



NEUROCHEMICAL PROCESSES OF LOVE

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ABSTRACT

Love, particularly in the beginning (i.e., falling in love), can sometimes be stressful. Love truly represents an essential “ingredient” of healthy and satisfying life. Reproduction and sexual behaviours are just one aspect of love. Community, social support, health and survival clearly indicate further beneficial properties of biological love concept. Present article analyses beneficial auto regulatory pathways of the brain that contribute to health by enabling one’s experiences of life – e.g. love – to benefit one’s health.

Key words: Neurophysiology, Chemical processes, Love.

INTRODUCTION

Love has consequences for health and well-being. Engaging in joyful activities such as love, may activate areas in the brain responsible for emotion, attention, motivation and memory, and it may further serve to control the autonomic nervous system.

Love is closely related to the concept of pleasure and „positive psychology“, i.e. joyful mental states, and therefore has become a feature not only of thorough psychological but also basic science research – e.g., neurobiology – and clinical medicine.

Stress management is form of medical life style modification towards a healthier or more stress-resistant life that has now proven to be efficient in a broad array of diseases and conditions, namely cardiovascular, immune, and neurological or psychiatric disorders, including prevent. In other words: Stress management may improve health. Stress management techniques regularly include social support, meditation/ relaxation techniques, and other pleasurable activities that induce feeling of well-being and protection, thereby facilitating positive affect, resilience, spirituality, „loving-kindness“, compassion, and closeness or connectedness – states that resemble the love concept as discussed above [1-3]. The placebo response may also be named here, since it depends on positive therapy expectations, trust or belief, and it potentially acts via the

same neuronal reward pathways related to love, pleasure, motivation and behaviour. Love and compassion, i.e., loving-kindness, are integrated in mindfulness trainings such as mindfulness-based stress reduction. Loving-kindness meditation has been used for centuries in the Buddhist tradition to develop love and transform anger into compassion. This type of intervention, delivered as an eight week program, helped to reduce chronic pain, psychological distress and anger [4-7].

Positive emotions, compassion and happiness help us to feel better, particularly in stress and further they improve bodily functions: Love, compassion and joy make our immune system function better and help to battle diseases. Well-being is now acknowledges and recognized as a powerful behavioural tool for supporting motivation and decision making, that is choosing activities that engage rather than numbs our minds: if we heed what gives us immediate pleasure and if we are sceptical of our “error-riddled” memories and predictions, we can learn to spend our money, time and attention in ways that make us happier [8-9]. Survival and reproduction depend on the ability to adapt patterns of social and reproductive behaviours to environmental and social demands. Moderate pleasurable experiences are able to enhance biological flexibility, complexity and health protection.

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Pleasure can be a resistance resource or it may serve salutogenesis and prevention. Furthermore, love and pleasure facilitate trust and belief into the body's capability of restoring or maintaining health, i.e. self-healing capacities.

In humans, cognition and belief are vital for reward and pleasure experiences. Social contacts provide pleasure, hence survival. These functions of love and pleasurable experiences may even stimulate personal growth and development. Love and pleasure clearly are capable of stimulating health, well-being and (re)productivity: this wonderful biological instrument makes procreation and maintenance of organisms and their species a deeply rewarding and pleasurable experience, thus ensuring survival, health and perpetuation.

Love and pleasure carry the ability to heal or facilitate beneficial motivation and behaviour, in addition to ensuring survival of individuals and their species. After all, love is a joyful, yet useful, activity that encompasses wellness and feelings of well-being – a rather holistic and integrative medical procedure!

The Neurobiology of Love

Love is complex neurobiological phenomenon, relying on trust, belief, pleasure and reward activities within the brain. These processes critically involve oxytocin, vasopressin, dopamine and serotonergic signalling. Moreover, endorphin and endogenous morphinergic mechanisms, coupled to nitric oxide auto regulatory pathways, play a role. Naturally rewarding or pleasurable activities are necessary for survival and appetitive motivation, usually governing beneficial biological behaviours like eating, sex and reproduction [16-20]. Yet, a broad basis of common signalling and beneficial neurobiological features exists with connection to the love concept, thereby combining physiological aspects related to maternal, romantic or sexual love and attachment with other healthy activities or neurobiological states. Love, pleasure and lust have stress-reducing and health-promoting potential, since they carry the ability to heal or facilitate beneficial motivation and behaviour [6]. In addition, love and pleasure ensure the survival of individuals and their species. Love is a joyful and useful activity that encompasses wellness and feelings of well-being.

Love is strong, passionate affection for person. Love is an emotion often associated with consensual sexual activity or the willing, and even eager, participation of the individuals involved. However, only recently has biology of love and in particular its neurobiological aspects, become a focus of basic science [7,11].

