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Regional brain activity during early-stage intense romantic love predicted relationship outcomes after 40 months: An fMRI assessment

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HIGHLIGHTS

- We followed up with participants from an fMRI study of early-stage romantic love.
- Follow-up assessed relationship status, happiness, and commitment 40 months later.
- Early-stage activations and deactivations in several regions predicted better outcomes.
- We discuss results in relation to reward, evaluation, mood, and emotion regulation.

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ABSTRACT

Early-stage romantic love is associated with activation in reward and motivation systems of the brain. Can these localized activations, or others, predict long-term relationship stability? We contacted participants from a previous fMRI study of early-stage love by Xu et al. [34] after 40 months from initial assessments. We compared brain activation during the initial assessment at early-stage love for those who were still together at 40 months and those who were apart, and surveyed those still together about their relationship happiness and commitment at 40 months. Six participants who were still with their partners at 40 months (compared to six who had broken up) showed less activation during early-stage love in the medial orbitofrontal cortex, right subcallosal cingulate and right accumbens, regions implicated in long-term love and relationship satisfaction [1,2]. These regions of deactivation at the early stage of love were also negatively correlated with relationship happiness scores collected at 40 months. Other areas involved were the caudate tail, and temporal and parietal lobes. These data are preliminary evidence that neural responses in the early stages of romantic love can predict relationship stability and quality up to 40 months later in the relationship. The brain regions involved suggest that forebrain reward functions may be predictive for relationship stability, as well as regions involved in social evaluation, emotional regulation, and mood.

Neuroimaging studies of romantic love have investigated early-stage, intense romantic love [5,28,34,36] as well as longer-term romantic love [1,6,11,27,38]. However, little is known about how brain activations during early-stage romantic love are associated with relationship outcomes.

Several models speak to the long-term implications of early-stage relationship quality. The enduring dynamics model emphasizes the importance of the initial relationship stage, as dynamics tend to persist and predict later outcomes [16–18]. The disillusionment model [33] suggests that people initially over-idealizing their partner and relationship, and that this inevitably declines, which can lead to negative outcomes, although a certain level of idealization can be beneficial [24]. Finally, the emergent distress model downplays the importance of initial assessments as most couples initially feel positively, and focuses instead on negative factors that emerge as the relationship progresses [18].

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Early stage love is associated with activations in dopamine-rich reward and motivation regions of the brain, particularly in the ventral tegmental area (VTA) and caudate. Romantic love past the early stage is not only associated with reward region activations (e.g., caudate and putamen, medial orbitofrontal cortex), but also elicits a much broader range of activations in areas rich in oxytocin, vasopressin, and opioids, which are important for social bonding [3,6,9,27].

Thus far the only neuroimaging study that has addressed the association between early stage intense romantic love and any later relationship stage has been Xu et al. [34] who scanned participants during early-stage and recontacted participants 18 months after scanning to assess relationship happiness. Xu et al. [34] found that activation of the subgenual cingulate and the superior frontal gyrus (while viewing images of the partner) during the initial scan was positively correlated with reported relationship happiness 18 months later. Consistent with the enduring dynamics model, the results suggested that the more rewarding a relationship was during the initial stage, the more likely it was to be rewarding in the future. However, those findings were limited in two key respects that the present study is able to address: (1) there were too few participants who had broken up at 18 months to permit reliable assessment of relationship stability, and (2) it was limited to only 18 months, which may not have been sufficient for processes such as disillusionment or emergent distress to appear.

The current study is a 40-month follow-up of these same participants, investigating the relationship between early-stage love brain activation and subsequent relationship longevity (whether participants were still together); the study also investigated happiness and commitment 40 months after initial assessment, influential relationship factors [4]. Strengths of this study were (a) it used an objective measure, fMRI activity and (b) it used a central measure, whether together or apart, which is a clear behavioral indicator. Although our sample size was modest, the results replicated other findings from other fMRI studies of relationship satisfaction and long-term love, and were consistent with other findings about positive social motivation [1,2,15].

1. Method

1.1. Participants

Participants were 18 Han Chinese right-handers (10 women) who at the time of scanning reported being intensely in love on a translated and slightly modified version of the Passionate Love Scale [see 34] and who were still in the early stages of their relationship. Relationship lengths at the time of the scan ranged from 1.3 to 13 months; $M = 6.54$, $SD = 3.19$. Participants' mean age at the time of the scan was 21.61 ($SD = 1.75$) and they were not taking psychoactive medications.

