

Differences in Neural Response to Romantic Stimuli in Monogamous and Non-Monogamous Men

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Abstract In non-human animal research, studies comparing socially monogamous and promiscuous species of voles (*Microtus*) have identified some key neural differences related to monogamy and non-monogamy. Specifically, densities of the vasopressin V1a receptor and dopamine D2 receptors in subcortical reward-related and limbic areas of the brain have been linked to monogamous behavior in prairie voles (*Microtus ochrogaster*). Similar brain areas have been shown to be correlated with feelings of romantic love in monogamously pair-bonded humans. Humans vary in the degree to which they engage in (non-)monogamous behaviors. The present study examined the differences in neural activation in response to sexual and romantic stimuli in monogamous ($n = 10$) and non-monogamous ($n = 10$) men. Results indicated that monogamous men showed more reward-related neural activity when viewing romantic pictures compared to non-monogamous men. Areas with increased activation for monogamous men were all in the right hemisphere and included the thalamus, accumbens, striatum, pallidum, insula, and orbitofrontal cortex. There were no significant differences between groups in activation to sexual stimuli. These results demonstrate that the neural processing of romantic images is different for monogamous and non-monogamous men. There is some overlap in the neural areas showing increased activation in monogamous men in the present study and the neural areas that show differences in the vole models of monogamy and affiliation. Future research will be needed to clarify whether similar factors are contributing

to the neural differences seen in monogamous and non-monogamous humans and voles.

Keywords fMRI · Monogamy · Non-monogamy · Sexuality: visual sexual stimuli · Romantic love

Introduction

Animal research on pair-bonding and mating reveals that monogamy is rare, occurring in less than 3% of non-human mammals (Kleiman, 1977). For humans, there is cross-cultural variability in the endorsement and practice of monogamy, but even within cultures that promote social monogamy, there is evidence of non-monogamous behavior. Infidelity in the so-called monogamous relationships is not uncommon. A national survey of Americans found that 25% of men and 15% of women reported engaging in infidelity at some point in their marriage (Laumann, Gagnon, Michael, & Michaels, 1994). Additionally, more attention and research is being focused on consensual non-monogamy with lifetime prevalence rates of consensual non-monogamy ranking as high as 21% (Hauptert, Gesselman, Fisher, Moors, & Garcia, 2016). Data collected from an online sample of North American men and women show that there is a wide spectrum of attitudes and behaviors ranging from highly non-monogamous to highly monogamous in both men and women (Pujols, Hamilton, Seal, & Meston, 2007).

Self-report alone cannot explain the underlying factors that contribute to differences in levels of monogamy. The present study focuses on expanding our knowledge of factors that correlate with monogamy and non-monogamy by exploring neural differences that might correlate with behavioral differences in monogamy. The present study examined these differences in men who were on either side of the monogamy–non-monogamy spectrum.

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Much of what is known about the neural substrates of monogamy is drawn from the vole model that compares the closely related montane and meadow voles (*Microtus montanus* and *Microtus pennsylvanicus*) with the prairie vole (*Microtus ochrogaster*) and, less frequently, with the pine vole (*Microtus pinetorum*). Prairie and pine voles are socially monogamous; males and females of these species form long-lasting pair-bonds, share nests, and rear offspring together (reviewed by Carter, DeVries, & Getz, 1995). Montane and meadow voles do not form pair-bonds, and they mate freely with many partners. Male montane and meadow voles are not involved in parental care, and females spend much less time with their young and cease brooding a litter more quickly than prairie voles (Gruder-Adams & Getz, 1985; Oliveras & Novak, 1986; McGuire & Novak, 1984). Studies comparing the montane and prairie voles have identified oxytocin (OT), vasopressin (AVP), and dopamine (DA) in subcortical limbic and reward areas of the brain as playing key roles in the pair-bonding observed in the prairie voles (see Young, Gobrogge, Liu, & Wang, 2011; Young & Wang, 2004 for a comprehensive review).

One of the key differences in the neuropeptide systems between the monogamous and promiscuous species of voles is the difference in AVP and OT receptor densities in specific areas of the brain. AVP receptor V1a (V1aR) density has been found to be higher in the thalamus, ventral pallidum, medial amygdala, and the bed nucleus of the stria terminalis in prairie voles compared to montane voles (Insel, Wang, & Ferris, 1994). OT receptor densities have been shown to differ between prairie and montane voles in the nucleus accumbens, prelimbic cortex, bed nucleus of the stria terminalis (BNST), lateral amygdala, and medial thalamus with prairie voles having higher densities (Insel & Shapiro, 1992).

