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REVIEW ARTICLE

Neuroanatomy of Romantic Love

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Abstract

Romantic love is defined as the early stage of love. As a result of neural and endocrine stimuli, some emotional, physiological and biochemical changes occur in romantic love and as a result, some physical symptoms are observed. Certain chemical and biological changes, called neurotransmitter storm, activate neurons in some parts of the brain in the person in romantic love and make the rest of the body out of control. It is known that romantic love stimulates the reward and motivation system in the brain and causes an increase in dopamine levels. Dopamine is the neuromodulator responsible for the brain's reward system. In this review, neuroanatomical factors and changes that cause passionate and romantic love are explained. Changes in the brain reward and motivation system, *ventral tegmental area, nucleus accumbens, caudate nucleus* and limbic system were evaluated mainly within the framework of functional magnetic resonance imaging and electroencephalography evidence.

Key words: Romantic love; Neuroanatomy; Functional magnetic resonance imaging; Electroencephalography.

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Introduction

In general, an intense, passionate and romantic love can be described as a sense of commitment and a passionate love for another person, including the feeling of lust and sexual intercourse. The romantic love described here defines passion and pure love to the extent that only has desire for her/him. When a person falls in love, emotional, physiological and biochemical changes occur and as a result, some physical symptoms and signs are observed.[1] Let's remember the first time we saw someone we love. When we saw her/him, we have experienced some changes such as blushing, tongue twitching, tripped speech, stuttering, nonsense words, silly speech and sweaty palms. Tachycardia and facial flashing are the first physiological changes in romantic love.[2]

Behind the songs, poems, novels and films written over the years about passionate and romantic love, there is a complex and chaotic biological process. Although authors, poets and composers have associated this feeling with the heart as a metaphor, scientific data shows that the heart does not have such a function. Anyone can fall in love, but most of us have trouble describing this feeling. Those indescribable warm feelings that we associate with the heart are formed by the effect of some neural chemicals and hormones released from our brain. Apparently, intense romantic love is all about the brain. As a result of some chemical and biological changes in the brain (which we can call a neurotransmitters storm), neuron activations in some cerebral areas make the rest of the body out of control.[3]

In general, it has been claimed that romantic love (early stage of love) causes changes in key neurotransmitters such as increased dopamine (DA)

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levels and correspondingly decreased serotonin concentrations as a result of activation of certain structures of the limbic system. The second stage of love (long-term relationship) is mainly regulated by the attachment system and supported by the hormones oxytocin (OT) and vasopressin (VP).[1]

Dopamine is the hormone responsible for most of the brain's reward system. This means controlling both the good and the bad things. We also experience DA fluctuations in our virtues and vices. Obviously these changes are mainly mediated by autonomic nervous system. In this article, the neuroanatomical factors that participate in causing passionate and romantic love are tried to be explained. Some biological, biochemical and physiological factors cause fall in love and some of them can be explained by neuroanatomic knowledge. Spiritual and metaphysical factors are not the subjects of this article.

Cerebral areas which are stimulated in the romantic love

Functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) methods have been used to detect the areas of the brain that are stimulated and active in romantic love.[3] FMRI studies in romantic lovers provide evidence for the hypothesis that romantic love is associated with some functional changes in the reward and motivation systems. Showing individuals photos of their loved one (visual tests) or saying their name (verbal tests) causes more activation in reward and motivation systems such as *ventral tegmental area* (VTA), *caudate nucleus* (NC), *accumbens nucleus* (NAc), *anterior cingulate cortex, substantia nigra* and *medial insula*.[3-6] Based on these findings, some researchers have suggested that romantic love can simulate a form of addiction.[6-8]

a) Brain reward and motivation system

Ventral tegmental area, *ventral striatum* (VS) (NAc and olfactory tubercle), *dorsal striatum* (DS) (NC and *putamen*), prefrontal *cortex, insular cortex*, limbic areas (*hippocampus* and *amygdaloid* body (AB)), *thalamus* and *hypothalamus* are cerebral areas that form the "basic reward system" (*mesocorticolimbic* circuit). The main neuromodulator secreted from the reward system is DA. DA allows people to do things that make them feel good and happy. High levels of DA and noradrenaline are released during attraction, which is being affected by a beloved.[9]

