# NEUROENDOCRINOLOGY OF ROMANTIC LOVE

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**UNIVERSITY OF RIJEKA**
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Thesis mentor: Assoc. prof. Sanja Klobučar, MD, PhD

The graduation thesis was graded on _____ in _____, before the Committee composed of the following members:

1. assist. prof. Duška Petranović, MD, PhD
2. prof. Ivan Bubić, MD, PhD
3. prof. Ines Mrakovčić Šutić, MD, PhD

The graduation thesis contains _____ pages, _____ figures, _____ tables, _____ references.

# Contents

**List of abbreviations**

| | |
|---|---|
| fMRI | Functional Magnetic Resonance Imaging |
| OXT | Oxytocin |
| VP | Vasopressin |
| ACC | Anterior Cingulate Cortex |
| BOLD | Blood Oxygen Level-Dependent |
| PAG | Periaqueductal Grey Matter |
| OFC | Orbitofrontal Cortex |
| LPF | Lateral Prefrontal Cortex |
| FG | Fusiform Gyrus |
| STS | Superior Temporal Sulcus |
| NAcc | Nucleus Accumbens |
| VTA | Ventral Tegmental Area |
| AMY | Amygdala |
| SNP | Single Nucleotide Polymorphism |
| ASD | Autism Spectrum Disorder |
| SAD | Social Anxiety Disorder |

| | |
|---|---|
| GET | Gratitude Expression Treatment |
| IU | International Units |
| AA-task | Approach-Avoidance Task |
| MFG | Medial Frontal Gyrus |
| VMPFC | Ventromedial Prefrontal Cortex |
| AI | Anterior Insula |
| OXTR | Oxytocin Receptor |
| VPR | Vasopressin Receptor |

# 1. Introduction

Romantic love is a strong human feeling difficult to define and yet almost everyone has experienced it at some point in life to a certain extent. Here I will try to investigate it through scientific glasses and analyze it as a complex manifestation of three different systems of motivations and drives with different characteristics and purposes working together with the aim of human survival and reproduction. Subjectively strong emotion of romantic love results from the involvement of diverse brain regions and hormones and neurotransmitters. Basic human sex drive or lust is priming individuals to seek sexual partners and is in major part influenced by sex hormones affecting mostly the amygdala in the temporal lobes. Attraction drives individuals to select specific partners and is driven mostly by dopamine residing in the ventral tegmental area (VTA) in the midbrain and nucleus accumbens (NAcc) as a part of the ventral striatum. Finally, attachment or bonding motivates individuals to remain together longer, procreate, and take care of their offspring. It is influenced mostly by oxytocin and vasopressin, affecting the ventral pallidum within the basal ganglia and raphe nuclei in the brain stem. (1)

| | Lust | Attraction | Attachment |
|---|---|---|---|
| Characteristic and purpose | Seeks sexual union with any appropriate member of the species | Select partners and focuses attention on genetically appropriate individuals saving mating time and energy | Sustain affiliative connections long enough to complete parental duties |
| Predominant hormones* | Testosterone and estrogen | Dopamine norepinephrine and serotonergic system | Vasopressin and oxytocin |
| Predominant nuclei | Amygdala | Ventral regimental area and nucleus accumbens | Ventral pallium, raphe nucleus |

*More than one system involved - differentiation made for illustrative purposes

*Figure 1: Comparison of three motivations involved in "love"*

*Source: Seshadri KG. The neuroendocrinology of love. Indian J Endocrinol Metab. 2016 Jul-Aug;20(4):558-63. doi: 10.4103/2230-8210.183479. PMID: 27366726; PMCID: PMC4911849.*

### 1.1 Hormones/neurotransmitters involved in romantic love

Oxytocin (OXT) and vasopressin (VP) are closely associated with attachment and bonding. Both are produced by the hypothalamus, stored in the pituitary gland, and released into the blood during orgasm in both sexes and during childbirth and breastfeeding in females. In addition, OXT and VP are made throughout the body with local effects on diverse tissues, including the uterus, testes, digestive system, kidney, and thymus and both are involved in modulating reproductive behaviors. Oxytocin, often called a "love hormone" is a peptide regulating a variety of functions, including love and positive emotions, also providing resilience to stress. It has strong anti-inflammatory properties and facilitates social interactions and the capacity to physically and emotionally heal in the face of stress or trauma. In males, vasopressin is associated with aggression towards other males. Interestingly, the concentration of both neuromodulators increases during the phase of intense romantic attachment. (2)

### 1.2 Oxytocin and vasopressin receptors

The receptors for both neuromodulators are distributed in many parts of the brain and are activated during both romantic and maternal love. OXT and VP and their receptors are interactive components of the OXT–VP pathway (Figure 2). (2) The OXT–VP pathway allows the body to adapt to emotional situations and develop selective attachment such as sexual behavior, parental behavior, and pair bond formation, as well as regulation of the autonomic nervous system.

The gene (OXTR) for an oxytocin receptor (OXTR) is found on human chromosome 3. The same OXTRs located in the breast, uterus, and neural tissue are also present in many other tissues. Three VP receptor subtypes are expressed in different tissues, and their genes are located on separate chromosomes. The V1aR is found in the nervous system and throughout the cardiovascular system related to a wide set of behavioral functions. The VP V1b receptor is not only found in the pituitary but also brain areas with a role in the management of stress and aggression and the VP V2 receptor is localized primarily to the kidney with a classical role in fluid balance.

OXT and VP receptors are variable, across species, individuals, and brain regions, and these receptors are capable of being epigenetically tuned. This variation may help to explain experience-related individual and sex differences in behaviors that are regulated by these

peptides, including the capacity to form social attachments and the emotional consequences of these attachments. (2)

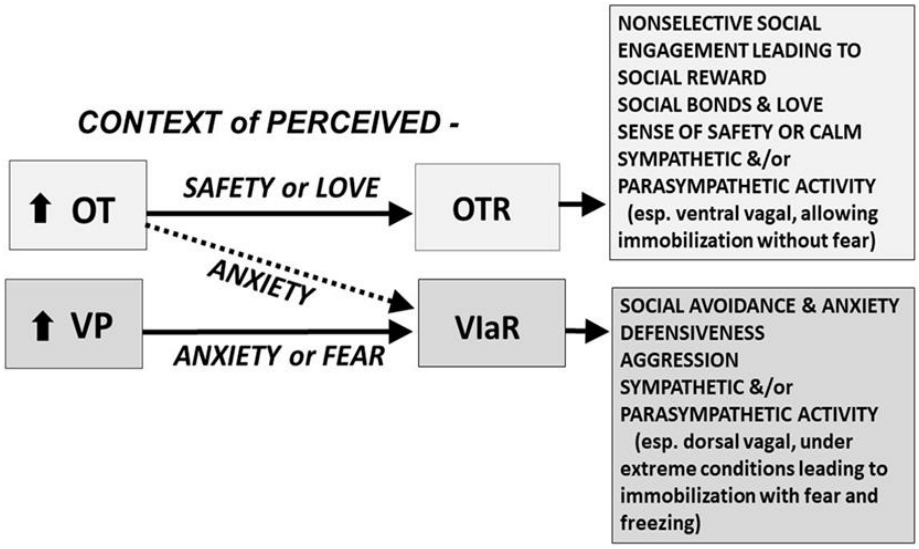


*Figure 2: Oxytocin fosters social bonding in safe contexts via its receptor, while in anxiety or fear, both oxytocin and vasopressin act on the V1a receptor, promoting defensive behaviors and dissociation.*