In addition to structural differences in OT and AVP receptors in the brains of prairie and montane voles, manipulation of AVP and OT or their receptors causes changes in behaviors related to pair-bonding and affiliation in monogamous voles. Administration of AVP or OT increased affiliative behaviors in prairie voles such that both males and females were quicker to form a pair-bond and spend more time with their partner (Cho, DeVries, Williams, & Carter, 1999; Winslow, Hastings, Carter, Harbaugh, & Insel, 1993). Although AVP may be more important for pair-bonding in males and OT may be more important for pair-bonding in females, both are capable of facilitating pair-bonding in both sexes (Cho et al., 1999). Blocking V1aR in the ventral pallidum has been shown to have the most negative impact on pair-bonding in male prairie voles, and it has been suggested the ventral pallidum is the key structure involved in facilitating pair-bonding in male prairie voles (Lim & Young, 2004).

Genetic studies have shown that manipulating the V1aR gene so that it is over-expressed increases pair-bonding activity in the already monogamous prairie voles (Pitkow et al., 2001) and the promiscuous montane voles (Lim et al., 2004). Altering the genetic expression of V1aR in other species, such as mice,

has also been shown to increase their affiliative behavior (Young, Nilsen, Waymire, MacGregor, & Insel, 1999), so the effects of AVP on V1aR do extend to other species.

Many of the areas innervated with high levels of OT and AVP receptors are also rich in DA receptors and are involved in the reward circuitry. The interaction between DA and OT/AVP in the mesolimbic reward pathway is critical for the pair-bonding that occurs in prairie voles. Prairie voles have much higher density of D2 dopamine receptors compared to montane voles in the nucleus accumbens, thalamus, and other areas in the reward pathway (Aragona, Liu, Curtis, Stephan, & Wang, 2003; Aragona et al., 2006). While mating is rewarding for all vole species, it appears that the combination of high levels of AVP/OT receptors and DA receptors in specific areas is necessary for long-term pair-bonding. Thus, in the monogamous male prairie voles, these brain areas involved in reward are also involved in bonding, more so than in the promiscuous voles.

Do similar neural substrates correlated with (non-)monogamy in humans? Research on infidelity and consensual non-monogamy has demonstrated that there is diversity in tendencies and preferences for monogamy in humans (e.g., Atkins, Baucom, & Jacobson, 2001; Barker & Langdrige, 2010), so it is not unlikely that this diversity would be represented in neural responses to sexual stimuli. At least one study found differences in physiological measures between people who were in different types of relationships; specifically, people in polyamorous relationships had higher testosterone than people in monogamous relationships (van Anders, Hamilton, & Watson, 2007). Monogamous pairings are the culturally predominant relationship type in Western cultures, and there is evidence of cultural pressure toward monogamy. There is documented stigma toward people who engage in consensual non-monogamy (Conley, Moors, Matsick, & Ziegler, 2013), and most men who engage in dating infidelity state that monogamy is their eventual goal (Anderson, 2010).

It is unclear at this point the degree to which monogamy is a trait characteristic or if it is state (relationship/age/life circumstances) dependent, but there is plenty of evidence of non-monogamy within supposedly monogamous pair-bonds. Our working hypothesis, based on both the animal and human literature, is that monogamy is a trait characteristic, and this is reflected in our approach at comparing responses to men who have demonstrated monogamous tendencies throughout their lives to men who have demonstrated non-monogamous tendencies throughout their lives.

Researchers have taken steps toward understanding neural correlates of pair-bonding in humans. When people who were “madly in love” were shown pictures of their romantic partner, they showed increased activation in limbic and reward-related areas of the brain when compared to activation corresponding to pictures of non-romantic friends (Aron et al., 2005; Bartels & Zeki, 2000; Xu et al., 2011) or to pictures of their children (Bartels & Zeki, 2004). Specifically, brain areas related to

romantic love include the ventral tegmental area (VTA), caudate, putamen, insula, and either the anterior or posterior cingulate cortex. In addition, most of the studies have shown more right hemisphere activation than left hemisphere or bilateral activation, indicating that the right hemisphere plays a larger role in pair-bonding in humans.

A study on men and women who were in monogamous, long-term relationships (mean relationship length = 21 years) and reported still having feelings of intense love showed results most closely aligned to research in the vole model. When shown a picture of their long-term partner contrasted with a familiar acquaintance, participants in long-term, intense-love relationships showed increased activation in bilateral pallidum, thalamus, caudate, putamen, and substantia nigra. They also had increased activation in the right hemisphere VTA and nucleus accumbens. All of these differences occurred in brain areas involved in the bonding and/or reward neural circuits. These participants also showed more cortico-limbic activation, including bilateral insula and both bilateral anterior and left hemisphere posterior cingulate when viewing a picture of their partner versus a familiar acquaintance (Acevedo, Aron, Fisher, & Brown, 2012).

The research on both voles and humans indicates that there are many areas of overlap between the neural substrates of reward and pair-bonding. Compared to the promiscuous montane and meadow voles, the monogamous prairie voles have more neural links between bonding and reward, and it was predicted that human men who are highly monogamous would also have stronger connections between pair-bonding and reward than highly non-monogamous men. The present study was designed to explore potential differences in neural activation, as measured by fMRI blood oxygen level-dependent (BOLD) responses, between monogamous and non-monogamous men when exposed to romantic and sexual stimuli.

