

The Brain in Love: Has Neuroscience Stolen the Secret of Love?

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ABSTRACT

No one knows when the story of love began in the history of mankind, though from a religious point of view it started with Adam and Eve and the *Forbidden Fruit*. Scientifically speaking, love probably made its appearance with *H. neanderthalensis* between 350 and 30 thousand years ago. Neanderthal graves have yielded the pollen of brightly coloured flowers brought from different regions, and these have been associated with some kind of loving relationship between the living and the dead. If love started with the Neanderthals, anthropological studies have shown that today, 147 out of 166 societies in the world have a word for love or at least the concept of love, while for the other nineteen, it has been suggested that not enough questions of the right kind have been asked to discover whether it exists or not. For this reason, love is accepted as a universal or near-universal feeling.

Key Words: love, romantic love, maternal love, neurobiology, fMRI, passion, dopamine, oxytocin, vasopressin

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Why Do We Feel Love?

You would get different answers to this question from psychiatrists, theologians and evolutionary biologists. If you asked a psychiatrist, you would be told that from the viewpoint of psychoanalysis, love is the external expression of an oedipally suppressed feeling and a precious flower which the super ego has raised up to the skies. According to Oedipal suppression, boys are in love with their mothers and girls with their fathers, and at around the age of six this is suppressed. Later, when they meet a member of the opposite sex with similar characteristics to the parent, passionate love occurs. According to theologians, human love is a small reflection of divine love. It is a small attempt to attain that great love, one of the small steps on the ascent

to divine love. There is a beautiful story concerning this: a man took his son from Anatolia to a religious teacher in Baghdad, and said to him, "Make this boy your student, and let him learn the way of God." The sheikh said to the boy, "Are you in love with anyone?" When the boy answered "Yes, I love a girl back in the village," the sheikh said, "My child, we can do nothing for a person who already has someone in their heart." And to the father he said, "Take him home and let him get married." The man returned to his village and this time took his younger son to the sheikh in Baghdad. The teacher asked, "My child, have you ever been in love?" "No, sir," said the boy. At this the sheikh turned to the father and said, "Take this one home too, and bring him back after he has been in love."

The loves of Joseph and Mevlana are passionate expressions of Divine Love. In folk tales, the loves of Leila and Majnun, Kerem and Ashi, Farhad and Shirin, and Tahir and Zuhre are small human steps in that direction.

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Why do People Fall in Love with a Particular Type?

There is no certain answer to this question, only a number of approaches and findings. The first steps in the process happen in 30% of people when they encounter a face which appears to have good symmetry. What actually starts it is not so much beauty, but along with it such important indicative factors which will add to the richness of the person's own life as intelligence, trustworthiness, kindness, and charm. The factors which determine falling in love are formed in particular under the effects of the testosterone levels to which we are exposed in the 8-16th weeks of pregnancy, the attention which is paid to us in childhood, and adolescent hormones. Again, love may start as a great surprise when the opposite person shows liking. The desire for small contacts may make this more apparent (Fisher, 2006; Zeki and Romaya, 2010).

But what concerns us most here is not what type or person we fall in love with, but rather the question of what happens in our brain when we fall in love. In neuroscientific terms, the question is whether love has a neurobiological or chemical equivalent, and whether there is a romantic system or neural circuit in the brain.

What Happens in the Brain in Love?

In neuroscience, love is much stronger than a basic emotion or state of mind. Emotionally, it means thinking obsessively and repeatedly about the beloved. This takes up around 85% of waking time. The person's own priorities change and there is a continual, compulsive desire for closeness. Anxiety and fear are reduced, and risk-taking is made easier. A feeling of ecstatic, euphoric happiness takes over the person, and he or she is ready to die for the beloved. All the possessions of the beloved are seen as extensions of him/herself and even a simple piece of trash from the beloved is imbued with a kind of sacred quality. At the same time love has deep physiological effects on the body. Among these are a reduction in appetite and a loss of interest in food-drink, and pain sensitivity, an increase in the pulse rate, palpitations, sweating, trembling, intestinal activity, and an increase in stomach acidity and the rate of swallowing. Over the ages, these physiological responses have made people think that the heart was the instrument of falling in love.