*Source: Carter CS. The Oxytocin-Vasopressin Pathway in the Context of Love and Fear. Front Endocrinol (Lausanne). 2017 Dec 22;8:356. doi: 10.3389/fendo.2017.00356. PMID: 29312146; PMCID: PMC5743651.*

### 1.3 Neurophysiology of romantic love

The physiology underlying romantic love involves multiple regions in the brain, particularly the ventral tegmental area (VTA), which is central to the brain's reward system, known as the mesolimbic circuit. This mesolimbic reward-motivation system, associated with dopaminergic pathways, includes the VTA, the corpus striatum (comprising the ventral striatum, which includes the nucleus accumbens (NAcc) and ventral pallidum (VP), and the dorsal striatum, including the caudate nucleus and putamen), the substantia nigra (SN) in the midbrain, the prefrontal cortex, the anterior cingulate cortex, the insular cortex, the hippocampus, the hypothalamus, the thalamus, the subthalamic nucleus, the globus pallidus, and the amygdala. (3)

### 1.4 Animal data

Although this thesis reviews the research studies in humans, it is important to indicate the animal studies that pioneered in this field of science about love. Delbiec et al. diligently described their research in prairie voles (*Microtus ochrogaster*), the monogamous rodent, that enhanced our understanding of physiology of the pair bonding. Following mating, these rodents

form monogamous relationships and after losing their companion for some reason, they would generally not seek out new mates. In contrast, closely related montane voles do not form pair bonds with each other but are rather promiscuous. Comparative studies of these two species, along with findings from human functional magnetic resonance (fMRI) studies, provided insights into the neurobiology of romantic love.

Numerous studies demonstrated the important roles of vasopressin and oxytocin in the formation of partner bonds in prairie voles, but the presence of these peptides in the brain is not sufficient to establish the relationship. Because adding the exogenous VP or OXT, did not influence bonding in non-monogamous montane voles, research further focused on the distribution of oxytocin and vasopressin receptors in the brains of both rodent species. In comparison to montane voles, prairie voles have higher densities of oxytocin receptors (OXTRs) in the nucleus accumbens and the lateral amygdala. Additionally, they have an increased expression of vasopressin receptor 1a (V1aR) in the ventral pallidum and the medial amygdala. Through viral vectors, promiscuous montane voles were engineered to express V1aRs like their monogamous relatives. This manipulation facilitated partner bond formation following mating in the species that do not naturally bond. Thus, the alteration of vasopressin receptor distribution may produce major behavioral changes, which profoundly affect social behavior. (4)

## 2. Aims and objectives

This review seeks to offer an in-depth analysis of the neuroendocrine mechanisms underpinning pair bonding, or romantic love, in humans. Through a comprehensive overview of existing research, this paper will clarify the primary hormonal and neurotransmitter systems involved, while also identifying potential avenues for future investigation. Emphasis will be placed on the role of oxytocin, the principal hormone associated with romantic attachment.

Specific objectives include:

1. Examination of neuroendocrine mechanisms: investigation of roles of key hormones and neurotransmitters, such as oxytocin and vasopressin, in the development and maintenance of romantic love
2. Neuroimaging insights - to review neuroimaging studies that explore brain regions activated during feelings of romantic love, including the ventral tegmental area, caudate nucleus, and putamen

3. Stage-specific analysis: to analyze how neuroendocrine processes differ across various stages of romantic love, including initial attraction, deep attachment, and long-term commitment
4. Clinical implications: to discuss the implications of neuroendocrinological findings for clinical practice, particularly focusing on mental health issues such as depression, anxiety, and relationship counseling
5. Identify research gaps: highlight gaps in current literature and propose future research directions, focusing on the long-term effects of romantic love and its interaction with other forms of attachment.

Through these objectives, the review seeks to deepen the understanding of the neuroendocrinological basis of romantic love, offering valuable insights for both academic research and clinical applications.

## 3. Methods

I searched the online database PubMed on 5 May 2024, using the following terms in the title and abstract fields: " [(love OR romance OR romantic) AND (oxytocin)], using following filters: Abstract, Free full text, Clinical Trial, Meta-Analysis, Multicenter Study, Randomized Controlled Trial, Review, Systematic Review, to review scientific evidence on the underlying interdependence of chemical and physiological mechanisms that form the biological foundations of the romantic love [(love OR romance OR romantic) AND (oxytocin)] - Search Results - PubMed (nih.gov). The search provided 43 results. I have then selected only articles reporting original research studies and meta-analyses with abstracts, free full-text availability, and excluded reviews and opinion articles. Application of these exclusion criteria resulted in 16 relevant articles - [(love OR romance OR romantic) AND (oxytocin)] - Search Results - PubMed (nih.gov). An additional 1 study missing from initial searches was identified through cross-references and relevant review articles. Upon thorough review of all 17 articles, 11 manuscripts were selected for this thesis and 6 were discarded for the following reasons - 1 did not have open access available, 5 did not research romantic love - their focus was either parental love or kind of social interactions.

*Table 1 : Selected articles*

| yes/no | Authors | Title/link | Socioemotional Context | Sample Size | Sex | Main Stimuli Comparison |
|---|---|---|---|---|---|---|
| Yes | Bartels A, et al. | The neural basis of romantic love | Romantic love | N=17 | 11 females 6 males | Viewing photographs of partners vs photos of three friends of similar age, sex, and duration of friendship as their partners |
| Yes | Bartels A, et al. | The neural correlates of maternal and romantic love. | Romantic love Parental love | N=20 | 20 females | Own child's photographs vs other child's photographs |
| yes | Van IJzendoorn MH, et al. | A sniff of trust: meta-analysis of the effects of intranasal oxytocin administration on face recognition, trust to in-group, and trust to out-group | Romantic love | | | Recognition of facial expressions of emotions |
| yes | Scheele D, et al | Oxytocin enhances brain reward system responses in men viewing the face of their female partner | Romantic love | N=20 | 20 males | Romantic partner VS unfamiliar woman, or of a nonface control stimulus, a house photograph |
| yes | Scheele D, et al | Oxytocin Modulates Social Distance between Males and Females | Romantic love | N =86 | 86 males | Physical distance between single and pair-bonded men and attractive unfamiliar female |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | responses to positive (attractive women or beautiful landscapes) and negative (mutilations or dirt) pictures |
| yes | Li J, et al. | Association of Oxytocin Receptor Gene (OXTR) rs53576 Polymorphism with Sociality: A Meta-Analysis | Social interaction Romantic love Parental love | | | rs53576 polymorphism impact on general sociality, close relationships and depression |
| yes | Kreuder AK, et al. | How the brain codes intimacy: The neurobiological substrates of romantic touch | Romantic love | N = 192 | | Subjective pleasantness of the partner's touch |
| yes | Kreuder AK, et al. | Oxytocin enhances the pain-relieving effects of social support in romantic couples | Romantic love | N = 194 | 32 females 65 males | Pain while holding a partner's hand, an unfamiliar male/female experimenter's hand, or a rubber hand |
| yes | Eckstein M, et al. | Oxytocin Increases Eye-Gaze towards Novel Social and Non-Social Stimuli. - PMC (nih.gov) | Romantic love | N = 82 | | Pictures of parent-child dyads, romantic couples engaging in non-erotic or explicit Sexual activities, and non-social pictures |
| yes | Marsh N, et al. | Eye-Tracking Reveals a Role of Oxytocin in Attention Allocation | Romantic love | N = 73 | 45 females 28 males | Gaze duration toward the eye-region |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Towards Familiar Faces | | | | |
| yes | Chang YP, et al. | Implementation intentions to express gratitude increase daily time co-present with an intimate partner, and moderate effects of variation in CD38 | Romantic love | N = 250 | | Daily time spent in the physical presence of a partner |