Attachment, commitment, intimacy, passion, grief upon separation and jealousy are but a few of the emotionally-loaded term used to describe that which love represent. In science love appears to be a hypothetical and multi-dimensional construct with many interpretations and

implications. Love and its various emotional states and behaviours are rarely investigated by scientific means. Emotions and feelings such as attachment, couple and parental bonding and even love – presumably typical of higher mammals and neglected of centuries by the experimental sciences – have now come into the focus of neuroscientific research in order to elucidate their biological mechanisms and pathways [12-15].

The concept of love involves having an emotional bond to someone for whom one yearns, as well as having sensory stimulation that one desires. The word “love” derives etymologically from word meaning “desire”, “yearning” and “satisfaction” and shares a common root with “libido”. Psychological sense of love can be interpreted as referring to the satisfaction of a yearning, which may be associated with the obtaining of certain sensory stimulation. Love therefore possesses a close connection not only with reward and pleasure phenomena, but also with appetitive and addictive behaviours.

Love can be viewed as a dynamic process that represents the result of different components probably subserved by distinct neural substrates at different times. As such, some steps can be identified, e.g., its beginning (“falling in love”), which is the process of attraction, followed by the attachment process that, in some cases, can last forever [7-8].

Selective social attachment and the propensity to develop social bonds are necessary features of love concept. Furthermore, this concept is associated with parental as well as sexual behaviours. Both types of attachment and love (sexual or romantic versus parental or maternal) can provide a sense of safety and reduce anxiety or stress – important for a healthy life and balanced way of decision making. Biologically, to “fall in love” is the first step in pair formation, involving attachment and bonding as well as romantic, sexual and parental behaviours and experiences, e. g. lust, pleasure, joy and happiness. Clearly, love has positive connotation. However, it seems to be a rather complex phenomenon and not only implicates sensational elements or behaviours, i. e., sensation – and approval-seeking, but also psychological, emotional and neurobiological portions. In the end, it all has to serve biological goals: its function exceeds that of reproduction alone, since love also facilitates the establishment of long-lasting relationships that are related to trust and belief and may ensure support or protection under challenging circumstances [3-5].

The most accepted form of an enduring social bond, within the love concept, is maternal attachment. The idea of motherly love implies a selective behavioural response by the parent to its offspring, i. e. parental love. Hence, the tender intimacy and selflessness of a mother's love for her infant occupies a unique and exalted position in human conduct. It provides one of the most powerful motivations for human actions and behaviours. Sexual behaviour, on the other hand, is closely related to

attachment as well, but they are not synonymous. Sexual activity can occur in the absence of social attachment, and many forms of attachment exist that do not involve sexual behaviours. However, in humans, the most desired sexual partner is often the object of strong feeling of attachment [1, 11].

Love, e.g. when experiencing symptoms such as sweating, heart beat acceleration, increased bowel peristalsis and even diarrhea, can be quite a stressful experience. However, love is certainly known, primarily, for its relation to feelings that we usually like to experience.

In recent reviews on the role of stress in human attachment, it has been discussed that stressor can trigger a search for pleasure, proximity of altered physiological and psychological states. It is surmised that some degree of strong, yet manageable, stress may be necessary for very strong bonds to form. However, if socializing “in the face of stress” does not occur, diseases may be introduced. Forced isolation, anxiety, fear and other forms of stress are associated with increased levels of stress hormones like cortisol. Excessive stress (i.e. chronic) that could compromise health and survival, e.g. (hyper)intense grief, may lead to depression or the breakdown of social relationships.

While acute stress obviously induces subsequent reproductive behaviours and social contact, chronic stress may lead to a strong reduction in the abilities to propagate. Furthermore, with an increasing population density (i.e. in rodents and primates) social stress aggression rise, accompanied by enhanced infertility rates, susceptibility to infections, blood pressure, atherosclerosis, neural, cardiovascular and renal damage or diseases. It is important for biological organisms to possess programs and strategies that buffer against stress and social isolation. Hence, love can be such a mechanism [4-6]. On the other hand, higher animals bear a mechanism within themselves that negatively selects individuals with unsuitable behavioural abilities, leading to infertility or, ultimately, death. Thus, stress and love are biologically interconnected: individuals that possess better or more effective strategies to come with stress also show better immune functions and sexual performance and have direct benefit for survival and reproduction. Taken together, happiness, pleasure and well-being, as well as touch, social contact and support, are related to the love concept and, via stress reduction and protection, represent a distinct and important evolutionary factor. This may be the reason why biological organisms tend to be pleasure – seekers. After all, these biological phenomena have a biological match and it is imbedded in central nervous system (CNS) structures and pathways.