Forty months after the scan, we contacted participants via email and phone and asked them whether they were still with their partner. Of the original 18 participants, 12 (7 women) responded. For these 12, the average relationship length at the time of the scan was 5.78 months ($SD = 2.53$) and the average age was 21.5 ($SD = 1.62$). Analysis of variance tests showed that there were no significant differences in age, sex, relationship length, or any other variable assessed during early-stage between follow-up participants and those who could not be re-contacted, $ps > .34$.

1.2. Measures at 40 months after early-stage love fMRI scan

Of the 12 follow-up participants, 6 were still together with their partner and rated their current level of relationship happiness ("our relationship makes me very happy") as well as their current level of relationship commitment ("I am committed to maintaining my relationship with my partner") on a 1–7 scale.

1.3. fMRI scanning protocol during early-stage love

Baseline scanning was done on a 3 T Trio at the Beijing Center for Brain Research [see 34 for details]. Stimuli were (a) Partner: a headshot of their romantic partner; (b) Countback 1: a serial countback task presented after the Partner photo to prevent emotion spillover effect into the control Neutral condition; (c) Neutral: a headshot of a familiar, neutral acquaintance that was the same age and sex as their partner; (d) Countback 2: a serial countback task presented after the Neutral photo. Participants were asked to think of memories of their partner and acquaintance when they saw each respective image [see 34 for detailed protocol].

1.4. Analysis of fMRI data taken at the early stage of love

We used Statistical Parametric Mapping software (SPM2; Wellcome Department of Imaging Neuroscience, London, UK). Functional images were normalized to the SPM EPI template brain and realigned and smoothed with a Gaussian kernel of 4 mm. Each stimulus type (Partner, Countback 1, Neutral, Countback 2) was treated as a separate regressor and modeled as a boxcar function convolved with the canonical hemodynamic response function. We applied a high-pass filter with a cut-off of 128 s to remove low frequency signal components. Motion covariates were removed. Contrast images for each comparison for each participant were created and analyzed across participants using a mixed-effects general linear model, treating participants as a random effect, and conditions as a fixed effect.

All analyses were done using the Partner versus Neutral Contrast. Using a *t*-test in SPM2, we compared the six participants who were still together with the six who were apart at 40 months. We investigated regions that were affected during early-stage love in the Xu et al. [34] study. We applied a sphere as a region of interest (ROI) (sphere radius = 2–10 mm, $p \leq .05$, FDR corrected) to each of the areas. We also conducted an exploratory whole brain analysis ($p \leq .001$, uncorrected; $\geq$15 voxels).

For the six participants that were still together, we investigated correlations between brain activity and relationship happiness and commitment. For correlations performed on each voxel, we accepted $p < .01$ (uncorrected) for the single peak voxel in a cluster (with minimum 15 voxels). We accepted this low threshold because the areas were regions of interest, involved in the main contrast and other studies of romantic love.

Because our sample was small, we considered that our low power may lead us to miss experimental effects, particularly for the correlational analyses, and thus limit the completeness of our results. However, the standards for reaching significance with such a small group require quite substantial effect sizes, and we inspected all the correlations for outliers.

2. Results

2.1. Early-stage brain activity associated with relationship longevity

Still together > apart

There was greater activity during early-stage love in those still together after 40 months than those who were broken up in the caudate tail (Table 1), a region similar to where Xu et al. [34] found activation for the entire group in the early stage of love. Whole

Table 1
Regional brain activation during an early-stage love scan that predicted relationship outcomes after 40 months. Comparison contrast was Partner versus Neutral Acquaintance.

Brain region	Group results during early-stage love Xu et al. [34]								Regions where there were differences in early-stage activation between the group that was still together compared to those who were apart 40 months after the scan							
	Left				Right				Left				Right			
	x	*y*	*z*	*p*	*x*	*y*	*z*	*p*	*x*	*y*	*z*	*p*	*x*	*y*	*z*	*p*
Still together > apart																
Region of interest analysis																
Caudate tail	−32	−44	4	.004	32	−44	12	.004			NS		32	−44	10	.01
Orbitofrontal cortex, mid			NS		38	28	−12	.05			NS			NS		
Cerebellum, vermis			NS		4	−60	−24	.04			NS			NS		
Whole brain analysis (*not significant*)																
Still together < apart																
Region of interest analysis																
Accumbens n., medial			NS		9	10	−12	.005			NS		9	10	−12	.04
Subcallosal cingulate[a]			NS			NS							5	18	−9	.01
Amygdala	−22	−12	−20	.04	20	−1	−20	.03			NS			NS		
Orbitofrontal cortex, medial			NS		2	54	−14	.005	2	57	−10	.01	2	57	−10	.01
Whole brain analysis																
Parieto-temporo-occipital area									−50	−66	17	.001				
Precuneus									−3	65	35	.<001	4	−65	33	<.001
Temporal lobe, posterior																
Middle gyrus									−59	−27	−9	.001				
Inferior gyrus									−59	−41	−19	.001				

