REVIEW ARTICLE

# Attachment in integrative neuroscientific perspective

**Radovan Hrubý [1], Jozef Hašto [2], Peter Minárik [3]**

[1] Psychiatric Outpatient Department, Martin, Slovak Republic; [2] Department of Psychiatry, Faculty Hospital, Trencin, Slovak Republic; [3] Sanofi-Aventis Pharma Slovakia, Bratislava, Slovak Republic.

*Correspondence to:* Radovan Hruby, MD., PhD. Psychiatric Outpatient Department, Andreja Kmeta 42, 036 01 Martin, Slovak Republic. TEL: + 421434135467; E-MAIL: radhru@gmail.com

*Submitted: 2011-03-01* *Accepted: 2011-03-20* *Published online: 2011-04-30*

*Key words:* **attachment; development; neurobiology; neural regulations; mentalizing**

Act Nerv Super Rediviva 2011; **53**(2): 49–58 ANSR530211R01 © 2011 Act Nerv Super Rediviva

## DEDICATION

The authors dedicate this article to prof. Peter G. Fedor-Freybergh, MD, PhD, who is founder of the first University Institute of Prenatal and Perinatal Psychology and Medicine in the world, including the Department of Integrated Neurosciences, and world wide authority to spread the idea of integrated neurosciences.

**Abstract**

Attachment theory is a very influential general concept of human social and emotional development, which emphasizes the role of early mother-infant interactions for infant's adaptive behavioural and stress copying strategies, personality organization and mental health. Individuals with disrupted development of secure attachment to mother/primary caregiver are at higher risk of developing mental disorders. This theory consists of the complex developmental psycho-neurobiological model of attachment and emerges from principles of psychoanalysis, evolutionary biology, cognitive-developmental psychology, ethology, physiology and control systems theory. The progress of modern neuroscience enables interpretation of neurobiological aspects of the theory as multi-level neural interactions and functional development of important neural structures, effects of neuromediattors, hormones and essential neurobiological processes including emotional, cognitive, social interactions and the special key role of mentalizing. It has multiple neurobiological, neuroendocrine, neurophysiological, ethological, genetic, developmental, psychological, psychotherapeutic and neuropsychiatric consequences and is a prototype of complex neuroscientific concept as interpretation of modern integrated neuroscience.

## Introduction

**Bowlby's attachment theory** is a general theory of social and emotional development and is one of the most successful complex psychological concepts (Shaver & Mikulincer 2009). It reflects the importance of early close mother-infant relationships and psychosocial factors for mental health and personality organization as well as its substantial etiological and pathogenetic influence in the pathophysiology of mental disorders (Hašto 2005). The theory emphasizes the importance of the quality of mother-child and family relations in early childhood. These relations, in critical periods of childhood, significantly form the child's behavioural characteristics and they can be further employed as a protective or, conversely, as a risk factor for the development of mental disorders. The author of the theory – John Bowlby (1907–1990) created the theoretical framework, which enables conceptualization of human behaviour in close relationship to others. The theory postulates a genetically programmed repertoire of behaviour (attachment behaviour), which human infants are born with and which is, in an appropriate environment, more or less strongly focused on a particular person. **Attachment** and **attachment behaviour** represent the basic terms of the theory. **Attachment** is a strong need for contact with certain people, the tendency of proximity-seeking to significant others and it is a continuous, relatively stable feature of attachment behaviour. **Attachment behaviour** has developed during evolution to assure proximity and create special bonds to these significant others (caregivers). Permanent relational bonds are formed by children only to several preferred significant persons (mother, father, sibling etc.) and these are designated as **attachment figures.** Attachment figures provide protection, promote safe exploration of the environment and help the infant learn to regulate emotions in a pro-adaptive, effective way. The child's proximity-seeking behaviours are organized by the behavioural system (the attachment behavioural system) and this complex behavioural strategy emerged in evolution to increase the likelihood of survival and reproduction (Hašto 2006; Shaver & Mikulincer 2009). Experiences with interactions in attachment are represented in memory as the **internal working models**. According to Bowlby (1995a,b) the formation of internal working models is conditioned mainly by real caring behaviour of the mother or caregiver. These important social interactions with attachment figure/s are internalized and stored as schemas in an associative memory network (Hašto 2006; Shaver & Mikulincer 2009). Thus formed internal models have a tendency to remain unchanged and distinctively affect the formation of new relations. Faulty internal models and attachment styles can be of special importance in the pathogenesis of some mental disorders. The less qualitative the attachment to the parent, the more difficult is the inhibition of anxiety and calmness of a child in a stressful situation. In children up to 1 year of age it is possible to find a type of attachment which is distinctively conditioned by the behaviour of the mother towards the child and these formed strategies of reaction in attachment behaviour are in certain modified forms carried over even to adulthood. There are several types of attachment in the infant stage, whereas the physiological one is the so called **secure type of attachment.** The safe type is characterized by accessibility of the mother whom the child uses as a "safe base" by the correct evaluation of the child's signals from the mother's side and fulfilling its needs. **Secure attachment** is a protective factor for psychosocial development, while **insecure attachment** occurs significantly more often in patients with mental disorders (Agrawai & Gunderson 2004; Hašto 2005; 2006). According to Bowlby (1983) attachment behaviour remains potentially active for life and is markedly activated in anxiety, tiredness, disease and associated with the need for affection and care (Hašto 2005). The attachment and attachment styles can be assessed as well as measured by means of several validated scales such as s EMBU (shortened version of EMBU – Egna Minnen Beträffande Uppfostran in Swedish; My memories of upbringing in English), ECR-R (Experiences in Close Relationships – Revised), AAI (Adult Attachment Interview) (Brennan *et al* 1998; Arrindell *et al* 1999; Shaver & Mikulincer 2009; Bieščad & Hašto 2010).