## 4. The neurobiological foundation of love

The study exploring the neural underpinnings of romantic love used fMRI to examine the neuroendocrine mechanisms involved. In this research, the brain activity of 17 participants who claimed to be deeply in love was recorded as they looked at pictures of their partners. This activity was then compared to the brain responses triggered by viewing images of three friends, matched for age, sex, and duration of friendship. The aim was to identify brain regions connected to romantic love by comparing two positive emotions: romantic love and friendship. Surprisingly, the studies revealed that the neuroendocrine systems involved in the complex sentiment of love are highly focused and restricted to a few locations in the cortical and subcortical parts of the cerebrum.

When participants viewed pictures of their partners, there was no activity detected in the visual area of the occipital lobe or the fusiform gyrus, responsible for attention to faces and facial recognition. The blood oxygen level-dependent (BOLD) signal, when participants viewed images of their romantic partners, indicated modest activation in two primary cortical regions distinct from the visual brain: the left middle insula and the anterior cingulate cortex on both sides. Additionally, there was bilateral activation in the posterior hippocampus. Significant activations were also observed in two subcortical brain regions: the head of the caudate nucleus and the putamen, both more pronounced on the left side, as well as in certain parts of the cerebellum.

Significant deactivations were noted in regions typically associated with negative emotions such as the amygdaloid region. Additionally, the study compared its findings with those in studying brain activity during sexual arousal, noting no direct overlap in activations. The study found similarities with regions activated during euphoria (e.g., from drugs like cocaine) suggesting a potential neuroendocrine link between romantic love and euphoric states implying that romantic love might trigger neuroendocrine responses like those seen in reward and pleasure pathways (5).

The insula is connected to various affective functions. Injuries in the insula may bring deleterious emotional consequences, including those that are associated with the interpretation of visual input. More precisely, the anterior part of the insula was shown as a site of localized activity in negative emotional experiences imaging studies, unlike the middle one in this study. (5) This may help us understand how various emotions and their subjective perceptions are processed in different parts of the brain.

Also, other studies showed the left side of the insula activation with perceiving unfamiliar faces as attractive, which overlaps with the one activated in this study.

The anterior cingulate cortex (ACC) comprises multiple components with unique functions, notably those associated with emotional function. Even though many previous imaging studies investigating various emotions grouped the activity to the ACC, many of its subdivisions with specific roles can be identified. Attention to other people's feelings, own feelings, other people's emotional states, as well as those of self, and feelings of happiness, activated more dorsal parts of the ACC, unlike in this study, where activity peaked in the more ventral part of the ACC with viewing a loved one's face.

The subcortical areas, the caudate nucleus, and the putamen were previously known as areas activated in the processing of emotions, positive or negative. They are a part of the extrapyramidal motor system, so the inquiry was, are they activated because of a possible increase of imagery or motor planning related to their loved one?

However, in studies on motor imagery, execution, or mental rotation, these parts of the brain were not activated. This may lead to the conclusion that they are a part of the extrapyramidal motor system, but primarily hold a role in emotional processing (5).

Deactivations are also a very important aspect of this topic, as it is in balance with neural activations, and may affect the intensity and nature of experienced emotions.

Generally, feeling happiness deactivated the right prefrontal cortex and bilateral areas of the parietal and temporal cortices. On the other hand, feelings of sadness and depression activated the aforementioned parts, specifically the right prefrontal cortex. Its artificial inactivation, achieved by transcranial magnetic stimulation, proved to be a fruitful treatment for depression.

Notable deactivation was noted in the amygdala. Amygdaloid activity correlated with sadness, aggression, and fear. It is also considered a mediator of emotional learning. In a study of facial expressions, the highest activity was with viewing a fearful facial expression, and it was lower viewing a happy facial expression. Furthermore, in this study, the amygdala was more active viewing friends, rather than lovers (5).

## 5. Neural underpinnings of motherly and romantic love

In this study, mothers were shown a picture of their child and an acquainted child of a similar age to analyze the brain regions associated with maternal love using fMRI imaging studies. This study then compared the results to the fMRI findings in the previous study, where couples viewed their partner's photo, trying to find similarities and differences in brain regions activated by feelings of romantic vs maternal love. Many overlapping regions were identified, the striatum, consisting of the putamen, globus pallidus, and caudate nucleus, as well as the middle insula, and the dorsal part of the anterior cingulate cortex. These are areas predominantly abundant in oxytocin and vasopressin receptors. A specific brain region was activated in maternal love - periaqueductal grey matter, suggesting a role in maternal behavior. Deactivated brain regions included those that involve critical social behaviors and negative emotions. These studies illuminated neural mechanisms that underlie attachment, the role of oxytocin and vasopressin in attachment-related disorders, and their potential role in the pharmacological treatment of such disorders. (6)

### 5.1 Brain regions involved in maternal love

The activity was reported bilaterally in the cortex, more precisely medial insula, and the cingulate gyrus dorsal and ventral of the genu, which all overlap with that found in the romantic context. Ventral genu activity in the romantic setting was observed only in females.
Uniquely activated regions in this study included the following regions: the lateral orbitofrontal cortex (OFC) and the lateral prefrontal cortex (LPF). Furthermore, activation was observed in

areas indirectly linked to advanced cognitive or emotional processing, an area close to the frontal eye fields, the occipital cortex in the vicinity of the visual region V3, and the lateral fusiform cortex.

- **The medial insula**

The insula, with its various subparts, plays a role in processing visceral sensations and is believed to be involved in generating the intuitive 'gut feelings' associated with emotional states. One study recently discovered a neural tract for what's termed 'limbic touch,' which activates the middle insula directly rather than going through the somatosensory cortices. This pathway is responsible for eliciting pleasant sensations from touch and controlling emotional, hormonal, and bonding responses to gentle, bare-skin contact between individuals. The patterns of brain activity observed in this study align closely with those found in the research on both maternal and romantic love. This overlap likely reflects the shared sensory and emotional components crucial for fostering caring relationships. Conversely, the anterior portion of the insula, which is inactive here, is consistently activated by adverse stimuli.

- **The anterior cingulate cortex**

The anterior cingulate cortex (ACC) consists of many functional and anatomical subdivisions, many of which are intricately involved in social and emotional processing. Identifying the activation in this study may aid in localization of the site in the ACC which, if injured, has led to disturbed maternal behavior in animals.

