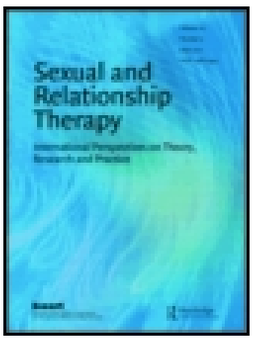

Sexual and Relationship Therapy

ISSN: 1468-1994 (Print) 1468-1749 (Online) Journal homepage: https://www.tandfonline.com/loi/csmt20

The obsessions of the green-eyed monster: jealousy and the female brain

Nadine Steis, Silvia Oddo-Sommerfeld, Gerald Echterhoff, Aylin Thiel, Jürgen Thiel, Katja Briem, Angela Ciaramidaro, Christine M. Freitag, Axel Mecklinger, Katja Unterhorst & Aglaja Stirn

To cite this article: Nadine Steis, Silvia Oddo-Sommerfeld, Gerald Echterhoff, Aylin Thiel, Jürgen Thiel, Katja Briem, Angela Ciaramidaro, Christine M. Freitag, Axel Mecklinger, Katja Unterhorst & Aglaja Stirn (2019): The obsessions of the green-eyed monster: jealousy and the female brain, Sexual and Relationship Therapy, DOI: 10.1080/14681994.2019.1615047

To link to this article: https://doi.org/10.1080/14681994.2019.1615047

Published online: 21 May 2019.

SEXUAL AND RELATIONSHIP THERAPY
https://doi.org/10.1080/14681994.2019.1615047

The obsessions of the green-eyed monster: jealousy and the female brain

Nadine Steis[a*], Silvia Oddo-Sommerfeld[b*], Gerald Echterhoff[c], Aylin Thiel[d], Jürgen Thiel[d], Katja Briem[e], Angela Ciaramidaro[a,f], Christine M. Freitag[a], Axel Mecklinger[g], Katja Unterhorst [h] and Aglaja Stirn[h]

[a]Department of Child and Adolescent Psychiatry, Psychosomatic Medicine and Psychotherapy, Goethe University, Frankfurt, Germany; [b]Department of Obstetrics, Goethe University, Frankfurt, Germany; [c]Department of Psychology, Social Psychology Group, University of Münster, Münster, Germany; [d]Im Bangert 9a, Kiedrich, Germany; [e]Department of Psychosomatic Medicine and Psychotherapy, Johannes Gutenberg University, Mainz, Germany; [f]Department of Education and Human Sciences, University of Modena and Reggio Emilia, Reggio Emilia, Italy; [g]Experimental Neuropsychology Unit, Saarland University, Saarbrücken, Germany; [h]Institute for Sexual Medicine and Forensic Psychiatry and Psychotherapy, Centre for Integrative Psychiatry, University of Kiel, Kiel, Germany

ABSTRACT

The present brain-imaging study assessed neural correlates of romantic jealousy in women who had suffered real infidelity by their partner. We predicted to find activation across different brain structures associated with the processing of negative emotions and cognitive processes as well as obsessive-compulsive behavior. FMRI scans were administered while participants listened to descriptions of their own or another person's experience of infidelity and jealousy, or to nonsense words. In the self-experienced (vs. other-experienced) jealousy condition, activity was greater in areas commonly associated with the interaction between different negative emotions (i.e., insula, anterior cingulate cortex, medial prefrontal cortex) such as fear, anger, sadness and cognitive processes like rumination. Enhanced activity was also found in the fronto-striato-thalamo-frontal circuit, a network implicated in habit formation and obsessive-compulsive disorder. Activation in the above networks was not enhanced when participants listened to other-experienced infidelity reports, as indicated by comparisons with the neutral condition. We discuss implications for the understanding and treatment of jealousy.

ARTICLE HISTORY
Received 25 July 2018
Accepted 22 April 2019

KEYWORDS
Jealousy; brain imaging; fMRI; obsessive-compulsive disorder (OCD); infidelity

Shakespeare called it the "green-eyed monster," haunting those who fear infidelity by a loved one. Jealousy can be broadly defined as the response to the threat of losing a real or imagined relationship with a target person, caused by a human rival (White & Mullen, 1989). It is a ubiquitous and socially relevant phenomenon that can pose

CONTACT Katja Unterhorst k.unterhorst@posteo.de Institute for Sexual Medicine and Forensic Psychiatry and Psychotherapy, Centre for Integrative Psychiatry, Arnold-Heller-Str. 3, Haus 28, 24105 Kiel, Germany.
*Both authors contributed equally.

serious threats to the well-being of the involved individuals (Oubaid, 1997). Jealousy is an issue among one third of all couples undergoing couple therapy (White & Mullen, 1989), and one reason for intimate partner violence (Southworth, Finn, Dawson, Fraser, & Tucker, 2007). In extreme cases, jealousy can trigger psychological disorders such as depression (Marazziti et al., 2010).

Given the prevalence and significance of jealousy, it is surprising that there is only scarce neuroscientific research on this topic (Takahashi et al., 2006; Sun et al., 2016). An EEG study by Harmon-Jones, Peterson, and Harris (2009) showed that jealousy involves pronounced approach motivation, specifically, tendencies to approach the desired target person and angry impulses directed at the rival. In one of the few functional brain imaging studies, Takahashi et al. (2006) found different brain activation patterns in male and female students during instructed imagination of sexual and emotional infidelity. Similarly, Sun et al. (2016) conducted an fMRI study in which they used jealousy-inducing scenarios to investigate the neural basis of romantic jealousy. They found that the jealousy scenarios induced activity in the basal ganglia. The intensity of romantic jealousy perceived by the participants was correlated with ventromedial prefrontal cortex activity. This relation was mediated by the intensity of romantic happiness, which was also induced through imagination. However, the participants in these two studies did not experience real infidelity but merely imagined how they would hypothetically react to infidelity. Because imagined and experienced infidelity differ in critical ways (Harris, 2003), these data may have limited validity.