However, a feeling with so many emotional and physiological effects would surely be expected to be reflected in the brain.

In order to understand whether there is a system in the brain for taste, sight, smell, touch, hearing, or at a more complex level violin playing for example, the most-used method is functional MR brain imaging (fMRI). This is a method which can show which regions of the brain operate in response to a particular stimulus or for a specific purpose. The basic principle is simple: changes in blood flow (haemodynamic response) and oxygen (blood-oxygen-level-dependent – BOLD) take place in certain parts of the brain in connection with operations which the brain is performing. Differently functioning brain regions can be shown by fMRI by comparing them with the brains of normal people, i.e. individuals who are not performing those operations.

In 2004, Semir Zeki and his colleagues, (Bartels and Zeki, 2000; 2004) who had spent years, investigating the organisation in the brain cortex of the human visual system, published the first study on the question of what happens in the brain of a person who sees a photograph of someone whom they love, and the findings provoked a large response. Eighteen people who were passionately in love were included in the study, and their brain activity was investigated by fMRI when they were shown a picture of the person they loved. When they first saw it, their brain's subcortical reward system showed great activity. Among these regions, activity in the caudate head, putamen, insular cortex, hippocampus, anterior cingulate cortex cerebellum and ventral tegmental area was noticeable. The results were a surprise to everyone. Certain brain regions, especially those which gave rewards, were responding to the events (Xu *et al.*, 2011). A reward obtained will certainly cause a repetition of the activity which produced the reward. This includes food, water, sex, cigarettes, cocaine and positive social interactions, and the result is subjective satisfaction (Burkett and Young, 2012). When the reward cells are eventually satiated with the stimulus, they enter a quiet state. Repeated activity slowly comes to an end (Zeki, 2007; Bartels and Zeki, 2000; 2004).

What then are the deeper functions of these parts of the brain which spring into action when the lover sees the beloved? The



most remarkable of these regions is the A10 region in the ventral tegmental area (VTA). The VTA, along with the substantiva nigra, is the source of 90% of the dopamine in the brain. Because of this region's richness in dopamine, it is active in all reward stimuli. In addition, it contributes to wakefulness, attention, increased libido, motivation and reward-seeking. The basic function of dopamine is the "want" in the reward system. At the same time, dopamine is closely associated with novelty-seeking and creativity. It is the source of reiterative thought and behaviour. The clinically pathological state of this can be seen in schizophrenic and Parkinson's patients during excessive dopaminergic stimulation in dopamine dysregulation syndrome. At the same time dopamine creates the feeling of unity with the beloved. It is dopamine which causes poets to write poetry when they are in love, and musicians to make music. The pallidum and the caudal nucleus integrate sensory input with motor output in order to bring it into action. This provides the detection of reward and purposeful behaviour. The anterior cingulate cortex evaluates internal and external stimuli, and creates suitable emotional responses to them. It provides decision-making, risk analysis and self-awareness. The hypothalamus, as is known from previous studies, deals with both sexual stimuli and loving stimuli. The autonomic system is the central producer of various sexual hormones. It also regulates hunger, thirst and body temperature. The insular cortex creates that feeling of restlessness when we are in love, and reflects our emotions on to our bodies in the form of a rise in the pulse rate and sweating (Zeki, 2007; Ortigue *et al.*, 2010).

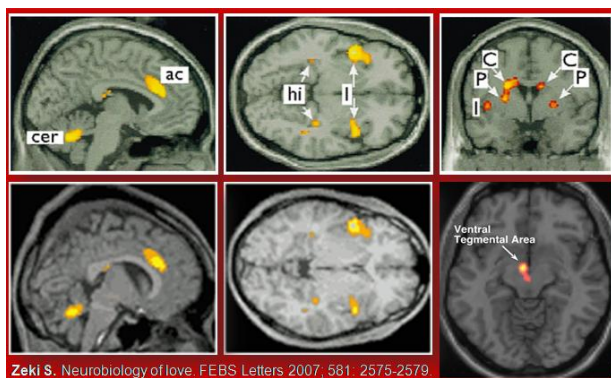


Figure 1. Brain regions showing activity in people madly in love. Modified from Zeki S. Neurobiology of love. FEBS Letters 2007; 581: 2575-2579.