The study had the following hypotheses.

1. Since sexual behavior is inherently pleasurable, we expected that there would be similar activation in subcortical reward-related areas of the brain in response to sexual stimuli for both monogamous and non-monogamous men. This was not a primary hypothesis, but was included for descriptive purposes to compare to past research.
2. For romantic stimuli, we hypothesized that there would be between-group differences in response to the romantic stimuli (comparing romantic versus neutral contrasts) such that monogamous men would show more activation than non-monogamous men in the limbic and reward areas identified in both the vole and human romantic love literature, including the medial amygdala, pallidum, nucleus accumbens, putamen, and caudate. This would support the notion that the romantic/pair-bonding stimuli are more rewarding/reinforcing to monogamous men.

3. We expected that monogamous men would have a stronger cognitive association between romance and sex compared to non-monogamous men. Specifically, for Hypothesis 3, we predicted that a within-group comparison of activation differences between romantic and sexual stimuli would reveal more differences in activation between the two conditions for non-monogamous men compared to monogamous men.

Method

Participants

Participants were 20 heterosexual men who were currently sexually active with at least one female partner. All participants were interviewed over the phone prior to coming to the laboratory in order to screen for monogamy status and to ensure they would not be at risk during imaging. For the purposes of this study, we only accepted participants who qualified as highly monogamous and highly non-monogamous in both their behaviors and their attitudes.

Since there are no measures, to our knowledge, that are able to categorize the degree of non-monogamy, we first defined monogamy conceptually as romantic and sexual interest in one partner at any given time (encompassing attitudes, desires, and behaviors related to monogamy). Then, through data derived from an online survey of 700 participants (partial data have been presented in Hamilton, Pujols, & Meston, 2012; Pujols et al., 2007), we were able to determine clusters of participants based on the degree to which their behaviors, attitudes, and desires aligned with monogamy or non-monogamy. In the online sample, approximately one-third of participants qualified as highly monogamous, one-third qualified as highly non-monogamous, and one-third fell in between those two categories. To be considered monogamous, participants had to report never dating more than one person at a time, never engaging in an extra-partner affair, and not having any desire to engage in an extra-partner affair (even if there was hypothetically no risk of being caught or having any negative consequences). An additional variable that was found to distinguish monogamous from non-monogamous men based on the data from the larger study was the number of sexual partners they had and how often they fantasized about women other than their partners. We included these factors in the screening tools. Monogamous participants had to have fewer than five sexual partners in their lifetime and report fantasizing about women other than their current partner less than once per month. Non-monogamous participants had previous or current relationships with multiple partners (includes both cheating and consensual non-monogamy), more than five sexual partners in their lifetime (all were much higher), and indicated a preference for multiple concurrent partners.

From the screening questions, we selected 10 men who were highly monogamous and 10 age-matched men who were highly non-monogamous to participate in the study. Participants in the groups ranged in age from 22 to 50 with a mean age of 34 years. See Table 1 for further demographic and relationship data.

Materials

Demographics Questionnaire

This questionnaire assessed basic demographic information including age, ethnicity, religion, income, and relationship details. There were also health and psychological well-being screening variables to ensure participants would not be harmed by their participation in the study.

Derogatis Sexual Function Inventory—Experience Scale (DSFI-E; Derogatis & Melisaratos 1979)

This scale measures the range of participants' sexual experience by having them indicate whether or not they have engaged in 24 sexual behaviors. Participants answered the questionnaire twice,

once to indicate their lifetime experience and once to indicate their experiences in the past 60 days. Participants responded on a Yes/No scale, and the score was calculated by summing the number of "Yes" responses for a maximum score of 24.

Sociosexual Orientation Inventory (SOI; Simpson & Gangestad 1991)

The SOI is a 7-item survey that was designed to assess the degree to which individuals are willing to engage in casual, uncommitted sexual activity. Items address past sexual behavior (e.g., "With how many different partners have you had sex within the past year?") and current attitudes toward sexual behavior (e.g., "I can imagine myself being comfortable and enjoying 'casual' sex with different partners."). This scale was used as part of our assessment of monogamy. This questionnaire was also included in the phone screen.

Events with Others

This scale was adapted from Buss and Shackelford's (1997) study on the susceptibility of infidelity of spouses. Participants

Table 1 Demographic, sexuality, and relationship information

	Monogamous (<i>n</i> = 10)	Non-monogamous (<i>n</i> = 10)
Age in years (SD)	34 (10.5)	34 (10.2)
Ethnicity		
Asian	0	1
Black/African-American	1	1
Latino	1	2
White	8	6
Relationship status		
Dating	0	7
Long-term relationship	2	1
Cohabiting/married	8	1
Other	0	1
Income (per year)		
<\$25,000	1	2
\$25,001–\$50,000	2	4
\$50,001–\$100,000	4	2
>\$100,000	3	2
No. of sexual partners		
Past year mean (SD)	1 (0)	6.6 (6.5) ^a
Lifetime median (range)	5 (1–5) ^a	30 (15–200) ^a
Sexual experience (DSFI)		
Mean (SD)		
Lifetime	21.8 (2.0)	21.1 (3.4)
Past 60 days	18.5 (2.7) ^a	20.1 (2.5) ^b

