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The Neurobiology of Love

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It is only relatively recently that neurobiologists have started to probe into the neural basis of one of the most powerful and exhilarating states known to humans, namely love. In this, they have been aided by the advent of imaging techniques which allows them to ask questions about the neural correlates of subjective mental states which, given their subjectivity, had been impervious to objective scientific investigation. What we can say today about those neural correlates is therefore, of necessity, limited and sketchy but it is almost certain that rapid advances in this field of research will be made in the coming years. In probing the neurobiology of love, neurobiologists of the future will also be looking into evidence derived from the world literature of love, since that literature is itself a product of the brain and its careful study gives strong hints about how the romantic system in the brain is organized. But here I restrict myself more to considering the neural correlates of love derived from experimental studies.

More often than not, romantic love is triggered by a visual input, which is not to say that other factors, such as the voice, intellect, charm or social and financial status do not come into play. It is not surprising therefore that the first studies to investigate the neural correlates of romantic love in the human should have used a visual input. These studies showed that, when we look at the face of someone we are deeply, passionately and hopelessly in love with, a limited number of areas in the brain are especially engaged. This is true regardless of gender. Three of these areas are in the cerebral cortex itself and several others are located in subcortical stations. All constitute parts of what has come to be known as the emotional brain, which is not to say that they act in isolation. Romantic love is of course a complex emotion that includes, and cannot be easily separated from, other impulses such as physical desire and lust, although the latter can be loveless and therefore distinguishable from the sentiment of romantic love. This is not surprising and is consistent with a simple neurobiological rule – that if one can tell the difference it is because different brain areas, or cells, are involved. Consistent with this rule, nervous structures that correlate with romantic love in all its complexity are very distinctive even if they share brain areas with other, closely linked, emotional states.

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Kognitif IV Uluslararası Kognitif Nörobilim Sempozyumu'nda sunulmuştur.

Brief outline of the neurochemistry of love

The areas that are involved are, in the cortex, the medial insula, anterior cingulate, and hippocampus and, in the subcortex, parts of the striatum and probably also the nucleus accumbens, which together constitute core regions of the reward system (see Figure 1). The passion of love creates feelings of exhilaration and euphoria, of a happiness that is often unbearable and certainly indescribable. And the areas that are activated in response to romantic feelings are largely co-extensive with those brain regions that contain high concentrations of a neuro-modulator that is associated with reward, desire, addiction and euphoric states, namely dopamine. Like two other modulators that are linked to romantic love, oxytocin and vasopressin (see below), dopamine is released by the hypothalamus, a structure located deep in the brain and functioning as a link between the nervous and endocrine systems (Figure 2). These same regions become active when exogenous opioid drugs such as cocaine, which themselves induce states of euphoria, are ingested. Release of dopamine puts one in a "feel good" state, and dopamine seems to be intimately linked not only to the formation of relationships but also to sex, which consequently comes to be regarded as a rewarding and "feel-good" exercise. An increase in dopamine is coupled to a decrease in another neuro-modulator, serotonin (5-HT or 5-Hydroxytryptamine), which is linked to appetite and mood. Studies have shown a depletion of serotonin in early stages of romantic love to levels that are common in patients with obsessive-compulsive disorders. Love, after all, is a kind of obsession and in its early stages commonly immobilizes thought and channels it in the direction of a single individual. The early stages of romantic love seem to correlate as well with another substance, nerve growth factor, which has been found to be elevated in those who have recently fallen in love compared to those who are not in love or who have stable, long-lasting, relationships. Moreover, the concentration of nerve growth factor appears to correlate significantly with the intensity of romantic feelings.

