emotional states. Chang, Gianaros, Manuck, Krishnan, and Wager (2015) detected a consistent pattern that was highly predictive of the intensity of negative emotions experienced but did not represent a traditional specific “emotion brain region” or a predefined network. In this study, participants viewed negative valence images from the International Affective Picture System (IAPS) in an MRI scanner and rated their affective experience while viewing each image. Saarimaki et al. (2015) used similar methodology to identify unique and specific patterns of activation that tracked six discrete emotions (disgust, fear, happiness, sadness, anger, and surprise). Participants watched emotion-inducing movie clips and engaged in emotional mental imagery exercises in the MRI scanner. Classifiers (distinct patterns of voxels) were identified for each of the six emotions and these classifiers (as in the pattern of activation within these predefined voxels) generalized across participants and methods of emotion induction.
Studies using these methods create classifiers, patterns, or neural activation maps that can be applied to other datasets to test the validity of the patterns and also decode information from the brain activation of subjects in other studies exposed to novel stimuli. The current study applied patterns of discrete emotions (Kragel & LaBar, 2015) and specific markers of empathy-tenderness and distress (Ashar, Andrews-Hanna, Dimidjian, & Wager, 2017) to decode the brain activation of subjects recalling the emotion they experienced during a conflict interaction.

**Study Aims and Hypotheses**

Overall, advances in fMRI data acquisition and analysis (such as multiband and machine learning pattern classification techniques) offer an exciting new way to examine complex human experiences. Given that conflict interactions between romantic partners are so common and are strongly associated with a range of relationship and individual health outcomes, this is an important topic to study at all levels of analysis. The current study, designed to investigate the neural correlates of viewing one’s own and another couple’s conflict interaction, is novel in three ways. Specifically, the study seeks to (a) identify the neural correlates of a topic – romantic couple conflict interactions – that no published study has investigated at the neural level; (b) use a design that has a much higher level of ecological validity than many past emotion elicitation neuroimaging studies that do not directly involve human interaction, such as cyberball; and (c) apply brain activation patterns created in other emotion elicitation studies to a naturalistic social task.

The current study has three broad aims.

1. To use continuous emotion ratings to evaluate neural activation patterns at the level of the individual and the couple that are associated with completing an emotion elicitation task of viewing one’s own conflict interaction.
2. To use continuous emotion ratings to examine neural activation patterns that are associated with watching another couple’s conflict interaction.

3. To apply whole brain voxel level patterns representing specific emotion states from past studies to neural activation patterns that are associated with completing the emotional elicitation task of viewing one’s own conflict interaction.

Method

Study Design

Couples participation in the study included two visits to the laboratory. In the first visit, couples engaged in a video-recorded conflict interaction and completed questionnaires. In the second visit, both partners underwent a MRI structural scan and two fMRI scans during which they each watched the video of their own conflict interaction and a video of the conflict interaction of a different couple who had participated in a previous study. After the scan, both partners watched their own video and the other couple’s video and provided continuous emotion ratings.

Subjects

Twenty heterosexual couples in committed romantic relationships completed the study. All subjects qualified for the study according to the inclusion and exclusion criteria detailed below.

Inclusion criteria. Subjects were required to be between the ages of 18 and 55 years. This age range was selected to minimize difference in brain structure because of ongoing maturation or aging. All couples were required to have been in their relationship for at least two years because research suggests this may be when attachment is fully formed (Hazan & Zeifman, 1994). In addition, requiring a minimum relationship duration of two years was adopted to
increase the likelihood that couples would have a relationship history of sufficient duration that they would be able to engage in a substantive conflict discussion.

**Exclusionary criteria.** Subjects were excluded from participation for any of the following: (a) inability to tolerate the scanning procedures (e.g., claustrophobia); (b) metal in body or prior history working with metal fragments (e.g., as a machinist); (c) any other contraindications for MRI examination (e.g., metallic implants such as pacemakers, surgical aneurysm clips, or known metal fragments embedded in the body); (d) alcohol intake within 48 hours prior to participation in fMRI; (e) left-handedness or ambidextrousness; (f) history of closed head trauma with loss of consciousness; (g) being actively treated for any psychiatric disorder with medication or psychotherapy; (h) a past history of any significant neurological or cerebrovascular disease (e.g., stroke, transient ischemic attack); or (i) a nonfluent or nonnative speaker of English.

Couples were recruited using Craigslist ads, Department of Psychology and Neuroscience paid psychology subject pool, flyers, campus online newsletters, and promotional materials created by the Intermountain Neuroimaging Consortium. All advertising material directed couples to complete individual online screeners to determine their eligibility. Couples who met inclusionary and exclusionary criteria were invited to participate in the study.

Subject demographics can be found in Table 1. On average, subjects had been with their current partner for approximately 5 years (range: 2-15 years). Just over 1/3 (35%) of subjects were currently married, 5% were engaged, and 60% were dating. Most subjects had never been married: 33% had been married once and one subject had been married 3 times. Five of the subjects, or 12.5% of the sample, had children. Most of the children were under the age of 10 years old, although one subject had a 22-year-old child.
Table 1

Demographics

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Procedure

Couples who qualified for the study and agreed to participate were sent an email and asked to attend two appointments at the Center for Innovation and Creativity (CINC) at the University of Colorado Boulder. A scheduling email was then sent to the couple. The email also included a link to a short online survey asking whether either partner recognized a picture of the couple from the “Other” conflict video used in the study. All subjects reported that they did not recognize the “Other” couple. The couple was then sent a confirmation email, which included instructions not to discuss their day with their partner before coming to the laboratory.