FMRI studies show that intense romantic love feelings activate regions of the brain's reward system, particularly DA pathways associated with energy, focus, learning, motivation, ecstasy and craving, such as the VTA, NC and NAc. These three regions are also the primary regions associated with substance and non-substance addictions.[3,7,8]

In an article published in 2005, researchers evaluated the results of fMRI activation of 17 people (right-handed, average age 21 years, 10 women) who experienced intense romantic love. The intense love experience of the participants was confirmed with the Passionate Love Scale (PLS) and the Affect Intensity Measure (AIM). During the fMRI scanning session, participants were first shown a photograph of their beloved (positive stimulus) and asked to think about particularly pleasurable, but not sexual, experiences with the loved one. This process took 30 seconds. After the neutral waiting period, the same participants were shown a photograph (neutral stimulus) of an acquaintance of the same age and gender as the beloved, but emotionally neutral (neutral). This process (sequence) was repeated six times. Based on the results of the study, the researchers found the following findings: 1. When participants looked at their beloved, specific activations occurred in the right ventral midbrain, which includes the VTA and in the dorsal NC body and tail. 2. A decrease in AB activity was observed. 3. The fMRI activations in the septum-fornix and the right anteromedial NC (body) regions correlated (positively) with the PLS results. That is, people who reported high levels of romantic love had increased fMRI activations in these specified regions. 4. Compared with neutral stimuli, those with a more aesthetically pleasing partner showed more neural activity in the left VTA than those with a less attractive partner. 5. There was a (positive) relationship between the length of the love relationship and activations in limbic cortical regions (*anterior* and *posterior cingulate, mid-insula* and *retrosplenial cortex)*, cortical areas (parietal, inferior frontal and middle temporal cortices) and some *basal nuclei* (left *ventral putamen* and a small region of *pallidum*). As a result of these findings, the researchers suggested that intense romantic love induces the activation of subcortical reward and motivation systems, especially rich in DA.[3]

In a recent study, the emotional responses of first-time newlyweds (n = 13) to facial images of their loved ones were analysed using fMRI. Besides, the correlations of the distributions of some genes related to VP, OT and DA in saliva, romantic love scale responses (Eros) and fMRI results were analysed. These processes were repeated in the first moments of their marriage and then in the 1st year. Results showed activations in the right *substantia nigra* (SN) (a DA-rich region) and left paracentral lobe (related to sexual activation) in response to partner facial images on fMRI in both time periods. There were also positive correlations between these results and Eros scores. At the beginning of their marriage, partner activations predicting the maintenance of romantic love were observed in the *raphe* nuclei, *pons*, *medial prefrontal cortex* and *paracentral* lobe, right *perirhinal/fusiform*, *superior frontal gyrus*, *superior temporal gyrus* and *left praecuneus*. On the other hand, at the first year of their marriage, visual tests showed activation of right AB/*globus pallidus, left middle insula*, *bilaterally occipital cortex*, *supplementary motor area, precentral gyrus,* left and right *superior frontal gyrus* and *parietal area*. As a result of these findings, the authors suggested that romantic love and its maintenance are regulated by DA, VP and OT rich brain regions.[4]

b) Ventral tegmental area (VTA)

The VTA is located in the *mesencephalon*. This area is one of the parts of the primitive brain. The VTA contains dopaminergic cells that send projections to various brain regions, including the NC and is a DA-producing centre that manages our brain's impulses such as reward, motivation and cravings. It has been shown that situations such as cocaine addiction, making money and chocolate addiction etc activate the VTA through the reward system.[3, 7, 10-12]