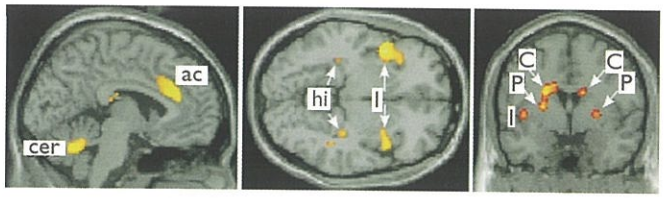

Figure 1. Activity (shown in yellow and red) elicited when subjects viewed pictures of their loved partner compared to that produced when they viewed pictures of their friends. The activity, restricted to only a few areas, is shown in sagittal (left), transverse (central), and coronal sections superimposed on slices taken through a template brain.

Oxytocin and another chemically linked neuro-modulator, vasopressin, seem to be particularly linked to attachment and bonding. Both are produced by the hypothalamus and released and

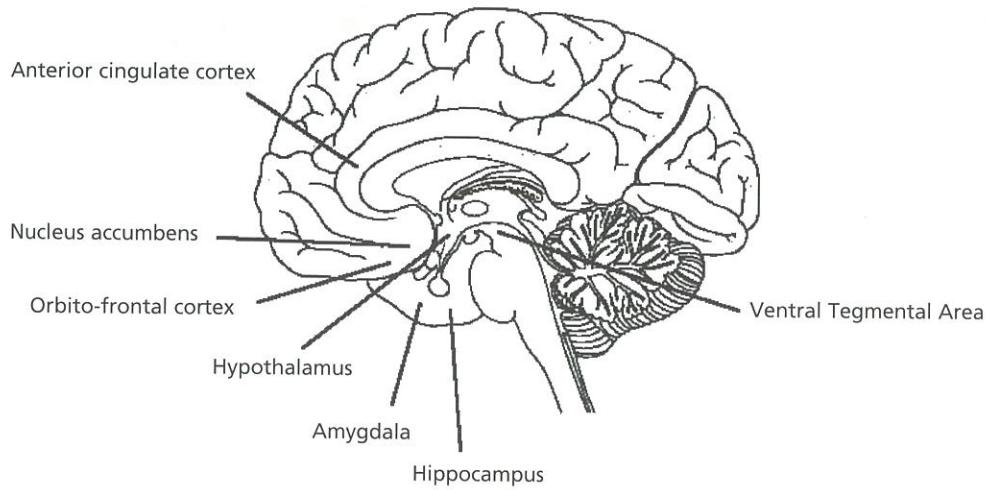

Figure 2. Some of the brain areas and structures discussed in the article. The arrows are guidelines only, and some of the structures are hidden from view.

stored in the pituitary gland, to be discharged into the blood, especially during orgasm in both sexes and during child-birth and breast-feeding in females. In males, vasopressin has also been linked to social behaviour, in particular to aggression towards other males. The concentration of both neuro-modulators increases during the phase of intense romantic attachment and pairing. The receptors for both are distributed in many parts of the brain stem which are activated during both romantic and maternal love.

It is noteworthy that sexual arousal activates regions adjacent to -and in the case of the hypothalamus overlapping with- the areas activated by romantic love, in the anterior cingulate cortex, and in the other subcortical regions mentioned above. Especially interesting in this regard is the activation of the hypothalamus with both romantic feelings and sexual arousal, but not with maternal love. Its activation may thus constitute the erotic component present in romantic, but not in maternal attachment. Moreover, sexual arousal (and orgasms) de-activate a region in the frontal cortex that overlaps the de-activated region observed in romantic love. This is perhaps not surprising, given that humans often take "leave of their senses" during sexual arousal, perhaps even inducing them to conduct which they might later, in more sober mood, regret. In fact, this intimacy in terms of geographic location between brain areas engaged during romantic love on the one hand and sexual arousal on the other is of more than passing interest. Judged by the world literature of love, romantic love has at its basis a concept – that of unity, a state in which, at the height of passion, the desire of lovers is to be united to one another and to dissolve all distance between them. Sexual union is as close as humans can get to achieving that unity. It is perhaps not surprising to find, therefore, that the areas engaged during these two separate but highly linked states are juxtaposed. Indeed the desire for unity through sexual union may be a consequence of it.

