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Neural responses to instructed positive couple interaction: an fMRI study on compliment sharing

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Abstract

Love is probably the most fascinating feeling that a person ever experiences. However, little is known about what is happening in the brains of a romantic couple—the central and most salient relationship during adult age—while they are particularly tender and exchanging loving words with one another. To gain insight into nearly natural couple interaction, we collected data from $N = 84$ individuals (including $N = 43$ heterosexual couples) simultaneously in two functional magnetic resonance imaging scanners, while they sent and received compliments, i.e. short messages about what they liked about each other and their relationship. Activation patterns during compliment sharing in the individuals revealed a broad pattern of activated brain areas known to be involved in empathy and reward processing. Notably, the ventral striatum, including parts of the putamen, was activated particularly when selecting messages for the partner. This provides initial evidence that giving a verbal treat to a romantic partner seems to involve neural reward circuitry in the basal ganglia. These results can have important implications for the neurobiological mechanisms protecting and stabilizing romantic relationships, which build a highly relevant aspect of human life and health.

Keywords: social interaction; brain imaging; ventral striatum; couple relationships; compliment reward

Introduction

In almost all human cultures, romantic love is viewed as a central concept to giving meaning and joy to a person's life. Social identity theory states that individuals derive parts of their identity from belonging to a group, a family, or a romantic relationship (Scheepers and Ellemers, 2019) and such social identification is related to less harmful stress as mediated by social support (Haslam *et al.*, 2005). Specifically being in a functional couple relationship is even linked to better health and longer lives (Braithwaite and Holt-Lunstad, 2017).

The health-related impact of couple relationships is very likely centrally mediated with interacting neural networks and structures, such as the limbic reward system and its neurotransmitters. An interaction of the neuromodulator oxytocin and the neurotransmitter serotonin in the nucleus accumbens (Dölen *et al.*, 2013) has been shown to mediate social reward. Oxytocin interacting with dopamine has been suggested to contribute to the formation and maintenance of social bonds in animals (Bosch and Young, 2018) and in humans, for instance, via a positive evaluation of the own relationship (Scheele *et al.*, 2013; Aguilar-Raab *et al.*, 2019).

As parts of the dopaminergic reward system, the nucleus accumbens, together with putamen and ventral tegmental area (VTA) among others, are involved in the initiation of joyful behaviors and feelings in general, but especially social reinforcements (Izuma *et al.*, 2008; Dölen *et al.*, 2013). Functional activation of the dopaminergic reward systems might thus be one (of several) underlying mechanism supporting initializing and maintaining human couple relationships (Bartels and Zeki, 2004) and is therefore in the focus of the present study. In previous research, interacting with the partner or observing a partner picture was associated with elevated activation in the VTA, hippocampus, insula (Bartels and Zeki, 2004), anterior cingulate cortex (ACC) (Aron *et al.*, 2005), posterior superior temporal sulcus (pSTS) and anterior temporal lobe (Van der Gaag *et al.*, 2007).

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One precondition for functional social interaction and for romantic couple relationships, in particular, is a theory of mind (ToM), the ability to infer the status of knowledge of another person. ToM is related to activation of the superior temporal brain, temporal and frontal areas (Dodell-Feder *et al.*, 2015), while actual empathy recruits the anterior insula (Kennedy and Adolphs, 2012; Thornton *et al.*, 2019). During empathy-related processes, the accumbens is also interacting with the ACC (Smith *et al.*, 2021). In addition, the mirror neuron system, which comprises parietal and frontolateral brain areas, is involved in social perception and action (Mier *et al.*, 2010).

Furthermore, social integration and the perception of belonging increase positive affect and self-esteem (Ellemers *et al.*, 1999). Presumably, positive feedback acts as an indicator of social integration. For romantic couples, a constructive way of communication has been shown to be related to better relationship satisfaction and even to buffer a lack of sexual satisfaction (Litzinger and Gordon, 2005) and communicating compliments in everyday life has been linked to better relationship satisfaction with a stronger sensitivity toward compliments specifically in women (Doohan and Manusov, 2004). Imaging studies have shown that receiving compliments from a stranger or from one's own mother involved the dorsolateral prefrontal cortex (DLPFC) (Hooley *et al.*, 2005), ACC and temporal areas (Miedl *et al.*, 2016). Based on this, receiving compliments from the partner can be considered highly relevant to evaluating the social self, the level of integration and affection and, thereby, act in a particularly rewarding and health beneficial way. To investigate the neural responses to tender partner compliments, we have adapted the previously established standard instructed partnership appreciation task (Pfeifer *et al.*, 2020; Warth *et al.*, 2020) for a functional imaging (fMRI) paradigm. We compared compliments from the partner to 'self-compliments' (i.e. attributes that the participants defined about themselves), since the mental reflection of positive attributes per se could improve mood (Nicolson *et al.*, 2020) by activating reward-related brain areas (Izuma *et al.*, 2008; Frewen *et al.*, 2020).