Appointment One. During the first appointment, which was generally scheduled for the late afternoon and early evening, each partner completed the consent form and a MRI compatibility screener. Each partner then completed the Marital Agendas Protocol (MAP; Notarius & Vanzetti, 1983), which is a list of 19 common topics of disagreement. The MAP asked each partner to rate the severity of each problem and likelihood of the topic being resolved.
Couples then completed three interaction tasks, during which partners sat in two chairs angled towards each other; all discussions were recorded by a webcam on a recording stand. Partners were first asked to discuss the events of their day with each other as if they were at home for about 10 minutes after the experimenter left the room. This interaction allowed the couple to become acclimated to the experiment room before engaging in the conflict discussion. After 10 minutes had passed the experimenter returned to the room and asked the couple to discuss the highest rated (i.e., most severe) topic of disagreement on the MAP. The experimenter then left the room and recorded this discussion. The first conflict discussion was stopped after 10 minutes and the couple was asked to discuss the second highest rated conflict topic of disagreement for another 10 minutes. The couple was then thanked and each partner was paid $12 an hour for his/her time.

**Appointment Two.** If the couple engaged in an authentic and on-topic discussion, as determined by the experimenter, they were invited back to CINC for the second appointment. Out of the 24 couples who engaged in a conflict interaction, 20 were invited back for appointment two. These appointments all took place within approximately 3 weeks of the first appointment.

During this appointment, each partner underwent a structural scan and two 8.5 minute fMRI scans, for a total of 30 minutes. Pulse rate and galvanic skin conductance were also recorded. Scans used a Siemens Tim Trio 3 tesla system with a 32-channel head coil. Structural images were acquired using a sagittal T1-weighted interleaved sequence (repetition time [TR] = 2400 ms, echo-time [TE] = 2.01 ms, echo spacing = 7.4 ms, field-of-view = 256 mm x 256 mm x 180 mm, slice thickness = 0.8 mm, voxel resolution = 0.8 x 0.8 x 0.8 mm, and flip angle = 8°). Functional images used a multiband accelerated pulse sequence, which acquires slices
significantly faster than typical sequences and were acquired in the A>P direction. Acquisition used T2* weighted images with interleaved slice acquisition using a multiband sequence (multiband acceleration factor = 8, TR = 460 ms, TE = 29.0, bandwidth = 2772 Hz/Px, flip-angle = 44°, echo-spacing = 0.51 ms, field-of-view = 248 x 248 x 168 mm, voxel resolution = 3.0 x 3.0 x 3.0 mm, slice thickness = 3.0 mm, number of slices = 56).

During the functional scans, subjects viewed an 8-minute video of their own conflict discussion and an 8-minute video of another couple’s conflict discussion; both partners from the “other” couple, who participated in an earlier study, provided written consent for their video to be used in this way. Of the two videotaped conflict interactions obtained during Appointment 1, the conflict interaction with the highest level of emotional variability and intensity of conflict was selected for viewing during the fMRI scan. The video in which the couple spent the highest percentage of time discussing the conflict topic and most frequently expressed negative emotions was selected. During the fMRI scans of their own conflict discussion, partners were instructed to imagine they were currently engaged in the discussion, and not just watching the video. For the other couple video, partners were instructed to passively view the video. The video order was counterbalanced across couples.

After completing the structural and fMRI scans, each partner watched their own video twice and the other couple’s video once, during which they provided continuous emotion ratings. For the first viewing of their own video, they were instructed to rate how they recalled feeling at the time (i.e., as the conflict interaction was filmed). For the second viewing of their own video, they rated how they thought their partner was feeling during the interaction. Last, each person rated how s/he felt watching the other couple’s video. Whether they rated their own emotions or their partner’s emotions in the first viewing of their own interaction was counterbalanced, and
everyone watched the other couple’s video last. For each of the viewings, subjects were asked to rate their emotional experience on a scale from positive to negative with neutral as the center of the scale. The scale appeared to the side of the video as a vertical line with a movable bar. The scale was labeled “negative” on the top and “positive” on the bottom, without numbers or other demarcations. Ratings were converted to a scale ranging from 0 to 1. Subjects were able to move the bar up and down to rate their affect continuously throughout the video. Past studies have shown that when couples watch videos of their conflict interactions, they show nearly identical physiological responses as those that are obtained when they are engaged in the conflict interaction (Gottman & Levenson, 1985). This finding suggests that couples in the current study were likely to have similar neural activity and provide emotion ratings that were comparable to those experienced during the actual conflict interaction. By having subjects rate their affect outside the scanner, the possibility of movement artifacts was reduced and subjects could fully engage in watching the interactions.

Finally, each partner completed a battery of online questionnaires in the laboratory during this appointment including the Couple Satisfaction Index (CSI-16), Support and Strain Scale, and the Commitment Scale (Funk & Rogge, 2007). Data from the other questionnaires that were completed were not examined in this study.

The CSI-16 is a 16-item measure that assesses general relationship satisfaction. Most items are scored on a 6-point scale and one on a 7-point scale where lower scores indicate lower levels of satisfaction. Totals can range from 0 to 81 with scores below 51.5 suggesting significant relationship dissatisfaction.

The Support and Strain Scales consist of two sets of 6 questions are scored on 4-point scales from 1- A Lot to 4- Not At All so that high scores indicate high level of support and strain
(Walen & Lachman, 2000). The scales measure each partner’s perceived experience of how positive and negative the relationship is.

The Commitment Scale is a 15-item measure of commitment to the relationship where low scores indicate a low level of commitment and high scores a high level (Rusbult, Kumashiro, Kubacka, & Finkel, 2009). Each item is scored on a 9-point scale from Do Not Agree At All to Agree Completely. All the items were then averaged.

Subjects were also asked to rate on an 11-point scale, “How similar was this discussion to a usual discussion you might have with your partner about an ongoing topic of disagreement?” and “How genuine was this discussion with your partner?” from Not at all Similar/Genuine to Extremely Similar/Genuine with Neither Similar/Genuine or Dissimilar/Genuine as the middle of the scale.