Clearly, a challenge for research is to study genuine jealousy under laboratory conditions (Harmon-Jones et al., 2009). In the present study we tackled this challenge by recruiting women with recent infidelity experiences, and sought to identify neural correlates of their jealousy experience with functional magnetic resonance imaging (fMRI). To activate jealousy, we presented the participants with their own reports about the infidelity experience.

The analyses were guided by the following predictions. First of all, brain activity during real, self-experienced jealousy should involve a more complex network and should be more emotionally driven than the neural activities during the imagination of another person's infidelity experiences. It has been convincingly argued that jealousy comprises several emotional and cognitive components and hence is a complex phenomenon (Pines, 1992). Thus, we predicted enhanced activation across several brain structures associated with the processing of negative emotions (e.g. sadness, fear, anger, and rejection) and cognitive processes (like autobiographical recollection and rumination). Specifically, activity was expected in the anterior cingulate cortex (ACC) and the insula (Eisenberger, 2012; Phan, Wager, Taylor & Liberzon, 2002), which have been linked to relationship distress (Gillath, Bunge, Shaver, Wendelken & Mikulincer, 2005), grief about the loss of a significant other (Gündel, O'Connor, Littrell, Fort & Lane; 2003) and (social) pain (Eisenberger, 2014; Lieberman & Eisenberger, 2015). Especially the dorsal ACC (dACC) and the anterior insula (AI) have been associated with the affective component of social pain, although more recent research has suggested that this circuitry might not be specific to social pain but seems to include positive social evaluation as well, as long as it is self-related (Dalgleish et al., 2017; Perini et al., 2018). During the reliving of a socially painful

experience, activity in the dACC and AI was correlated with the magnitude of self-reported pain (Meyer, Williams, & Eisenberger, 2015). This is especially relevant for our study, since the participants had to re-experience a painful social event that happened in the past. Activity was also expected in cortical midline structures, which have been implicated in autobiographical memory (Oddo et al., 2010), self-referential processes (Northoff et al., 2006) and rumination (Denson, Pedersen, Ronquillo & Nandy, 2009).

Researchers have identified typical features of excessive or pathological jealousy vis-à-vis normal romantic jealousy (for a review, see Kingham & Gordon, 2004). Many studies have linked excessive jealousy to psychiatric disorders, or have detected increased occurrence of psychopathological symptoms in jealousy (e.g., Landazabal, 2006). Marazziti et al. (2003) investigated the relationship between excessive jealousy and different forms of psychopathology. They found evidence for increased prevalence of psychopathological conditions in participants who reported having excessive jealousy concerns. Interestingly, the jealousy group displayed lower density of 5-HT transporter proteins. Similar alterations of the serotonin system are associated with various psychiatric disorders, such as depression and obsessive-compulsive disorder. Soyka and Schmidt (2011) assessed delusional jealousy ratings in a sample of psychiatric patients and found the highest prevalence rates of delusional jealousy in patients with schizophrenia and other psychotic disorders.

Furthermore, compulsive tendencies as well as undesired impulses and habits are a hallmark of jealousy, and clinical observations have suggested parallels between jealousy and obsessive-compulsive behaviors (Marazziti et al., 2010; Val, Nicolato, Salgad, & Teixeira, 2009; Sheikhmoonesi, 2017). Marazziti et al. (2010) developed a questionnaire to measure subtypes of normal jealousy in a large sample of students. Their factor analysis identified "obsessionality" as one out of five factors, and thus as one subtype of jealousy. Obsessive-compulsive disorder has been linked to anomalous activities in the fronto-striato-thalamo-frontal circuit (e.g. Sakai et al., 2011), especially the thalamus (Rotge et al., 2012). More broadly, the fronto-striato-thalamo-frontal circuit has been implicated in formation of habits (Yin & Knowlton, 2006). Also, parts of the circuit are activated during the perception of one's romantic partner (Aron et al., 2005). Hence, we expected enhanced activity in the fronto-striato-thalamic-frontal circuit during jealousy.

Method

Participants

Participants were recruited via flyers in public places in Frankfurt and a website for student networking (studivz.de). Of 23 potential participants, 12 were excluded based on the criteria described below, resulting in a sample of 11 healthy heterosexual, right-handed, German-speaking women (mean age= 29.9 years, SD = 9.36; range: 20–50). All women had been in an intimate relationship with an average duration of one year (range: 0.5–6) and had been betrayed by their partners within the last 12 months.

Exclusion criteria were evidence for psychiatric diseases and MRI contraindications. To enhance the validity and precision of our measurement, we also excluded potential participants who were in a new relationship. Indeed, studies have found a negative association between romantic jealousy and romantic happiness (Kawamichi et al., 2016; Sun et al., 2016). In addition, the feeling of love is thought to deactivate regions in the brain that are associated with negative emotions, inference of others' emotions, and social judgement (de Boer, van Buel & Ter Horst, 2012; Zeki, 2007). Thus, new romantic love could substantially interfere with neural activities involved in jealousy. Psychiatric conditions were assessed with two screening instruments: the German version of the Brief-Symptom-Inventory (BSI; cut-off: t score > 63; normative t scores: 40–60) by Derogatis (Franke, 2000), and the German version of the Hospital Anxiety and Depression Scale (HADS-D; normative T-values: 40–60; Herrmann, Buss, & Snaith, 1995). Written informed consent was obtained from all participants. The study was approved by the Ethics Committee of the University Hospital Frankfurt (file number: 126/09).

Stimuli and materials

Three weeks before the fMRI-session, the participants reported their infidelity experience in semi-structured interviews (average length: 60 min) that were administered by a female interviewer and tape-recorded. Participants were asked to recall the infidelity experience spontaneously and as detailed as possible, and then asked for specific details such as the discovery of the infidelity and characteristics of the rival.

From each interview we selected 40 sentences, formulated in the first-person perspective, that were related to the jealousy experience. In the self-experienced jealousy condition (JC) the sentences were from the participants' own report, whereas in the other-experienced (control) condition (CC) the 40 sentences were taken from another person's jealousy report. The CC sentences were taken from the report of a potential participant who was excluded due to MRI contraindications. The 40 sentences in both conditions, which contained details from the reported story, were presented only once. Sentences were recorded with *Goldwave* 4.04 in the same female voice, with a maximum duration of 6 s. For the neutral condition (NC) nonsense words (taken from a German intelligence screening instrument; Lehrl, 2005) were recorded in the same voice and served as a high-level baseline (for examples, see Table 1).