Cortical de-activations and the madness of love

It may seem surprising that the face that launched a thousand ships did so through this limited set of areas. But the story of Paris and Helen of Troy should in itself be enough to tell us that these neurobiological results, viewed on their own, can lead to deceptive interpretations. For romantic love is all-engaging, transforming people's lives and inducing them to both heroic and evil deeds. It is not surprising to find therefore that this core of brain areas that become engaged during romantic love has rich connections with other sites in the brain, both cortical and sub-cortical. Among these are connections with the frontal, parietal and middle temporal cortex as well as a large nucleus located at the apex of the temporal lobe, known as the amygdala. Increase in activity in the romantic core of areas is mirrored by a decrease in activity, or inactivation, of these cortical zones. The amygdala is known to be engaged during fearful situations and its de-activation, when subjects view pictures of their partners as well as during human male ejaculation, implies a lessening of fear. As well, the all-engaging passion of romantic love is mirrored by a suspension of judgement or a relaxation of judgemental criteria by which we assess other people, a function of the frontal cortex (Figure 3).

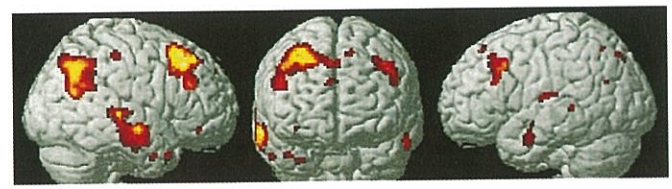

Figure 3. Cortical deactivations in the cortex (shown in yellow and red) produced when subjects viewed pictures of their loved partners.

This cortical zone, along with the parietal cortex and parts of the temporal lobe, has also been commonly found to be involved in negative emotions. Its inactivation in romantic as well as maternal states -when faced with the loved one- should not therefore be surprising because, when deeply in love, we suspend those critical judgements that we otherwise use to assess people. The prefrontal cortex, the parieto-temporal junction and the

temporal poles constitute a network of areas invariably active with "mentalizing" or "theory of mind," that is, the ability to determine other people's emotions and intentions. It is noteworthy, from the point of view of "unity-in-love" that one feature of mentalizing in terms of the "theory of mind" is to distinguish between self and others, with the potential of ascribing different sets of beliefs and desires to others and to oneself. To obtain an imagined "unity-in-love," so that the self and the other are merged, this process of mentalizing, and thus distinguishing between self and the other, must be rendered inactive. But critical judgement of others is also often suspended with the trust that develops between individuals and certainly with the deep bonding that develops between a mother and her child. Here, then, is a neural basis not only for saying that love is blind, but for the concept of "unity-in-love." It is not surprising that we are often surprised by the choice of partner that someone makes, asking futilely whether they have taken leave of their senses. In fact, they have. Love is often irrational because rational judgements are suspended or no longer applied with the same rigour. In Plato's Phaedrus, Socrates comments: "The irrational desire that leads us toward the enjoyment of beauty and overpowers the judgement that directs us toward what is right, and that is victorious in leading us toward physical beauty when it is powerfully strengthened by the desires related to it, takes its name from this very strength and is called love." Nor are there moral strictures, for judgement in moral matters is suspended as well. After all, moral considerations play a secondary role, if they play one at all, with Anna Karenina, or Phèdre, or Emma Bovary or Don Giovanni. And morality, too, has been associated with activity of the frontal cortex.

Euphoria and suspension of judgement can lead to states that others might interpret as madness. It is this madness that poets and artists have celebrated, Plato considering it in Phaedrus as a productive, desirable state because this kind of "madness comes from God, whereas sober sense is merely human."