One of the structures first activated in romantic love is the VTA. Recognising a potential reward, the VTA begins to produce and secrete a chemical called DA, a "feel-good neurotransmitter". Jumping from one neuron to another, DA stimulates some regions in the limbic system via the mesolimbic pathway and prepares the brain to pay attention and respond to the expected rewards from many positive (or negative) actions.[3, 13]

In an fMRI study, it was reported that when participants looked at their beloved, specific activations occurred in the right VTA and "fire like crazy".[3] Another study showed that activation of the left VTA is particularly associated with a face deemed aesthetically pleasing (liking). In contrast, right VTA activation was increased during presentation of a face that participants would like to see longer (ie, fall in love, wanting).[14] Aron et al also showed that participants with a more aesthetically pleasing partner had more neural activity in the left VTA than those with a less attractive partner.[3]

c) *Accumbens nucleus* (NAc)

The NAc is located in the basal forebrain and posterior to the preoptic region of the *hypothalamus*. Each cerebral hemisphere has one NAc and consists of two subregions, the core and the shell. These substructures have different morphology and cognitive functions. The NAc and olfactory tubercle together form the *ventral striatum* (VS). The VS and the *dorsal striatum* (NC and *putamen*) form the *striatum*, which is the main component of the *basal nuclei*. The dopaminergic neurons of the mesolimbic pathway project to the GABA-ergic (gamma-aminobutyric acid) neurons of the NAc and olfactory tubercle. The NAc has an important role in reward, motivation, aversion and reinforcement learning. It has an important role in addiction because it is included in the reward system.[7, 15]

Activation in the mesolimbic pathway stimulates the NAc. FMRI studies have also shown that NAc is activated in people who are passionately in love. This stimulation speeds up DA production and fills our brains with increased feelings of happiness, euphoria and desire. These feelings will also cause more attraction to the person we fall in love with. The vicious circles of substance abusers resemble the first phase of romantic love. NAc, which is also activated when calculating our gains and losses, is also activated when we decide to take big risks. For this reason, people in romantic love can feel strong enough to leave everything in their lives and take radical decisions.[3, 16]

Addiction is a chronic and recurrent brain disease caused by changes in neural circuits in different parts of the brain. In addition to the VTA and NAc, known as reward centres, certain brain areas such as the *prefrontal cortex* and AB are associated with addiction. Excessive DA release from the reward centre with substance ingestion triggers structural and neurochemical changes in anatomical circuits in the long term and leads to addiction.[10] Similar changes are thought to occur in passionate love.[7]

d) *Basal nuclei* (*Nucleus caudatus* - NC)

The NC is one of the structures that constitute the *corpus striatum*, a component of the *basal nuclei*. NCs are a C-shaped collection of neurons located mainly above the *thalamus*. Each hemisphere of the brain has one NC and has subregions from front to back, called the head (*caput*), body (*corpus*) and tail (*cauda)*. In addition to motor coordination tasks, the NCs are involved in learning (procedural and associative) and inhibitory control of action functions. They are also part of the *cortico-basal nucleus-thalamic* circuit that forms the reward system. The NC and putamen together form the DS. The DS is divided into medial (NC) and lateral (*putamen*) subsections via the internal capsule.[17]

The NC and VTA play important roles in reward and motivation in the human brain. Especially the anteromedial region of the NC is activated during monetary reward expectation, reward-based stochastic learning, attention, spatial and temporal somatosensory discrimination tasks and simple passive visual processing. This region is most likely associated with the rewarding, visual and perhaps attractive aspects of romantic-passionate love. Intense and focused attention to an individual is one of the main behavioural signs of romantic love. Visual attention, reward, motivation and motor planning are generally associated with NC function.[3]