- **Lateral fusiform gyrus**

The activation in the lateral fusiform gyrus (FG), specialized in facial recognition, seen in maternal love, may stem from two factors: increased attention to faces and heightened emotional response. However, even after accounting for emotional impact, FG activity persisted, contrasting with the absence of such activation in visual areas for romantic love. Additionally, while both attention and emotional valence typically engage the superior temporal sulcus (STS), its suppression in our study suggests a unique mechanism specific to maternal attachment. (6)

Continual changes in infants' facial features and the significance of their interpretation may necessitate ongoing updates to facial recognition processes, resulting in heightened FG activity.

Activity in subcortical regions, observed bilaterally, overlapped with the findings in the romantic love study in the striatum (putamen, globus pallidus), along with somewhat lower activities in the head of the caudate nucleus, substantia nigra, and subthalamic regions.
Uniquely 'maternal' activation patterns, not found in the previous study, were localized in the posterior-ventral region of the thalamus and an area that coincides with the periaqueductal grey matter (PAG) in the midbrain. The activity in the midbrain exhibited similarity with the reticular formation, the locus ceruleus, and the raphe nuclei. Its point of origin is probably PAG because This area contains a dense concentration of oxytocin receptors (as well as the locus ceruleus) and is recognized for its role in maternal behavior (6).

Deactivations in maternal love, present but in a weaker manner, were remarkably alike to those identified in romance. The pattern was observed on both sides and was mainly concentrated in the right hemisphere of the cerebrum. They included the middle prefrontal cortex, associated with sadness and depression, the parietal-occipital junction/superior temporal sulcus, the medial prefrontal/paracingulate cortex, the temporal poles, the posterior cingulate gyrus, the medial cuneus, and the amygdaloid region.

Deactivation of the judgmental social assessment network was observed in both motherly love and romance, comprising two separate groups of brain regions. The first group of regions, primarily located in the right hemisphere includes the middle prefrontal, inferior parietal, and middle temporal cortices. It is known for its involvement in cognitive processes such as attention and memory. These regions have also been implicated in emotional processing, particularly of negative emotions. However, their variable engagement in pleasant and unpleasant feelings suggests a modulatory role influenced by limbic/paralimbic regions. The second group of regions that are inactivated includes the amygdala, temporal poles, parietotemporal junction, and mesial prefrontal cortex, consistently associated with unpleasant feelings and societal cognition tasks such as theory of mind. These regions are activated during tasks involving mentalizing, assessing social trustworthiness, interpreting facial expressions, moral judgment, and attending to one's own emotions. (6)

### 5.2 The contrast between a mother’s love and romantic partners

The concordance of the findings was astonishing. Several regions overlapped precisely, in contrast to others, specific to a certain type of love/attachment.

Matching brain areas included the ones within the striatum (caudate nucleus, putamen, globus pallidus), the middle part of the insula, and the dorsal portion of the anterior cingulate cortex. A separate analysis of results based on gender revealed that all regions were activated in both genders.

Activity exclusive to a mother's love comprised of the lateral orbitofrontal cortex, and the periaqueductal grey matter (PAG) subcortically.

The activated regions were densely concentrated with oxytocin and vasopressin receptors and belonged to the reward system.

Both types of attachment suppress brain regions linked to negative emotions and areas involved in judgmental social evaluation. This suggests that a deep emotional bond with another person does not merely reduce negative emotions overall but also influences the process of making social evaluations about that individual.

The findings in both studies suggested that brain areas related to emotional attachment interact with the reward pathway of the cerebrum (substantia nigra, nucleus accumbens, striatum, sublenticular extended amygdala).

The striatum contains areas that react to rewards related to food and beverages, as well as money reward, cocaine, and sexual arousal in humans and primates. (6)

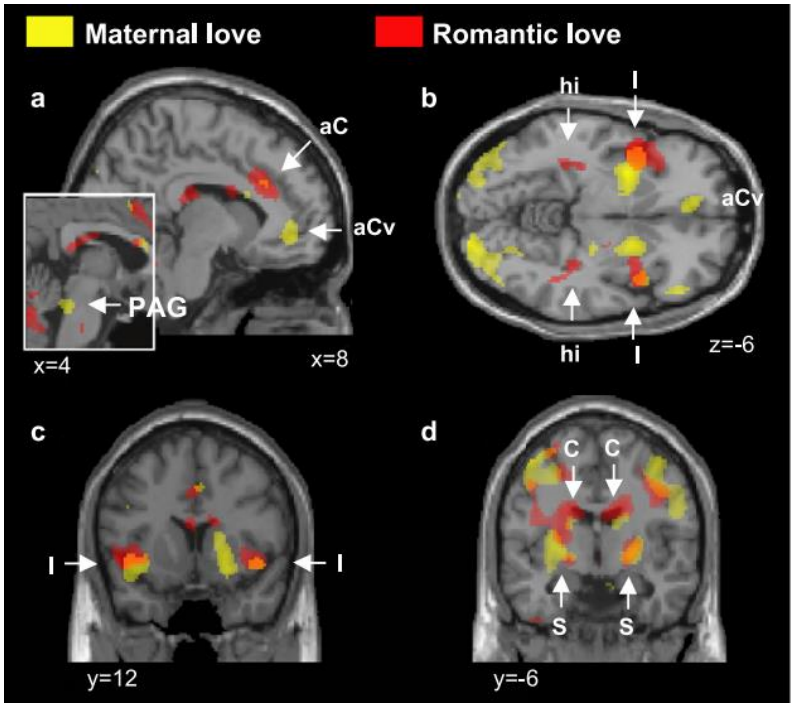


*Figure 3: fMRI overlap between the activity of maternal love and romantic love*

*Source: Bartels A, Zeki S. The neural correlates of maternal and romantic love. NeuroImage. 2004 Mar;21(3):1155–66.*

### 5.4 Attachment and neuropeptides

Neuropeptides oxytocin (OXT) and vasopressin (VP) were identified as crucial for parent-child attachment and adult mating partnerships in animals and most regions activated in the studies contain a rich network of receptors for these neurohormones.

PAG, a region that is specific to human maternal behavior, also has a high concentration of OXT and VP binding sites and is involved in endogenous pain suppression during childbirth and this is mediated by the action of oxytocin. PAG is directly connected to the orbitofrontal cortex, also specifically activated in maternal love, which activates with enjoyable sight, touch, and smell sensations

Perhaps the connection of these two reflects feelings of pleasure related to motherhood. Activation of the VTA corresponds to the research of maternal behavior in rats, which may be promoted or disturbed depending on the existence or nonexistence of OXT.