For general compliment processing, we expected that receiving compliments from the partner would result in elevated activation in a broad network including VTA, hippocampus, insula, ACC and pSTS, (Van der Gaag *et al.*, 2007). In addition, reward-related task phases as well as phases of reward anticipation (Filimon *et al.*, 2020) should be related to activation in the dopaminergic system: the ventral striatum including the nucleus accumbens. While a participant is actively choosing a compliment, we expected activity known for reading and decision-making, and when a participant is sending the compliment, the areas relevant for ToM should be activated, along with mirror neuron areas when they are observing partners' reactions. These activation patterns should become evident using whole brain approaches.

Methods

Participants

Eighty-six heterosexual participants (from 43 romantic couples) who were in love and exclusively dating for at least 6 months were recruited in the Rhine-Neckar metropolitan area, Germany; see Table 1 for sample characteristics. In addition to sociodemographic data, participants provided information on their relationship quality [Partnership Questionnaire (PFB) (Hahlweg, 1979)]. Particularly happy couples (reporting at least five on a 6-point single-item rating scale on general relationship satisfaction) were included in the study. All participants were eligible for magnetic resonance imaging (MRI), right-handed, without history of mental disorders, and knew sufficient German language to fully understand all instructions. Couples provided written informed consent and were reimbursed 80€ per couple for their participation. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Heidelberg University Medical Faculty (#2011-222N-MA).

Paradigms

In an interview session with the individual participants prior to the MRI session, all participants were handed a list of 23 areas of individual traits and relationship aspects, based on factors of the PFB (e.g. trust, humor and intimacy). Based on these areas, participants were asked to generate up to 18 short positive messages (compliments) about their partner for use in the upcoming experiment. In addition, participants created up to 18 compliments about themselves to be viewed as control stimuli. The compliments were kept confidential until the MRI session. Non-German native speaking couples were allowed to provide compliments in their native language. The paradigm consisted of 15 trials per condition (receiving, sending and self-compliment). In the send and receive compliment condition, each trial consisted of two phases, lasting for 10 s each. In the first phase, the sender chose one of the four compliments shown on his/her screen, and the receiver waited for the partner to select the message. In the second phase of the trial, the compliment was revealed to both partners. In the self-compliment paradigm, running on both scanners simultaneously, trials consisted of two phases as well: in the first phase, the text 'Please wait, computer is choosing your compliment' was displayed to both participants, and in the second one, the text appeared: 'Computer has chosen: compliment_text'. Both phases of each trial were jittered on average by 775 ms, and one whole trial lasted for 32.5 s. All texts were presented on the left-hand side of the screen. On the right-hand side, a live video of the partner taken with a wide-angle camera (MRC Systems GmbH, Heidelberg, Germany) in infrared light was shown continually during all paradigms in order to keep general effects of partner contact constant over conditions. The participants were randomly assigned to one of the two scanners. The order of which partner sent first,

Table 1. Sample characteristics. Available data presented for participants included for the corresponding fMRI analyses or self-report data (number of participants in brackets)

	Sending (77), questionnaires (72)				Receiving partner compliment (79), questionnaires (74)				Receiving self-compliments (77), questionnaires (72)			
	Mean	**std**	**Min**	**Max**	**Mean**	**std**	**Min**	**Max**	**Mean**	**std**	**Min**	**Max**
Age (years)	24.4	2.8	19	32	24.2	3.0	19	32	24.4	3.1	19	32
Education (years)	12.5	1.6	3	15	12.5	1.6	3	15	12.5	1.6	3	15
Relationship duration (years)	3.1	2.8	0.5	12	3.1	2.7	0.5	12	3.1	2.80	0.5	12

as well as the assignment of sexes to the scanner and the orders to the scanner, was balanced. The temporal order of paradigms (partner *vs* self) and the initial sender-sex-scanner matching was randomized and balanced across the sample. However, the first send/receive condition was always followed by the complimentary send/receive condition. The task followed an anatomical measurement and a joint attention paradigm (Bilek *et al.*, 2015).

A follow-up questionnaire directly after the fMRI session assessed the participants' overall evaluation of sending and receiving partner compliments with: 'How much did you enjoy sending and receiving the messages?' and 'How much did you enjoy reading your own positive attributes?' on a 9-point scale from 'not at all' to 'very much'.