In brief, when people in love see their beloved, they fall into an ocean of dopamine in the reward pathways in their subcortical structures. So then what happens in the brain cortex? According to the results of the same fMRI studies, there is a *deactivation* in various cortical areas in contrast to the subcortical active regions in the brain cortex of people who are in love. Regions which show deactivation or reduced activity are the prefrontal region, the parieto-temporo-occipital region, and the temporo-parietal region (Zeki, 2007; Bartels and Zeki, 2000; 2004; Esch and Stefano, 2005). The *prefrontal region* in humans is the most important region for visualisation, intention and decision-making and logical deduction. It is the source of logic and adherence to social rules, morality and respect. The reduction in the activity of this region in people in love results in a weakening or loss of its functions. This is possible because the brain regions responsible for logic and the rules of social morality have stopped working properly. Another example is the story of the fall of Troy, in which Paris, the young prince of Troy, is a guest of Menelaos, king of Sparta in Greece, and falls in love with the king's wife Helen. He carries her away to Troy, with the result that Menelaos and his brother Agamemnon lay siege to the city. And the rest is history, or at least legend: the wooden horse and the destruction of Troy. When you're in love, the rules of logic aren't applied. Love comes in, and sense goes out the window. It is for this reason that people in love tend to take stupid and illogical risks. In the case of an impossible love, they are not persuaded by people trying to make them see sense. The *parieto-temporo-occipital region* provides a person's sense of position in space, and spatially separates the self from the other. When this region is deactivated, the separation between self and other is suspended, and the person experiences "unity" with the beloved. In this way, just as a person cannot conceal the fact that he is drunk, he or she cannot conceal the fact of being in love.

The Difference between Men and Women

Is there a difference between the active brain regions of men and women when they are in love? To answer this question, seven men and ten women who were in love were examined by fMRI, and different areas were assessed. In



men, greater activity was seen in the right dorsal insula, associated with penile tumescence, the region for seeing beautiful faces, and the visual integration area. In women, the regions for attention, memory and emotion showed greater activity (Ortigue, 2010). From this we can understand that men fall in love with women and their faces in a way that includes sexual arousal, while women are more interested in the romantic aspect of love – that is, they fall in love with love itself (Marazziti *et al.*, 2010)

The Love of a Mother for her Child and the Love of a Lover for the Beloved

To investigate this, fMRI studies were carried out comparing mothers and lovers (Bartels and Zeki, 2001). The mothers were shown pictures of their child, while the lovers viewed pictures of the face of their beloved. When the fMRI images of the mothers and the lovers were superimposed, just about the same regions of the brain showed activity in the two groups, except for one. These areas were the anterior cingulate cortex, the caudate nucleus, the bilateral insular region, the striatum (formed from the putamen + caudate nucleus and the globus pallidus), the Periaqueductal gray matter (PAGM), and the hippocampus. The only difference in mothers looking at their children was that increased activity was seen in the PAGC. The PAGC has been confirmed in many other studies as specific to mother's love, and this region was not active in lovers. Why the PAGC? This region is in particular a region where the endogenous reduction and pain relieving mechanisms and the encephalinergetic system are concentrated. The secretion of endorphin and dinorphins blocks mu receptors and the secretion of Substans P, which is a transmitter in the pain pathways behind the spinal cord (Kendrick, 2004). Stimulation of this region provides substantial analgesia and is probably one of the regions providing analgesia during birth.

While this is happening in the deep brain structures of mothers, is anything happening in the brain cortex which is different from lovers? In mothers, deactivation is seen in the parieto-temporo-occipital, prefrontal region and the medial temporal region. These are the same regions as the deactivated cortical regions seen in lovers. This means that mothers have the same problems of visualisation, intention and decision-making

and logical deductions as lovers. Also, as with lovers, there is no distinction between “self” (the mother) and “other” (the child).

Is Love a Morbid Obsession?