Table 1. Examples of stimuli in the three conditions.

Jealousy Condition (JC)	
1.	While Jim is in the living room, he gets a text message on his mobile in the kitchen
2.	I see that Jim received a short message from his co-worker Tina and I read it
3.	Tina writes: The night with you was wonderful, I can't stop thinking of you
4.	I run into the living room and take Jim to task
5.	Jim tells me that he had sex with Tina last night in her apartment
Control Condition (CC)	
1.	My boyfriend Billy tells me on phone that he is on a short vacation with Lina in Munich while I am in London
2.	Billy travels with Lina to Munich even though we both have planned doing this trip together
3.	Billy tells me on phone that Lina and himself share a bed in the hotel
4.	After calling Lina, she tells me that she had sex with Billy in the hotel
5.	Lina tells me on detail how gentle Billy was to her while having sex together
Nonsense words (NC)	
1.	Kulinse
2.	Pamme

Postscanning behavioral data: reports of emotional involvement and valence

After the scanning session, participants rated all JC and CC stimuli on 6-point scales regarding their emotional involvement (*How emotional was the scene?* 0 = not emotional at all, 5 = very emotional) and valence (*How pleasant or unpleasant was the scene?* 0 = very unpleasant, 5 = very pleasant).

Design: fMRI paradigm

Stimuli from the three conditions (JC, CC, and NC) were presented in a randomized block design. In the JC and CC the 40 stimuli were divided into eight blocks of five sentences. Within one block a brief, but coherent scene from the jealousy report was presented. Each block lasted for 40 s, with an interstimulus interval of 2 s. The JC and CC were separated by the NC. The NC contained 17 blocks, each for 16 s, consisting of a randomized sequence of different nonsense words. The complete data recording lasted 912 s. All stimuli were presented via headphones. For the JC and CC, participants were instructed to listen attentively to the stimuli and to imagine the scenarios as vividly and emotionally as possible. For the NC they were asked to repeat the nonsense words silently.

fMRI data acquisition

The images were acquired on a Siemens Allegra 3 T scanner with a one-channel head coil at the Brain Imaging Centre in Frankfurt am Main. Multislice T2*-weighted echo planar images were obtained from a gradient-echo sequence with the following parameters: repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, field of view (FOV)= $192 \times 192\,mm^2$, flip angle = 90°, matrix size = 64×64, slice thickness= 3 mm, in-plane resolution = $3 \times 3 \times 3\,mm^3$. Thirty-six axial slices were aligned to the anterior and posterior commissure (ACPC-line) and covered the whole brain. High-resolution T1-weighted anatomic images were acquired for anatomic comparison (MP-RAGE) with the following parameters: TR = 2300 ms, TE = 3.93 ms, inversion time (TI) = 1100 ms, $\alpha = 12°$, FOV = $256 \times 256\,mm^2$, 256 slices with a thickness of 1.0 mm.

fMRI data analysis

Image realignment, image normalization, smoothing and data analysis were performed with statistical parametric software package (SPM5 software; Wellcome Department of Imaging Neuroscience, London) and MATLAB (The Mathworks Inc. Sherborn, USA). The first four images of each time series were discarded to allow the MR-signal to reach steady state. The remaining images were realigned to the first image to correct for head movements between scans and co-registered to the three-dimensional anatomical images.

Images were then normalized to the stereotactic space of the Montreal Neurological Institute (MNI, Montreal, Canada) provided as template in SPM5. Transformed functional data were smoothed with an isotropic Gaussian kernel using 6 mm of full width half maximum to compensate for individual variability in macro-anatomical structures across participants.

Functional image analysis was performed with SPM5. The main aim of the analysis was to compare the neural correlates of the two experimental conditions (JC, CC). We also compared both conditions with the neutral condition (JC > NC, CC > NC). In the first level of analysis, each participant was analyzed separately. Regressors were defined for JC, CC, and NC separately and convolved with the hemodynamic response function. In a random effects group analysis, the resulting three contrast images per participants were used for a second-level analysis to account for between-individual variance and used in one-sample *t*-tests. To check for potential overlap brain areas for general jealousy-related activation, we ran a conjunction analysis for the CC and JC. For all results, the significance threshold was set at $p < .05$ corrected for false discovery rate (FDR), using an extent voxel size of $k = 10$.

Analyses of postscanning ratings

To analyze pair-wise differences in the postscanning ratings across the experimental conditions (JC vs. CC), we conducted post-hoc *t*-tests with Bonferroni corrections at $p < .05$.

We also calculated correlations between participants' postscanning ratings of emotional involvement and experienced valence (pleasantness) of the JC stimuli (descriptions of self-experienced infidelity), and the activation in the thalamus, which has been closely associated with obsessive-compulsive behavior (Rotge et al., 2012). To examine the two regions of interest, the right and left thalamus, we used the second-level random effects group analysis described above (one-sample *t*-tests for JC vs. CC). Individual data were then extracted from the group maximum for each individual at 9-12-9 for right thalamus activation and 9-12-6 for left thalamus activation. Data were analyzed using SPSS Statistics 17.0.

Results

Behavioral measures

The analysis of the BSI responses revealed significant differences from the normative sample ($t = 50$) on the Anxiousness scale, but the scores were below the cut-off

Table 2. Results of Brief Symptom Inventory and Hospital Anxiety and Depression Scale.