MNI coordinates for highest intensity voxel in a cluster. The cluster may be elongated in any direction. ROI *p* values are for False Discovery Rate correction ($p \leq .05$). Whole brain analyses are uncorrected (threshold $p \leq .001$).
[a] Including BA25 and extending into accumbens.

brain analysis yielded no other significant areas that were more active at early-stage love for those still together versus those apart at 40 months.

Still together < apart

Xu et al. [34] reported accumbens, orbitofrontal cortex, and bilateral amygdala deactivation during early-stage love. ROI analyses showed less activity during early-stage in those still together (versus broken up) in the right accumbens and medial orbitofrontal cortex (Fig. 1A and B; Table 1). There was also less activation in those still together in the subcallosal cingulate (including BA25 and extending into the accumbens). Whole brain analysis showed deactivation in the parieto-temporo-occipital region, precuneus, and the temporal lobe (see Table 1; Fig. 1A and B).

2.2. Questionnaire scores at 40 months after the early-stage love scan

Relationship happiness at 40 months for those still together ($M = 5.83$, $SD = .98$) was *positively* correlated with early-stage activity in a posterior region of the medial orbitofrontal cortex (Table 2; Fig. 1B) and caudate tail (Table 2). Relationship happiness was *negatively* correlated with early-stage activity in an anterior region of the medial orbitofrontal cortex, the accumbens, and the subcallosal cingulate (including BA25) (Fig. 1A–C). The negative correlations overlapped substantially with the deactivation at the early stage of the relationship if the participant was still with their partner compared to those apart after 40 months. (Fig. 1A and B).

Relationship commitment for those still together ($M = 6.17$, $SD = .68$) was *positively* correlated with early-stage activity in the caudate tail and *negatively* correlated with activity in the medial orbitofrontal cortex (Table 2).

Table 2
Participants still together after 40 months: Regional brain activity at the early stage of love that correlated with reported relationship happiness and commitment after 40 months.

Brain region	Left				Right			
	x	*y*	*z*	*p*	*x*	*y*	*z*	*p*
Positive correlation								
Relationship happiness								
Subcallosal cingulate area[a]					13	45	−10	.01
Caudate tail	−32	−45	6	<.001				
Commitment								
Caudate tail	−34	−45	7	<.001				
Negative correlation								
Relationship happiness								
Subcallosal cingulate area[b]					9	26	−11	.001
Accumbens					9	10	−12	.001
Orbitofrontal cortex, medial					6	55	−14	.001
Commitment								
Orbitofrontal cortex, medial					6	56	−16	.001

MNI coordinates are at maximum value for cluster, which may be elongated in any direction. Threshold was $p \leq .01$, uncorrected.
[a] Similar to relationship happiness after 18 months [34].
[b] Including area 25.