But of course, if it comes from God, it transcends the world of rationality and is beyond the grasp of the intellect or logos. Perhaps the neurological explanations, of a de-activation of those parts of the brain that are involved in the making of judgements, makes the frequent apparent irrationality of love more comprehensible. As Nietszche once wrote, "There is always some madness in love. But there is always some reason in madness," the reason to be sought in the pattern of neurobiological activation and deactivation that romantic love entails, which serves the higher purpose of uniting for biological purposes even unlikely pairs, and thus enhancing variability. If "the heart has its reasons of which reason knows nothing," it is quite literally, because reason is suspended. When Blaise Pascal uttered these words he could not have known that reason is suspended because the frontal lobes are (temporarily at least) also suspended. In fact, we can draw a neurobiological lesson from this selective suspension of judgement. For, if those in love suspend judgement about their lovers, they do not necessarily as well suspended judgement about other things. They could, for example, be perfectly able to judge the quality of a book or of a scientific work. They could as well be perfectly able to have a theory of mind regarding persons other than the one they love. The suspension of judgement is selective, and argues for a very specific set of connections and brain operations when it comes to love.

Neural correlates of maternal love

Equally interesting is that this pattern of areas activated by romantic yearnings shares parts of the brain that also become active when mothers view pictures of their own children, as opposed to other children (Figure 4). Maternal and romantic love share a common and crucial evolutionary purpose, that of maintaining and promoting the species. They also share a functional purpose, in that both require that individuals stay together for a period of their lives. Both are thus calculated by nature to ensure the formation of firm bonds between individuals, by making of them rewarding experiences. It is not surprising to find that both sentiments share

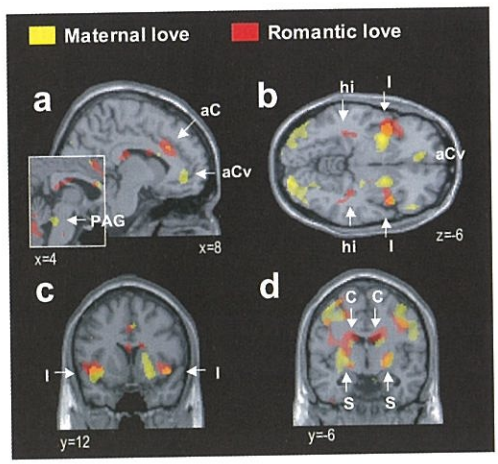

Figure 4. Brain activity produced by maternal love and romantic love (in both males and females) (shown in red and yellow). Note that there are considerable areas of overlap, although there are as well regions that are activated only by maternal or romantic love.
Abbreviations: aC = anterior cingulate cortex; aCv = ventral aC; C = caudate nucleus; I = insula; S = striatum (consisting of putamen, caudate nucleus, globus pallidus); PAG = periaqueductal (central) gray; hi = hippocampus.

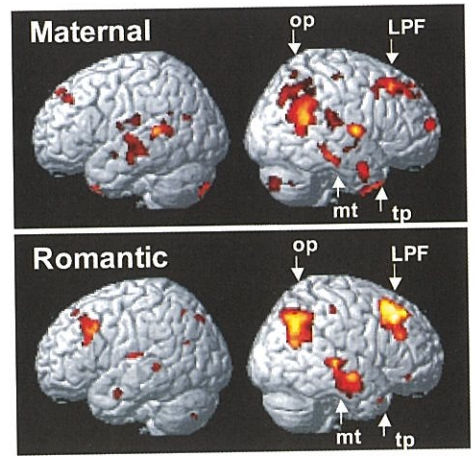

Figure 5. Deactivated regions with maternal and romantic love, shown in red and yellow.
Abbreviations: mt = middle temporal cortex; op = occipitoparietal junction; tp = temporal pole; LPF = (ventral) lateral prefrontal cortex.

common brain areas. But, given the neurological axiom stated above, that if you can tell the difference it is because different brain areas are involved, it is also not surprising to find that the pattern of brain activation that correlates with maternal love is not identical to the one that correlates with romantic love. An interesting difference lies in the strong activation of parts of the brain that are specific for faces in maternal love. This may be accounted for by the importance of reading children's facial expressions, to ensure their well being, and therefore the constant attention that a mother pays to the face of her child. Another interesting difference is that the hypothalamus, which is associated to sexual arousal, is only involved in romantic love. The commonly activated regions between the two types of love are located in the striatum, part of the reward system of the human brain. It is also true that in maternal love, no less than in romantic love, judgement is somewhat suspended, in that mothers are a good deal more indulgent with their children and perhaps less likely to fault them. Once again, we find that there is a pattern of cortical de-activation produced by maternal love which is remarkably similar to the one produced by romantic love and in particular the frontal cortex that is involved in the formation of judgements (Figure 5).