Data acquisition

Data were acquired with two synchronized three Tesla Siemens Tim TRIO scanners, where one scanner was triggered by the other one. Twelve-channel head coils were used. A T2* gradient echo-planar imaging sequence was applied with the following parameters: 28 axial slices, with transversal orientation, oriented first to anterior commissure/posterior commissure line and then flipped by −25°, a slice thickness of 4 mm, a gap of 1 mm, a field of view of 192 mm and a voxel size of $3 \times 3 \times 4\,mm^3$. The repetition time was 1.55 s with the sampling delay of 10 ms and 1.54 s. The echo time was 30 ms, and the flip angle was 73°. Slices were acquired in descending order, with the A/P phase encoding direction. The Generalized Autocalibrating Partial Parallel Acquisition method with an acceleration factor of 2 was used. A total of 327 (triggering)/324 (triggered scanner) scans were collected per condition. The first seven (triggering)/four (triggered scanner) scans were discarded during conversion of Digital Imaging and Communications in Medicine files into 4d niftis by MRIConvert (version. 2.0 rev. 216) to account for saturation effects, resulting in 320 scans available for analysis per condition.

A high-resolution (voxel size $1 \times 1 \times 1$ mm) T1 anatomical scan was acquired for individual anatomical registration purposes.

Data analyses and preprocessing

fMRI data were analyzed using SPM12 (v771). The anatomical image was segmented and normalized to the Statistical Parametric Mapping (SPM12) Montreal Neurological Institute (MNI) template. Preprocessing of the functional data involved slice-time correction, realignment to the mean image and co-registration of the functional images (mean and others) to the anatomical image. The co-registered functional data were normalized to MNI space, resampled to $3\,mm^3$ voxels and smoothed with a Gaussian kernel with a full-width-at-half-maximum of $8 \times 8 \times 8$ mm. Volumes affected by small movement artifacts were identified with the Artifact Detection Tools toolbox (http://www.nitrc.org/projects/artifact_detect; parameters: framewise displacement >0.5 mm, image intensity change $z > 4$ and exclusion criterion for a measurement: >25% affected volumes).

Of the original 86 fMRI measurements, we had to exclude nine from the activation analysis of the send paradigm (resulting in $N = 77$) and seven measurements from the activation analysis of the receive paradigm (resulting in $N = 79$) due to excessive head motion, technical problems or aborted measurements due to time constraints. In total, this resulted in 14 participants having to be excluded from the comparison of the receive paradigm with the self-compliment paradigm ($N = 72$).

First, we analyzed the task-related activation in the individuals' brains by means of general linear modeling. A first-level model with three sessions for the three separate conditions of the experiment was set up to allow for both within-session and across-session contrasts. With the conditions, the individual phases (waiting for and receiving a compliment, as well as selecting and observing shared compliments) were modeled as blocks. Signals from cerebrospinal fluid and white matter, 24 movement parameters (six standard parameters, their backward derivatives and their squared versions) and ART dummy regressors were included as nuisance regressors. A high-pass filter with a frequency cutoff of 128 s was applied, as well first-degree autoregression.

In the group analyses, age, sex and scanner were included as covariates. Analyses were conducted using one-sample *t*-tests over the respective contrasts. Contrasts of interests were [Receiving > Waiting] within blocks (partner compliment and self-compliment) and [Receiving > Waiting] compared between blocks (partner compliment and self-compliment) as well as a contrast between the active block [Choosing compliment > Observing sent compliment] and the passive block [Receiving > Waiting]. All activation results are reported with $P < 0.05$ whole-brain familywise error (FWE)–corrected significance. Beta estimates were additionally extracted, only for visualization of the activity of the ventral striatum (anatomical region-of-interest from the Automatic Anatomic Labeling-90 atlas) during conditions (Figure 4).

Questionnaire data were analyzed using SPSS 27 (IBM).

Results

Activation of individuals when receiving a compliment

When participants were passively receiving compliments (from both the partner and self-compliments) as compared to the waiting phases (within blocks), increased activation in a broad network of inferior frontal gyrus (IFG), DLPFC, ventromedial prefrontal cortex (VMPFC), midbrain-structures and temporal gyri was observed, see Tables 2 and 3 and Figure 1A and B.

Activations of individuals when receiving partner *vs* self-compliments

Contrasting receiving compliments from the partner with self-compliments (between the two passive blocks) showed increased VMPFC, ACC and IFG activities for receiving self-compliments (Table 4 and Figure 2A) and higher insula, temporal and amygdala activities when receiving partner compliments. (Table 5, Figure 2B).