	M	*SD*	*t-value*	*p-value*
BSI scales				
Somatization	50.2	6.48	0.098	.924
OCD	52.2	9.84	0.707	.497
Interpersonal Sensitivity	54.2	8.07	1.647	.134
Depression	52.6	4.65	1.769	.111
Anxiousness	58.2	8.51	3.048	.014*
Aggression	53.9	6.14	2.010	.075
Phobic Anxiety	54.9	6.77	2.288	.048*
Paranoid Ideation	51.0	2.67	1.186	.266
Psychoticism	54.9	7.30	2.214	.063
HADS-D scales				
Anxiety	58.1	10.5	2.441	.037*
Depression	54.7	7.24	2.052	.070

BSI = Brief-Symptom-Inventory; HADS-D = Hospital Anxiety and Depression Scale; German Version; OCD = Obsessive Compulsive Disorder; M = Mean; SD = Standard Deviation, *$p < .05$

Table 3. Post-scanning ratings of emotional involvement and valence as a function of experimental condition.

	Jealousy condition		Control condition			
	M	*SD*	*M*	*SD*	*t-value*	*p-value*
Emotional Involvement	4.01	0.40	2.20	0.46	10.69	.000082*
Valence	1.94	0.39	2.95	0.33	−6.36	.000001*

M = Mean; SD = Standard Deviation.
*$p < .05$

Table 4. Brain activation in jealousy condition relative to control condition.

	MNI coordinate					MNI coordinate				
Brain area	*X*	*Y*	*Z*	*t*	*k*	*X*	*Y*	*Z*	*t*	*k*
	Right hemisphere					Left hemisphere				
Medial frontal gyrus	9	42	30	4.75	247	−3	45	27	9.36	247
Thalamus	9	−12	−9	4.19	11	−9	−12	6	3.39	11
Ventral anterior nucleus	9	−3	6	3.72		−12	−6	11	3.24	
Medial dorsal nucleus	3	−10	9	4.45		−8	−13	9	5.88	
Ventral lateral nucleus	18	−12	12	4.17		−9	−12	9	5.88	
Anterior nucleus	6	−3	6	5.57		−9	−6	12	3.24	
Medial geniculum body						−16	−24	−3	3.62	
Lateral geniculum body						−21	−24	−3	3.82	
Caudate	13	13	4	8.71	85	−12	12	3	3.49	11
Caudate body	15	12	9	5.68		−15	13	8	6.49	
Caudate head	9	12	6	6.83		−6	10	−3	3.70	
Caudate tail	34	−27	−9	2.98		−34	−27	−9	2.69	
Substantia nigra	9	−15	−9	4.77	11	−9	−18	−12	4.31	10
Putamen	18	12	−6	7.47	85	−18	9	−3	4.71	82
Medial globus pallidus	12	0	−3	4.61	17	−18	−8	−3	4.54	25
Lateral globus pallidus	18	−3	−3	3.00	17	−24	−10	−3	3.39	25
Subthalamic nucleus	12	−12	−3	3.50	12	−6	−12	−6	2.66	10
Anterior cingulate	3	33	15	3.51	247	−3	33	16	3.98	247
Posterior cingulate	9	−54	15	3.25	90	−9	−54	15	5.81	83
Cingulate gyrus	6	−21	36	4.83	25	−12	−45	36	6.13	12
Insula	36	−36	21	2.83	25	−39	18	15	6.84	85
Parahippocampal Gyrus	24	−21	−9	3,82	26	−24	−21	−9	5.98	24
Hippocampus	33	−28	−9	2.98	24	−30	−20	−12	3.96	26
Claustrum	27	18	12	3.00	18	−34	3	2	2.88	35
Red Nucleus	8	−18	−3	3.88	7	−6	−18	−3	3.23	10
Hypothalamus	3	−3	−12	2.86	17	−3	−3	−11	3.52	19
Inferior Frontal Gyrus	24	9	−21	4.18	16	−39	15	−12	2.79	18
Fusiform Gyrus	24	−87	−27	4.95	118	−24	−87	−27	2.52	17
Cuneus						−21	−72	9	6.19	95
Precuneus	6	−57	21	2.55	85	−9	−63	21	3.66	85
Angular Gyrus						−33	−54	33	3.55	11
Supramarginal gyrus	40	−40	33	3.00	92	−51	−45	34	3.89	83
Inferior parietal lobule	51	−39	33	3.76	85	−51	−54	39	10.39	112

All coordinates are in Montreal Neurological Institute Space. MNI coordinates and *t*-scores refer to the peak of each brain region. For all results, the significance threshold was set at $p < .05$ corrected for false discovery rate (FDR), with a 10-voxel extent threshold.

(*t* score < 63). The Anxiety scale in the HADS-D also differed significantly from the normative sample but did not reach a psychopathological level (see Table 2). The analysis of the postscanning ratings revealed that the JC reports were rated more negatively and evoked stronger emotional involvement than did the CC reports (see Table 3).