DSFI Derogatis Sexual Function Inventory. The Experience subscale has a max score of 24

^a Data missing for 1 participant

^b Data missing for 2 participants

were asked their likelihood of engaging in various acts of infidelity (flirting, passionately kissing, going on a date, having a one-night stand, having a serious affair). They were asked to report on the likelihood of engaging in these behaviors behind their partner's back or with their partner's consent. This scale was used as part of our assessment of monogamy. This questionnaire was also included in the phone screen.

Perspectives on Monogamy

This questionnaire was developed by the researchers and asked participants about their current and ideal relationship style, their fantasy about and attraction to their partners and women other than their partners, and hypothetical questions about monogamy. Examples of hypothetical monogamy questions include: "If you lived in a world where everyone had open relationships (people having concurrent partners), would you be monogamous?" and "In a steady relationship, could you ever engage in a brief sexual encounter with someone other than your partner? (Assuming zero chance of pregnancy, disease or discovery by a partner)." This questionnaire was also included in the phone screen.

Stimuli

Stimuli included still images that were categorized into the following four categories: neutral landscapes, neutral with people, romantic, and sexual. Neutral and romantic images were gathered from various Web sources. Sexual images were drawn from the images used in a previous eye-tracking study (Rupp & Wallen, 2007). Pilot testing in the scanner indicated that one participant (of two) showed some reward activation to the neutral stimuli containing two people. We added a second neutral category that just included landscapes in order to ensure we had a truly neutral condition. All neutral images with people had two people doing daily tasks (e.g., barbecuing) that were not likely to be construed as romantic. Romantic images all included a man and a woman engaging, fully clothed, in romantic situations (e.g., hugging, hand holding). Sexual stimuli all included a man and a woman who were wearing little to no clothing and engaging in penetrative vaginal intercourse. Before inclusion in the study, all images were viewed and ranked by undergraduate men. Rankings were done on a 7-point scale (1 = not at all; 7 = extremely) for the following descriptors: Romantic, Enjoyable, Pleasure, Love, Sexual, Disgusting, Interesting. Only those ranked high in "love" and "romance" were included in the romance condition, and only those ranked high in "sexy" and "pleasure" were included in the sexual condition, although many of the romantic pictures also ranked high in "pleasure." All neutral images were ranked low on all of the emotional descriptors.

Once we had identified the most sexual, romantic, and neutral images, we combined them into blocks of 4 pictures per category

(neutral, neutral with people, romantic, sexual) and had undergraduate men come to the laboratory to rank the chosen images again, in the format they would be presented to the fMRI participants. Results from these rankings are presented in Fig. 1. These images were then used for the present fMRI study.

Procedure

Participants were informed prior to participation of the sexually explicit nature of the study. Upon arrival for the scanning procedures, participants had the study explained to them verbally and also read and provided written informed consent. The Institutional Review Board and the authors' institution approved all study procedures.

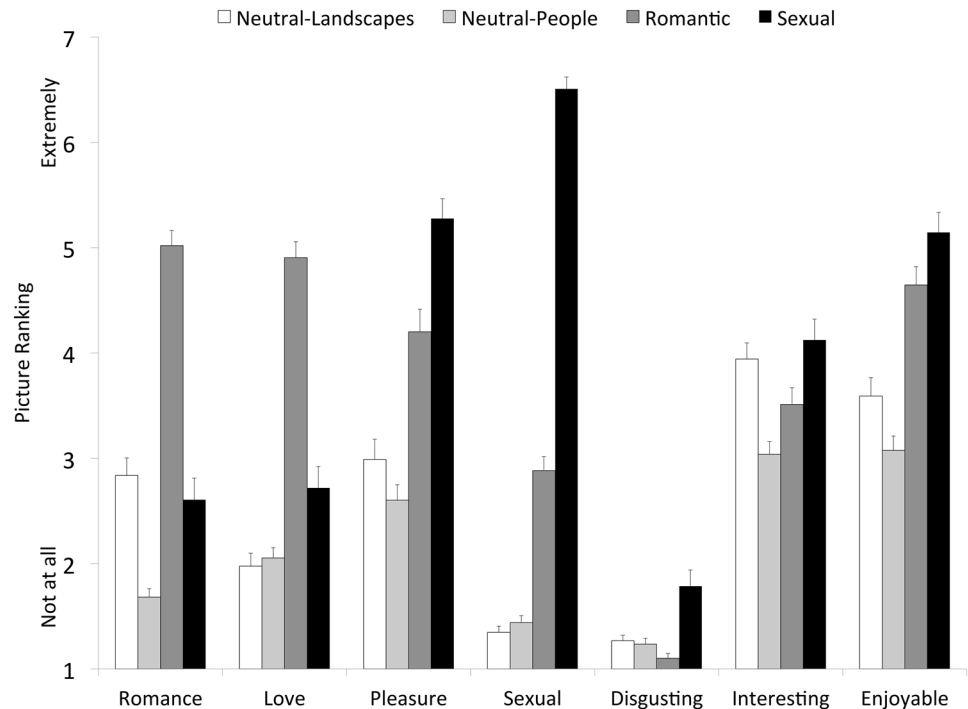
Once in the scanner, participants were shown alternating blocks of images. Each block had 4 pictures from a single category that were presented for 3.5 s each, making each block a total of 14.06 s including transition time between images. Block order was counterbalanced across two functional scans, and each scan consisted of 4 repetitions of each block type. Images were projected into the scanner and reflected by a mirror so that participants could view them on a screen directly above them. Participants were instructed to attend to the pictures presented on the screen. Similar to previous fMRI studies of sexual images (Hamann, Herman, Nolan, & Wallen, 2004), we did not require participants to respond to the stimuli, so as not to interfere with their attention and emotional response to the stimuli. To control for increases in arousal that might result from viewing sexual pictures, participants were asked to complete a 15-s countback task after each block of sexual pictures (Aron et al., 2005). Specifically, the countback screen instructed participants to count (silently) backward by 3 from a large number.