Activation of individuals when sending compliments

Comparing brain responses during the blocks of sending and receiving of partner compliments, we found that receiving involves larger insula and hippocampus activity (Table 6 and Figure 3A), but selecting/sending compliments for the partner involved an even broader limbic and reward network, including a large cluster around the ventral striatum, temporoparietal junction and the cingulate gyrus (Table 7 and Figure 3B; for beta estimates for the activity of the ventral striatum, see Figure 4).

We found no sex differences in any comparison.

Taken together, these results suggest similar activation patterns for self-compliment and partner compliment in the paradigm: elevated activation in DL/VMPFC, precuneus and temporal gyrus when receiving compliments. DLPFC and posterior cingulate are especially sensitive to receiving partner compliments, while temporal lobe and amygdala respond to the anticipation of partner compliments. Interestingly, choosing and

Table 2. Brain responses to (receiving partner compliments > waiting for partner compliments)

Peak	Peak	MNI-coordinates			Region
P(FWE-corrected)	*T*	x	y	z	Automated anatomical labeling atlas (Tzourio-Mazoyer *et al.*, 2002)
< 0.001	16.79296303	3	14	65	Superior frontal gyrus/supplementary motor area
< 0.001	12.37275314	−6	5	77	Superior frontal gyrus
< 0.001	11.77529621	6	17	38	Middle cingulate gyrus
< 0.001	15.70023251	−39	−70	−22	Cerebellum
< 0.001	15.21589851	−42	17	−28	Superior temporal gyrus
< 0.001	15.20484543	−45	17	−7	Inferior frontal gyrus
0.0049	5.602838039	66	−40	26	Inferior partietal lobule/supramarginal gyrus
0.0065	5.522605896	66	−58	11	Superior temporal gyrus
0.0447	4.955034733	−15	−25	−31	Cerebellum

Whole brain analyses

Table 3. Brain responses to (receiving self-compliments > waiting for self-compliments)

Peak	Peak	MNI-coordinates			Region
P(FWE-corrected)	*T*	x	y	z	
< 0.001	17.5258503	−42	26	−4	Inferior frontal gyrus
< 0.001	17.06056023	−3	20	59	Superior frontal gyrus/supplementary motor area
< 0.001	15.37069511	48	26	−1	Inferior frontal gyrus
< 0.001	6.319052696	30	−13	−31	Parahippocampus
0.0042	5.719283581	33	−52	53	Superior parietal gyrus
0.0050	5.673546314	−21	−76	23	Precuneus
0.0054	5.654490948	−3	−52	−16	Vermis/cerebellum
0.0212	5.255188942	30	−22	35	Postcentral gyrus
0.0353	5.101302147	−9	−16	80	Superior frontal gyrus

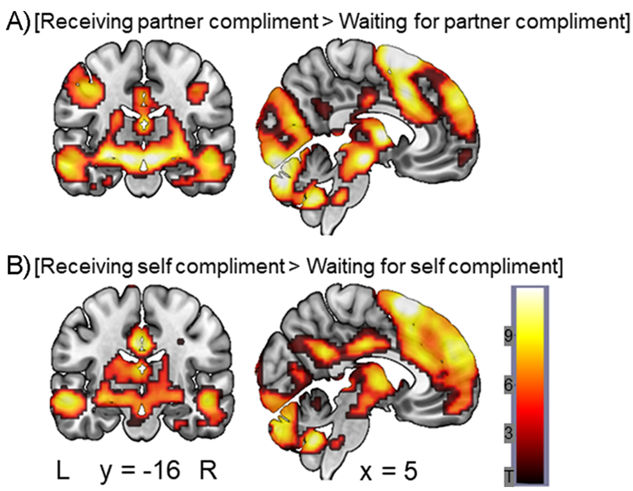

Fig. 1. Higher activation during receiving compliments than during waiting, (A) receiving partner compliments and (B) receiving self-compliments. All figures have $P < 0.05$, whole-brain FWE-corrected ($x = 5$, $y = -16$), *T*-scale applies for both panels.

sending compliments yielded the strongest activation patterns in the limbic, mentalizing (ToM) and reward systems.

Results of questionnaire data

A Wilcoxon test (with $N = 86$, who completed the questionnaires) suggest that participants reported significantly ($z = -7.223$, $P < .001$) more subjective joy during the partner compliment phase (median = 9, range 5–9) than during the self-compliment phase (median = 6, range 2–9).