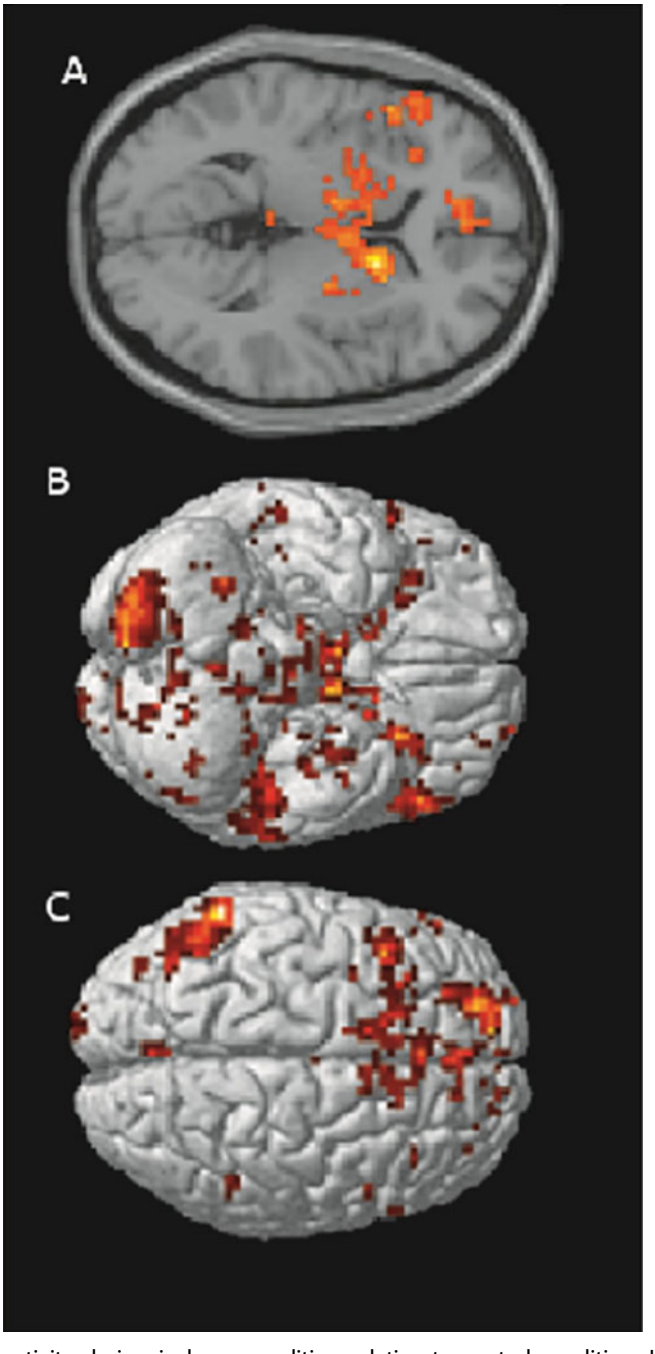

Figure 1. Neural activity during jealousy condition relative to control condition. Increased activity of fronto-striato-thalamo-frontal circuit during jealousy condition (JC) relative to control condition (CC). (A) sagittal slice, $z = 4$; (B) inferior view; (C) superior view.

fMRI

Increased neural activity in the JC compared to the CC was observed in a large network of cortical and subcortical areas, predominantly in the fronto-striato-thalamo-frontal circuit and in cortical midline structures like medial prefrontal cortex, anterior and posterior cingulate cortex (see Table 4 and Figure 1). No decreases were found for JC > CC. The reverse contrast (CC > JC) revealed no areas of increased activation. The contrast JC > NC showed similar results as the statistically stronger contrast JC > CC and no further activated regions, whereas JC > CC additionally involved the insula, substantia nigra, globus pallidus, nucleus subthalamicus, and hypothalamus. Therefore we decided to present and discuss only the data relating to JC > CC in detail. We also performed the analysis CC > NC, which revealed no significant differences in neural activity.

Moreover, the conjunction analysis (JC + CC) revealed activations mainly in medial frontal, temporal and subcortical areas (amygdala, insula, putamen). The contrast JC > CC activated areas that were not included in the conjunction analysis, mainly new subcortical areas (the whole caudate part, a broader thalamic activity), anterior and posterior cingulate, hippocampal and angular gyrus. Finally, we found no significant association between brain activity and the behavioral measures (Table 1).

Correlation between postscanning ratings and brain activation

We found a negative correlation, $r = -0.71$, $p = .022$, between the reported valence of self-experienced jealousy stimuli and the BOLD signal in the left thalamus. Hence, participants who rated the jealousy stimuli more negatively showed more activation in the left thalamus, a key region of the fronto-striato-thalamo-frontal network that has been linked to obsessive-compulsive-disorder (OCD). The other three correlations (between right thalamus activation and valence; and between right/left thalamus activation and emotional involvement) were not significant, $rs < -0.2$, $ps > .50$.

Discussion

Our fMRI study investigated for the first time the neural correlates of genuine, self-experienced romantic jealousy in betrayed heterosexual women. Our research strategy was to examine activity in sets of regions and networks, not to localize one brain region that "causes" or reflects jealousy. Due to the greater selectivity of brain responses in specific networks, the present approach arguably allays methodological issues related to the mapping of psychological phenomena to brain activation (Poldrack, 2006). By employing self-experienced infidelity reports instead of imagined hypothetical scenarios, our study goes beyond the findings by Takahashi et al. (2006) and Sun et al. (2016). Thus, the fMRI activities we observed provide clues for a more complete, and ecologically more valid, understanding of jealousy.

The most distinctive result is the enhanced neural activity in the fronto-striato-thalamo-frontal circuit during self-experienced jealousy (vs. control conditions). At a general cognitive level, these findings suggest that jealousy involves processes also found in habit formation (Yin & Knowlton, 2006). Furthermore, the observed activations are remarkably

similar to the pattern of activation in OCD (e.g. Sakai et al., 2011). As reported in the study of Sakai et al. (2011) with unmedicated OCD patients, abnormalities in the basal ganglia circuitry are a hallmark of OCD. Observations of the behavior and cognitions of people who experience severe jealousy suggest that the similarities between neural substrates in our JC (vs. CC or NC) condition and OCD correlates are plausible. Jealousy involves obsessive tendencies in terms of repetitive and uncontrollable thoughts and worries regarding the partner's infidelity. People experiencing acute jealousy often have the continuous impulse to observe and control the partner. In line with the incidence of anxious tendencies in OCD, our participants did not show clear OCD symptoms in the OCD scale of the BSI but increased values in the anxiety/anxiousness subscales of the BSI and HADS. Future research should compare jealousy and OCD within the same fMRI study to examine overlap of neural activity more directly.

As indicated by the CC > NC comparison, which revealed no significant fMRI differences, activation in the above networks was not enhanced when participants listened to infidelity scenarios they did not experience themselves. The JC + CC conjunction analysis revealed activation in the amygdala and orbitofrontal areas, indicative of rather general emotional involvement. Also, the fronto-striato-thalamic network (especially, the thalamic and striatum part) was less active in the conjunction analysis. These findings further support the specificity of activation during self-experienced jealousy evoked by infidelity of a real romantic partner.

Compared to self-experienced jealousy (JC), our other-experienced jealousy condition (CC) was more similar to the task given to participants in the study by Takahashi et al. (2006). Because the imagination of a hypothetical infidelity scenario did not elicit the activation patterns we found, our data support Harris' (2003) analysis of the differences between imagined and self-experienced jealousy at the brain level. However, Sun et al. (2016) found activation patterns similar to those in our study, i.e., activation of caudate nucleus and putamen, which are part of the basal ganglia. In their study, they used hypothetical scenarios as well. It is possible that the sentences used in the study by Takahashi et al. (2006) did not elicit a strong enough emotional reaction to evoke the same activation patterns that were found by us and Sun et al. (2016).