Despite their interconnection, OXT and VP have different receptor locations in the brain and distinct functions in romantic and maternal love. Specific activation of dentate gyrus/hippocampus with romantic love, and its specificity for vasopressin shows novel evidence for similar functional/neurohormonal association in humans. (6)

In summary, the research indicates that both romance and a mother’s love activate specific regions within the brain's reward pathway while simultaneously suppressing activity in areas associated with social assessment and negative emotions. Given the limited understanding of social cognition in the human brain, the uncertain nature of the interpretations must be acknowledged, with expectations that future studies will provide further insights. However, a potential model suggests that once familiarity with a person is established, the need for social evaluation diminishes, resulting in reduced activity in corresponding brain systems. These findings shed light on the neurological basis of the phenomenon known as "love is blind." The suppressed neural mechanisms may mirror those responsible for maintaining emotional barriers towards unfamiliar individuals, akin to avoidance behaviors observed in animals, which are modulated by oxytocin administration. The balanced activation and deactivation of brain regions associated with attachment are crucial for healthy social interactions and may have implications for understanding psychological and clinical disorders resulting from disruptions in this circuitry. Furthermore, the involvement of oxytocin and vasopressin receptors offers potential avenues for pharmacological intervention to modulate attachment-related feelings. In essence, the findings suggest a nuanced interplay between attachment

mechanisms, wherein certain brain areas deactivate negative emotions and social assessment while activating reward mechanisms. While the results provide some insight, they underscore the complexity of the neural basis underlying the fundamental evolutionary drive for reproduction and social bonding, which ensures the survival and perpetuation of the species. (6)

## 6. Oxytocin and trust in social interactions

IJzendoorn and alumni conducted a meta-analysis to determine if experiments involving intranasal administration of oxytocin confirmed the proposed effect of oxytocin. Two aspects of oxytocin effects have been studied extensively: the identification of emotional facial expressions such as happiness, anger, and fear; and sensations of trust towards other people....
Trust in-group and out-of-group has recently been differentiated. Evolutionarily speaking, Oxytocin may boost the tendency to safeguard offspring from predators, thereby heightening defensive aggression against threats from strangers.
Additionally, intranasal oxytocin use has become widely used in recent years because, unlike when it is intravenously administered, it seems to cause consistent alterations in brain activity and behavior, likely because of an easy passage through the blood-brain barrier.

Individual results of the studies were transformed in a program into the widely used measure known as Cohen's d, which quantifies the standardized difference between the intervention and control conditions
It established that oxytocin applied intranasally enhanced the identification of facial displays of various sentiments.
The effect of oxytocin on face recognition is modest, with a Cohen's d of 0.21.
It additionally increased the in-group trust with a medium magnitude of effect (Cohen's d of 0.43).
Contrary to some expectations, oxytocin did not significantly decrease out-group trust.
The overall effect sizes for oxytocin's impact on trust are modest and may be overstated in popular media. (7)
The current body of research is not yet saturated, and further studies are necessary. There is a need for more research that separates in-group and out-group trust. Moderator analyses (e.g., gender, type of placebo, awareness of administration) were limited due to the small number of studies.

Most studies used a 24 IU dose of oxytocin with a 35 to 50-minute observation window, leaving uncertainties about the effects of different doses and time frames. Future research could explore oxytocin's role in enhancing psychological or behavioral interventions aimed at improving the closest personal relationships. (7)

# 7. Oxytocin receptor gene polymorphisms and sociality

This chapter delves into the intricate role of the oxytocin receptor (OXTR) and its genetic basis, exploring how variations in the OXTR gene influence social and emotional behaviors.

## 7.1 Oxytocin Receptor (OXTR)

The oxytocin receptor (OXTR) is a protein encoded by the OXTR gene. This receptor is crucial for mediating the effects of oxytocin, a neuropeptide hormone known for its significant role in social bonding, reproductive behaviors, and emotional regulation. Oxytocin functions within the brain, impacting the reward system and modulating stress and anxiety by interacting with various regions, including the amygdala, nucleus accumbens, and prefrontal cortex. Due to its widespread distribution, oxytocin can influence a wide range of physiological and psychological processes. The primary role of OXTR is to facilitate social and emotional behaviors, such as maternal care, pair bonding, social recognition, and the regulation of stress, depression, and anxiety.

## 7.2 Genetic Basis of Oxytocin Receptors

The OXTR gene is subject to genetic variation, and therefore an important area of research. These variations, known as polymorphisms, can significantly affect the expression and function of the OXTR. Polymorphisms in the OXTR gene can affect how individuals respond to oxytocin, which influences their social behaviors and emotional regulation.
Understanding such genetic variations is essential for exploring diverse effects of OXT on sociality and emotional health, as they may aid in explaining the variability in social and emotional responses among different individuals.

The subsequent section will delve into some specific polymorphisms of the OXTR gene and their associations with social behaviors, attachment, and social cognition.

### 7.3 OXTR gene rs53576 polymorphism and sociality

Variant rs53576 is a commonly investigated OXTR single nucleotide polymorphism (SNP) that is associated with personal characteristics and actions linked to social interactions, albeit with an inconsistent pattern of published results. A meta-analysis was performed by Li et al. to evaluate the associations more closely. Individuals with two copies of the G allele (GG genotype) and individuals who carry at least one A allele (AA/AG genotypes) were compared and two indices of sociality were evaluated independently: 1) Overall social behavior (24 studies, total sample size of 4955 participants) and 2) Intimate relationships (15 studies, total sample size of 5262 participants), or how individuals react to those they are in a close relationship with (romantically or parent-child connections). (8)

The results indicated that the G allele homozygotes are in general more social than the carriers A allele. Additionally, no association between the rs54576 variant and depression was found, indicating that its genetic link to overall sociability was probably not affected by depression, individuals homozygous for the G allele (rs54576) exhibit higher amygdala activation compared to those carrying the A allele when processing socially significant information. (8) This may be linked to the differences in general social behavior between the two genotypes.

However, future animal and human neuroimaging studies are necessary for further exploration of the exact biological mechanisms that may account for this relationship. (8)

On the other hand, there wasn't a large variation found in the personal relationships between the genotypes. This leads to the conclusion that the rs53576 polymorphism in the OXTR gene foresees how one interacts with people overall, however, it may not be related to variations in close personal connections such as those between a child and parent or romantic partners.

Another OXTR SNP, rs2254298 was found to be associated with individual differences in attachment.

Genetically engineered mice whose OXTR receptors were completely disabled displayed social memory deficits and exhibited autistic-like symptoms.

The limitations of this analysis deserve to be mentioned. It is based mostly on findings of other studies and the participant number was quite limited thus it might diminish the statistical robustness of the meta-analysis. Moreover, it has been proposed that the interaction between the rs53576 polymorphism and cultural contexts can influence social behaviors. However, this

study could not examine this potential interaction due to the limited number of samples available. In addition, due to the insufficient number of studies focusing on individual measures of sociability, various indicators of general sociality (such outgoingness, compassion, seeking companionship, or assistance) had to be combined into a single phenotype.

Consequently, potential genetic associations with specific measures (like empathy) were not able to be investigated. Further studies are necessary to investigate these potential connections in detail. (8)

To conclude, this study provided conclusive proof linking the rs35376 SNP to overall sociability. It is a possibility that overall sociability serves as a characteristic trait of certain disorders linked to social behavior like the autism spectrum disorder (ASD) or social anxiety disorder (SAD). Recent studies demonstrated that there are some OXTR SNPs linked with ASD, even if this connection doesn't exist concerning rs53576. There are several possible explanations for the absence of a link between the rs53576 SNP and ASD in this study. These include: 1) a genuine absence of genetic correlation, and 2) insufficient statistical robustness (N = 2800, 5 independent samples). Further research with robust methodology is necessary to investigate the relationship between OXTR polymorphisms and these related mental disorders.