Discussion

For most adult humans, couple relationships are *the* most relevant social relationship, and interacting with the partner modulates momentary affect and long-term health-related outcomes (Braithwaite and Holt-Lunstad, 2017). Exchanging praise and compliments are one element of positive couple interaction, and specific compliments in the relationship are assumed to increase social identity (Ellemers *et al.*, 1999). The rationale of the present study was to investigate the neural responses when sending and receiving such compliments, as well as receiving self-compliments. In summary, we found that both receiving compliments from the partner and self-generated positive attributes activated the salience and limbic networks, as well as the mirror neuron system, as hypothesized. Differential effects occurred especially during the anticipation of the response to a compliment.

The complex activation pattern to receiving compliments corresponded to the activation seen in previous research investigating the reading of emotionally loaded content (Hsu *et al.*, 2014). Prefrontal and temporal areas, as well as the insula, were involved in both receiving partner compliments and self-compliments. This is in line with the notion that the general processing of self-referential information involves the reward circuitry (Frewen *et al.*, 2020), and the dorsal striatum, in particular (as part of the nigrostriatal pathway), is involved in comparing predicted and received rewards (Oyama *et al.*, 2010).

Amygdaloid responses during the anticipation of partner compliments relate not only to the ‘emotional’ salience network but also to social reward (Chan *et al.*, 2018). Receiving partner compliments included activation of ACC and temporal gyri. Such activation patterns are part of the ‘social brain’ (Kennedy and Adolphs, 2012) and are involved in successful communica-

Table 4. Brain responses to (receiving self-compliment > waiting for self-compliment) > (receiving partner compliment > waiting for partner compliment)

Peak	Peak	MNI-coordinates			Region
P(FWE-corrected)	T	x	y	z	
< 0.001	7.01081753	−9	26	−10	Anterior cingulate
< 0.001	6.95619154	−6	35	−22	Rectal gyrus
< 0.001	6.37565708	−21	41	−13	Middle frontal gyrus
< 0.001	6.97407198	42	50	−4	Middle frontal gyrus
0.0070	5.5989995	24	53	−1	Superior frontal gyrus
0.0002	6.51676655	54	−52	50	Inferior partietal lobule
0.0050	5.69650269	42	−64	53	Angular gyrus
0.0026	5.87921333	3	−28	59	Medial frontal gyrus
0.01062	5.47870684	−9	−31	65	Medial frontal gyrus
0.0064	5.625525	−36	−22	20	Insula
0.0070	5.59888983	36	−19	17	Insula
0.0098	5.50063801	42	23	47	Middle frontal gyrus
0.0122	5.435884	−9	35	−1	Anterior cingulate
0.0189	5.30584526	24	41	−13	Middle frontal gyrus
0.0251	5.21994162	−42	−58	56	Partietal inferior gyrus
0.03185	5.14777374	−54	−55	41	Partietal inferior gyrus

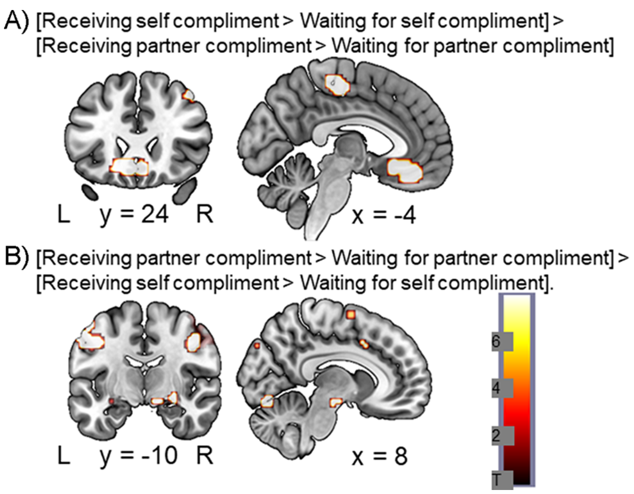

Fig. 2. Higher brain activation during partner than during self-compliments, (A) receiving self-compliments (receive self-compliments (receive > wait) > receive partner compliments (receive > wait)) (x = −4, y = 24) and (B) receiving partner compliments (partner compliments (receive >wait) > self-compliments (receive > wait)) (x = 8, y = −10).

tion and mentalizing (Van Overwalle and Baetens, 2009; Laurita et al., 2017). Here, they might serve as an indicator of ToM and the sender's mental engagement with choosing a particular compliment.