Once the scanner portion of the study was completed, participants completed a series of questionnaires that confirmed the information provided in their screening interviews, as well as the additional questionnaires listed above. At the conclusion of the study, participants were fully debriefed and paid \$50 for their participation.

Image Acquisition and Data Analysis

Structural and functional MR images were acquired using a GE Sigma EXCITE 3.0 Tesla scanner. During stimuli presentation, functional EPI images were collected using a GRAPPA parallel sequence utilizing whole-head coverage with slice orientation to reduced artifact (approximately 20 degrees off the AC-PC plane, TR = 2 s, 1 shot, TE = 30 ms, 35 axial slices oriented for best whole-head coverage, acquisition voxel size = 3.125 × 3.125 × 3 mm with a .3-mm inter-slice gap). The first four EPI volumes were discarded to allow scans to reach equilibrium. In addition to the functional scans, one or two high-resolution T1 SPGR scans that have been optimized for high contrast between

Fig. 1 Descriptive statistics for rankings on the image categories. Means (\pm SEM)



gray and white matter, as well as between gray matter and cerebrospinal fluid, were acquired. These images were acquired in the sagittal plane using a 1.3 mm slice thickness with 1 cubic mm in plane resolution.

Structural and functional images were created, registered, and analyzed using FMRIB Software Library (FSL; www.fmrib.ox.ac.uk/fsl) software. BOLD responses for all picture conditions (sexual, romantic, neutral with people, neutral landscapes) and the countback condition were modeled separately as predictors and then contrasted against one another in analyses of interest using FEAT (FMRI Expert Analysis Tool) version 5.98, part of FSL software. Within FEAT, images were preprocessed using MCFLIRT for motion correction and BET for removal of non-brain components of the image. Each participant's functional data were registered with their own high-resolution T1-weighted structural scan and then to the 2-mm-resolution MNI-152 template brain. Functional data were smoothed using a 5-mm kernel. Within-subject compilation of runs, and contrasts were conducted using fixed effects analyses. Higher-level analyses tested between-group and within-group differences using a random effects FLAME 1 and 2 analysis with cluster size thresholding *t* tests to control for multiple comparisons. The threshold was set at $Z = 2.3$, $p < .01$, and the cluster-wise threshold was set at $p < .01$ (Worsley, 2001).

Although there were some key areas of interest derived from previous literature on voles and on human romantic relationships, since this was the first study to compare activation between sexual and romantic stimuli, we did not want to limit our analyses to specific regions of interest. The exploratory nature of the research

and the diffuse nature of activation in response to sexual stimuli were the primary reasons for opting for whole-head analyses.

Results

For Hypothesis 1, to assess the similarities and differences in neural activation in response to sexual stimuli, we first calculated the sexual versus neutral contrast for each participant and group. To do so, we subtracted the average of the two neutral conditions from the sexual condition. We then compared the activation patterns in the monogamous and non-monogamous groups. There were no significant differences between the groups in their BOLD responses to sexual stimuli based on this sexual versus neutral contrast.

For descriptive purposes, and for comparison to other studies, we included the combined activation for all participants in their sexual versus neutral contrast in Fig. 2a–c. Significant cortical activation was shown bilaterally in the occipital and parietal (mostly superior) cortices, the superior frontal gyri, the precentral and postcentral gyri, the fusiform gyrus, the anterior cingulate cortex, and the left hemisphere insula. Subcortical activation included bilateral activation in the amygdala, nucleus accumbens, caudate head and body, substantia nigra, and thalamus, as well as activation in the left hemisphere hypothalamus and left hemisphere putamen.