## 8. Genetics, gratitude, and oxytocin

Close relationships significantly contribute to psychological and physiological well-being and contribute to longer life spans. Affirmative behaviors toward others (like verbalizing thankfulness) may be crucial in strengthening these bonds. Existing evidence supports this idea, but it is mainly correlational, possibly due to difficulties in behavior change and maintenance within personal connections.

A 5-week field experiment collected daily data from couples and demonstrated the effectiveness of a brief, low-cost behavioral technique known as the gratitude expression treatment (GET). This intervention was designed to enhance the daily expressions of gratitude toward romantic partners. The research aimed to establish causality by having one partner demonstrate thankfulness, highlighting its impacts on the relationship.

136 couples (272 individuals) were recruited for the study, attending three laboratory sessions over five weeks. Couples were assigned at random to either a test group, where one partner created a plan to express gratitude frequently (GET condition), or a control group with no such

instructions. Nightly questionnaires were used to track time spent together and relationship behaviors. Participants in the GET condition were guided through a four-screen online task to plan and rehearse gratitude expressions in response to partner actions.

This study used two theoretical frameworks: the find-remind-and-bind theory of gratitude, which suggests that expressed gratitude strengthens relationships, and the implementation intention theory, which involves forming plans for specific behavioral responses in certain situations. Its goal was to promote the expression of gratitude consistently over time. The outcome measure of interest was the time physically spent together, as it is considered an index of social bonding in both animal and human literature. Then the results were linked to the oxytocin system, drawing parallels from animal research that showed preferences for spending time with bonded partners. It suggested that expressing gratitude may influence the oxytocin system, impacting the time couples spend together.

Moreover, the study incorporated a genetic analysis, particularly focusing on the CD38 gene variant rs6449182, which is associated with oxytocin secretion and social behavior, and suggested a pathway of neurochemicals implicated in the outcomes of expressing gratitude.

Overall, the research goals were to provide insights into the neural pathways involved in fostering relationships and to understand how behavioral interventions may influence social connections, particularly within romantic relationships.(9)

The GET condition led to a notable rise in the regularity of gratitude expressions by one designated partner, which, in turn, increased the time both partners spent together daily. Couples in the experimental condition spent over 60 additional minutes together daily compared to the control group. The increase in time spent together was mediated by the increase in gratitude expressions, highlighting the potential for simple behavioral interventions to enhance relationship quality and health outcomes.

The study found a link between the rs6449182 SNP in the CD38 gene and the expression of gratitude, suggesting a neurochemical basis for these behaviors. Participants with certain genetic predispositions (CC genotype) benefited more from the intervention. They were found to express gratitude more frequently compared to those with CG or GG genotypes, suggesting a genetic predisposition that influences how often someone expresses gratitude.

Additionally, the CC genotypes benefited more from the intervention in terms of increased time spent with their partner. This highlights a potential pathway through which genetic predispositions can enhance the benefit of positive social behavior on relationship quality.

More than half of the participants (63.6%) had the CC genotype, which can indicate that a significant portion of the population may have a genetic capacity to benefit from gratitude expression interventions.

The study suggests the need for further research to experimentally manipulate oxytocin signaling in the human brain. This could validate the proposed pathways and offer a deeper understanding of how genetic factors and oxytocin interact to influence social behaviors and relationship quality.

## 9. Brain responses to partners in long-term romantic relations

Scheele et al. investigated the impact of administering intranasal oxytocin (OXT) on the behavior and neuronal reactions to facial stimuli of longstanding romantic partners in a group of 20 heterosexual men. Results supported the hypothesis that OXT contributes to pair bonding in humans. Specifically, the OXT administration heightened men's positive perception of their female partners' faces, making them appear more appealing than unfamiliar women's faces. This outcome was associated with increased activation in the brain's reward circuitry. (10)

The findings aligned with previous research showing that OXT promotes social bonding by increasing social distance from attractive female strangers (11) and highlighting that OXT effects depend on the context and individual. This positive bias towards a partner may enhance long-term relationship satisfaction, serving as a resilience factor. (10)

In the left nucleus accumbens (NAcc), OXT heightened the neuronal reaction toward partners compared to both known and unknown women. Interestingly, OXT also increased responses to previously known women in the caudate body, suggesting it may affect various types of attachments via specific areas of the striatum. Future research is needed for clarification of these interactions.

Three phases of romantic relationships have been identified, each involving different brain systems: the initial "in love" phase, the "passionate love" phase, and the long-term "companionate love." Participants in the study were in the second phase, which is characterized by high passion despite declining initial euphoria. OXT likely plays a crucial role in forming pair bonds during this stage.

OXT enhanced neural responses in the NAcc and ventral tegmental area (VTA) to partner faces, indicating increased reward value. This suggests OXT affects these dopaminergic areas

similarly to monogamous voles. Furthermore, OXT hasn't impacted the state of anxiety or mood, and subjects could not confirm whether they were administered with OXT or a placebo, ruling out nonspecific effects.

In conclusion, OXT may strengthen pair bonds by causing men to see their partners as more appealing and fulfilling, potentially fostering biparental care and reducing male competition for mates. This opens an evolutionary pathway towards more cooperative in-group behavior. (10)

## 10. Oxytocin and pain relief

Kreuder et al. aimed to understand how intranasal oxytocin (OXT) in the dose of 24 IU influences the impacts of social support on pain perception in partners in a romantic relationship.

The findings in the placebo group reflected previous studies, showing that support from a romantic partner effectively reduced the uncomfortable sensations of shocks compared to support from a stranger or a lack thereof. From a neurological perspective, both partner and stranger support reduced pain-related activity in the anterior insula (AI), which processes the salience of stimuli.

However, only partner support increased activation of the medial frontal gyrus (MFG), involved in regulating emotions through cognitive processes. Notably, the effect of handholding was not observed on ventromedial prefrontal cortex (VMPFC) activity under a placebo. This contrasts with previous studies using partner photographs, suggesting that handholding may provide a more salient safety signal. Additionally, sex differences may drive variations in VMPFC activity, with women showing greater pain sensitivity and attention to pain.

The OXT group showed reduced unpleasantness ratings for shocks, supporting the analgesic effects of OXT. This result occurred regardless of the support conditions, indicating that oxytocin does not change how individuals perceive social support subjectively. However, OXT did enhance the beneficial outcome of partner support by reducing AI activation and accelerating MFG activation and connectivity. This may reflect OXT's anti-nociceptive effects observed in both human and animal studies.

OXT's increased action in the prefrontal cortex, where OXT receptors are abundantly present, may enhance cognitive control, modulating pain perception via the AI and amygdala (AMY). Interestingly, oxytocin did not significantly impact the neural mechanisms involved in support from strangers, and its benefits were stronger in subjects with higher levels of perceived love. This raises questions about OXT's effects in different relationship stages and qualities.