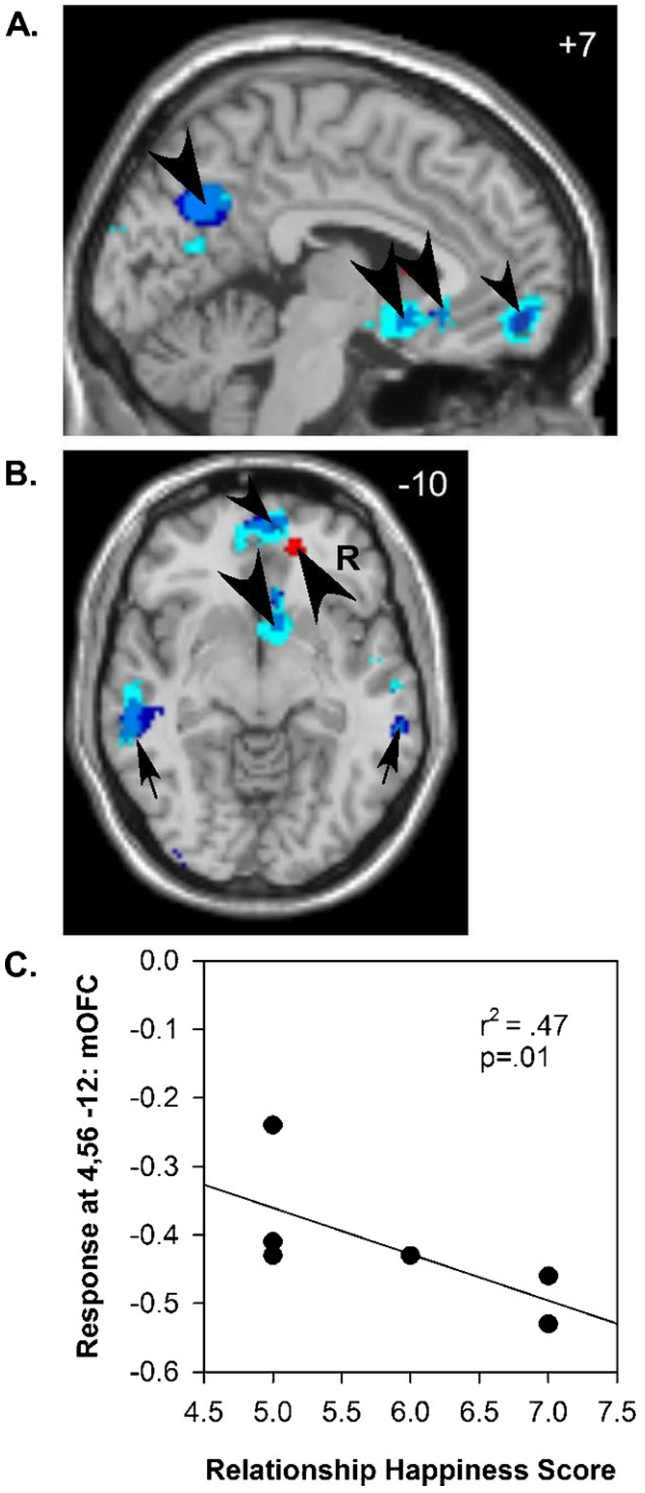

Fig. 1. Regions of brain deactivation (still together < apart) during early-stage romantic love that predicted relationship longevity (dark blue) and negative correlation between brain activation and relationship happiness at 40 months (light blue) show major overlap. Areas that showed a positive correlation between relationship happiness and brain activation are shown in red. (A) Sagittal section shows the mOFC (right arrowhead), subcallosal (right arrow), accumbens (middle arrow), and precuneus (left arrow) regions of deactivation and negative correlation with relationship happiness. (B) Axial section shows the mOFC region of deactivation in A (top arrowhead), mOFC region of a positive correlation with relationship happiness (arrow to red blob), and accumbens region in A (bottom arrow). Small arrows show areas of the temporal lobe with overlap of deactivation and a negative correlation with relationship happiness. (C) The graph shows the correlation between participants' relationship happiness scores and their brain responses in the mOFC. mOFC, medial orbitofrontal cortex; R, right. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

3. Discussion

These findings suggest that physiological markers present in the early stages of romantic love relationships may predict relationship longevity, satisfaction, and commitment 40 months later. The results are consistent with the enduring dynamics model. They suggest that there are, indeed, some factors in the initial stages of relationships which are important to later stages of enduring relationships.

Several brain regions are of special interest, which may be important for lasting relationships. Activation in the caudate tail, activated during early-stage intense passionate love [34], was associated with remaining together (versus breaking up) and greater self-reported commitment at 40 months follow-up assessment. These results are consistent with prior research linking caudate tail activity with relationship satisfaction [2,34]. The tail of the caudate, rich in dopamine receptors, is involved in visual processing [8,10,31,35], and receives projections from the inferior temporal cortex [35], another visual processing region where we found changes in activation. In addition, the medial orbitofrontal cortex and nucleus accumbens that showed deactivations during initial early-stage love [34] also showed less activity associated with relationship longevity, commitment, and happiness at 40 months. Acevedo et al. [3] found an *activation* at the same coordinates as this study in the medial orbitofrontal cortex for a group of participants in love for 10 or more years with their spouse. This strongly implicates the region in relationship longevity, even though the direction of the effect is different. Input strength and direction could easily change over time based on experience with the partner. The direction of an effect in an fMRI study is not as important as the localization data.