Everyone accepts that up to a point love is an obsessive condition. The lover constantly thinks about the beloved. In the case of head-over-heels love, this may occupy about 85% of waking time. The desire to see and touch the beloved is constantly repeated in their thoughts. Obsession is known as a compulsive, involuntary, compelling cyclical thought pattern. The person is aware of it, but cannot stop thinking these thoughts. This can lead to distress. In order to relieve this stress, ritual-type compulsive behaviour may develop. In obsessive disorders, a reduction has been shown of 5-HIAA, a breakdown product of serotonin, in the spinal fluid and blood. At the same time, obsessive disorders show a good response to drugs which stimulate the serotonergic system. In other words, there is a consistent relationship between the serotonergic system and obsessive disorders.

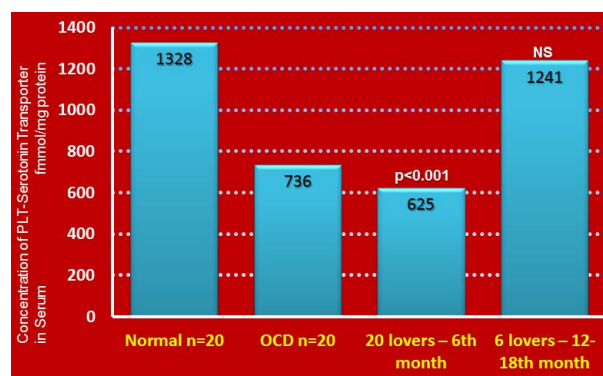


Figure 2. Differences in serum thrombocyte serotonin transporter (PLT-ST) concentration between normal people, those diagnosed with obsessive-compulsive disorder, and people in the 6th and 12-18th months of being in love. Levels are lower than normal in the 6th month of being in love, but this gradually returns to normal. Modified from Marazziti D *et al.*, *Psychol Med* 1999; 29(3):741-5.

Could the early stages of being in love be a similar condition to obsession? In searching for an answer to this question, measurements were made of the concentrations of serum thrombocyte serotonin transporter (PLT-ST) in 20 normal people, 20 people who had been newly diagnosed according to DSM-IV with obsessive disorder but who had not taken any medication, and 20 people who were in the 6th month of being deeply in love (Marazziti *et al.*,



1999). As expected, PLT-ST concentrations of people with obsessive disorder were found to be considerably higher than those of normal people (1328 as against 736 fmmol/mg protein). What was interesting was that the value for the people who were in love was even lower than that of the obsessives (624 fmmol/mg protein). The researchers wondered how PLT-ST levels in the lovers would change over time; they measured the values of six of the lovers in the 12-18th month when they were still (but no longer passionately) in love, and found that values were no different from normal (1241 fmmol/mg protein). From this it can be seen that in the period of passionate, head-over-heels love, there is a change in PLT-ST levels consistent with obsessive disorder. Passionate love is an obsession, and from the point of view of serotonin chemistry it lasts around 12-18 months.

Love's Traditional Home – the Heart

Love has traditionally been associated with the heart, and even today we draw a heart to represent love. The reason for this is the rising central (in the brain) and peripheral level of nor-epinephrine (NE). In the periphery, the increase in NE causes tachycardia, palpitations, a rise in blood pressure and trembling hands in the presence of the beloved. With this exaggerated stimulus effect on the heart, love is perceived as centred not in the brain but in the heart. This increase in the central nervous system effects the locus ceruleus, and causes an increase in attention and in focus on the beloved. This focussing and attention means that small details about love are remembered. At the same time it causes sleepless nights and a loss of appetite. NE also causes an increase in sexual motivation. Amphetamine given at a suitable dose will potentialize all of these effects on dopamine and NE in the same way.

The Puzzle of Testosterone

In the period of passionate and intense love there is also a change in the sex hormones. These hormones have receptors in the brain. The change in testosterone is one of the most interesting of these changes. In this early period, testosterone levels fall in men but rise in women, a finding which is in conflict with the expectation that it would rise in men. However, the reason why it should fall in men

and rise in women can be found logically. First, a reduction in testosterone in men softens their masculine characteristics and reduces their extroversion. It makes it easier to concentrate on one person. At the same time it causes a reduction in masculine aggressiveness, and this softening is reciprocated by the woman. With regard to the increase in testosterone levels in women, there are a number of logical explanations. In the novelty of love there is a risk arising from uncertainty. The rise in testosterone in women makes it easier to take on that risk. During ovulation, a rise in testosterone increases sexual desire in women. At the same time it increases a woman's extroversion and awakens her masculine attributes. As a result, just as love begins, the changes in men's and women's testosterone levels bring the two sexes closer together, if only for a short time (Marazziti and Canale, 2004).