The findings suggest that OXT strengthens romantic connections by enhancing the perceived appeal and rewarding value of a partner, promoting long-term pair bonding, and reducing male competition for mates. This supports recent conceptualizations of OXT's role in maintaining romantic relationships by enhancing the hedonic value of partner interactions. These findings potentially offer insights into therapeutic approaches for stress-related disorders.

However, the study has limitations. The experimenter's involvement in handholding may not reflect naturalistic social support, and the condition blinding was not perfect. Despite these limitations, the discoveries enabled a fresh understanding of the neurochemical mechanisms by which OXT enhances social support and alleviates pain in romantic relationships. (12)

## 11.Social dynamics modulated by oxytocin

The 'love hormone' oxytocin was identified as a key facilitator of romantic relationships and the formation of parental attachment. However, it wasn't clear whether it contributed to the maintenance of monogamous pair bonds after their formation. The researchers used intranasal oxytocin (24 IU) in men who were either single or in a monogamous relationship and the halt-distance method to determine an ‘optimal distance’ for an interaction with an appealing female experimenter and the distance at which participants began to feel uncomfortable. They also used another approach-avoidance task (AA-task) which measures how people respond to different images. Participants use a joystick to decide whether to approach or avoid each picture. It helps researchers understand subconscious preferences and reactions to various stimuli.

The data in this randomized, double-blind, placebo-controlled trial strongly support the idea that OXT's behavioral effects are influenced by situational factors and individual traits like

partnership status, providing the first clear proof of OXT's function in maintaining exclusive relationships among people.

OXT seems to promote fidelity by making men in monogamous relationships maintain greater distance from attractive female strangers, both physically and in photograph-based tests. Importantly, these effects of OXT do not stem from conscious changes in attitude toward other women, as there were no significant changes in subjects' impressions or arousal. This suggests the inherent appeal of other women persists unchanged, supported by the absence of interaction between OXT and gaze direction.

The initial hypothesis was that OXT might cause single men to approach women more closely, but there is no evidence for this, possibly indicating that approach distances are already optimized to avoid intimate space intrusion. The AA task was designed to assess valence discrimination, including both positive and negative stimuli, and no evidence of diminishing the cognitive worth of other women was found, suggesting norm compliance was not a factor.

The specificity of OXT's effect on social distance is evident, as it did not affect distances kept from unfamiliar males. The fidelity-enhancing effects of OXT require endogenous release triggered by the presence of a female partner before encountering other women. While OXT levels are elevated in couples during early romantic love and remain high for six months, further endogenous OXT release is necessary for these fidelity effects. This may involve offsetting a relative deficiency or diminishing already ideal levels. Naturally occurring OXT release in men could be stimulated by sexual activity or the mere companionship and physical contact of their partner. OXT may also increase personal space regardless of relationship status. In scenarios where a female experimenter kept eye contact while advancing, single individuals on OXT exhibited slightly larger distances, though this was likely due to outliers considering the lack of interaction effects overall and greater variance in personal space among OXT-treated singles compared to pair-bonded men.

Exploring how different elements of pair bonding interact with oxytocin (OXT) to enhance loyalty in monogamous males in future research is essential for unraveling the intricate neurobiology of human pair bonding. (12)

## 12.Oxytocin and increased attention to novel stimuli

Other researchers wanted to understand the function of OXT in elementary social cognitive processes toward non-erotic attachment stimuli and stimuli associated with reproduction in humans.

This goal was to explore the effects of intranasal OXT in the dose of 24 IU administration on various aspects of social cognition in different contexts. The researchers analyzed the effects of OXT on arousal and attention toward different types of stimuli, including parent-child bonding, pair bonding, and erotic material.

Overall, the findings showed that OXT increased arousal and attention toward all stimuli categories, particularly during their initial presentation. This effect was observed in both men and women. Notably, an increase in pupil size, a sign of arousal of the central nervous system, increased in response to all stimuli under OXT, suggesting heightened attentional focus.

The study also examined the effects of OXT on areas of interest (AOIs), such as the eyes, and mouth, as well as areas of physical contact in images. OXT increased fixation on these AOIs during the initial presentation of stimuli, but this effect diminished during subsequent presentations.

While previous research has suggested that OXT enhances focus on specific social stimuli, such as faces, this study found that OXT increased arousal and attention towards a wide range of social and non-social stimuli.

Interestingly, the study did not find differential effects of OXT on different types of social relationships or stimuli categories. Instead, OXT increased arousal and attention towards all types of stimuli. This suggests that OXT may enhance overall alertness toward social contexts but may not have specific effects on different types of social relationships.

The study also considered the order of substance administration and possible carry-over effects. Results indicated that OXT administration during the first session led to larger pupil dilation and increased fixation on AOIs compared to placebo, particularly during subsequent presentations. This suggests that the effects of OXT may be more salient during initial exposure to stimuli.

Overall, these findings contribute to our understanding of how OXT influences social cognition processes and suggest that OXT may enhance arousal and attention toward social stimuli, particularly during initial exposure.

In the context of romantic love, these results suggest that OXT can influence physiological responses and behaviors associated with romance, such as enhancement of the initial attraction and focused attention toward potential romantic partners because of the increased arousal and focus on novel social stimuli. This aligns with the increased pupil dilation and attention to socially relevant features observed in the study. OXT effects are stronger during initial exposure to stimuli, indicating its importance in the early stages of a relationship. The carry-over effect suggests that its influence may diminish with repeated interactions, highlighting its role in initiating, rather than maintaining romantic attraction. (13)

## 13.Neurobiological substrates of intimacy

In another study, which was randomized and placebo-controlled, between-group, involving 192 healthy volunteers (96 heterosexual couples) 24 IU of oxytocin was administered intranasally in one of the partners. Their brains were scanned using functional magnetic resonance imaging (fMRI) while being touched. They assumed it was their partner or an unknown person of the opposite gender, but it was the same experimenter, and the touches were nearly identical. The aim was to investigate the behavioral and neural responses to touch between romantic couples, particularly examining the role of intranasal oxytocin (OXT) in the dose of 24 IU in modulating the processing of a partner's touch.

The findings supported the hypothesis that OXT ameliorates the pleasurable experience of partner touch by activating reward-related brain areas. OXT increased neural responses to partner touch not solely in networks related to touch, which are the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), and insula, but also in the nucleus accumbens (NAcc), unlike in a stranger's touch.

The study noted that OXT did not induce a general increase in sensitivity to touch but rather varied based on social context. This selective enhancement in neural activation was more pronounced in the context of a romantic partner, suggesting that OXT interacts with mesolimbic dopamine pathways to increase the hedonic value of intimate partner contact. This interaction is crucial for forming and maintaining pair bonds, as seen in prairie voles, where OXT and dopamine receptor activation in the NAcc are essential for pair bonding.

Moreover, OXT's effect on enhancing partner touch responses was more evident in women, possibly due to higher estradiol levels enhancing OXT receptor density in the NAcc. This gender-specific response underscores the nuanced role of OXT in social bonding and partner perception.

Additionally, the study highlighted that touch increases well-being, reduces anxiety, and promotes relationship stability. OXT's modulation of partner touch may support monogamous pair bonding by increasing the attractiveness of one's partner and reducing the appeal of touch from strangers, thus acting as a protective factor against infidelity.