The compliment choosing phase was associated with complex activation patterns in the senders' brains, which included the dopaminergic reward system. The ventral striatum and neural midline structures showed the strongest activation when choosing a compliment as compared to the other conditions (see Figure 4). While this was not hypothesized, these results are well in line with previous reports, indicating that emotion sharing might be rewarding (Wagner et al., 2014), and can be associated with striatal activation during the anticipation of reward (Filimon et al., 2020). Since there was no other experimental condition including non-emotional decision-making to compare these data with, we have to interpret this finding with caution, though. Other examples of rewarding anticipation of prosociality include supporting financially family members, which elicits activation in the mesolimbic dopaminergic system (Telzer et al., 2010), as well as deciding to donate to charities, which recruited the ventral and dorsal striatum and VTA (Moll et al., 2006). Similarly, Harbaugh et al. (2007) found that both mandatory and voluntary contributions to charities recruited the same areas. Finally, Izuma et al. (2010) reported that ventral striatum activity to charitable donations increased in the presence of others, suggesting that this region may be particularly sensitive to social rewards. Our present results add to this line of literature by showing for the first time, the differential contributions of dorsal striatum to receiving a treat oneself and of ventral striatum to selecting a treat for someone else during live social interaction.

Our data imply that throughout all conditions, the senders paid close attention to the reaction of their partners during compliment sharing: activation in oculo-, pre- and motor areas, as well as areas associated with showing emotional, mostly happy, faces such as pSTS and dorsomedial prefrontal cortex suggest involvement of the emotionally 'extended mirror neuron network' (Van der Gaag et al., 2007). Positive affect and frontal activity during emotional partner interaction were also reported in a recent study using electroencephalogram (Packheiser et al., 2021).

In summary, by using a somewhat naturalistic interaction paradigm, the present study design builds on previous research on reward-related brain activation in romantic couples such as seeing pictures from the partner (Acevedo et al., 2012) and extends existing data to a more dynamic couple interaction. To our knowledge, this work is the first to investigate the neural underpinnings of positive emotional interaction between romantic couples using individually meaningful attributes characterizing the relationship and the participants involved, namely, self-generated compliments.

The specific areas found to be involved in couple's compliment sharing are known for social cognition processes, social reward processing, ToM and facial mimicry (Jabbi and Keysers, 2008; Kennedy and Adolphs, 2012). The involvement of the dopaminergic reward system, in particular, might serve as an important neurobiological mechanism underlying the ever rewarding aspects of lasting couple relationships. Interestingly, these brain areas are also involved in the action of neuropeptides promoting social

Table 5. Brain responses to (receiving partner compliment > waiting for partner compliment) > (receiving self-compliment > waiting for self-compliment)

Peak	Peak	MNI-coordinates			Region
P(FWE-corrected)	T	x	y	z	
< 0.001	7.21621704	−30	−64	−22	Cerebellum
< 0.001	6.71068478	−42	−61	−25	Cerebellum
< 0.001	6.43157673	−12	−67	−16	Cerebellum
< 0.001	7.18531132	−48	−13	41	Pre-/postcentral gyrus
0.0072	5.59245872	−48	−10	59	Precentral gyrus
< 0.001	6.9873867	42	17	−28	Superior temporal gyrus
0.0012	6.0868845	48	8	−7	Insula
0.0140	5.39685678	36	−1	−25	Amygdala
< 0.001	6.43445444	−39	11	−28	Superior temporal gyrus
0.0011	6.10743856	45	−10	41	Precentral gyrus
0.0014	6.04848385	57	−4	44	Precentral gyrus
0.0017	5.99132061	48	−1	59	Frontal middle gyrus
0.0054	5.67191124	27	−7	−13	Amygdala
0.0073	5.58856153	−6	−88	−10	Calcarine/lingual gyrus
0.0093	5.51773834	3	2	68	Superior frontal gyrus/supplementary motor area
0.0100	5.4936924	−15	−1	80	Superior frontal gyrus
0.012	5.44215488	9	−13	−13	Hippocampus
0.0125	5.42972374	−6	−82	17	Cuneus
0.0197	5.29384518	3	−85	38	Precuneus
0.0242	5.23110056	−30	−13	−13	Hippocampus
0.0357	5.11234665	9	14	38	Middle cingulate
0.0458	5.03419256	−30	−61	−49	Cerebellum
0.0469	5.02685928	15	−19	−13	Hippocampus

Table 6. Brain responses to (receiving partner's compliment > waiting for partner's compliment) > (choosing compliment for partner > observing sending)