## Basic scopes

The theory of attachment comes from knowledge and principles of psychoanalysis, evolutionary biology, cognitive-developmental psychology, ethology, physiology and control systems theory. It could be interpreted from various aspects and has substantial theoretical and practical consequences. The attachment emerges from special and intense kinds of mother/caregiver-infant interactions and is exclusively enabled by specific neural coordination of essential quality during the critical early life period. This theoretical framework is supported by the **critical period concept**, which defines that specific critical conditions or stimuli which are necessary for development and can influence development only during that period (Schore 2001). **The attachment relationship** between infant and his caregiver is critical for **human development** – **optimal social**, **emotional**, and **cognitive development** (Strathearn *et al* 2009). These special interactions within attachment have types of unique patterns, which are of significant importance to create essential neurobehavioral regulations for individual survival. Initially, unique sensory motor information sharing between mother and child is the key starting point to establish the consequent intensive neural and behavioural regulations which develop next. Between these early subsequent regulations, **affect regulation** and **emotional processing** take special importance. Interdisciplinary research and clinical data have affirmed the concept that in infancy and beyond, the regulation of affect is a central organizing principle of human development and specific motivation systems (Schore 2001; Madlafousek 2004). Affect regulations are crucial to coordinate other behavioural characteristics and emotional reactions to novelty and stress. Socio-emotional learning during the attachment period is internalized consequently and leads to an individual capacity to regulate, generate and maintain emotional security during life (Schore 2001). Moreover, the secure type of attachment (as a result of appropriate secure mother behaviour) is crucial for mental health because of its facilitating effect on adaptivity, stress copying abilities and social functioning as well as for somatic health because of its affective, neuroendocrine and psychosomatic regulations and influence on immunity. The established attachment relationships represent a fixed pattern of strategies. For example, ethological research showed birds and mammals dispose of **basic neural coordination** to develop basic attachment strategies. Their youngsters show imprinting mechanisms to help them create a bond to the mother quickly and effi-


Copyright © 2011 Activitas Nervosa Superior Rediviva ISSN 1337-933X (print), e-ISSN 1338-4015 (online) **www.rediviva.sav.sk/**