The study acknowledged some limitations, such as the controlled nature of the touch administered by an experimenter and the potential influence of the MRI setting. Future research could benefit from more naturalistic settings and exploring different body regions and long-term relationship dynamics. Overall, the findings suggest that OXT plays a significant role in enhancing the emotional and neural responses to partner touch, potentially strengthening romantic bonds and contributing to relationship satisfaction (14).

## 14. Eye contact, oxytocin, and familiarity

Attention is quickly drawn to the eye region of a face, even before we become consciously aware of it, and this influences whether social interactions lean towards approach or avoidance.

This study investigated the impact of 24 IU of intranasal oxytocin (OXT) on visual attention to the eye region across different categories of faces - own face, romantic partner, close friend, or stranger.

The results showed that OXT increased the time spent looking at the eyes of familiar faces, suggesting that OXT enhances visual attention towards personally familiar faces rather than one's own or unfamiliar faces. This aligns with evidence that OXT influences neural reward circuits during socially relevant cues.

The study found that OXT's impact on eye gaze was stronger for familiar faces, likely due to increased feelings of trust, comfort, and safety. This supports the idea that OXT's effects vary based on individual and situational factors. Unlike previous research, this study did not find a gender-specific effect of OXT, possibly due to the sample size and gender distribution (45 females, 28 males).

Additionally, individuals with high autistic-like traits spent less time looking at the eye region, consistent with previous findings that people with autism spectrum disorder (ASD) avoid direct eye contact. This behavior is seen as an adaptive strategy to reduce social discomfort. However, the study participants had typical levels of autistic-like traits, indicating the need for further research focusing on clinical ASD populations.

The study's sample was limited to pair-bonded undergraduate students, which may affect the generalizability of the results. The study did not account for menstrual cycle phases or hormonal contraceptive use in female participants, which could influence OXT effects. Future research should include diverse age groups, relationship statuses, and more detailed assessments of female hormonal cycles to better understand OXT's influence on attention to familiar faces. Despite these limitations, the study enhances understanding of oxytocin's role in visual attention and social interactions. (15)

## 15.Discussion

The study explored the neurobiological basis of romantic love, highlighting the activation of specific brain regions and the deactivation of others. The fMRI scans revealed significant activation in the left-side middle insula, anterior cingulate cortex, and posterior hippocampus when participants viewed images of their loved ones. Additionally, the caudate nucleus and putamen showed pronounced activation, suggesting their involvement in emotional processing and the reward system. Interestingly, regions typically associated with negative emotions, such as the amygdala, were deactivated. This pattern of activation and deactivation implies that romantic love not only engages the brain's reward pathways but also suppresses areas linked to negative emotional responses, contributing to the overall positive experience of being in love.

Comparative analysis with studies on maternal love indicated substantial overlap in the brain regions activated by both romantic and maternal love. Key areas, such as the striatum, middle insula, and anterior cingulate cortex, were activated in both types of love, underscoring the shared neurobiological mechanisms. These regions are rich in oxytocin and vasopressin receptors, highlighting the significant role these neurohormones play in forming and maintaining emotional bonds. The study further noted that the activation patterns in the anterior cingulate cortex differed slightly, reflecting the diverse emotional functions this region supports.

These findings have important implications for understanding the neural underpinnings of attachment and emotional bonding. The involvement of the brain's reward system suggests that romantic love triggers neuroendocrine responses similar to those elicited by euphoric states, such as those induced by certain drugs. This could explain the intense feelings of pleasure and reward associated with romantic relationships. Moreover, the deactivation of brain regions related to negative emotions indicates a neural mechanism that may help sustain positive emotional states in romantic relationships, potentially mitigating feelings of anxiety or stress.

Furthermore, the therapeutic potential of these findings is significant, particularly in the context of psychological disorders such as autism spectrum disorder (ASD) and anxiety. Oxytocin, often referred to as the "love hormone," has been shown to enhance social cognition and reduce anxiety. For individuals with ASD, oxytocin administration has been linked to improved social recognition and reduced social anxiety, due to its ability to modulate brain regions involved in social and emotional processing. Similarly, oxytocin's anxiolytic properties may help alleviate symptoms of anxiety disorders by promoting positive social interactions and reducing social threats.

However, the study is not without limitations. The small sample size and the focus on individuals who reported being deeply in love limit the generalizability of the findings. The use of fMRI, while providing valuable insights into brain activity, only shows correlations and cannot establish causation. Additionally, the complexity of emotional processing and individual differences in emotional experiences suggest that these findings might not apply universally to all types of love or attachment.

Future research should address these limitations by including larger and more diverse samples to validate and expand upon these findings. Longitudinal studies could provide deeper insights into how the neural mechanisms of love evolve over time and across different stages of relationships. Furthermore, exploring the therapeutic potential of neurohormones like oxytocin and vasopressin in treating attachment-related disorders could lead to new interventions aimed at enhancing social bonds and emotional health. By better understanding the neural and hormonal foundations of love, we can develop strategies to improve relationship satisfaction and psychological well-being, ultimately fostering healthier and more fulfilling social connections.

## 16.Conclusions

The research reviewed provides significant insights into the neurobiological foundations of love, highlighting the activation and deactivation of specific brain regions during experiences of romantic and maternal love. Romantic love activates brain areas related to emotional processing and reward, while deactivating regions associated with negative emotions. Both romantic and maternal love share common neural pathways, emphasizing the role of oxytocin and vasopressin in bonding and attachment. Oxytocin enhances social bonding, trust, and positive social behaviors, and genetic variations in the oxytocin receptor gene influence these behaviors. Practical applications of these findings include developing therapeutic interventions for social disorders such as autism spectrum disorder (ASD) and social anxiety disorder (SAD), as well as enhancing relationship therapies by targeting oxytocin pathways. Future research should continue to explore the complex neural mechanisms underlying love and attachment, focusing on diverse populations and naturalistic settings. Understanding these mechanisms could lead to innovative pharmacological treatments for psychological and clinical disorders related to disrupted social bonds, ultimately improving social functioning and emotional health.

## 17.Summary

This review paper explores the neurobiological mechanisms underlying romantic and maternal love, focusing on specific brain regions and the role of the neuropeptide oxytocin. Using functional magnetic resonance imaging (fMRI), the studies examined brain activity in individuals experiencing love, revealing that romantic love activates areas such as the middle insula, anterior cingulate cortex, caudate nucleus, and putamen, which are associated with emotional processing and reward. Deactivations in regions linked to negative emotions, such as the amygdala, were also observed, suggesting that love enhances positive feelings while suppressing negative ones. Comparing romantic and maternal love, the studies found overlapping activation in brain regions abundant in oxytocin and vasopressin receptors, highlighting their importance in bonding and attachment. Oxytocin was shown to play a crucial role in enhancing social bonding, trust, and positive behaviors. It increases the recognition of emotional expressions and promotes in-group trust. Genetic variations in the oxytocin receptor gene (OXTR) were found to influence social behaviors and attachment. Behavioral interventions increasing gratitude expressions, facilitated by oxytocin, improved relationship

quality and time spent together. These findings suggest that oxytocin enhances partner touch responses and visual attention to familiar faces, supporting its role in social bonding.

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## 19.CV

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