The medial orbitofrontal cortex (mOFC) is another region that may be important for long-term relationships. It plays a role in reward, learning, emotion, and cognitive decision making [22]. Activations in this region have been associated with making judgments about close others and the self [21,25]. Deactivations in the mOFC region have been associated with relationship satisfaction in long-term relationships [2], cognitively regulating emotions [26], and inhibitory cognitive control of cocaine cravings [32]. Importantly, deactivation in the mOFC, within 10 mm anterior–posterior to the present coordinates was correlated with assessments of the self as being "above average" [7], and with positive assessments of a close, romantic other as "above average" [15]. As Hughes and Beer [15] suggest, the mOFC may be part of a system for social cognition, reflecting overly positive evaluations of a romantic partner. Zeki [37] has proposed that the deactivations in the frontal lobe observed for romantic and maternal love is associated with suspension of critical judgments of the beloved. He suggests that deactivations in areas of the temporal lobe and precuneus where we saw deactivations in this study are also involved in moderation of critical judgments. Emotional regulation and positive social evaluations may be important for initiating the romantic bond, feeling satisfied in the relationship, and choosing to continue the relationship.

The nucleus accumbens showed both a deactivation associated with being together, and a negative correlation with relationship satisfaction. It plays a role in reward and decision-making [22], and deactivation in the nucleus accumbens is associated with satiety [12] as well as inhibitory cognitive control of craving in cocaine addicts [32]. Deactivation there was also associated with long-term love [2] (coordinates for long-term love: 8, 10, −10; coordinates for those together after 40 months at the early stage o love: 9, 10, −12). These results leads us to speculate that relationship satisfaction and inhibitory cognitive control during the early stage of a relationship influence better relationship outcomes at 40 months.

Activity in one part of the subcallosal cingulate area (which included BA25) was negatively associated with relationship happiness at 40 months. Acevedo et al. [2] also found a negative association between activity in this region and relationship happiness. Deactivation in this part of the subcallosal cingulate has been related to satiety while eating chocolate [30]. The region included some of BA25, which affects a large network associated with mood, appetite, self-esteem, and memory [19]. This subcallosal area was also less active in those who stayed together compared to those who broke up. This region is also close to an area of the ventral anterior cingulate cortex found to be associated with intimacy [15]. The results implicate this region in functions necessary for relationship happiness and longevity.

The findings illustrate that long-term relationship outcomes, particularly relationship happiness, involve more than simply the reward and motivated drive associated with basal ganglia activation that is the hallmark of intense romantic love. In addition to the drive for a partner, long-term relationship happiness and longevity are also reflected in brain regions involved in satiation when receiving a partner-related reward (e.g., seeing a picture of the beloved and recalling memories of them), emotion regulation, the ability to exert inhibitory cognitive control (of craving toward the partner) and social evaluation.

We also found potentially informative results with whole-brain analyses. Specifically, there was less activation for those still together in the parieto-temporo-occipital area; the precuneus, an area associated with representations of the self [20,23,29]; and posterior temporal regions, associated with visual processing, particularly for faces [13,14]. Decreased activation in posterior temporal regions is particularly interesting as Xu et al. [34] also found decreased activation in an area associated with visual processing and facial recognition: the fusiform face area. Since participants during the scan were asked to recall memories of their partner when they saw their partner's face, it could be that those who were better at immersing themselves in those thoughts and memories (and/or had richer memories of their partners), rather than just focusing on viewing the image, had better relationship outcomes 18 and 40 months later. Zeki [37] has proposed that deactivations in the temporal and parietal lobes may indicate a merging of the self with the beloved, obtaining "imagined unity-in-love."

3.1. Future directions

Future studies are necessary to confirm our findings about relationship longevity, happiness, and commitment. Future longitudinal neuroimaging studies should include larger *N*s than we used. This is not only because attrition should be expected, but also because as couples break up, this lowers the *N* for any correlational analyses on relationship factors such as happiness or commitment. It is important to keep in mind that the proportion of participants who "break up" versus "stay together" is difficult to predict and a skewed result may lead to insufficient power to compare the two groups.

Future studies should also investigate personality and attachment style, as these are factors that influence relationship outcomes. Future studies could also investigate negative outcomes of relationships (e.g., those who stay with their partner but are unhappy).

Our study was limited by the fact that the follow-ups were questions asked of the participants without a rescan. Thus, we were unable to investigate how activations in various regions of the brain change from early stage to later stages of the relationship. Future studies that use fMRI and other non-explicit measures at multiple time-points would greatly add to our basic understanding of the underlying mechanisms in relationship development.

3.2. Conclusions

This study provides initial evidence supporting the enduring dynamics model of relationship development. Factors present early in the relationship may play a major role in the development and longevity of the relationship. Also, these results, especially those that replicate other findings, help to identify the physiological systems and factors that are most important to stable relationships and may help us to teach individuals, couples, and families how to thrive.

Conflict of interest

We verify that none of the authors has a conflict of interest related to the work in this manuscript.

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