In an fMRI study, when participants looked at their beloved, it was reported that activations increased in the right VTA and regions of the NC including the dorsal body and tail.[3] In the other recent study, the emotional responses of first-time newlyweds to the facial images of their beloved immediately and in the first year were analysed by the fMRI method. In both time periods, positive correlations were found between activations in the right *substantia nigra* and left paracentral lobe and Eros (romantic love) scores in response to partner's facial images.[4]

e) Septal region (SR)

Septal region is formed by cortical *subcallosal* and paraterminal gyrus with the complex of septal nuclei located under these gyri and partially in the base of the septum *pellucidum*. They are composed of two laminae of both white and grey matter.[18] SR is one of the first regions found regarding the motivation and reward system. This area is activated by the VTA and the medial forebrain bundle. It has been shown to play a role in various emotional responses in animals, including relief from aversive emotional states. Aron et al showed in their study that individuals with intense romantic love have increased fMRI activations in the septum-fornix region.[3]

f) Limbic system

The limbic system mainly consists of the *hypothalamus*, *anterior thalamus, hippocampal formation*, AB, *basal nuclei* and *cingulate gyrus*. Parts of this system are located deep within the brain, above the brain stem and underneath the *cerebral cortex*. The limbic system is called the paleomammalian brain.[19] The limbic system, which consists of brain regions where the desire to live (self-protection) and reproduction (sex) come to the fore, is more active in animals. This system is also active in animal urges and behaviours in humans.[20, 21]

In the limbic system, there are three areas (but not limited to) related to feelings of love, affection and compassion: the *hippocampus*, the *medial insula* and the *anterior cingulate gyrus*. These three regions regulate the sense of reward. In the central nervous system, some areas of the limbic system, such as the *hippocampus*, are the primary areas that cause us to fall in love. These regions deactivate the *prefrontal cortex*, which is the logical region, and cause a feeling of love.[22]

In a study, it was reported that fMRI activations were observed in some cerebral cortical areas and some *basal nuclei* structures, as well as in some limbic cortical regions such as the *anterior* and *posterior cingulate*, *mid-insula* and *retrosplenial cortex* in people who experienced intense romantic love. Besides, there was a positive relationship between these activations and the length of the relationship in love.[3]

i) *Cingulate cortex* and *insula*

The *cingulate cortex* (which means belt in Latin) consists of the *cingulate gyrus* and its cortical grey matter, located between the *cingulate* and *callosal sulci*. As its name suggests, it wraps the corpus *callosum* in the form of an arch from the front, superior and back. The *cingulate* cortical Brodmann areas 29 and 30, located at the back of the *splenium corpus callosum* are called the *retrosplenial cortex*. Like the *cingulate cortex*, the *retrosplenial cortex* is responsible for performing several cognitive functions, including episodic memory, navigation, imagination and planning for the future.[23, 24]

In an fMRI study, a positive relationship was found between long-term romantic love and activations of the anterior *cingulate, retrosplenial cortex* and *mid-insula*. Correlations in the *anterior cingulate* are particularly important in this study. This region is associated with "obsessive thinking", which is a key feature of romantic love. It is thought that such feelings as passionate love, not giving up the lover, always thinking about her/him, not seeing anyone else, etc are related to this area.[25]

ii) *Amygdaloid body* (AB)

The AB is a pair of limbic systems and *rhinencephalon* complex that are almond-like (*amygdala* means almond in Latin), located in front of the *hippocampal* body (*pes hippocampi*). It is a crucial structure that performs three major cerebral functions, including the expression of emotions, memory processing and managing stimulant input. Besides, the AB borders with secondary olfactory areas and *paleocortex* structures.[20, 26]

g) *Cerebral cortex*

Aron et al determined that individuals who experienced intense romantic love had increased fMRI activations in some cerebral cortical areas such as the parietal, inferior frontal and medial *temporal cortex*, along with some *basal nuclei* structures and some limbic cortical regions. In addition, there was a (+) relationship between these activations and the length of the relationship or time in love.[3]