For the between-group comparison of neural response to romantic images (Hypothesis 2), we calculated the romance versus neutral contrast by subtracting the average activation

for the two neutral conditions from the average activation for the romantic condition. As predicted in Hypothesis 2, monogamous men had increased activation in limbic and reward-related areas of the brain compared to non-monogamous men. For the romantic versus neutral contrast, the monogamous men had increased activation in the right hemisphere thalamus, nucleus accumbens, caudate, pallidum, putamen, insula, and prefrontal cortex (Table 2, Fig. 2d–f). There were no areas for which the non-monogamous men had higher levels of activation than the monogamous men for the romantic versus neutral contrast.

The final hypothesis was that non-monogamous men would show more differences in activation patterns between romantic and sexual stimuli than monogamous men. We tested Hypothesis 3 by subtracting the sexual condition from the romantic condition separately for both groups of men (romantic versus sexual). For the monogamous men, there was no significant activation for this contrast, indicating that areas that were active in response

to the romantic stimuli were still active in response to the sexual stimuli. This indicates that there is similar activation for both sexual and romantic stimuli in monogamous men. For the non-monogamous men, the romantic versus sexual contrast showed increased activation in several regions of the cortex, including bilateral frontal and orbitofrontal cortex, RH pre- and postcentral gyri, bilateral superior temporal cortex, and LH angular gyrus (Table 3, Fig. 3). This supports the hypothesis that there was a greater difference between romance and sex for the non-monogamous men.

Discussion

Using the neurobiology of monogamy model developed in studies of voles, the present study was designed to explore the neural correlations of monogamous and non-monogamous behavior in

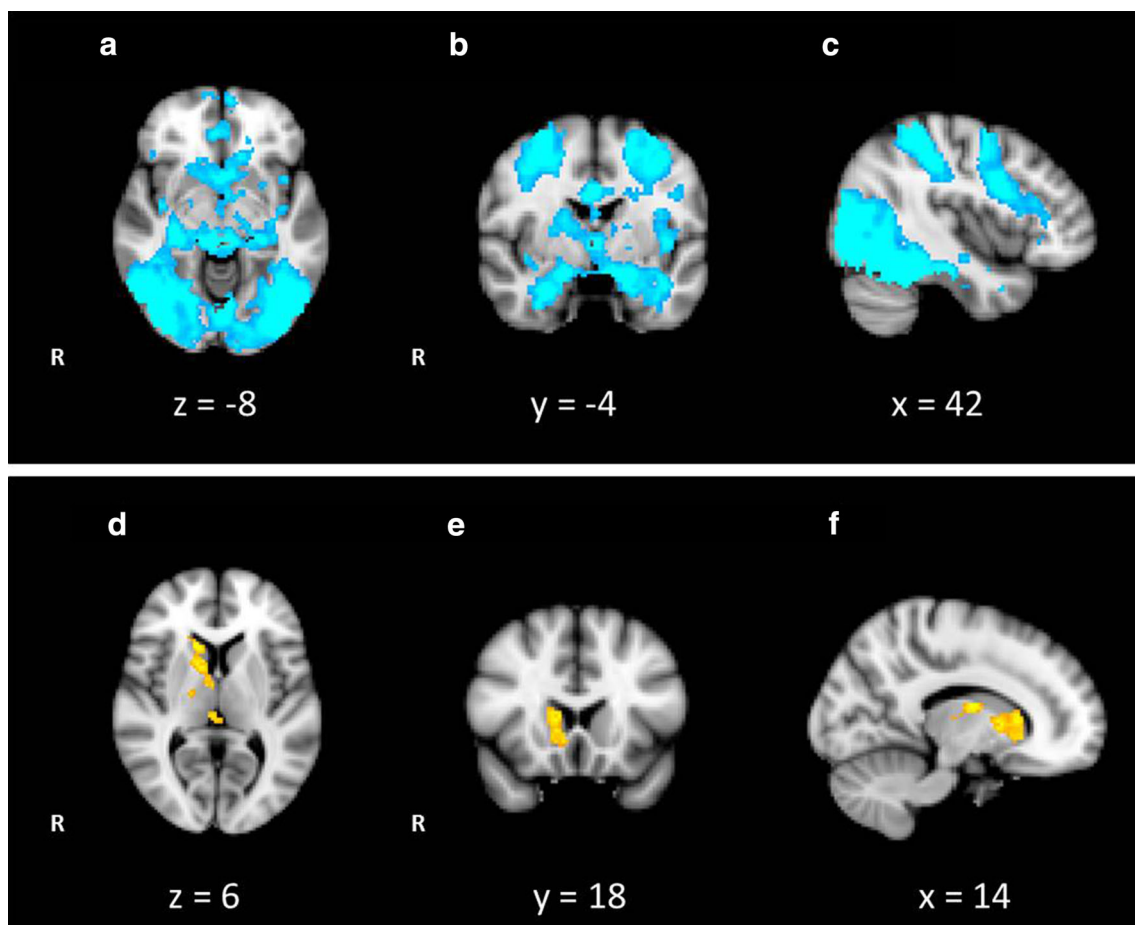


Fig. 2 *Top panel (blue)*. Activation for all participants in response to sexual stimuli (sexual > neutral). There were no significant differences between groups. **a** Horizontal slice showing bilateral occipital, inferior temporal, anterior cingulate, nucleus accumbens, and substantia nigra activation. **b** Coronal slice showing bilateral prefrontal gyrus, anterior cingulate, amygdala and thalamus, caudate, and LH insula activation. **c** Sagittal slice showing occipital, parietal, and frontal cortex activation.