Feeling of security and support lead to the facilitation of trust and belief, including “meaning and spirituality”, thereby inducing positive motivation and behaviour. Oxytocin, a major player in love physiology,

has also been associated with stress reduction. In humans, oxytocin, inhibits sympathoadrenal and stress response activity, including the release of adrenal corticoids. The effects of oxytocin on pair bonding or other forms of social attachment may therefore be related to the autonomic, i.e. autoregulatory, role of oxytocin in stress reduction. Positive stress appears to be important for the formation of social contact and attachment since a moderate level of stress has been demonstrated to promote this kind of relationship, i.e. social bonding [8]. Love seems to be a complex phenomenon and with regard to stress, an ambiguous experience, i.e., double-edged sword: love itself can be stressful, but it potentially serves to lower stress levels over the long term.

Motivation concerns aspects of intention or activation. Consequently, it lies at the core of biological, cognitive and social regulation. Motivation is highly valued in health care since it produces behavioural changes or adjustments and can mobilize others to act. A large amount of behaviour can be explained by simple processes of approaching pleasant and avoiding painful stimuli, i.e. motivational behaviours [5, 11].

Motivation may be divided into two categories – appetitive and aversive motivation. Appetitive motivations concerns behaviours directed towards goals that are normally associated with positive or hedonic, i.e. pleasurable, processes (food, recreational drugs, sex etc.). In contrast, aversive motivation involves getting away from hedonically unpleasant conditions. Consequently, two fundamental forces rule motivation and subsequent behaviour: pleasure and pain.

Trust and belief often have a negative connotation in science. For example – the placebo effects. Trust and belief undoubtedly play a major role in health, science and medicine. It has been suggested that the placebo effect is basically mediated by dopaminergic – and possibly morphinergic – reward mechanisms and that this placebo-related reward physiology is associated with positive therapy expectations. The placebo response, as described, relies on trust and belief, and this connection has its neurobiological roots predominantly in limbic or frontal/prefrontal brain activity. Belief has an emotional component in the brain’s motivation and reward circuitry, linked to memory processes, will be reinforced with a positive emotional valence attached to the person, idea or thing that is believed. Pleasure and emotion may reinforce a belief or trigger positive physiological reactions even against rationality [11, 14]. Thus, belief in doctor, therapy, sexual partner etc., as well as the belief in love, in general, may stimulate naturally occurring health processes. These subjective processes may predominantly be based on endogenous autoregulatory signalling molecules like endorphins and endocannabinoids, possibly originating in limbic pathways. Moreover, belief affects mesocortical-mesolimbic appraisal of a pleasurable experience, leaving one, for example, well and relaxed. Taken together, the

subjective modulation of incoming information in the brain, may be an important fact in love, pleasure and placebo phenomena. This may be particularly true when positive qualities or experiences like pleasant sensations, touch, attention and feelings of protection, in general, are involved.

The biological mechanism mediating behaviour motivated by events commonly associated with pleasure is called “reward”. It is usually governing normal behaviour through pleasurable experiences. Pleasure, however, describes a “state or feeling of happiness or satisfaction resulting from an experience that one enjoys”. Pleasure is a subjective phenomenon. It is the “good feeling” that comes from satisfying homeostatic needs such as hunger, sex and bodily comfort. Hence, an intimate association between reward and pleasure exists. In neurobiology, pleasure is a competence or function of the reward and motivation circuitries that are imbedded in the CNS (central nervous system). Anatomically, these reward pathways are particularly linked to the brain’s limbic system.

Hormones and Central nervous system

Love has the capacity to influence the autonomic-emotional integration system, i.e. limbic system. Here, the autonomic nervous system (ANS) and emotions are wired together. Furthermore, sympathetic activity and stress hormone production are imbedded in underlying autoregulatory circuits. The influence of love on vital functions such as breath, respiratory rate, blood pressure and cardiac output, as a result of the autonomic-emotional integration, can lead to a different consciousness, or altered state of mind, when in love. Hence, an activation of the brain’s reward system produces changes ranging from slight mood elevation to intense pleasure and euphoria and these physiological states usually helps to direct behaviour towards natural rewards, i.e. love [5, 7-8].

Pleasure and reward may not only serve entertainment or enjoyment, but may also govern behaviour, sexual reproduction and personal growth. The striatum contains cells that respond to food and drink reward and it is activated by monetary reward stimuli or psychomotor stimulants. Psychomotor stimulants, opiates and natural rewards like food and sex, seem to predominantly activate the reward pathways by their molecular or pharmacological actions in the VTA (ventral tegmental area) and nucleus accumbens, as well as amygdala and other related structures, i.e. mesolimbic or frontal/prefrontal areas. Other neurotransmitters may also play a critical role in reward physiology.