The amplitude values (ie frequency bands or waves) obtained in electroencephalography (EEG) are as follows *delta* (~1–4 Hz), *theta* (~4–8 Hz), *alpha* (~8–13 Hz), *beta* (~ 13–20 Hz) and *gamma* (~> 20 Hz), respectively. For example, the lower *delta* and *theta* frequency bands are high during sleep. However, *alpha* frequency bands are high during relaxation and *beta* and *gamma* frequency bands are high during cognitive processing.[27] In a study on the effect of love emotion on face perception, the EEG recordings were taken by showing pictures of the loved person, appreciated friend, unfamiliar person and a blank page to people in a romantic love relationship (20 women). As a significant finding of the study, they observed that higher *delta* amplitude values (0.5-3 Hz) occurred on the frontal electrodes when the picture of the person they fell in love with was shown. Although it is debatable, this frontal increase in *delta* power has been interpreted as reflecting the love felt toward the romantic partner.[28]

Frontal *alpha* asymmetry in EEG reflects the balance between the left and right frontal lobe activation. A higher left frontal activation indicates motivation to approach, whereas a higher right frontal activation indicates motivation to avoid. Since *alpha* power is inversely proportional to brain activation (because it occurs during the relaxation phase) and romantic love is related to the motivation to approach the lover, it is predicted that beloved stimuli will reveal greater left frontal *alpha* activation.[29] In a very recent study, EEG recordings and *alpha* activity asymmetry were examined during some tasks (tasks of love induction and picture viewing) to university students in love (n = 22) and not in love (n = 20). As the findings of the study, during the love induction task, they observed higher *alpha* activity in the right occipital region in love group, while they observed higher *alpha* activity in the left occipital region in the not in love group.[30]

h) *Hypothalamus* and pituitary gland

The *hypothalamus* is located in the inferior-anterior part of the *diencephalon* and is considered as the centre of the limbic, endocrine and autonomic nervous systems. Some areas of the reward centre (or system) are located in the *lateral hypothalamus*. This centre has an important role in falling in love. In addition, mediators (DAs) and hormones (VP and OT) that enable the feeling of love are secreted from the *hypothalamus*, stored in the posterior pituitary (VP and OT) and then they are released to the whole body through the blood.[31, 32]

Apart from their primary effects, VP and OT play a role in the formation of feelings of connection, commitment and jealousy concerning passionate love. The OT is also called the "cuddle hormone" and activates reward systems through interactions with brain DA in some people.[33] The VP, on the other hand, is associated with physical and emotional mobilisation and supports the vigilance necessary to protect the partner. The long-term relationship can be sustained by the presence of these two hormones.[34] These two hormones facilitate partner selection, bonding and mating. The difference between the two is that OT has stress-reducing effects, while VP creates a stress response by increasing fear. Thus, the reward centre of the brain is activated, while AB is inhibited.[33, 34]

The pituitary gland is an endocrine organ located in the lower part of the *hypothalamus* and in its special bony cavity (*sella turcica*) and it produces many hormones and secretes them into the body. Activation of the mesolimbic pathway stimulates the adrenal glands via adrenocorticotropic hormone (ACTH) and increases the production and secretion of adrenaline into the blood.[35] With follicle-stimulating hormone (FSH) secreted from the pituitary gland, the production and secretion of testosterone and oestrogen hormones increase from the gonads (testes and ovaries). In addition, FSH stimulating and inhibitory factors secreted from the *hypothalamus* control the secretion of FSH in the pituitary gland. Testosterone increases libido, which we can translate as "sex desire" in almost everyone. In oestrogen, this desire is relatively less pronounced. However, it is known that some women are more sexually motivated during ovulation when oestrogen levels are highest.[36]

Passionate love can be divided into three emotional stages: lust, attraction and attachment. Each stage is characterised by its group of hormones. Testosterone and oestrogen stimulate the lust emotion, which is a very good reward for the need for reproduction and perpetuation of the species. DA, noradrenaline and serotonin increase the sense of attraction. While OT and VP mediate feelings of attachment and loyalty.[2, 22]