Bottom panel (yellow). Increased activation for monogamous men compared to non-monogamous men (romantic > neutral). **d** Horizontal slice showing RH inferior frontal gyrus activation, RH caudate head, caudate body, and thalamus activation. **e** Coronal slice showing RH caudate, thalamus, putamen, and nucleus accumbens activation. **f** Sagittal slice showing thalamus, caudate, and thalamus activation (Color figure online)

Table 2 Regions with increased activation for monogamous men compared to non-monogamous men for the romantic > neutral contrast

Brain region	Max Z	x	y	z
R Thalamus	4.22	14	−6	14
R Accumbens	4.07	10	18	−6
R Caudate (head)	3.68	12	18	8
R Caudate (body)	3.33	10	6	6
R Pallidum	3.20	12	6	−8
R Putamen	3.42	24	8	−8
R Insula	3.52	32	24	−4
R Inferior frontal/orbitofrontal	3.49	42	42	−6

Coordinates are MNI-152

Table 3 Regions with increased activation for non-monogamous men compared to monogamous men for the romantic > sexual contrast

Brain region	Max Z	x	y	z
R Operculum	4.43	42	−16	14
L Operculum	3.92	−38	−30	18
R Superior temporal	4.25	58	−10	2
L Posterior superior temporal	3.70	−56	−26	0
R Precentral gyrus	4.18	24	−26	70
R Postcentral gyrus	4.11	28	−30	18
R Frontal middle gyrus	4.40	28	58	0
L Frontal middle gyrus	3.56	−34	52	2
L Frontal pole	4.06	−36	58	−8
R Frontal pole	4.05	36	52	−8
L Angular gyrus	4.15	−46	−62	46

Coordinates are MNI-152

human men. Both monogamous and non-monogamous men had similar responses to sexual stimuli, as expected. Our results closely mirrored the findings from a meta-analysis on fMRI activation of heterosexual men in response to erotic pictures in heterosexual men (Stoléru, Fonteille, Cornélis, Joyal, & Moulier, 2012).

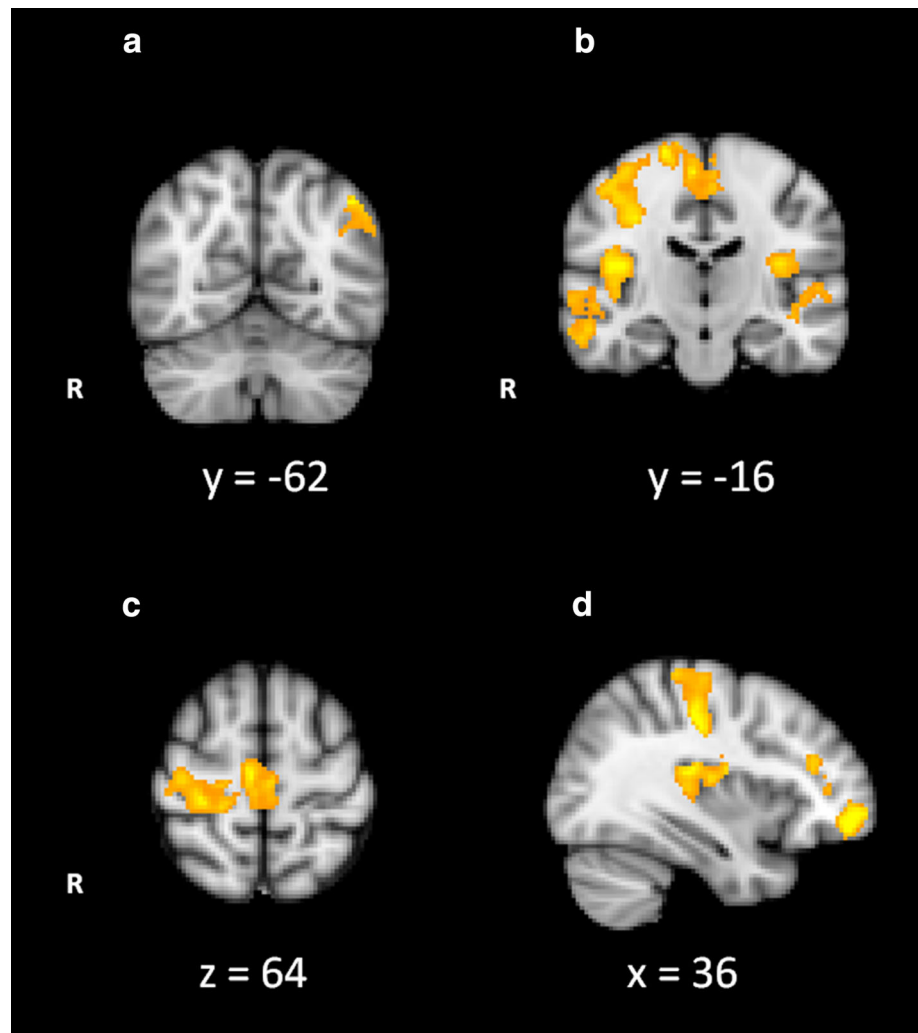
The primary results of interest for this study were those involving romantic stimuli. We hypothesized that when viewing romantic pictures, monogamous men would show more BOLD activation in subcortical reward- and pair-bonding-related areas of the brain compared to non-monogamous men. Previous studies on the underpinnings of romantic love have only studied men who report being monogamous in their current relationships. The present study used images to evoke the concepts of love and romance independent of the participants' own relationships, which would likely be less rewarding than the images of loved ones used in previous studies. Even with these less personal images, we found that men who identified as highly monogamous showed greater activation in brain areas related to both reward and pair-bonding than non-monogamous men when shown images of couples in