ciently and display vocalization when separated from their mothers (similar mechanisms such as the crying protest in human infants). The mother-youngster bond is strongly facilitated by relatively simple signals, for example the mother-youngster odour stimuli. Primates do not dispose of such early behavioural mechanisms and their attachment is created in steps following multiple interactions with the mother (Hašto 2005). There is evidence for a wide range of maternal and social bonding strategies and behavioural responses in mammalian species. In the majority of small-brained mammals, the formation of a maternal bond requires individual recognition by olfactory cues, activation of neural mechanisms concerned with social reward by these cues and gender-specific hormonal priming for behavioural output. The **evolutionary increase of neocortex** seen in monkeys and apes has lead to an increase of the complexity of social relationships and bonding. Olfactory recognition and stimuli to areas of the brain associated with social reward are down regulated and recognition is based on integration of multimodal sensory processing requiring an expanded neocortex, particularly the association cortex. The emancipation from relatively simple olfactory and hormonal signals of bonding has been facilitated by the **increased importance of social learning** that is of critical importance for living in a complex social world, especially in human world (Broad *et al* 2006). A separation from the mother typically activates a stress reaction in the infant, which is accompanied by the activation of the autonomous nervous system and elevation of cortisol in plasma (Levine *et al* 1991). In the very early period these stress reactions are very intense and emergent, showing only subsequent modulations according to the type of created attachment bond in later life stages. The secure type of attachment serves as a protective factor, which positively decreases the intensity of the stress reactions, enhances stress copying capabilities and could also be manifested as a lower tendency to increase cortisol in plasma in stressful situations. On the other hand, the insecure type of attachment imposes as a factor, which increases vulnerability to stress, discomfort and disrupted resistance to stressful situations and promotes raising activation of stress reactions with enhanced cortisol release (Gunnar 2005). **The complex developmental psycho-neurobiological model of attachment** suggests direct links between secure attachment and adaptive infant mental health, as well as between traumatic attachment and maladaptive infant mental health (Schore 2001). Many studies have shown that insecure attachment (especially attachment-related anxiety) is inversely related to well-being and positively associated with depression, anxiety, eating disorders, substance abuse, conduct disorder and personality disorders (Shaver & Mikulincer 2009). These data support exceptional value of early mother-infant relationships in the process of forming the mental capacity to cope with inner and external (e.g. interpersonal, environmental) loading factors. The attachment relationships, if disrupted in early childhood, could contribute to the susceptibility to mental disorders during the whole of life. Individuals with attachment type distinct from the secure one significantly more often suffer from mental disorders. In this context, education of future first mothers on how to create the secure type of attachment could potentially be an important factor in preventive strategy against many mental and other pathological conditions in childhood as well as in later human life periods. The growing body of modern neuroscientific research reveals many neurobiological findings, which are crucial to formulate the attachment theory as a complex neuroscientific model with multiple levels of neurobiological, psychological, social, environmental and other interactions.

## Neurobiological aspects of attachment

The area of neurobiological aspects of attachment is very wide and complex, still growing through new findings in various neuroscientific disciplines. The neurobiological basis of attachment could be interpreted as functional interactions and development of important neural structures, effects of neuromediattors, hormones and essential neurobiological processes including emotional, cognitive, social and other interactions.

**Serotonin** is one of neuromediattors, which probably also participates in specific maternal behaviour. Mice knocked-out for **pet-1 gene**, which is important for adequate serotonin system development failed in maternal care. Their offspring died within 5 days because of insufficient maternal care against cold (Lerch-Haner *et al* 2008). A special problem is the role of the **allele for serotonin transporter gene**, also known as the "risk" allele for impulsivity, aggressivity and other behavioural disturbances, in the setting of genetic-social environment interplay within attachment. Suomi (1999) demonstrated that only those macaque rhesus monkeys with the "risk" allele developed behavioural disturbances, and lacked a safe attachment to their mothers. Another neuromediattor which seems to be important in the physiology of attachment is **dopamine**. In rat suckling females an increase of dopamine level in the nucleus accumbens was observed after contact with their pups. Those mothers which manifested more maternal behaviour were also found to have a higher level of dopamine in the nucleus accumbens. Those mothers who manifested less maternal behaviour were observed to intensify their care of pups after an artificial drug-induced increase in the dopamine level. Probably, this observation could indicate dopamine is involved in the processes of positive emotional and motivational regulations (Champagne *et al* 2004). Important findings prompted additional genetic studies of the **allele for dopamine D4 receptor** and its role in mother-child interaction. It was hypothesized that polymorphism in the D4 alleles could be associated with pathophysiology of the disorganized type of attachment. It was supposed that children with "normal" (short version) allele for D4 receptor developed disorganized attachment because of their mother's disturbed communication and interaction style in particular. On the other hand, those that had "long" version (DRD4 7-repeat) of the D4 allele, developed the disorganized type of attachment without substantial importance of the mother's interaction style (Gervai *et al* 2007). So, it is probable there is an important interplay between genetic and environmental factors with its various involvement and interference in the physiology or pathophysiology of attachment. **Noradrenaline** is also involved in the regulation of parental behaviour. Female rats genetically disabled for synthesis of noradrenaline expressed no care of their youngsters. Despite this condition they developed maternal behaviour after application of noradrenaline, when noradrenaline was administered before, but not after the birth (Thomas *et al* 1997). Noradrenaline also plays an important role in emotional memory processing (Tully & Bolshakov 2010). It is known that the locus coeruleus (brain noradrenergic centre) is markedly interconnected with amygdala, hippocampus, frontal cortex and other structures associated with storing emotional memory. This type of early emotional interaction could be of special importance within the process of attachment development in the most convenient way. Animal studies also suggest **GABA** and **glutamate** are involved in the neurobiological processes underlying attachment (Caldji *et al* 2003; Hsu *et al* 2003; Ziabreva *et al* 2000).