Subjects were also contacted 6 months after Appointment 2 and asked to complete the same questionnaires online at home. Each partner was paid $12 an hour for the behavior portion, $24 an hour for the MRI scan, and $10 for completing the 6-month follow-up questionnaires.

**Communication Enhancement Training.** After completion of both appointments and the follow-up questionnaires, couples were invited to participate in a communication enhancement training session with a graduate student therapist. The training consisted of a one-hour session where couples were taught and asked to practice some communication skills traditionally used in cognitive behavioral couple therapy. This session was offered without charge as a benefit for couples that completed the study. Interested couples were also provided with referrals to therapists in the community.

**Preprocessing**
Preprocessing of Ratings. Continuous affect ratings for the Self, Partner, and Other video recall were all preprocessed using Python. Ratings were down sampled by averaging all samples every 460 ms to align with the fMRI scan TRs. Extreme values were limited to 3 standard deviations above each subject’s mean to remove outliers, which are likely accidental movements of the rater. The first 5 seconds of the ratings were set to the average of the first 10 seconds to remove any artifacts created by subjects testing the moving bar. Ratings were also convolved with a canonical hemodynamic response function (HRF) to model the blood oxygen level dependent (BOLD) responses. See Figure 1 for one subject’s preprocessed continuous rating and the rating convolved with HRF.

Figure 1. Continuous Raw Emotion Rating for the Self Condition and Convolved with HRF

Preprocessing of fMRI Data. The fMRI data was preprocessed using Nipype, which is an adaptation of the SPM 12 preprocessing pipeline, developed by Luke Chang (http://neurolearn.readthedocs.io/en/latest). For each scan, the first 10 images were removed as the scanner achieved steady state and to correct for motion, the remaining images were realigned to the first image in the sequence and coregistered to Montreal Neurologic Institute space. Images were then segmented into white matter, gray matter, and cerebrospinal fluid (CSF).
mask was created for the ventricles and the average activity of the mask was used as a covariate of no interest to account for physiological artifacts. The images were normalized and smoothed using a 6 mm Gaussian kernel (fwhm). No other filtering was performed to avoid removing important signal in this naturalistic design. To control for signal drift, a linear and quadratic trend were covaried out of each model, in addition to 24 motion covariates (6 estimated from realignment procedure and demeaned, 6 of their squares, and 6 of their temporal derivatives squared) and spikes. A high-pass filter was not used to preserve meaningful signal related to affect changes over the conflict discussion.

All images from the self video and other couple video scans were visually inspected and the noise variables were plotted. For both the self and other video condition, movement was fairly minimal and only one subject in each condition had slightly more than 2 mm of movement. For both conditions, subjects had an average of about 10 spikes. Subjects with ratings with very little variance (most of the trial recorded as the same rating) were not included in the analyses, which was typically around 2 subjects per model.

**Final Samples**

The fMRI data for all subjects were examined and all scans were within acceptable limits of movement (<2.5mm) within each run and did not have any noticeable artifacts that could impact the analyses. Two subjects were excluded because their scans failed to preprocess correctly. Two other subjects were excluded from most analyses because their ratings lacked sufficient variability to be a meaningful regressor. One subject was missing self-rating and another subject was missing ratings of their partner and the other couple, so they were excluded from analyses requiring those ratings.
Behavioral Analyses

All behavioral analyses were conducted using RStudio and R (R Development Core Team, 2008). Correlations between ratings from different conditions and between different partners were calculated using Pearson correlations.

Dyadic Data. All subjects were treated as individuals in all analyses, even though both partners within each couple watched the same video. The correlation between self-ratings for males and females within a couple was calculated using a Pearson’s correlation and averaged across all couples. The resulting correlation was .18. According to Kenny, Kashy, and Cook, (2006) a correlation around .1 is considered to be low so that the data from partners within a relationship can be treated as if they are independent. See Figure 2 for the distribution of correlations between self-ratings within each couple.

Figure 2

Correlations of Self Ratings Within Couples

Analyses Using Rating Data

For all of the following analyses (unless otherwise noted), rating scores were used as regressors and betas for each voxel in the brain were calculated creating a map of how strongly correlated each voxel’s activity was with changes in rating. A t-test was then run on all subjects’
beta maps and the results were corrected for false discovery rate (FDR) \((p < .05)\). Each model included a regressor containing self-ratings (made during the video recall of their own conflict interaction), ratings of one’s partner (made during the video recall of their own conflict interaction), and self-ratings made while viewing the other couple’s conflict interaction.

**Continuous Ratings.** Each subject’s continuous rating convolved with HRF was regressed on whole brain activation over the full 8 minutes. See Figure 1 for one subject’s ratings. This analysis included 35 subjects.