romantic situations, specifically in the thalamus, nucleus accumbens, striatum, pallidum, insula, and inferior frontal cortex. These findings are similar to those seen in previous studies comparing activations to a romantic partner versus an acquaintance (Aron et al., 2005). These data are the first to show a difference between monogamous and non-monogamous men in their processing of romantic visual stimuli.

These data suggest that these types of romantic stimuli are more rewarding/reinforcing to men who are more likely to engage in monogamous pair-bonding. There are many possible explanations for the cause of this difference. It is likely that men who are monogamous have had more rewarding pair-bonding experiences in their lives and have been conditioned to associate images of pair-bonding with pleasure. Whether the link between reward and bonding is a completely learned behavior, or whether these men have a biological predisposition toward monogamous behavior cannot be determined from the present study.

We also showed that the activation for romantic and sexual stimuli was more similar for monogamous men than for non-

Fig. 3 Activation for non-monogamous men (romantic > sexual). **a** Coronal slice showing angular gyrus activation, **b** Coronal slice showing bilateral precentral gyrus, bilateral insula, RH operculum, and bilateral temporal lobe activation. **c** Horizontal slice showing mostly RH pre- and postcentral gyri activation. **d** Sagittal slice showing RH insula, precentral gyrus, and frontal cortex activation



monogamous men. When sexual activation was subtracted from romantic activation in the group of monogamous men, there were no active voxel clusters, indicating that areas activated by viewing romantic pictures were also active while viewing sexual pictures. There is additional activation that results from viewing sexual stimuli, but this activation builds upon the romantic activation. By contrast, the non-monogamous men showed much greater cortical activity during romantic stimuli. Their lack of subcortical reward activation combined with increased levels of cortical activation is indicative of more conscious cognitive processing of the romantic images, as opposed to the more automatic subcortical activation seen in the monogamous men.

Although the sample size for the present study was small, the magnitude of the differences between groups was large enough to detect differences between the groups in their response to romantic stimuli. As hypothesized, we did not find any differences between the groups in their reward activation to sexual stimuli, but it is possible that the difference between the two

groups (if one exists) is smaller than the difference related to romantic stimuli. The small sample size precludes us from definitively saying that there is no difference between the groups because there may not have been enough power to detect the effect in the present study.

In this study, we were interested in differences related to monogamy; however, there are alternative explanations for the data that cannot be ruled out. We did not assess sexual desire or attachment style, and these could both be constructs that underlie the differences between these groups. Additionally, those who report not fantasizing about other women or not having interest in engaging in sexual activity might be more susceptible to social norms or be less liberal than those who report non-monogamy. None of our non-monogamous interviewees or our fMRI participants reported being in polyamorous relationships or in any form of open relationship with multiple *committed* partners, so our non-monogamous group did not include this subset of the population, who may respond differently than our current sample of non-monogamous men.

We did not have the participants rank the images they saw after they viewed them in the scanner. It would have been beneficial to know if there were self-reported differences between the monogamous and non-monogamous men in their rankings of romance and sexuality (and other variables used in the pilot study) that reflected the neural differences.

In conclusion, the present study identified differences between monogamous and non-monogamous men in neural responses to romantic stimuli. Monogamous men had more activation in dopamine-rich reward areas than non-monogamous men when viewing romantic pictures. The differences seen in the neural activation of the men in this sample are in brain areas that have shown structural and functional differences in monogamous and non-monogamous voles. Future research can explore the degree to which the vole model of affiliation and monogamy applies to humans to identify mechanisms that are similar and different across these species.

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