**Oxytocin** is a hormone, which is also known to have effects in the central nervous system, mainly in the limbic system structures involved in the regulation of emotions (Buijs *et al* 1985). Oxytocin plays an important role in "social" interaction between infant and mother to prepare a "positive emotional setting" and type of attachment in the uterus even before birth. That is why oxytocin also used to be defined as a **hormone of attachment.** Mothers with stronger maternal behaviour (striking, controlling of infant's safety, expressing more positive maternal emotions) displayed higher levels of serum oxytocin even during gravidity (Feldman *et al* 2007). Moreover, there is evidence for important linkage between oxytocin and dopamine reward system's pathways in the brain. Oxytocin receptors are located in the ventral striatum – a key dopaminergic brain region, and these receptors are functionally linked to maternal behaviour in the rat females (Olazabal & Young 2006). After birth, oxytocin is released by stimulation of the mother's nipples and besides smooth muscle relaxation it also induces positive maternal emotions. In rat females, inhibition of maternal behaviour was observed after use of oxytocin antagonists (Van Leengoed *et al* 1987). Moreover, oxytocin also plays an important role in establishing adequate quality of attachment in infants. In early childhood attachment is created mainly through mutual reciprocity and close relationship between child and mother and breast-feeding is probably one of the most important factors within these significant actions. During feeding oxytocin is released to the brain in both mother and child and is probably a special co-element to induce mutual mother-infant affection, interaction and calmness (Klaus 1998). Also, activity of **antidiuretic hormone** seems to be important for parental behaviour. As an example, it was demonstrated in a study that rat females exhibited higher maternal care when a higher activity of antidiuretic hormone was measured in their brains (Bosch *et al* 2008). Antidiuretic hormone seems to also be important for paternal behaviour. In the study, where vole males were injected with antidiuretic hormone to the lateral septum, an increase in care of youngsters was observed in injected ones (Wang *et al* 1994). As well as oxytocin, **prolactin** is also released during breast-feeding. It is known that intracerebral infusion of prolactin could induce parental behaviour, which is controlled by sexual hormones (Bridges *et al* 1990). Studies in mice, wolves and some primates even showed, prolactin supported paternal behaviour and this action was prolactin level dependent (Gubernick *et al* 1993; Ziegler *et al* 1996). Also paternal expression in human individuals was prolactin-dependent. Fathers with higher levels of prolactin tended to be more watchful and displayed more positive reactions to the infant's crying. Moreover, skilled fathers showed a higher increase in prolactin in comparison to less skilled ones (Fleming *et al* 2002).

From the genomic point of view, the attachment period is associated with a **significant increase of DNA** levels in the cortex. During this period the brain is rapidly generating nucleic acids that programme developmental processes. This massive production of both nuclear and mitochondrial genetic material in the infant's brain is directly influenced by events, especially by social-affective stimuli (Schore 2000). According to recent research, the mother-offspring bond seems to be important as well as an **epigenetic factor** influencing substantial processes on a genomic level. Zhang *et al* (2010) found that variations in maternal care stably influence DNA methylation, gene expression, and neural function in the offspring of rats. They examined whether maternal care affects *GAD1* (glutamic acid decarboxylase 1) promoter methylation in the hippocampus of adult male offspring of high and low pup licking/grooming (high-LG and low-LG) mothers. Compared with the offspring of low-LG mothers, those reared by high-LG dams showed enhanced hippocampal *GAD1* mRNA expression, decreased cytosine methylation, and increased histone 3-lysine 9 acetylation of the *GAD1* promoter. The authors suggest that maternal care influences the development of the GABA system, which is linked to the pathophysiology of serious neuropsychiatric diseases.