The conjunction analysis additionally supports the notion that self-experienced jealousy is represented differently in the brain than jealousy that is evoked by others' infidelity experiences or merely imagined infidelity. Humans become to emotionally involved when they are confronted with jealousy situations. The amygdala and orbitofrontal areas are the regions that were solely activated in the conjunction condition, showing a general emotional involvement. However, the JC > CC comparison in the conjunction analysis revealed a lower activation in areas that can be linked to obsessive-compulsive behavior (fronto-striato-thalamic network), especially thalamic and striatum structures. As indicated by the obtained correlations between postscanning ratings of emotional involvement and brain activation, thalamic activity, which has been closely associated with OCD (e.g., Rotge et al., 2012), was stronger when the experienced infidelity was rated more negatively. This finding underlines the distinctive involvement of the OCD network in self-experienced jealousy.

Whereas we found bilateral activation patterns under self-experienced jealousy, Harmon-Jones et al. (2009) found more strongly lateralized in EEG measures,

specifically greater left frontal cortical activation, in their jealousy (vs. control) conditions. How can this difference be explained? Harmon-Jones and colleagues induced the experience of jealousy experimentally in the laboratory with the ostensible rejection (vs. nonrejection) by an attractive, photographically represented partner in Williams' computer-based Cyberball game (Williams, 2007). This innovative experimental procedure arguably creates some level of self-experienced jealousy. However, its external validity is still limited because the game partner is not a real, long-term relationship partner and because the reason for jealousy is not infidelity by the partner. These differences might account for the differences in lateralization found in the study by Harmon-Jones et al. (2009) and our study: Stronger feelings of jealousy resulting from infidelity in an actual romantic relationship are associated with more distributed, bilateral activation.

Evidence consistent with our findings also comes from a study by Aron et al. (2005), which revealed greater activity in the caudate nucleus, putamen, and globus pallidus when participants viewed their beloved (vs. an otherwise, comparable, familiar individual). Clearly, the jealousy experience of our subjects involves thinking about the romantic partner, but also several other cognitions and emotions. Hence, it is plausible that in Aron et al.'s study only parts of the full fronto-striato-thalamo-frontal circuit were activated.

In addition to the fronto-striato-thalamo-frontal circuit, the present results showed a broader neural network underlying real experienced jealousy and support the notion that jealousy comprises several emotional and cognitive components and hence is a complex phenomenon (Pines, 1992). Specifically the JC > CC contrast also revealed activation of brain areas linking different emotional and cognitive functions, such as the MPFC, the insula, and the ACC. A cognitive process that has been related to increased activity in the MPFC is rumination (Denson et al., 2009), which figures prominently in obsessive-compulsive thoughts. Increased activation of the insula may reflect aversion against the partner and the rival (Benuzzi, Lui, Duzzi, Nichelli & Porro, 2008). Indeed, our participants reported strong feelings of dislike during the semi-structured interview and the postscanning debriefing in the JC (vs. CC). Increased activity in the ACC may represent anger (Denson et al., 2009; Phan et al., 2002), sadness (Liotti et al., 2000) and distress from social rejection and social pain (Eisenberger, 2012), that is, emotional responses that are phenomenal characteristics of jealousy. Greater activity was also found in cortical midline structures (in the JC), which have been implicated in autobiographical memory (Oddo et al., 2010) and self-referential processes (Northoff et al., 2006), showing again that experienced jealousy is different in nature than imagined jealousy.

To conclude, our study extended existing paradigms using imagined jealousy scenarios by investigating jealousy following real experienced infidelity. Our results suggest that investigating real infidelity can provide potentially important insights into the psychological mechanisms underlying jealousy. Clearly, future studies should be conducted with larger samples. If further corroborated, the findings have important practical implications. The parallels between jealousy and obsessive-compulsive tendencies suggest that acute jealousy might be a condition requiring treatment. Specific forms of behavioral therapy (Bloch, McGuire, Landeros-Weisenberger, Leckman, &

Pittenger, 2010) or selective-serotonin-reuptake inhibitors have been successfully employed in the treatment of obsessive-compulsive-disorder. Pre-post psychotherapy studies could be useful to assess the effect of such treatments of jealousy. Ultimately, the present line of research may thus provide novel approaches to the understanding of jealousy and the treatment of its extreme forms.

Declaration statement

The authors declare that there are no conflicts of interest.

Notes on contributors

Nadine Steis, is a clinician in private practice. Her research focuses on psychosomatic illnesses and psychotherapy research.

Silvia Oddo-Sommerfeld, PhD, leads the psychological division of the Department of Obstetrics and Perinatal Medicine, University Hospital Frankfurt, Goethe University Frankfurt, Germany. She also works as a clinician in private practice. Her research focuses on perinatal affective disorders and the impact of premature birth on women, men and children. Her research interests further comprise neuroscientific studies and bonding. She established a telefonic counselling service for postpartum depressive women.

Gerald Echterhoff, PhD (USA), is Professor of Social Psychology at the University of Münster, Germany, and a Fellow of the Academy of Sciences and Arts of North Rhine-Westphalia. His research passions include shared reality, social cognition, memory, interpersonal relations, and the psychology of refugee migration.

Aylin Thiel, PhD, is a clinician in private practice. Her research focuses on psychosomatic illnesses and psychotherapy research.

Jürgen Thiel, PhD, is a clinician in private practice. His research focuses on psychosomatic illnesses and psychotherapy research.

Katja Briem, PhD, is a clinician in the Department of Psychosomatic Medicine and Psychotherapy, University Medical Centre, Johannes Gutenberg-University, Mainz, Germany. Her research interests focus on psychosomatic illnesses, self-injurious behavior, and neuroscientific studies.