Brain Concepts of the Lover

It is a truism to say that most people develop a preference for the kind of person they want to love, and hence a concept of their potential lover(s); their likelihood of falling in love with that kind of person is that much greater. These preferences come in many different forms and are almost certainly conditioned by, among other things, parental influences, cultural predelictions and the kind of person that they may have met. A recent study has in fact charted the "average" man with whom women are most likely to fall in love. He is smooth-skinned and remote from the kind of macho type that many believe are attractive to women. The characteristics associated with the most desirable (virtual) man are not only linked to sexual attractiveness but also ones that suggest a caring attitude. Clearly, this average man, chosen by female students at St Andrews University in Scotland, is the result of a concept and may apply only to the environment in which the study was conducted. The importance of the study lies in showing us that we do indeed form a concept of the kind of person we would like to love. In the literature of love, perhaps nowhere is this more emphatically stated than in the work of Dante,

whose love for Beatrice is one of the most celebrated love affairs in Western literature. Yet Dante stated quite clearly in his first work, La Vita Nuova (The New Life), that what he really wanted to write about was not about Beatrice (who was dead by then) but about "lo gloriosa donna de la mia mente" (the glorious lady of my mind).

In matters of love and attachment, we can go a little further and sketch in outline form the chemistry that underlies the concept of the loved one that the brain forms. Unfortunately, we cannot do so for man yet but for much simpler animals, the prairie voles, rats, mice, marmosets and monkeys. But it would be hard to believe that similar, though almost certainly infinitely more complex mechanisms, do not operate in humans.

Perhaps the first step in this enquiry is to look at the chemistry of the human brain areas that are activated during romantic love, and in particular oxytocin, vasopressin and dopamine. Most brain regions, including subcortical regions, that have been determined to contain receptors for oxytocin and vasopressin are activated by both romantic and maternal love. To better understand the role of these chemicals in bonding, we have to rely on recent experiments on prairie voles.

Oxytocin and vasopressin have many effects but most relevant from our point of view is that, not only are they involved in bonding between individuals but have also been found to be effective in learning and memory, but only in a social context. Both are released when prairie voles have sex. They are intimately linked to dopamine, which is associated with reward. And although prairie voles are a long way from man, the release of these hormones in other animals, including man, under similar conditions makes it likely that their human counterparts are also strongly involved in activities associated with romantic and maternal love, which is not to say that these are their only functions. The story of voles is actually of great biological interest, especially when one contrasts two species, the prairie and the montane vole, the former having monogamous relationships (with the occasional fling thrown in) and the latter indulging in promiscuous sex without long-term attachment. If the release of these two hormones is blocked in prairie voles, they too become promiscuous. If, however, prairie voles are injected with these hormones but prevented from having sex, they will continue to be faithful to their partners, that is to have a monogamous though chaste relationship. One might have imagined that injection of these hormones into the promiscuous montane voles would make of them virtuous, monogamous, animals too. But that is not how things work out and injection of these hormones into montane voles does not render them monogamous. This may seem at first paradoxical, but there is a simple biological way of accounting for it and it is of substantial interest in the context of concept formation.