 Copyright © 2011 Activitas Nervosa Superior Rediviva ISSN 1337-933X (print), e-ISSN 1338-4015 (online) **www.rediviva.sav.sk/**

There is abundant motivation for understanding the important mechanisms of attachment which are demonstrated in the realm of **ethological research.** For example, the **imprinting mechanism** in young birds and mammals is well known. Goslings are, in a critical period of several days after the birth, fixed on their mother but also on other animals, a person or an object if it represents a source of relevant stimuli (e.g. imprinting is stronger if the stimuli are associated with a cackling sound). In primates, the activation of such an imprinting programme immediately after the birth does not occur and the bond is developed gradually over the course of infant development, as it requires a lot of interactions with a caregiver. In humans, especially, it could probably be explained by the fact that a child is born fairly "immature", with insufficient adaptive strategies to stay alive, if unprotected by parents. However, the child from birth disposes of basic neurobiological coordination such as intermediate inherited starting mechanisms and motor patterns as well as enormous dynamics in brain development (Hašto 2005). In animal research, Suomi (1991) demonstrated that the changes of attachment characteristics can be an important factor leading to continuous changes in the brain. In his experiment in young monkeys of macaque rhesus, separated from their mothers, abnormalities in behaviour which resembled manifestations of social phobia developed. They retreated only when they were exposed to the contact with their age brackets brought up by their own mothers and they manifested again when the young monkeys were exposed to unexpected and stressful situations. They also demonstrated higher levels of cortisol and ACTH in response to stress and lower levels of noradrenalin in liquor. Rosenblum and Andrews (1994) found in a similarly focused experiment that young monkeys of anxious mothers demonstrated lower dexterity in social interactions and were socially submissive (Hašto 2005). Another interesting finding led to experiments, in which macaque monkey youngsters isolated from their natural mothers lived only with two types of pseudo mother dummies – "soft mother" (covered with soft material and with a suck button) and "hard mother" (only a hard skeleton). Those youngsters which where in contact with "soft mothers" exhibited normal exploring activity even after striking stimuli alternating with returns to the mother. Those which were in contact with the hard mothers displayed less returns to the mother and expressed frightened reactions and depression like symptoms. After relocation to the normal monkeys group, the deprived monkeys compared to the normal monkeys were often attacked by others and exhibited evident adaptation problems (Höschl 2004).

This is also demonstrated in humans, but in a more specialized and complex way. The attachment style has expressive influence on the stress copying and other behavioural strategies – **affective regulation, early personality organization and mental health of infants.** During early human life development, there is evidence for the special role of the **right hemisphere**, which is dominant for processing socio-emotional and bodily information, stress copying functions, and self-regulation. These early emotional and social interactions are the crucial processes of early attachment creation. On the other hand, the early attachment period is critical for adequate right hemisphere development in order to receive and maintain social and emotional regulation capabilities, which are of critical importance for human adaptation, copying and complex behavioural strategy during life. The infant's early developing right hemisphere has deep connections into the limbic and autonomic nervous systems and is dominant for the human stress response. Processes occurring during this early development are critical for limbic system maturation and for limbic–autonomic circuit development, during which time experience or environmental events might participate in shaping synapse formation. The early maturing right hemisphere undergoes the highest growth in the first year and a half and is dominant for the first three years of life. It is the **orbitofrontal cortex** of the right hemisphere, which is of the highest importance to regulate the crucial neural interactions and maturation processes during early life. Hence, the early functional attachment strategy is formed, adequate conditions are prepared for the next essential neurodevelopmental processes. This efficient right brain function is a resilience factor for optimal development over the later stages of the life cycle. Mutually regulated psychobiological interactions between the infant and primary caregiver within attachment relationship are of critical importance for the optimal development of self-regulatory functions and the organization of personality (Schore 2000; 2001).