**Changes in Ratings.** To evaluate whether a specific pattern of brain activation was associated with times when subjects indicated an increase in negative affect or a decrease in negative affect, I calculated the derivative of the continuous rating. Times when the derivative was positive and negative were used as regressors. These time points reflected shifts in the ratings when they suddenly increased or decreased. See Figure 3 for one subject’s ratings and an indicator of increases and decreases in negative affect. These markers of emotion change were then used to create a contrast and were applied to the brain data. Activation during times of increase and decrease were separately contrasted with all other times when the subject did not indicate changing affect. Thirty-four subjects were included in the increasing negative affect analysis and 35 were included in the decreasing negative affect analysis.
High and Low Rating Cutoffs. It is possible that changes in continuous ratings might not be linearly associated with changes in brain activation. To evaluate whether a specific pattern of brain activation was associated with times when subjects were feeling especially negative or especially positive, relative to times when they were not feeling this way, cutoffs of less than .25 (Positive) and greater than .75 (Negative) were created from the continuous mood rating. The scale of the ratings ranged from 0 to 1. Thus, a value of 0.25 represents the point halfway between the midpoint of the scale and the lowest point of the scale (marked “positive”), whereas a value of 0.75 represents the point halfway between the midpoint of the scale and the highest point of the scale (marked “negative”). Brain activation during times when ratings were above or below these cutoffs was contrasted separately with all other times when the ratings were outside of the cutoff. See Figure 4 for one subject’s ratings and indicators of when ratings were above and below the cutoff points.
High and Low Rating Using Standard Deviation. Standard deviations were also used as cutoffs to evaluate whether a specific pattern of brain activation was associated with times when subjects were feeling especially negative or especially positive, compared to times when they were not feeling this way, relative to their own mean. Cutoffs of greater than 1 standard deviation above each subject’s mean (Negative) and less than 1 standard deviation below their mean (Positive) were created from the continuous mood rating. Brain activation during times when ratings were above or below these cutoffs was contrasted separately with all other times when the ratings were outside of the cutoff. See Figure 5 for one subject’s ratings and indicators of when ratings were above and below the cutoff points.
Contrast Between Negative and Positive Emotion. A contrast regressor was created to evaluate possible differences in brain activation between times when subjects reported feeling particularly positive compared to times when they reported feeling particularly negative, using the cutoff and standard deviation demarcations. Time points when high negative emotion was reported (>0.75 or > 1 SD above the mean) were coded as 1 and time points when high positive (or low negative) emotion was reported (<0.25 or >1 SD below the mean) were coded as -1 and time points in between as 0. See Figure 6 for one subject’s contrast codes.
Predicted Partner-Rating and Brain Activation of Partner. To evaluate the association between predicted partner-ratings and partner’s brain activation. Partner 1’s rating of the emotion they thought Partner 2 was experiencing during the interaction, obtained during the video recall of their own conflict interaction, was regressed on Partner 2’s brain data. The ratings of the partners looked similar to the self-ratings, depicted in Figure 1, and were entered in the model in the same way self continuous ratings were, except instead of using Partner 1’s brain data, Partner 2’s data were used. This model evaluated whether the partner’s predicted emotional experience corresponded with the neural representation of the partner’s experience.

Contrast Between Self-Rating of Own Conflict and Other Conflict. The next model evaluated whether the experience of watching one’s own conflict compared to watching another couple’s conflict is represented differently at the neural level. The model contrasted the brain activation associated with one’s self-rating while watching one’s own conflict and the brain activation associated with one’s self-rating while watching the other couple’s conflict.
Contrast Between Self-Rating and Partner-Rating of Own Conflict. A similar model was run to examine if there was a difference in brain activation patterns that were associated with subjects’ self-rating compared to subjects’ rating of their partner. The same first level models described above were run where both Partner 1’s continuous ratings (self and partner) were regressed on Partner 1’s brain data separately. The map of brain activation associated with the self-rating was contrasted with brain activation associated with the rating of their partner’s emotional experience at the second level of the model.

Analyses Using Emotion Patterns

For the following series of analyses, multivariate patterns developed in two past studies were used. The patterns were associated with specific emotion states reported by subjects in response to emotion eliciting stimuli in the scanner. The patterns created by Kragel and LaBar (2015) include seven emotions: anger, contentment, amusement, surprise, fear, sadness, and neutral. In their study, subjects watched movie clips and listened to standardized music clips and rated their emotional experience on a variety of different scales. Partial least squares discriminant analysis was performed on the brain data using the self-report measures to identify a different brain activation pattern for each emotion. Each pattern is a map of all the voxels in the brain with each assigned a different value for how much their activation “tracked” the subject’s experience of each of the emotions.

The patterns created by Ashar et al. (2017) represent two emotional states associated with compassion – empathic distress and tenderness. In this study, subjects listened to stories about individuals in need in the scanner and were asked to make a charitable donation to that individual using their payment from the study. Subjects also rated their emotional experience of distress and
tenderness in response to the clips and patterns were created using a machine-learning based regression technique based on the subjects’ ratings.

In applying these patterns to the data from the current study, brain activation for each subject was denoised (linear and quadratic detrending, 24 motion covariates, and spikes) and then the patterns were applied to the brain activation by calculating the cosine similarity at each voxel as a beta value. Continuous self-rating was regressed on the beta maps for each subject, creating one overall beta value per subject. This beta value represented the association between brain activation that matched each pattern and continuous self-rating, controlling for noise covariates. The beta values for each pattern were analyzed using a one-sample t-test to determine if on average across all the subjects, the continuous rating was significantly associated with the similarity between the brain activation and the patterns. Comparison between specific pattern strengths was done using paired t-tests.

**Results**

**Relationship Measures**

Based on their scores on the Couples Satisfaction Index (CSI; Funk & Rogge, 2007), most subjects were generally satisfied with their relationships, as the sample mean was 79.2 (SD = 12.23 range = 32-92), with only one subject reporting a score that fell below the cutoff of 51.5 for defining relationship distress. Based on their scores on Walen and Lachman's (2000) measure of social support, subjects’ level of support (M = 3.75, SD = 0.5, range = 1.5-4.0) and strain (M = 1.95, SD = 0.48, range = 1.17-3.17) in their interactions with their partner were comparable to levels reported by other researchers. For example, a population-based sample of over 2,000 married adults reported a mean of 3.76 for support and 1.97 for strain (Whisman & Li, 2015). On the Commitment Measure (Rusbult et al., 2009), subjects’ mean level of commitment (M = 6.41,
was comparable to levels reported by other researchers. For example, Wieselquist (2009) reported a mean of 6.68 in a sample of 129 individuals involved in a dating relationship.