Angela Ciaramidaro, PhD in Cognitive Science, is Assistant Professor (tenure track) at the Department of Education and Human Sciences (University of Modena and Reggio Emilia, Italy) and is also a Cognitive Psychotherapist. She has a strong multidisciplinary expertise in the fields of social neuroscience and clinical psychology and her research interests are focused on behavioral and neuroimaging studies investigating social cognition in healthy and clinical populations.

Christine M. Freitag is Professor for Child and Adolescent Psychiatry and Psychotherapy and Director of the Department of child and Adolescent Psychiatry, Psychosomatics, and Psychotherapy, University Hospital Frankfurt, Goethe University Frankfurt, Germany. Her research focuses on autism spectrum disorder, attention-deficit/hyperactivity and conduct

disorder in children and adolescents, and comprises clinical trials, diagnostic, neuropsychological, brain imaging, and genetic studies.

Axel Mecklinger is a Full Professor for Neuropsychology at Saarland University in Saarbrücken. Prior to this, he worked as a Senior Research Scientist at the Max-Planck-Institute for Human Cognitive and Brain Sciences in Leipzig. In 1999 he received the Distinguished Scientific Award for Early Career Contributions to Psychophysiology from the Society for Psychophysiological Research. He is Associate Editor of *Brain & Cognition* and member of the Editorial Board of the *International Journal of Psychophysiology*. His research interests are the Cognitive Neuroscience of Learning, Memory and Cognitive Control.

Katja Unterhorst is a psychologist and psychotherapist in training currently living in Kiel, Germany. Her research interests include human sexuality and the potential uses of psychedelics in psychotherapy and psychiatry.

Aglaja Stirn is Professor of Psychosomatic Medicine and Sexual Medicine at the University of Kiel. She is also Director of the Institute for Sexual Medicine and Forensic Psychiatry and Psychotherapy. Her areas of interest are psychosomatics and sexuality.

ORCID

Katja Unterhorst http://orcid.org/0000-0002-7079-7575

References

Aron, A., Fisher, H., Mashek, D., Strong, G., Li, H., & Brown, L. L. (2005). Reward, motivation, and emotion systems associated with early-stage intense romantic love. *Journal of Neurophysiology*, *94*(1), 327–337. doi:10.1152/jn.00838.2004

Benuzzi, F., Lui, F., Duzzi, D., Nichelli, P. F., & Porro, C. A. (2008). Does it look painful or disgusting? Ask your parietal and cingulate cortex. *The Journal of Neuroscience*, *28*(4), 923–931. doi:10.1523/JNEUROSCI.4012-07.2008

Bloch, M. H., McGuire, J., Landeros-Weisenberger, A., Leckman, J. F., & Pittenger, C. (2010). Meta-analysis of the dose-response relationship of SSRI in obsessive-compulsive disorder. *Molecular Psychiatry*, *15*(8), 850–855. doi:10.1038/mp.2009.50

Dalgleish, T., Walsh, N. D., Mobbs, D., Schweizer, S., van Harmelen, A. L., Dunn, B., … Stretton, J. (2017). Social pain and social gain in the adolescent brain: A common neural circuitry underlying both positive and negative social evaluation. *Scientific Reports*, *7*, 42010. doi:10.1038/srep42010

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

Denson, T. F., Pedersen, W. C., Ronquillo, J., & Nandy, A. S. (2009). The angry brain: Neural correlates of anger, angry rumination, and aggressive personality. *Journal of Cognitive Neuroscience*, *21*(4), 734–744. doi:10.1162/jocn.2009.21051

Eisenberger, N. I. (2012). The neural bases of social pain: Evidence for shared representations with physical pain. *Psychosomatic Medicine*, *74*(2), 126–135. doi:10.1097/PSY.0b013e3182464dd1

Eisenberger, N. I. (2014). Meta-analytic evidence for the role of the anterior cingulate cortex in social pain. *Social Cognitive and Affective Neuroscience*, *10*(1), 1–2. doi:10.1093/scan/nsu120

Franke, G. (2000). *Brief symptom inventory von L.R. Derogatis (Kurzform der SCL-90-R). German version*. Göttingen: Belz Test GmbH.

Gillath, O., Bunge, S. A., Shaver, P. R., Wendelken, C., & Mikulincer, M. (2005). Attachment-style differences in the ability to suppress negative thoughts: Exploring the neural correlates. *Neuroimage*, *28*(4), 835–847. doi:10.1016/j.neuroimage.2005.06.048

Gündel, H., O'Connor, M.-F., Littrell, L., Fort, C., & Lane, R. D. (2003). Functional neuroanatomy of grief: An FMRI study. *The American Journal of Psychiatry*, *160*(11), 1946–1953. doi: 10.1176/appi.ajp.160.11.1946

Harmon-Jones, E., Peterson, C. K., & Harris, C. R. (2009). Jealousy: Novel methods and neural correlates. *Emotion*, *9*(1), 113–119. doi:10.1037/a0014117

Harris, C. R. (2003). Factors associated with jealousy over real and imagined infidelity: An examination of the social-cognitive and evolutionary psychology perspective. *Psychology of Women Quarterly*, *27*(4), 319–329. doi:10.1111/1471-6402.00112

Herrmann, C., Buss, U., & Snaith, R. (1995). *HADS-D hospital anxiety and depression scale – German Version: Ein Fragebogen zur Erfassung von Angst und Depressivität in der somatischen Medizin*. Bern: Huber.

Kawamichi, H., Sugawara, S. K., Hamano, Y. H., Makita, K., Matsunaga, M., Tanabe, H. C., … Sadato, N. (2016). Being in a romantic relationship is associated with reduced gray matter density in striatum and increased subjective happiness. *Frontiers in Psychology*, *7*, 1763. doi: https://doi.org/10.3389/fpsyg.2016.01763

Kingham, M., & Gordon, H. (2004). Aspects of morbid jealousy. *Advances in Psychiatric Treatment*, *10*(3), 207–215. doi: http://doi.org/10.1192/apt.10.3.207

Landazabal, M. G. (2006). Psychopathological symptoms, social skills, and personality traits: A study with adolescents. *The Spanish Journal of Psychology*, *9*(2), 182–192. doi: doi:10.1017/S1138741600006089

Lehrl, S. (2005). *Mehrfachwahl-Wortschatz-Intelligenztest MWT-B* (5th ed.). Göttingen: Hogrefe.