The discovery of the **mirror mechanism** could be considered as an important landmark step forward in elucidating these complex human interactions. This mechanism is enabled by the action of the specific neural population called the mirror neurons. **The mirror neurons** were originally discovered in the ventral premotor cortex of the macaque monkey. The main characteristic of these neurons is that they fire both when the monkey performs a motor act and when the monkey observes another individual performing a similar motor act. In humans, the mirror mechanism is organized into two main cortical networks, the first being formed by the parietal lobe and premotor cortices, and the second by the insula and anterior cingulate cortex. Its role is to provide a direct understanding of the actions and emotions of others without higher order cognitive mediation (Rizzolatti *et al* 2009). Such function and organization enable early identifications and emotional reactions and could have an enormous importance for early mother-child interplay. For example, it is well known that the human infant is an excellent imitator. Human infants are motivated to imitate a wide range of acts even without explicit rewards for doing so. Infant imitation serves a social-emotional function of communication and bonding. It also serves a cognitive function, as a mechanism for acquiring motor skills, causal information, and tool-use techniques. Before language emerges (pre-verbal period), imitation is one of the chief mechanisms for early learning in Homo sapiens (Meltzoff *et al* 2009). There is evidence for a special EEG rhythm called the **mu rhythm** in adults. It is characterized by marked desynchronization and reduction of the amplitude associated with the performance of movement. Recent findings from the adult EEG literature have shown that the mu rhythm is also desynchronized during the observation of others' actions. Moreover, mu-like rhythm was also observed in infants and is related to the action perception and action production in early human development. So, it is hypothesized that those EEG rhythms could probably reflect physiological processes connected with the activity of the neural mirroring systems (Marshall & Meltzoff 2010). Of course, close interactions in the infant's early life are bidirectionally active (mother/caregiver-infant), which seems to be especially important to create the appropriate attachment. During early life, interplay between the right hemispheres of both mother and child seems to be crucial for the regulations involved in the optimal attachment development. It is because the infant's right hemisphere is dominant for the infant's recognition of the maternal face, for visual emotional information and for the emotional tone of the mother's voice. This early adaptation brain programme is focusing the mother's attention on and is regulated by the output of the mother's right hemisphere, which is dominant for nonverbal communication. Some functional magnetic resonance imaging (fMRI) studies showed that rapid metabolic change occurs in the primary visual cortex of infants at about eight weeks of life. It was hypothesized that this finding could reflect the onset of a critical period during which synaptic connections in the occipital cortex are modified by visual experience. With this maturational advance, the visual stimuli emanating from the mother's emotional expression becomes the most potent stimulus in the infant's social environment (Schore 2001). However, the infant disposes of special behaviour strategies to induce a specific mother's brain response, which determines the optimal attachment relationship development. For example, Strathearn *et al* (2009) examined new mothers to test if differences in attachment (according to the Adult Attachment Interview) had some influence on the response of **the brain's reward system** and **peripheral oxytocin levels** as the reaction to infant cues (smiling or crying facial expressions). They found by using fMRI and measuring the peripheral oxytocin blood levels, that mothers with the secure type of attachment displayed greater activation of brain reward regions, including the ventral striatum as well as the oxytocin-associated hypothalamus/pituitary region on viewing their own infant's cues (smiling or crying). Moreover, their peripheral oxytocin response to contact with the infant was significantly higher in comparison to mothers with the insecure type of attachment. The insecure/dismissing mothers showed greater insular activation in response to their own infant's sad faces. The authors suggest that individual differences in maternal attachment styles and brain structure activities may be linked with differences in the development of the dopaminergic and oxytocinergic neuroendocrine systems in the brain. Leibenluft *et al* (2004) examined mothers who viewed faces of their own children and underwent fMRI to detect functional changes in their brain structures. The sight of their own child activated regions that mediate emotional responses – **amygdala, insula** and also those associated with "theory of mind" (see below) functions – **anterior paracingulate cortex** and **posterior superior temporal sulcus**. The authors concluded that these activations may reflect the intense attachment, vigilant protectiveness, and empathy that characterize normal maternal attachment.

Another important conception closely related to the function of neural mirror mechanism is the theory of mind. **Theory of mind** or **mentalizing** could be explained as a man's ability to read other people's gestures and faces within identification of their underlying emotions and mental states. Humans are constantly reading each others' actions, gestures and faces to recognize our underlying mental states and emotions, in an attempt to figure out what other people are thinking and feeling, and what they are about to do next (Frith & Frith 2005; Blakemore 2010). It is supposed that it is just the brain mirror system, which is fundamentally involved in the neural processes allowing us to share emotions, intentions and actions of others. The human brain has the unique ability to represent the mental states of the self and others and the relationship between these mental states, making possible the communication of ideas (Frith & Frith 2006). Such neural processes underlying social interactions are already active in infants, exhibiting gradual enhancement during development. A large body of research indicates that theory of mind typically develops in children during the first few years of life. The basic features of mentalizing emerge in the first 18 months, understanding false belief by 4 years or younger and second order meta-representation by 6 or 7 years of age. Moreover, some studies indicate theory of mind could take shape between late adolescence and early adulthood, mostly by the interactions with executive functions (Dumontheil *et al* 2009). Behavioural-genetic models of data received from large-sample studies showed a substantial portion of environment factors (superior to genetic factors) in variance of the theory of mind. Mentalizing involves important emotional, cognitive and interpersonal processes and is suggested to be a pivotal factor in the evolution of attachment (Allen *et al* 2008). Several studies have been conducted to identify the brain's areas and neural structures involved in the mirror mechanism and mentalizing. These studies used mentalizing