**How Typical Were the Conflict Interactions?**

Subjects reported that the conflict interactions they engaged in for this study were fairly similar to ones they engage in at home ($M = 7.86, SD = 2.40$, range = 1-11) and were very genuine ($M = 10.02, SD = 1.11$, range = 8-11). Specifically, out of 36 responses received, 58% reported that their interaction was more similar than not to ones they engage in at home. All subjects reported that the discussion was more genuine than not.

**Analyses Between Partner’s Ratings**

Pearson correlations were computed between emotion ratings for self and partner made while viewing one’s own conflict interaction. The largest correlation was obtained between Partner 1’s self-rating and Partner 1’s predicted partner-ratings made during the video recall of their own interaction ($r = .31$): the more negative a person felt throughout the interaction, the more negative they predicted their partner felt. The correlation between Partner 1’s self-rating and Partner 2’s self-rating was fairly small ($r = .18$): time points when one partner felt negative during the interaction were generally different than time points when their partner felt negative. Similarly, the correlation between Partner 1’s self-rating and Partner 2’s predicted partner-rating (how Partner 2 thought Partner 1 was feeling) was also small ($r = .17$): time points when one person felt negative during the interaction were generally different than time points when his or her partner thought the person felt negative.

**Analyses Between Rating Data and Neural Activation**
**Self.** I first evaluated the association between neural activation associated with subjects watching the video of their own interaction and subjects’ ratings of how they recalled feeling during the interaction, made while watching the video outside the scanner. The analysis of continuous self-rating in response to one’s own interaction regressed on brain activation revealed five significant clusters that survived FDR correction (Figure 7). Table 2 contains $p$ values for each cluster. Significant clusters were located in the superior temporal sulcus (STS), superior temporal gyrus (STG), auditory cortex, and the right motor and premotor areas.

**Figure 7.** Self Emotion Ratings Regressed on Brain Activation in the Self Condition

**Table 2.** Significant Clusters for Self-Rating Condition

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**Partner.** Next, I evaluated the association between neural activation associated with watching the video of their own interaction and subjects’ ratings of how they thought their partner was feeling, made while watching the video outside the scanner. The analysis of continuous partner-rating (Partner 1’s rating of Partner 2) in response to one’s own interaction regressed on brain activation, revealed five significant clusters that survived FDR correction (Figure 8). Table 3 contains $p$ values for each cluster. Significant clusters were located in the STS, STG, and auditory cortex.

![Figure 8. Predicted Emotion Ratings of the Partner Regressed on Self Brain Activation in the Self Condition](image)

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Other. Finally, I examined the association between neural activation associated with subjects watching the video of another couple’s interaction and subjects’ ratings of how they felt while watching the other couple’s video, made while watching the video outside the scanner. The analysis of continuous other-rating in response to the other couple’s interaction regressed on brain activation, revealed six significant clusters that survived FDR correction (Figure 9). Table 4 contains p values for each cluster. Significant clusters were located in the STS, STG, auditory cortex, occipital cortex, and dorsal medial prefrontal cortex (DMPFC).

Figure 9. Self Emotion Ratings Regressed on Self Brain Activation in the Other Condition
Table 4. Significant Clusters for Other-Rating Condition

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</table>

Given the activation located in the auditory cortex, the sound feature of loudness was extracted from the videos using OpenSmile (Eyben, Weninger, Gross, & Schuller, 2013) at one observation a second. Loudness was then resampled to be consistent with the scanning TR of 460ms and was included as a covariate in the self, partner, and other continuous rating conditions. Results from the models for the self and partner condition, including loudness, were nearly identical to those without loudness. For the other condition, clusters were slightly smaller and weaker but the results remained statistically significant.

All other analyses using other indices of self, partner, and other affect ratings and neural activation did not survive FDR correction. Specifically, there were no statistically significant associations between neural activation and (a) changes in ratings (derivatives), (b) cutoffs of high and low negative emotion (numeric cutoffs and standard deviations), (c) contrasts between high and low negative emotion, (d) contrasts between self- and partner-ratings or between self- and other-ratings, and (e) Partner 1’s rating regressed on Partner 2’s brain activation.

**Analyses Using Emotion Patterns**

The next set of analyses examined the associations between continuous rating of one’s own affect made during the video recall of one’s own interaction and degree of similarity between brain activation and emotion patterns. The pattern application analyses revealed significant positive associations between self-rating and similarity between brain activation and
emotion patterns associated with anger (β = .022, t = 4.12, p < .0005), amusement (β = .036, t = 4.05, p < .0005), and sadness (β = .011, t = 2.87, p < .01). These results indicate that brain activation patterns elicited while watching the video of one’s conflict interaction became more similar to the anger, amusement, and sadness emotion patterns as the subjects’ continuous rating of their own mood became more negative (Figure 10). Anger and amusement had the strongest associations with the affect ratings and both had significantly stronger correlations than sadness (anger: t = 2.31, p < .05, amusement: t = 3.55, p < .005). There were also several emotion patterns that were negatively correlated with changes in self-rating, including neutral (β = -.029, t = -4.70, p < .0001), contentment (β = -.029, t = -5.28, p < .0001), and empathic distress (β = -.011, t = -2.52, p < .05). For these patterns, brain activation was present in the areas specified by these patterns when continuous self-rating of their mood became less negative (or, said differently, became more positive). The similarity between neural activation and the emotion maps of fear, surprise, and tenderness were not associated with self-rating.