Peak	Peak	MNI-coordinates			Region
P(FWE-corrected)	T	x	y	z	
< 0.001	12.1697969	21	−91	−34	Cerebellum
< 0.001	6.47661924	3	−88	−19	Cerebellum
< 0.001	11.8543653	−33	−88	−31	Superior/middle occiptal gyrus
< 0.001	11.2321196	−21	−79	−34	Cerebellum
< 0.001	10.5057125	0	−1	20	Corpus callusum
< 0.001	10.3181181	−12	−4	29	Middle cingulate
< 0.001	8.00352383	−18	−22	29	Nucleus caudatus/middle cingulate
< 0.001	9.35983181	−54	−67	41	Angular gyrus
< 0.001	8.50362015	−60	−58	29	Supramarginal gyrus
< 0.001	8.44472694	−60	−46	50	Supramarginal gyrus
< 0.001	8.84178734	57	−61	11	Superior temporal gyrus
< 0.001	6.97519064	66	−55	20	Superior temporal gyrus
0.0054	5.63413525	69	−40	29	Supramarginal gyrus
< 0.001	8.6882925	6	56	38	Superior frontal gyrus
< 0.001	8.64810467	6	26	68	Superior frontal gyrus
< 0.001	7.82007265	−6	50	26	Medial frontal gyrus
< 0.001	7.84036493	−33	−52	2	Lingual gyrus
0.0014	6.01714706	−24	−37	14	Hippocampus
0.0025	5.84849262	−18	−43	14	White matter
< 0.001	7.54454184	27	−7	−7	Globus pallidus/lentiform nucleus
< 0.001	7.52939987	48	2	−28	Middle temporal gyrus
< 0.001	7.01410103	48	11	−28	Temporal pole
< 0.001	7.29358339	−45	20	53	Middle frontal gyrus
< 0.001	7.24051571	−42	11	−34	Middle frontal gyrus
< 0.001	7.18364382	45	−10	35	Precentral gyrus
< 0.001	6.34821653	33	−46	2	Lingual gyrus
< 0.001	6.16943264	3	−55	32	Middle cingulate/precuneus
0.0010	6.10089874	−57	−28	−19	Temporal inferior gyrus
0.0023	5.8795042	−63	−19	−19	Temporal middle gyrus
0.0012	6.0625968	0	−28	17	Thalamus
0.0020	5.90837193	57	−1	11	Insula
0.0028	5.81837273	−42	−13	35	Postcentral/precentral gyrus

(continued)

Table 6. (Continued)

Peak	Peak		MNI-coordinates		Region
0.0042	5.7014122	−36	−13	26	Insula
0.0053	5.63772678	42	5	−4	Insula
0.0069	5.56073284	−27	−1	−22	Amygdala
0.0192	5.25661325	54	−25	−13	Temporal middle
0.0212	5.22633171	57	11	2	Insula
0.0247	5.1791029	51	23	5	Inferior frontal gyrus
0.0339	5.08146048	57	20	−28	Middle temporal pole
0.0399	5.03027153	−33	−7	−19	Parahippocampus
0.04829	4.96986198	−54	−61	−28	Cerebellum

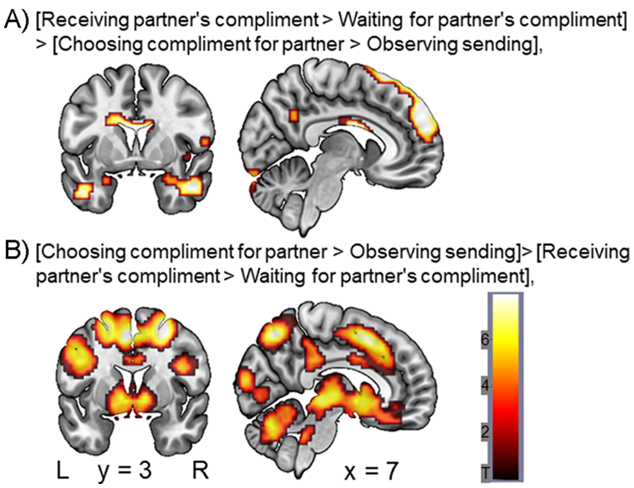

Fig. 3. Activation during receiving compared to compliment sending. (A) Receiving partner compliment (receive > wait) > sending (choose > observe). (B) Sending (choose > observe) > receive partner compliment (receive > wait), both x = 7, y = 3, t-scale applies to both panels.

behavior, such as oxytocin (Riem *et al.*, 2012; Kreuder *et al.*, 2018). Oxytocin has been shown to interact with the reward system, for example, when study participants observed the face of their romantic partner (Scheele *et al.*, 2013), and also to influence the appraisal of the relationship (Aguilar-Raab *et al.*, 2019). Furthermore, oxytocin is known to promote health beneficial effects such as regulation of the stress axes during couple interaction (Ditzen *et al.*, 2009; Zietlow *et al.*, 2018). Therefore, the neural networks reported here and the role of oxytocin might provide a potential neurobiological pathway underlying the association of couple relationships and health.