Once secreted by the pituitary, these neuro-hormones can only act if there are receptors for them. In the prairie vole there is an abundance of receptors for vasopressin and oxytocin in the reward centres of the brain. These centres are not clearly defined as yet but include many structures that have been found to be active in reward conditions. Many are located in the sub-cortex. Receptors for oxytocin and vasopressin are missing or not as abundant in the reward centres of the montane voles. Hence injecting montane voles with a surplus of these two neuro-hormones does not make them mono-gamous, since there aren't sufficient receptors for them in the reward centres. It is as if these two hormones, strongly implicated from other evidence with bonding, are the ones that keep voles faithful and monogamous and as if the absence of receptors for them makes of their relatives promiscuous animals. There is no evidence that these two neuro-hormones act in the same way in humans; it would be surprising if they did, given the infinitely more complicated structure of the human brain. But it would not be surprising if we find in the vole a vestigial system to account for the sexual and romantic nature of humans. Mankind is often, but very mistakenly, considered to be monogamous. The evidence from divorce rates, adultery and other more

or less clandestine and casual encounters, as well as the flourishing trade in prostitution and pornography, suggests otherwise, which is not to say that many among the human race do not maintain monogamous, or serially monogamous, relationships. It would be highly interesting to learn whether monogamous humans have a higher concentration of oxytocin and vasopressin, as well as a richer concentration of receptors for them in the reward centres of the human brain compared to their more promiscuous counterparts. One might even find that humans can be divided into three or more categories -ranging from the extremely promiscuous to the strictly monogamous, and that this distribution reflects the distribution of receptors for vasopressin and oxytocin, which is known to vary in species as far apart as voles and humans.

Oxytocin and vasopressin seem to play a crucial role in forming a concept of the kind of partner that an organism wants to be with, at least in the world of vole ideas. They appear to do so by building a strong profile of the mating partner through odour and, once they do so, the odour-derived concept seems to be very stable. The odour comes to be associated with a pleasurable and rewarding encounter with a particular partner. The same works in the visual domain, as has been shown in sheep – once oxytocin is released in the presence of a baby, the sheep will visually recognise the baby and behave in a motherly way toward it until it is grown up. If the gene for either of these two neuromodulators is disabled before birth by genetic engineering in a mouse, the mouse will no longer be able to form a profile – or a concept – of the mice that it meets. It becomes totally amnesic in this regard and hence promiscuous. It is not outrageous to suggest that this neurochemically mediated experience has all the hallmarks of concept formation, though concept formation at a very elementary, chemical, level. The concept formed is that of an individual; it is based on an encounter and sexual experience, is acquired postnatally and is associated with a pleasurable, rewarding, experience with a partner of a particular odour.

Love and Beauty

A beautiful person, as is commonly known, is perhaps the surest way of evoking the sentiment of love. Throughout history, from the days of Plato onwards, the path to love has been described as being through beauty. Dante falls in love with Beatrice because he finds her beautiful, and longs to see that which is hidden in her physique. The Lord Krishna "steals the mind" with his beauty and Majnun, in his love for Leila, is obsessed by her beauty, even if she does not seem beautiful to others. "To see her beauty," he declares, "you must borrow my eyes." Beauty and love are themselves never far from erotic desire, since the most intense love is strongly coupled to sexual desire and the two faculties share common areas in the brain, as described above. It is not surprising to find therefore that an attractive face on the one hand and sexual arousal, as well as the experience of visual beauty, engage a part of the brain known as the orbito-frontal cortex. Nor is this the only common brain region engaged by the two aspects of romantic love. The face of a loved person engages two cortical regions, the insula and the anterior cingulate (see Figure 2), as do sexually arousing visual stimuli. Attractive faces, as well as the faces of a loved person, de-activate not only the frontal cortex but also the amygdala (mentioned above), which is also de-activated when viewing the face of a loved person. This suggests that not only is judgement less severe when looking at a loved or desired person, but that the curiosity and apprehension with which we often survey faces for discomfiting signs are suspended. Moreover, the orbito-frontal cortex is connected with the amygdala and with other cortical areas and sub-cortical areas -the anterior cingulate cortex, the putamen and the caudate- that are engaged during the experience of romantic love. Hence the intimate experiential connection between love and beauty is probably nothing more than an expression of the intimate anatomical connection between the centres that are involved in these two experiences. So intimate must the anatomical link between them be that the experiences themselves become difficult to disentangle.