Feeding, maternal behaviour or sexual activity can each be facilitated by opiate activation of the reward system. The origin of VTA seems to provide an important neurochemical interface where opiates and opioid peptides of exogenous or endogenous origin can activate an ANS mechanism involved in appetitive motivation and reward. Obviously, endogenous morphinergic signalling plays a

significant role here. This is especially true since endogenous morphine biosynthesis, found in humans, vertebrates, mammals and invertebrates, involve elements of dopamine synthesis and its metabolism, thereby linking two critical signalling system. Specifically, endogenous morphine production has been demonstrated in limbic tissues [7, 8, 11].

Mating, i.e. sexual intercourse or sexual stimulation, releases oxytocin. Together with vasopressin, this peptide is key neurobiological transmitter in love and pair bonding. Moreover, vasopressin production, as it is directly inducible by sexual stimulation, may also be enhanced by testosterone release, as part of sex physiology. Since mating and love involve pleasurable experiences and, therefore, release dopamine and/or increase sympathetic activity, this act is substantially rewarding experience, yet facilitating appetitive motivation and arousal, which may increase the level of sexual stimulation.

Dopamine agonists, capable of inducing reward and pleasure, release oxytocin and interactions between oxytocin and dopamine have been reported in rats. Consequently, pleasure can be seen as an effective and important adaptive mechanism, the function of which is to ensure the procreation and survival of species.

Falling in love, given the initial uncertainty, lets our cortisol levels rise. Increased cortisol concentrations, however, together with lower follicle stimulating hormone (SH) and others, indicate the stressful and arousing conditions associated with the initiation of social contact. Furthermore, oxytocin plays a crucial role in parturition and lactation, i.e. postpartum period in mammals, which is characterized by milk production [9]. Oxytocin is a key player in sexual behaviour, since it is involved from its start – the process of falling in love. Also, oxytocin ensures trust, loyalty and devotion, which seems to be important for intact or beneficial and lasting relationships. Together with vasopressin, prolactin and endogenous opioids, oxytocin reduces HPA axis activity and it further reinforces the attachment between mother and child. Interestingly, milk contains high levels of oxytocin and prolactin, thereby additionally facilitating infant-mother attachment and bonding, as well as infant’s nervous system development and the structural tuning of stress response mechanisms [9-11].

Hormones generally act on the ANS to integrate attention, emotional states, motivation and social communication with behavioural, physiological or environmental demands. The ANS therefore is essential for social attachment and love and it also contains receptors for oxytocin and vasopressin. Clearly, catecholamines and other ANS signalling molecules, play a role in love phenomena and love, on the other side, acts on autonomic functions and states, i.e. stress and stress reduction. Falling or being in love makes us feel good and, at times, “out of this world”. In fact, love produces states that resemble obsessive behaviours or disorders; while, in the case of

love, thoughts much more than behaviours characterize the actual obsession, i.e. thinking about the object of love “all the time”. Vasopressin and oxytocin, the stress hormones norepinephrine and cortisol, as well as “pleasure molecules” like dopamine, endocannabinoids and endorphins – possibly together with endogenous morphine [7, 11-14].

Another important hormone showing changes under love and a somewhat surprising pattern of release, is testosterone since its concentrations vary in opposite directions in the two sexes: Men in love demonstrate decreasing testosterone levels, whereas women in the same condition produce more testosterone. It has been suggested that falling in love may therefore include the tendency to temporarily eliminate some of the biological differences between the sexes or to soften some male features in men and, in parallel, to increase them in women, including a more “outgoing” or aggressive behaviour style. However, this speculative aspect has to be thoroughly examined further before specific conclusions should be drawn.

The early phase of love may represent a rather extreme neurobiological state, even physiologically contradictory to subsequent phases and states. Within the brain, testosterone receptors are distributed, for example, around hypothalamic regions where testosterone eventually is aromatized. However, the specific pathways involved as well as the significance of related estrogen signalling still are speculative. A behavioural correlation between testosterone and serotonin levels has also been demonstrated [10]. Gonadal or sex hormones are involved in the neurophysiology of love, not surprisingly: gonadal steroids, including androgens and estrogen, may exert developmental effects on neural system that have been implicated in social attachment and they may mediate both genetic and environmental influences on the propensity to love and form attachments. These hormones may further regulate oxytocinergic or vasopressinergic functions, as well as the expression of other peptides and neurotransmitters, which in turn can also modulate oxytocin and vasopressin, i.e. feedback. However, social attachment apparently occurs even in the absence of gonadal steroids, pointing out their questionable role within the framework of love and social attachment. The complex interrelations of molecular signalling processes underlying love phenomena and sex-related behaviours [14-15].