![Figure 10. Emotion Patterns-Self Condition](image)

Note: Some variable names have been shorted. Pattern names have been grouped by result. Positive correlations: Anger, Amusement, Sadness, Negative correlations: Neutral, Contentment, and Empathic Distress, No correlations: Fear, Surprise, and Tenderness.
A parallel set of analyses was conducted using the partner-ratings (i.e., Partner 1’s rating of perceived emotion experienced by Partner 2 and Partner 1’s brain activation). Results were fairly similar to the analyses using self-ratings, which would be expected due to the moderate-sized correlation obtained between the same participant’s self- and predicted partner-ratings (Figure 11). While viewing the video of one’s own conflict interaction, participants ratings of their partners affect was positively associated with similarity between their own brain activation and anger and amusement patterns (anger: $\beta = .019$, $t = 3.37$, $p < .005$; amusement: $\beta = .031$, $t = 3.01$, $p < .005$). Specifically, when participants rated their partner’s affect as mostly negative, their own brain activation resembled the anger and amusement patterns. There were also several emotion patterns that were negatively correlated with partner-ratings, including neutral ($\beta = -.027$, $t = -3.50$, $p < .005$), contentment ($\beta = -.021$, $t = -3.26$, $p < .005$), and empathic distress ($\beta = -.013$, $t = -2.71$, $p < .05$). These negative correlations suggest that as ratings of partners’ affect became less negative (or, said differently, more positive), the brain activation patterns elicited while watching the video became more similar to these emotion patterns. The similarity between neural activation and the emotion maps of fear, surprise, sadness, and tenderness were not associated with partner-ratings.
Note: Some variable names have been shorted. Pattern names have been grouped by result. Positive correlations: Anger, Amusement, Negative correlations: Neutral, Contentment, and Empathic Distress, No correlations: Fear, Surprise, Sadness, and Tenderness.

**Discussion**

The current study was conducted to (a) evaluate the neural activation patterns associated with the naturalistic emotion elicitation task of recalling the affective experience of having a conflict interaction with a romantic partner, (b) examine neural activation patterns associated with watching another couple’s conflict interaction, and (c) apply patterns associated with specific emotions in other studies to subjects’ neural activation associated with completing the emotional elicitation task of viewing their own conflict interaction. In the sections that follow, I discuss the results associated with these aims.

**Analyses Using Rating Data**

Results showed significant patterns of activation were associated with the continuous rating in the self (own emotional experience while watching their own conflict interaction), partner (Partner 1’s rating of Partner 2’s emotional experience while watching their own conflict interaction).
interaction), and other conditions (own emotional experience while watching the other couple’s conflict interaction). Most notable clusters that survived FDR correction ($p < .05$) were located in the STS, STG, and auditory cortex for all three models. In addition, subjects’ ratings of their own emotional experience while watching their own conflict was associated with activation in the premotor and motor areas and subjects’ ratings of their own emotional experience while watching another couple’s conflict was also associated with activation in the occipital cortex and DMPFC. All other models and contrasts examining brain activation associated with variants of the emotion ratings did not survive FDR correction.

The results from the models examining the continuous ratings were fairly surprising, given that past studies have observed emotion-related activation in more “traditional” emotion regions such as the amygdala, hippocampus, thalamus, hypothalamus, basal ganglia, and cingulate gyrus (for a review, see Morgane, Galler, & Mokler, 2005). However, there is some debate in the field on how emotions are likely represented in the brain and many researchers believe that emotions are represented in diffuse networks across the brain rather than specific structures (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). A meta-analysis of 65 neuroimaging studies examining emotion found that a wide variety of areas across the brain appear to be associated with the perception and experience of emotions (Wager, Phan, Liberzon, & Taylor, 2003). The study found that procedure and method differences across studies impact the findings. Overall across studies, activation associated with emotion was not consistently found to be right-lateralized but varied by gender and brain region. For example, males showed more lateralization of emotion activity during affective paradigms and females tended to show more brainstem activation. The authors conclude that emotion is likely represented in the brain
across many regions in complex patterns that differ by gender, valence, and lateralization by region.

Another meta-analysis of neuroimaging studies of emotion found that affective stimuli often engage, or are associated with activation in, somatosensory input regions of the cortex (Satpute et al., 2015). The authors suggest that stimuli are first processed in sensory specific regions of the brain, before emotion specific regions. This first level of processing is sensitive to the affective nature of stimuli such that neural activation patterns associated with affective stimuli differ from neutral stimuli. Overall, the authors conclude that processing that occurs in sensory areas is important for the experience of emotion beyond simply processing input stimuli (Satpute et al., 2015).

This study’s finding of activation in the auditory cortex is especially interesting in light of Satpute et al. (2015) and other studies’ findings that suggest the auditory cortex may be important in decoding emotion-related stimuli and learning. Specifically, some studies have suggested that the auditory cortex may encode whether a sound indicates a reward or a potential punishment (Alexandrov, Klucharev, & Sams, 2007). For example, one study had subjects push a button when they heard a high-pitched tone but not when they heard a standard tone. In some conditions, subjects were cued before the trial that if they missed the high pitched tone they would lose money and in other trials that they would gain money by responding correctly. Results showed that event related brain potentials as measured by electroencephalogram (EEG) were significantly larger on the negative trials where subjects could lose money compared to the positive trials where they could gain money. In addition, several studies have suggested that the auditory cortex may be important in the creation of emotional memories and learning indicated
by auditory cortex plasticity (for a review see, Grosso, Cambiaghi, Concina, Sacco, & Sacchetti, 2015).