Does Love Rejuvenate the Brain?

Swimming in an ocean of dopamine in the period of being passionately in love is a principal source of creativity for poets and musicians. The main neurotrophic factor which keeps the brain young is neuron growth factor (NGF) (Levi-Montalcini, 1996; Marazziti, 2004; 2003). To find out whether there is a change in neurotrophin levels in people who are passionately in love, serum levels of NGF, brain derived neurotrophic factor (BDNF) and neurotrophin 3-4 were measured in 58 people who were in the first six months of being passionately in love and who thought about their beloved for at least four hours a day. Serum levels were compared between people who were not in love and those who had been in love for a short time (the first six months) and for a long time (49 months). Serum NGF levels in the newly passionate lovers were found to be significantly higher than those of people who were alone and not in love (277 as against 149 pg/mL) – almost double. NGF levels in the long-term lovers were found to have fallen to 45% of that of the passionate lovers in their first six months, and were even below that of normal people (143 as against 149 pg/mL). At the same time, a significant relationship was detected between the scores of these people on the Passionate Love Scale and their NGF levels. As their scores for passionate love increased, so did their NGF levels. No similar change was



measured in other neurotrophic factors (Emanuelle, 2006; 2011).

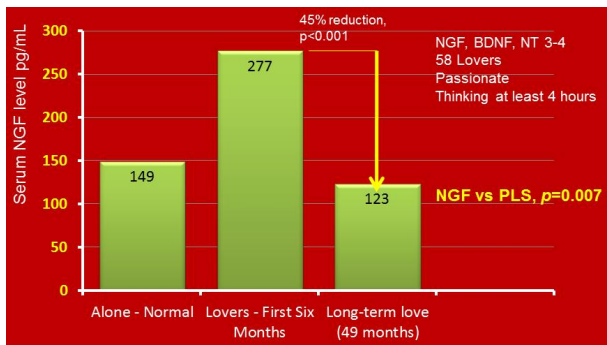


Figure 3. Compared with normal people, the neuron growth factor (NGF) serum levels of people in the first six months of passionate love scale (Langeslag *et al.*, 2012) are considerably raised, while as time goes on these levels even fall to below normal. BDNF: Brain-derived neurotrophic factor, NT: neurotrophin, PLS: Passion love scale. Modified from Emanuelle E *et al.*, Raised plasma nerve growth factor levels associated with early-stage romantic love. *Psychoneuroendocrinology* 2006; 31: 288-294.

So what is the advantage of this increase in NGF in the period of passionate love? NGF is essential for the life of neurons and dendritic growth. This is true both for the peripheral and the central nervous systems. It increases their myelination, speeds up healing and has angiogenic properties. Along with this, it increases opioid sensitivity and the secretion of cortisone and vasopressin. A fall has been associated with various pathological conditions such as neural degeneration, dementia, depression, autism, and an increase in sensitivity to pain.

Does Love Soothe Physical Pain?

One of the reasons why love causes bonding is the increase in encephalins, which pervade the concept of love. There are morphinergic and encephalinergic pathways in the reward-pleasure system. In particular, stimulation of the mu3 receptors causes a feeling of wellbeing. It erases negative memories, and strengthens positive and happy states in the memory. With this strengthening of good memories, the lover selectively only remembers the good things, so that he or she is prevented from seeing the true “whole picture” of the beloved. Everything is viewed through rose-tinted spectacles. And at the same time the morphinergic system can perform its expected role of non-pharmacologically reducing sensitivity to pain.