In conclusion, romantic love is an emotion mediated by different neural structures and is the result of a dynamic process consisting of varying constituents. Falling in love has three main effects on the human body, physiologically, emotionally and physically. These findings are mediated by some hormones and neurotransmitters. So, falling in love is not a pathological condition. However, unrequited romantic love can sometimes lead to pathological consequences. The emotional states of love, lust, affection, trust and belief are complex neurobiological events based on the activation of reward and motivation systems in the brain. It should be known that the subject is not as simple as the explanation above. Although all neurons have a similar histological structure and physiology, stimulation of them in different regions results in different functions. As in all subjects of neuroscience and behavioural sciences, there are many questions waiting to be clarified on this subject and new discoveries are needed.

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Conflict of interest

None.

References

1. Marazziti D, Palermo S, Mucci F. The science of love: state of the art. Adv Exp Med Biol 2021;1331:249-54.
2. Fisher HE. Lust, attraction, and attachment in mammalian reproduction. Hum Nat 1998;9(1):23-52.
3. Aron A, Fisher H, Mashek DJ, Strong G, Li H, Brown LL. Reward, motivation, and emotion systems associated with early-stage intense romantic love. J Neurophysiol 2005;94(1):327-37.
4. Acevedo BP, Poulin MJ, Collins NL, Brown LL. After the honeymoon: neural and genetic correlates of romantic love in newlywed marriages. Front Psychol 2020;11:634. doi:10.3389/fpsyg.2020.00634.
5. Zeki S, Romaya JP. The brain reaction to viewing faces of opposite- and same-sex romantic partners. PLoS One 2010;5(12):e15802. doi:10.1371/journal.pone.0015802.
6. Wang C, Song S, d'Oleire Uquillas F, Zilverstand A, Song H, Chen H, et al. Altered brain network organization in romantic love as measured with resting-state fMRI and graph theory. Brain Imaging Behav 2020 Dec;14(6):2771-84.
7. Fisher HE, Brown LL, Aron A, Strong G, Mashek D. Reward, addiction, and emotion regulation systems associated with rejection in love. J Neurophysiol 2010;104(1):51-60.
8. Fisher HE, Xu X, Aron A, Brown LL. Intense, passionate, romantic love: a natural addiction? How the fields that investigate romance and substance abuse can inform each other. Front Psychol 2016;7:687. doi:10.3389/fpsyg.2016.00687.