Other studies suggest that the auditory cortex may be especially tuned to decode emotional prosody in speech. For example, Buchanan et al. (2000) had subjects discriminate between words based on either phonemic characteristics or the emotional tone of how the word was said (angry, sad, happy, or neutral) while undergoing an fMRI scan. Activation in the auditory cortex showed differences across conditions; specifically, the authors found increased right hemispheric activity during the emotion detection than the verbal word detection. This suggests that the auditory cortex may be especially tuned to or processes emotional sounds differently than neutral words without emotional prosody. In a similar experiment, Ethofer, Ville, and Scherer (2009) had subjects listen to pseudowords spoken with different emotion specific prosody (anger, sadness, neutral, relief, and joy) in an fMRI scanner. The authors then used MVPA to find separate and robust patterns of activation that discriminated between the different emotion categories. The results of the current study may be indicative of a similar process occurring in the auditory cortex during the recall of a conflict interaction. The auditory cortex may be playing a role in extracting emotional meaning from the complex social situation and conversation. This seems especially likely given that the activation patterns were unchanged for the self and partner condition when loudness was included as a covariate in the models. This suggests that the activation in the auditory cortex was not only tracking changes in sound (loudness) but was also tracking other emotional elements, such as prosody, present in the interaction. This study offers an important step towards understanding the role of the auditory cortex in processing complex emotional stimuli during a naturalistic task.
The finding that significant activation in the STS was associated with the emotion rating is also interesting, given that the STS has been implicated in a variety of neural processes that could be related to the task used in this study. Similarly to the auditory cortex, the STS may play a role in decoding prosody in speech. For example, one study had subjects listen to words said in a neutral or angry tone (Grandjean et al., 2005). Results showed increased activation in the middle of the STS to the angry conditions. Activation remained even after being contrasted with conditions matched on fundamental frequency and sound amplitude, which suggests that the STS is especially tuned to prosody rather than other features of sound. Another study with a similar design also had subjects listen to meaningless utterances that were either angry or neutral and found increased activation in the right amygdala and bilateral STS in response to the angry stimuli (Sander et al., 2005).

The STS has also been implicated in a variety of other processes including decoding facial expressions (Johnston, Mayes, Hughes, & Young, 2013) and a variety of social processes including encoding voices, language, and theory of mind, or taking another person’s perspective (Beauchamp, 2015). This suggests that subjects may have been attending to the social content of the interaction and processing this information in the STS. Using theory of mind, processing facial expressions and understanding social language are likely very important in this task if subjects were recalling having the experience of the conflict interaction and were thinking about how their partner felt and their own emotional reaction. Understanding their partner’s reaction, particularly by engaging in theory of mind, is likely very important for informing each person’s own experience. This social aspect of understanding one’s emotional experience during a conflict interaction is an important finding that sheds light on the neural underpinnings of recalling engaging in a conflict interaction.
In the condition where subjects watched another couple’s interaction, significant activation associated with the emotion rating was observed in the DMPFC. The DMPFC has been implicated in a variety of processes but similar to the STS it has been most commonly connected to processing of social stimuli and reasoning about another person’s mental state. One recent study found that the DMPFC was especially responsive to situations involving social interactions (Wagner, Kelley, Haxby, & Heatherton, 2016). In this study, subjects viewed clips from the movie Matchstick Men and a reverse correlation analysis revealed that the DMPFC had a strong response to scenes where two people were having a conversation. The stimuli used in that study are very similar to the interactions that subjects viewed in the current study and suggest that the DMPFC may be especially important for processing and deriving emotional meaning from the social interactions of others.

Analyses Using Emotion Patterns

Results for the analyses using the emotion patterns revealed an interesting set of findings. For the self-rating condition (i.e., ratings of how people recalled feeling as they watched the video of their own conflict interaction), ratings of negative affect were positively correlated with the similarity between brain activation and the pattern for anger, sadness, and amusement, negatively correlated with the pattern for neutral, contentment, and empathic distress, and not correlated with the pattern for fear, surprise, and tenderness. For the partner-rating condition (i.e., ratings of how subjects thought their partner were feeling during their own conflict interaction), findings were generally similar to those from the self-rating condition. Specifically, ratings of partner negative affect was positively correlated with the similarity between brain activation and the pattern for anger and amusement, negatively correlated with the patterns for neutral, contentment, and empathic distress, and not correlated with the pattern for fear, surprise,
sadness, or tenderness. Overall, these results are consistent with past research on the types of emotions experienced during conflict interactions and serve as a confirmation that couples were likely engaging in the task both during the interaction and in the scanner. Specially, couples often report experiencing anger and sadness during these types of interactions and rarely report calm positive emotions such as contentment if they are discussing a topic that is important to them (e.g., Carrère & Gottman, 1999; Du Rocher Schudlich et al., 2004; Sanford, 2012). Interestingly, empathic distress was negatively associated with self-ratings, which means that subjects’ brain activation was more similar to the pattern associated with empathic distress when they were feeling more positive (i.e., when they rated negative affect lower). The study in which the empathic distress pattern was originally developed included vignettes of people experiencing suffering and was designed to elicit compassion (Ashar et al., 2017). The “empathic distress” pattern in the current study may be associated with feeling compassionate towards one’s partner, which may be experienced as a more “positive” emotion than anger, for example.

The only surprising finding was the positive association between negative affect and amusement. Some of the analyses conducted in Kragel and LaBar (2015) suggest that this marker of amusement may not correlate with arousal or pleasantness and so may actually represent something specific about the stimuli that was rated high on amusement. For example, the pattern could be detecting brain activation associated with social interactions and social meaning as often is present in jokes that involve norm violations or social commentary. The pattern of “amusement” may be tracking socially relevant information during the conflict interaction in a similar way. Alternatively, as was suggested by Cohan and Bradbury (1997), partners may be using humor as an avoidance strategy when they are feeling badly and do not want to engage in the discussion. This use of humor has been found to lead to dissatisfaction
over time. In the current study, the amusement pattern may be detecting times during the discussion when humor is used in response to negative emotion.

Overall, the results from the pattern analyses are an important replication of these patterns and their utility for detecting meaningful brain activation during emotion eliciting tasks. The current study is the first study to test the tenderness and empathic distress patterns in a separate sample and the second to test the other specific emotion patterns (Kragel, Knodt, Hariri, & LaBar, 2016). Continuing to test the accuracy of these patterns in detecting emotional states elicited in response to other stimuli across studies is important for future research to determine their ability to provide insights into the brain during complex emotion eliciting tasks. Last, the results are interesting in the context of couples and suggest that examining brain activation patterns associated with specific emotional states may contribute valuable information about how couples experience conflict at the neural level.