Lieberman, M. D., & Eisenberger, N. I. (2015). The dorsal anterior cingulate cortex is selective for pain: Results from large-scale reverse inference. *Proceedings of the National Academy of Sciences United Science of America*, *112*(49), 15250–15255. doi: https://doi.org/10.1073/pnas.1515083112

Liotti, M., Mayberg, H. S., Brannan, S. K., McGinnis, S., Jerabek, P., & Fox, P. T. (2000). Differential limbic-cortical correlates of sadness and anxiety in healthy subjects: Implications for affective disorders. *Biological Psychiatry*, *48*(1), 30–42. doi:10.1016/S0006-3223(00)00874-X

Marazziti, D., Rucci, P., Di Nasso, E., Masala, I., Baroni, S., Rossi, A., … Lucacchini, A. (2003). Jealousy and subthreshold psychopathology: A serotonergic link. *Neuropsychobiology*, *47*(1), 12–16. doi: doi:10.1159/000068869

Marazziti, D., Sbrana, A., Rucci, P., Cherici, L., Mungai, F., Gonnelli, C., … Osso, M. C. D. (2010). Heterogeneity of the jealousy phenomenon in the general population: An Italian study. *CNS Spectrums*, *15*(1), 19–24. doi: doi:10.1017/S1092852900000262

Meyer, M. L., Williams, K. D., & Eisenberger, N. I. (2015). Why social pain can live on: Different neural mechanisms are associated with reliving social and physical pain. *PLoS One*, *10*(6), e0128294. doi: doi:10.1371/journal.pone.0128294

Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain – A meta-analysis of imaging studies on the self. *Neuroimage*, *15*, 440–457. doi:10.1016/j.neuroimage.2005.12.002

Oddo, S., Lux, S., Weiss, P. H., Schwab, A., Welzer, H., Markowitsch, H. J., & Fink, G. R. (2010). Specific role of medial prefrontal cortex in retrieving recent autobiographical memories: An fMRI study of young female subjects. *Cortex*, *46*(1), 29–39. doi:10.1016/j.cortex.2008.07.003

Oubaid, V. (1997). *Eifersucht aus evolutionspsychologischer perspektive* [*jealousy from the perspective of evolutionary psychology].* Aachen: Shaker.

Perini, I., Gustafsson, P. A., Hamilton, J. P., Kämpe, R., Zetterqvist, M., & Heilig, M. (2018). The salience of self, not social pain, is encoded by dorsal anterior cingulate and insula. *Scientific Reports*, *8*, 6165. doi:10.1038/s41598-018-24658-8

Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional neuroanatomy of emotion: A meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage*, *16*(2), 331–348. doi:10.1006/nimg.2002.1087

Pines, A. M. (1992). Romantic jealousy: Five perspectives and an integrative approach. *Psychotherapy*, *29*(4), 675–683. doi:10.1037/0033-3204.29.4.675

Poldrack, R. A. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences*, *10*(2), 59–63. doi:10.1016/j.tics.2005.12.004

Rotge, J. Y., Aouizerate, B., Amestoy, V., Lambrecq, V., Langbour, N., Nguyen, T. H., … Guehl, D. (2012). The associative and limbic thalamus in the pathophysiology of obsessive-compulsive disorder: An experimental study in the monkey. *Translational Psychiatry*, *2*(9), e161. doi:10.1038/tp.2012.88

Sakai, Y., Narumoto, J., Nishida, S., Nakamae, T., Yamada, K., Nishimura, T., & Fukui, K. (2011). Corticostriatal functional connectivity in non-medicated patients with obsessive-compulsive disorder. *European Psychiatry*, *26*(7), 463–469. doi:10.1016/j.eurpsy.2010.09.005

Sheikhmoonesi, F. (2017). Obsessional jealousy: A narrative literature review. *Iranian Journal of Psychiatry and Behavioral Sciences*, *11*, e7273. doi:10.5812/ijpbs.7273

Southworth, C., Finn, J., Dawson, S., Fraser, C., & Tucker, S. (2007). Intimate partner violence, technology, and stalking. *Violence against Women*, *8*, 842–856. doi:10.1177/1077801207302045

Soyka, M., & Schmidt, P. (2011). Prevalence of delusional jealousy in psychiatric disorders. *Journal of Forensic Sciences*, *56*(2), 450–452. doi: doi:10.1111/j.1556-4029.2010.01664.x

Sun, Y., Yu, H., Chen, J., Liang, J., Lu, L., Zhou, X., & Shi, J. (2016). Neural substrates and behavioral profiles of romantic jealousy and its temporal dynamics. *Scientific Reports*, *6*, 27469. doi:10.1038/srep27469

Takahashi, H., Matsuura, M., Yahata, N., Koeda, M., Suhara, T., & Okubo, Y. (2006). Men and women show distinct brain activations during imagery of sexual and emotional infidelity. *Neuroimage*, *32*(3), 1299–1307. doi:10.1016/j.neuroimage.2006.05.049

Val, A. C., Nicolato, R., Salgado, J. V., & Teixeira, A. L. (2009). Morbid jealousy and obsessive-compulsive disorder (OCD). *Revista Brasileira de Psiquiatria*, *31*(2), 188–189. doi:10.1590/S1516-44462009000200021

White, G. L., & Mullen, P. E. (1989). *Jealousy: Theory, research and clinical strategies*. New York, NY: Guilford.

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*, 425–452. doi:10.1146/annurev.psych.58.110405.085641

Yin, H. H., & Knowlton, J. B. (2006). The role of the basal ganglia in habit formation. *Nature Reviews Neuroscience*, *7*(6), 464–476. doi:10.1038/nrn1919

Zeki, S. (2007). The neurobiology of love. *FEBS Letters*, *581*(14), 2575–2579. doi: doi:10.1016/j.febslet.2007.03.094