Our study has not only strengths but also some limitations. Investigating heterosexual romantic couples only and having them name, choose and send the compliments helped create an individualized interaction scenario. The paradigm comprised receiving unknown compliments from the partner and known self-compliments while always seeing the partner via video transmission as part of a naturalistic social exchange. Therefore, we can neither rule out that the found differences between partner- and self-compliment are due to novelty nor that some kind of interaction has taken place during the self-compliment phase via facial expressions. Other aspects that differed among task phases were the active or passive role of leading the interaction or making decisions in general.

The selected heterosexual monogamous sample allows no extrapolation to unacquainted individuals, platonic friend dyads or same-sex couples, though. Furthermore, the sample consisted of healthy young couples reporting high relationship satisfaction only. Given inconsistent effects of instructed partnership appreciation in clinical samples (Warth *et al.*, 2020) or couples in therapy (Aguilar-Raab *et al.*, 2018), we cannot extrapolate our findings to marital problems or patient populations (see, for instance, a study in couples with substance abuse by Flanagan *et al.*, 2018). On the other hand, our findings may still be applicable for some cultures or couple circumstances, since our participants came from Europe and North Africa (15 different nations

Table 7. Brain responses to (choosing compliment for partner > observing sending) > (receiving partner's compliment > waiting for partner's compliment)

Peak	Peak		MNI-coordinates		Region
P(FWE-corrected)	T	x	y	z	
< 0.001	16.525074	−36	−13	59	Precentral gyrus
< 0.001	15.8985653	−39	−31	53	Postcentral gyurs
< 0.001	15.8449984	18	−67	56	Superioral parietal gyrus
< 0.001	9.79416847	45	8	26	Inferior frontal gyrus
< 0.001	7.32125902	57	−46	−16	Inferor temporal gyrus
< 0.001	7.22525072	6	−31	29	Posterior cingulate
< 0.001	6.43974495	−3	−28	29	Posterior cingulate
0.0026	5.8363061	21	−40	−43	Cerebellum
0.0081	5.51446533	−15	−55	−46	Cerebellum
0.0084	5.50423813	−39	−4	14	Insula
0.0190	5.25947666	−48	11	−13	Superior temporal gyrus
0.0263	5.16038084	−30	−58	−34	Cerebellum
0.0304	5.11576033	−54	8	−10	Superior temporal gyrus

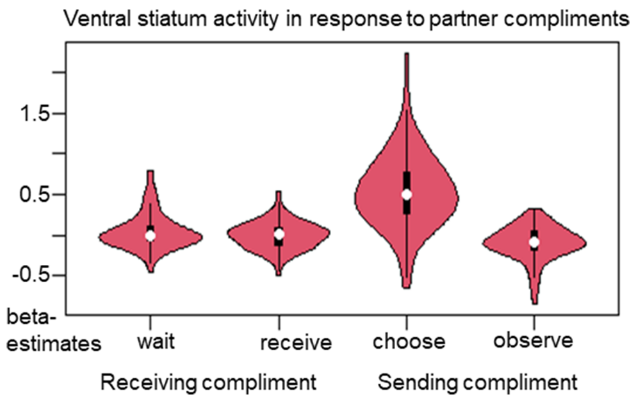

Fig. 4. Beta estimates on ventral striatum activation during the experimental phases of sending and receiving partner compliments; white dots indicate means, black bars indicate standard error of the mean.

and 12 mother tongues), and therefore, generalizability to those parts of the world is given and the individualized compliments have accounted for potential differences. Future studies could systematically investigate cultures and contexts, clinical samples and couples in the non-heterosexual (LGBTQIA+) spectrum. We assume similar basic neural effects in all couples though.

In conclusion, our data show substantial involvement of limbic structures during instructed yet individualized couples compliment sharing. The involvement of dopaminergic areas not only is evident when receiving compliments but also is strongest in the ventral striatum when selecting compliments for the partner. This suggests a role of neural reward processes when giving a treat to the loved one—which might contribute to the maintenance of lasting relationships beyond the mere receipt of affection and support.

Authors' contribution statement

B.D., P.K., G.S., E.B and M.E. designed the study; G.S. and M.E. lead the study; G.S., E.B. and M.E. collected the data; M.F.G. and E.B. established the experimental set-up; G.S. M.F.G and M.E. ran the reported analyses; M.E. and B.D. wrote the manuscript. All authors provided comments on the manuscript.

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Conflict of interest

The authors declared that they had no conflict of interest with respect to their authorship or the publication of this article.

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