But does love really reduce sensitivity to pain? In one study, 15 people in the first nine months of being in love were subjected to severe and slight thermal pain in the hand. When they were shown a picture of their beloved, pain scores for the severe pain fell from 7.2 to 6.2, and the score for slight pain fell from 3.7 to 2.4. That is, the scores on the visual pain scale for both severe and slight pain fell by about one point (Younger *et al.*, 2010).

Another study (Master *et al.*, 2009) examined the effect of holding the beloved’s hand and seeing his or her picture with thermal pain as a stimulus. Twenty-eight women in the first six months of being passionately in love were included in the study. When they held their beloved’s hand, their pain scores were measured as about 0.5 points lower, but when they held the hand of a stranger, it was found that their score rose by up to 1.5 points. A similar result was obtained when the subjects were shown a picture of their beloved: their pain score fell by about one point. When they looked at the picture of a stranger’s face or of an object, their pain score showed a very slight increase. That is, holding the hand of the beloved or seeing a photograph of them reduced their pain score, or in other words it caused them to feel less pain.

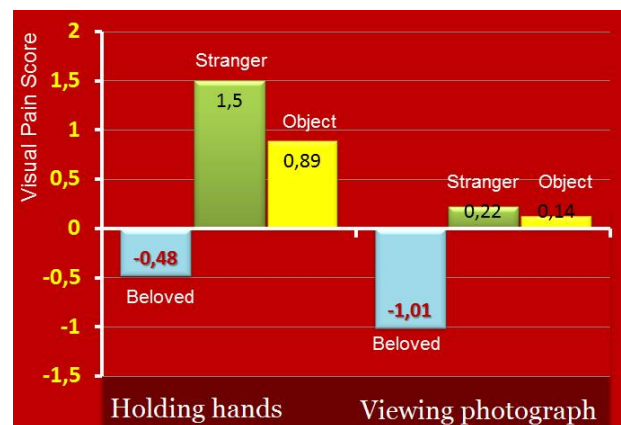


Figure 4. A reduction in pain scores is caused in lovers by holding the hand or seeing a photograph of the beloved compared with that of a stranger. Modified from Master SL *et al.*, A Picture’s Worth: Partner Photographs Reduce Experimentally Induced Pain. *Psychological Science* 2009; 20: 1316-1318

How can love reduce pain?

As we saw before, the morphinergic-encephalinergic system, which comes into operation in love, is an anti-nociceptive painkilling and pain reduction system. With NGF increasing at the same time, it



strengthens the painkilling encephalinergetic system. In addition, in fMRI studies of the brain, a reduction in activity has been shown in the ventro-lateral nucleus of the thalamus and the supplementary motor area. The ventro-lateral nucleus of the thalamus is the place through which pain is carried to the brain cortex. A reduction in the working of this nucleus weakens the direct transmission and interpretation of pain to the brain cortex. Also, the supplementary motor area is a region whose activity is seen to be reduced and which is important in pain integration. At the same time, the reward and pleasure system are directly activated and bring the reductive pain system into operation. Pain sensitivity is reduced through both systems. We saw that when mothers see pictures of their children, it is especially activated. This region is the most important place in the reductive painkilling system. When the love poet Cemal Süreya says “*I have imprisoned you in my fingertips. I feel you in every place that I touch, and my soul is burning*”, we must welcome it, because love only gives one point of non-pharmacological benefit on the visual pain scale!

When we think that love and the support of the beloved can reduce pain, lovers being together when they are in pain, or at least being able to see a photograph, can help as a non-pharmacological pain reliever. On the other hand, it makes it easy to understand why those unhappy in love constantly complain of headaches, backaches, and other aches and pains.

The Case of Unrequited Love

In the game of love, we often come across lovers who are rejected. Each rejection provokes a protest in the lover, and then follows an obsessive desire to regain the beloved. This is because the source of reward and pleasure is about to be lost. However, after a time, if this attempt is unsuccessful, acceptance of the loss begins to take effect. In this period, we often see hopelessness, anger, irritability, and social isolation. Signs of depression are seen in 40% of rejected lovers, and in 12% it results in medium to serious depression. At this time, aggression, suicide and murder also occur.