Dopamine has recently received special attention from psychopharmacologists and neurobiologists, due to its obvious role in mood, affect, and motivation regulation. The profound neurophysiological and neurobiological connection between love and reward has become obvious. Hence, the limbic reward and motivation system is involved in many other biological and physiological phenomena, including medicine. Activations in lateral frontal or prefrontal cortices can also be indicative of more generally positive mental states, i.e. positive affect, as seen

in relaxation techniques, listening to music or meditation. Taken together, CNS activation patterns related to positive effects and love are not equally shared between the two hemispheres. Deactivations are also of interest, since emotions are likely to be the product of both increases of activities in specialized regions.

On the neurochemical level, love and pleasure may involve substances that possess calming and anxiolytic capacities, including oxytocin, thereby facilitating feelings of well-being and relaxation. In addition, the pleasure of love may possess a co-ordinating influence on a network of cortical or subcortical limbic and paralimbic structures, regions that are intimately involved in the regulation of cognition, emotion and autonomic, endocrine or vegetative functions. Modulation of this neuronal network could initiate a sequence of effects through which pleasurable activities regulate multisystem functions [16-17]. Moreover, NO, endocannabinoid or endorphin and even endogenous morphine autoregulatory signalling have been demonstrated or discussed in association with pleasure-related experiences or therapies. These molecules that possess a strong CNS affinity and are further capable of reducing stress may also be involved in the placebo response, thus promoting beneficial effects associated with love.

Love activates specific regions in the reward system, as described above, and includes a suppression of activity in neural pathways associated with the critical social assessment of other people and with negative emotions. In particular, love reduces the ability to critically judge, i.e. impaired emotional judgment, decreases fear and lessens the assessment of social trustworthiness. Additionally, love-pleasure-related activation/ deactivation patterns of a person, the need to assess the social validity of that person is reduced [18-19].

Pleasure and reward can activate behavioural patterns, or they may even break up behavioural “torpidity”: curiosity drives our motivation and actual behaviours towards new goals and “fresh encounters”, stimulating a search for “new ways” and solutions, or partner, thereby involving spontaneity, appetite, and appetitive motivation. Biologically beneficial and/or pleasurable events that occur on our way, driven by curiosity, involve reward signalling, as described, yet again encouraging and amplifying these new behaviours. Rewarding behaviours henceforth get memorized for the goal of repetition and faster/ better recognition later on involving hippocampal mechanisms. However, negative events and experiences may cause the opposite neurophysiology to evolve, even including a physiological deactivation of behaviours and motivation patterns or memory deterioration. Hence, stress is a common trigger or cause of negative events, such as diseases and it has a major yet principally preventable, i.e. reducible, impact upon our life styles. Since love and pleasure may enhance positive or healthy behaviours and beneficial motivations

by their rewarding capacities, love can be a tool in stress reduction. Social support and bonding as they appear in the face of stress and challenge, may thus help to promote healthy life style modification, therefore involving “positive physiology” and “positive psychology”, i.e. feelings of wellness or well-being, yet integrating stress response and other molecular pathways.

CONCLUSIONS

Love is a complex neurobiological phenomenon, relying on trust and belief as well as brain reward activity, i.e. limbic processes. These processes critically involve oxytocin, vasopressin, dopamine and serotonergic signalling. Moreover, endorphin and endogenous morphinergic mechanisms, coupled to nitric oxide autoregulatory pathways, play role. Naturally rewarding or pleasurable activities are necessary for survival and appetitive motivation, usually governing beneficial biological behaviours like eating, sex and reproduction. Thus, love and its rewarding pleasure are much needed. Love and social bonding employ a push-pull mechanism

that activates reward and motivation pathways. Simultaneously, brain circuits that facilitate critical social assessment and negative emotions, as well as physical and mental stress or “cognitive dwelling”, get down regulated. This down regulating property of love may also include further physiological phenomena. However, early phases of love, such as falling in love and its related arousal and more pronounced behaviours and molecular signalling activities, are distinct from later stages or even long-lasting relationships. Nonetheless, a broad basis of common signalling and beneficial neurobiological features exist with connection to the love concept, thereby combining physiological aspects related to maternal, romantic or sexual love and attachment with other healthy activities and neurobiological states. Medicine can make use of this concept, i.e. mind/ body or integrative medicine.

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CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

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