Strengths and Limitations

In interpreting the current results, the strengths and limitations of the study should be taken into account. Strengths of the study include the use of a naturalistic emotion elicitation task with high ecological validity. Most studies of emotion, social interaction, and the brain use more controlled and less realistic stimuli. For example many studies elicit emotions through the use of images, such as the IAPS (for example Aldhafeeri, Mackenzie, Kay, Alghamdi, & Sluming, 2012), or clips from movies (for example Schlochtermeier et al., 2016), or simple social situations such as the cyberball task (Eisenberger et al., 2003). Although many of these common emotion elicitation tasks do result in self-reported changes in emotions, it is unclear how similar these experiences are to emotional responses to complex social situations, such as those that occur on a daily basis. In addition, the use of conflict interactions is important not only for the
study of general emotions but also because of their importance to a wide range of individual and relationship outcomes. As reviewed earlier, there is a substantial literature linking conflict to relationship satisfaction and stability, as well as mental and physical health outcomes (Beach et al., 1998; Carrère & Gottman, 1999; Du Rocher Schudlich et al., 2004; Gottman et al., 1977; Schmaling & Sher, 1997). This study is an important addition to the literature, given that it is the first study to examine romantic conflict interactions at the neural level. In future research, it will be important to examine whether neural activation associated with conflict interactions is associated with these individual and relationship outcomes, and whether these associations are incremental to more easily obtained indices of conflict, such as data that can be obtained from self-report or observational coding of couples’ conflict interactions.

Another strength of the study includes the use of continuous emotion ratings, which takes advantage of the full variability of emotional experience. Additionally, having continuous ratings resulted in a variety of options for ways the ratings and brain data could be examined. I was able to ask questions not only about how the ratings correlated with brain activation over time but also examine brain activation at times when high negative or positive emotion was reported or when there were large changes in emotion, and evaluate contrasts between different emotion states and across different conditions (self, partner, or other). Another strength of the study included the use of both traditional contrast methods and also a fairly novel application of brain activation patterns created in other studies to brain activation in response to an emotionally complex stimuli. Last, the analyses examined brain activation at the level of the individual by examining each subject’s affective ratings when watching their own conflict and the other couple’s conflict, and also at the level of the couple by examining ratings of subjects’ prediction
of their partners mood in relation to their own brain activation and their partners’ brain activation.

In addition to the many strengths of the study, several limitations should also be considered. First, the sample included in the study lacked diversity in demographics and length of relationship. Future studies should aim to recruit samples that are more racially diverse, include a wider age range, and more varied educational backgrounds since the current study included mostly white subjects who were young and highly educated. The study also included a majority of subjects who were dating but not engaged or married. Recruiting a sample of couples with a longer relationship history that are more committed may have resulted in interactions that were richer and had more emotional variability. Similarly, most couples were fairly satisfied in their relationships, which could have limited the range of emotions elicited during the interactions and resulted in fewer significant findings. Future studies that include more distressed couples may find stronger effects given that more intense negative interactions may allow for the measurement of brain activated patterns that track strong negative emotions during conflict interactions. Another limitation includes the low level of conflict in the “other” couple video. This video was the most engaging and conflictual interaction available from a previous study conducted in the laboratory. Choosing an interaction with more varied displays of emotion may have resulted in greater variability in emotion ratings and brain activation patterns, which would have provided a stronger test of the study aims. Last, the couples completed the conflict often several weeks before the scanning appointment. This delay may have decreased their ability to report accurately on their emotional experience during the interaction, although most subjects did not report this difficulty.

Future Directions
Emotion often occurs in the context of social interactions, but most fMRI studies do not use naturalistic social stimuli. Using paradigms such as the one used in this study is important to gain a clearer understanding of how the brain processes and represents emotions in response to complex social situations even though conducting these studies is challenging.

Future studies should use paradigms that include the assessment of a broader range of emotions than was within the scope of this study. Having subjects rate their experience using several emotional measures, rather than just valence (i.e., positive to negative), or using an emotional circumplex could produce more nuanced and detailed results about the neural representation of emotion elicited during social interactions. Future studies could also expand on this study by giving different instructions to subject while they were in the scanner. For example, studies of empathy could ask subjects in the scanner to imagine how their partner was feeling during the interaction to investigate the neural underpinnings of empathy and perspective taking that is so important in romantic relationships. In addition to evaluating neural activation associated with relationship-specific variables, future studies could examine associations between neural activation and specific communication behaviors obtained by having the conflict-interaction videos coded by impartial raters on emotion expressed by both partners, communication patterns such as those identified by Gottman (2014) in the SPAFF coding system, and nonverbal communication such as facial expressions or body language. Last, this method could be applied to other types of social interactions between romantic partners, such as social support interactions (Pasch & Bradbury, 1998), or to social interactions that occur between people who are not romantic partners, such as those between therapists and clients, doctors and patients, parents and children, and friends. The design of having subjects have an interaction and
then view that interaction in the scanner could provide rich and ecologically valid information.

Summary and Conclusions

In summary, the current study used a novel ecologically valid task to examine emotion elicited during a social interaction and the neural underpinnings of engaging in a conflict interaction between romantic partners. The study was also novel because it used not only traditional contrast and regression based methods for analyzing brain activation but also used emotion patterns created using MVPA in other samples and showed their viability for inferring emotions experienced by subjects in a very different type of task. Results showed that continuous emotion ratings made while viewing conflict interactions were positively associated with activation in the STS, STG, and auditory cortex, and patterns representing anger, sadness, amusement, and negatively associated with patterns representing neutral, contentment, and empathic distress. This study is an important step towards understanding neural activation that is associated with the interactions between partners in a romantic relationship, and the emotions they elicit, using an ecologically valid task.
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