What is happening in the brains of these rejected lovers? An fMRI study was performed on 15 rejected lovers who still spent 85% of

their waking time thinking about their beloved (we are not including in this what may have gone on in their dreams!), and the same active brain areas were seen as in those passionately in love. Even when they were rejected, their brains showed the same areas of activity as in people totally in love. What was different from happy lovers was greater activity in the right accumbens nucleus and the ventral pallidum. This same increase in activity in the right accumbens nucleus seen in people who have lost someone close to them (Emanuele, 2009). That is, rejection in love provokes a similar reaction in the brain to death and bereavement. Also, the ventral pallidum is a region which is rich in vasopressin (VZP) 1A receptors (Fisher, 2010). We will come back later to the importance of this region and its connection to VZP. Activity in this region declines as love continues and disappointments in love increase. Activity begins in the left insular cortex, an area which also shows activity in times of anxiety, weeping, and when pain is inflicted on the skin.

Fidelity, Cheating and Monogamy/Polygamy

If there is deep and passionate love and fidelity, how is it that we also see infidelity and cheating? In mammals there are two hormones which control fidelity: oxytocin (OXY) and vasopressin (VZP). VZP is also called arginine-VZP and the antidiuretic hormone. OXY and VZP are synthesised in the hypothalamic magnocellular supra-optic and paraventricular nuclei and released into the blood by axonal transport from the pituitary gland. These are the only hormones which are released from the pituitary gland and have a direct distant effect on the body. The two hormones have a similar structure, and partially affect each other's' receptors. In humans, they are both coded on the same chromosome, 20p13, while the receptors are coded on chromosome 2. They have a peptide structure formed from nine amino-acids, and differences in the third and eighth amino-acids make the difference between them. The hormone OXY is structured Cys-Thr-Ile-Gln-Asn-Cys-Pro-Leu-Gly-NH₃, while VZP has the structure Cys-Thr-Phe-Gln-Asn-Cys-Pro-Arg-Gly-NH₃. These hormones are also found in worms, rodents, birds, octopuses, elephants and whales, with variations in amino-acids in the same areas causing inter-specific



differences. They have peripheral classical effects: OXY causes milk production and contractions of the uterus during birth, while VZP is involved in water retention (especially on VZP-2 receptors).

Along with their peripheral effects, OXY and VZP have receptors which give them a greater effect on the central nervous system, in many regions from the brain stem to the spinal cord. OXY receptors are found in the accumbens nucleus, the amygdala and the hippocampus. OXY is involved in the formation of social memory (Martin-Du Pan, 2012; Atzil *et al.*, 2012; Kumsta and Heinrichs, 2012) the recognition of facial emotion, and the feeling of trust in other people, and causes aggression in pregnant women and mothers. It is fundamental to male-female pair-bonding, mother-child bonding (Weismann *et al.*, 2012; Scheele *et al.*, 2012). It passes from breast-feeding mothers to their children and increases mother-child bonding. When the OXY gene does not function, problems are experienced in memory of social events and recognition. The social memory is disrupted. When the OXY receptor is blocked in mothers, care for the infant decreases. Secretion of OXY from the rear pituitary rises in parallel with oestrogen in the blood. It rises appreciably in embracing and suckling, and during birth, sexual arousal and orgasm. OXY has been called the cuddling chemical. It is prominent in bonding in women, while VZP is more closely related to bonding in men (Ferguson *et al.*, 2000).

VZP, especially in men's brains, mostly has VZP1A receptors in the ventral pallidum and putamen region. In men it has functions such as the formation of pair bonding, aggression, territorial defence, protection of children and hierarchical organisation. The effects of OXY and VZP overlap to some extent in both men and women.

What We Learn from Rodents

How can monogamy and polygamy be explained? In nature, only 3-5% of all species – albatrosses and voles for example – are monogamous, that is they only have one mate. The most interesting thing about monogamy and polygamy is work that shows that a single hormone or gene is responsible for turning the one into the other. Two species of voles show different pair bonding and behaviour characteristics: prairie voles are

monogamous, while meadow voles are polygamous. But how do we know that a vole is monogamous? One male vole and five or six females are placed in a maze. The male smells only one of them, and generally pays attention to and mates with that one. When these voles lose their mate they take on the task of caring for the young and do not choose another mate.