9. Lewis RG, Florio E, Punzo D, Borrelli E. The brain's reward system in health and disease. Adv Exp Med Biol 2021;1344:57-69.
10. Breiter HC, Aharon I, Kahneman D, Dale A, Shizgal P. Functional imaging of neural responses to expectancy and experience of monetary gains and losses. Neuron 2001;30(2):619-39.
11. Breiter HC, Gollub RL, Weisskoff RM, Kennedy DN, Makris N, Berke JD, et al. Acute effects of cocaine on human brain activity and emotion. Neuron 1997;19(3):591-611.
12. Small DM, Zatorre RJ, Dagher A, Evans AC, Jones-Gotman M. Changes in brain activity related to eating chocolate: from pleasure to aversion. Brain 2001;124(Pt 9):1720-33.
13. Ranaldi R. Dopamine and reward seeking: the role of ventral tegmental area. Rev Neurosci 2014;25(5):621-30.
14. Aharon I, Etcoff N, Ariely D, Chabris CF, O'Connor E, Breiter HC. Beautiful faces have variable reward value: fMRI and behavioral evidence. Neuron 2001;32(3):537-51.
15. Ikemoto S. Brain reward circuitry beyond the mesolimbic dopamine system: a neurobiological theory. Neurosci Biobehav Rev 2010;35(2):129-50.
16. Carter RM, Macinnes JJ, Huettel SA, Adcock RA. Activation in the VTA and nucleus accumbens increases in anticipation of both gains and losses. Front Behav Neurosci 2009;3:21. doi:10.3389/neuro.08.021.2009.
17. Yager LM, Garcia AF, Wunsch AM, Ferguson SM. The ins and outs of the striatum: role in drug addiction. Neuroscience 2015;301:529-41.
18. Raybaud C. The corpus callosum, the other great forebrain commissures, and the septum pellucidum: anatomy, development, and malformation. Neuroradiology 2010;52(6):447-77.
19. Newman JD. Vocal communication and the triune brain. Physiol Behav 2003;79(3):495-502.
20. Rajmohan V, Mohandas E. The limbic system. Indian J Psychiatry 2007;49(2):132-9.
21. Songur A, Ozen OA, Sarsilmaz M. [Hippocampus]. Turk Klin J Med Sci 2002;21:427-31. Turkish.
22. Seshadri KG. The neuroendocrinology of love. Indian J Endocrinol Metab 2016;20(4):558-63.
23. Jumah FR, Dossani RH. Neuroanatomy, Cingulate Cortex. [Updated 2022 Dec 6]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. [Cited: 1-May-2023]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537077/.
24. Vann SD, Aggleton JP, Maguire EA. What does the retrosplenial cortex do? Nat Rev Neurosci 2009;10(11):792-802.
25. Bartels A, Zeki S. The neural basis of romantic love. Neuroreport 2000;11(17):3829-34.
26. Nikolenko VN, Oganesyan MV, Rizaeva NA, Kudryashova VA, Nikitina AT, Pavliv MP, et al. Amygdala: neuroanatomical and morphophysiological features in terms of neurological and neurodegenerative diseases. Brain Sci 2020 Jul 31;10(8):502. doi: 10.3390/brainsci10080502.
27. Langeslag SJE. Electrophysiological correlates of romantic love: a review of EEG and ERP studies with beloved-related stimuli. Brain Sci 2022;12(5):551. doi:10.3390/brainsci12050551.
28. Başar E, Schmiedt-Fehr C, Oniz A, Başar-Eroğlu C. Brain oscillations evoked by the face of a loved person. Brain Res 2008;1214:105-15.
29. Kelley NJ, Hortensius R, Schutter DJLG, Harmon-Jones E. The relationship of approach/avoidance motivation and asymmetric frontal cortical activity: A review of studies manipulating frontal asymmetry. Int J Psychophysiol 2017;119:19-30.
30. Cannas Aghedu F, Sarlo M, Zappasodi F, Acevedo BP, Bisiacchi PS. Romantic love affects emotional processing of love-unrelated stimuli: An EEG/ERP study using a love induction task. Brain Cogn 2021;151:105733. doi:10.1016/j.bandc.2021.105733.
31. Caria A, Dall'Ò GM. Functional neuroimaging of human hypothalamus in socioemotional behavior: a systematic review. Brain Sci 2022;12(6):707. doi:10.3390/brainsci12060707.
32. Castro DC, Cole SL, Berridge KC. Lateral hypothalamus, nucleus accumbens, and ventral pallidum roles in eating and hunger: interactions between homeostatic and reward circuitry. Front Syst Neurosci 2015;9:90. doi:10.3389/fnsys.2015.00090.
33. Carter CS. Sex, love and oxytocin: Two metaphors and a molecule. Neurosci Biobehav Rev 2022;143:104948. doi:10.1016/j.neubiorev.2022.104948.
34. Carter CS. The oxytocin-vasopressin pathway in the context of love and fear. Front Endocrinol (Lausanne) 2017;8:356. doi:10.3389/fendo.2017.00356
35. Stephens MA, Wand G. Stress and the HPA axis: role of glucocorticoids in alcohol dependence. Alcohol Res 2012;34(4):468-83.
36. Marazziti D, Canale D. Hormonal changes when falling in love. Psychoneuroendocrinology 2004;29(7):931-6.