When the brains of monogamous prairie voles were examined, it was found that there was a high density of receptors for OXY in the accumbens nucleus and a high density of VZP1a receptors in the ventral pallidum. It is known that the gene for OXY production was on chromosome 2 in prairie voles, so if this gene is knocked out, the hormone OXY can no longer be produced. This makes a prairie vole which has been monogamous from birth polygamous and promiscuous. He mates with any female he comes across, and takes no care of his young. This means that pair bonding can be prevented by a single gene. And if a substance is put into the empty spaces of the monogamous prairie vole's brain which blocks VZP1A receptors, this also transforms a monogamous animal into a polygamous one (Lim and Young, 2006).

Meadow voles on the other hand are polygamous in terms of breeding habits. They do not form pair bonds and are solitary. Their social memories are weak. When we examine the brains of these rodents, we find that in contrast to the monogamous prairie voles, the density of OXY and VZP1A receptors in the accumbens nuclei and ventral pallidum is low from birth. Giving these polygamous voles intracerebral ventricular OXY makes them monogamous. They lose their polygamous behaviour and turn into well-behaved fathers of the family. Maybe in the future polygamous tendencies in men might be shown up in gene analysis. Their identity cards might be marked "polygamous tendencies, good for one-night stands, does not bond", or otherwise "monogamous, a good father of a family", giving women the chance to choose accordingly.

So monogamous and polygamous behaviour in humans is also closely related to the hormones OXY and VZP and their receptors. And receptor and hormone concentrations are closely related to genetically related phenotypes (Ross *et al.*, 2009). For humans, we have evidence for the accumbens nucleus and the ventral pallidum



which is similar to that for the brains of voles (Beery and Zucher, 2010). At the same time, fMRI studies have shown marked activity in the accumbens nucleus and the ventral pallidum in cases of long-term bonding. This shows that the mechanisms in voles also function in humans.

Studies on OXY have also provided similar evidence. OXY was the first peptide hormone to be synthesised; the person who synthesised it in 1953 won the Nobel Prize. OXY is sold commercially as a nasal spray and for intravenous injection, and it is used mostly as a common way of increasing cows' milk production. In humans, the hormone's characteristic of providing "social trust" is very clear. It decreases social fear and anxiety, and it is used for this effect in the treatment of autism. It makes it easier to gain trust in relations with another person (both in love and when dealing with money!) When love ends or a marriage breaks up, the reason why we say "how did I ever trust the bastard?" is most likely the fall in OXY levels in our blood which happens alongside the reduction in bonding and trust as we come to our senses. That is, the false sensation of trust caused by OXY has been removed.

A group of people were told to place money with an investor. If the investor gained money they would win, but if the investor was untrustworthy and a cheat they would lose. Some of the subjects were given a placebo nasal spray, and the others were given an OXY spray. It was found that the group who were given the OXY nasal spray trusted the investor more and entered into twice the risk. That is, OXY increases trust, and makes it easier to take risks with money. In just the same way, new lovers trust each other with no regard for the long-term consequences. However, when

the same people were dealing with a computer rather than a human investor, the OXY spray did not have the same effect. That is, this hormone has an effect on person-to-person contacts, but not on human-to-machine relations. For this reason, it may be recommended that people do not take decisions involving financial risk when their OXY levels are raised by situations such as raised oestrogen levels in menstruation, sexual activity, and orgasm or breast-feeding.

When this effect became known it captured the popular commercial imagination, and OXY-containing perfumes were produced, and marketed with slogans like "Trust is Strength", and "*You will become irresistible, and both your social life and your wallet will be enriched.*"

Does all this mean that the secret of love has been stolen? When Newton explained the colours of the rainbow by the use of a prism, the Romantic poet John Keats wrote in his poem *Lamia*:

Do not all charms fly

At the mere touch of cold philosophy?

There was an awful rainbow once in heaven:

We know her woof, her texture; she is given

In the dull catalogue of common things.

Philosophy will clip an Angel's wings,

Conquer all mysteries by rule and line,

Empty the haunted air, and gnomed mine –

Unweave a rainbow

I don't think we have mistreated love in the same way, because love will always keep part of itself secret.



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