 Copyright © 2011 Activitas Nervosa Superior Rediviva ISSN 1337-933X (print), e-ISSN 1338-4015 (online) **www.rediviva.sav.sk/**

tasks and neuroimaging methods and have consistently showed activation of a **network of regions including the superior temporal sulcus at the temporo-parietal junction, the temporal poles and the dorsal medial prefrontal cortex** (Burnett & Blakemore 2009; Blakemore 2010). The medial frontal region is also engaged when subjects reflect upon their own mental states, as well as those of others with the more inferior orbital region responding especially to emotional states. These regions are thought to be an important part of the circumscribed network specialized for the social domain. This network is considered to be the **social brain** and mentalizing is one of the wide range of actions confronting this unique capacity of the human brain. Having theory of mind in attachment relationships creates the human capacity for rapid development of the social brain and consequently cultural learning (Frith & Frith 2005; Allen *et al* 2008). Another important part of this social domain conception could be considered **empathy**, because it also co-emerges from unique social interactions during the early attachment period (Schore 2001; Leibenluft *et al* 2004). It is suggested that empathy neuro-psychobiologically consists of two main mechanisms – bottom-up (automatically and unconsciously enacted understanding of other's emotions) and top-down (cognitive perspective taking of other people experiences, intentions and needs). The first one is thought to be an automatic processing mode related to the neural mirror systems (affective empathy) and the second one to be cognitive processing related to the theory of mind (cognitive empathy). Neuroimaging studies indicate that the same areas of the brain are activated when people experience their own emotions and when they observe such emotions in others and, in addition, automatic affective processing could be under modulating control of cognitive processing originating in the prefrontal cortex (Jankowiak-Siuda *et al* 2011).

Within the unique human functional brain development, the **capability of people to recognize themselves and separate themselves from the environment** has a particular placement. Recent neuroimaging studies (especially fMRI) revealed two main functional networks of special importance. The first one, the **extrinsic system** encompasses all the sensory motor areas engaged with processing and acting on information derived from the outside environment and includes the occipital, parietal and temporal primary and secondary sensory regions, as well as the frontal motor and premotor regions. The second one – the **intrinsic system** (or default mode network) is characterized by its activity, which is markedly anticorrelated with that of the extrinsic system. The intrinsic system displays a decrease in activity while performing various environment-dependent tasks and probably represents basic brain activity in the "resting state". It includes the prefrontal medial and superior frontal cortex, the posterior medial part of the cingulate gyrus and precuneus, and the bilateral inferior parietal cortex and is involved in various mental self-processing tasks, such as mental-state attribution, perspective taking, daydreaming, emotional processing and theory of mind. Moreover, several studies indicate the existence of additional components in a default system, which are typical of activation during the cognitive tasks as a potential anti-correlation activity to the rest of the deactivated system (Salomon *et al* 2009; Krajčovičová *et al* 2010).

As suggested above, postnatal human brain development is a very dynamic, multifactorial and intensive process, during which structural and functional changes occur, especially in some cortical regions as they interact and compete with each other to acquire their role in new computational abilities (Johnson 2011). In this process, which could be designated as **interactive specialization**, some cortical regions are involved in organizing patterns of inter-regional interactions and become more specialized with development. The onset of new behavioural competencies during infancy will therefore be associated with changes in activity over several regions. It is hypothesized that the **prefrontal cortex** (including orbitofrontal cortex ruling early right hemisphere development) could have a special dominant role in regulating this collective functional organization (including mentalizing functions) of other cortical regions during functional brain development (Johnson 2011). Within this functional development of the brain, neural processes involved in the attachment development could be one of the important early life regulatory factors for optimal development of cognitive, social, emotional and other domains and functioning of many important brain networks including the "key" extrinsic and intrinsic systems. The processes underlying early attachment formation are necessary for both optimal psychic and behavioural functioning and early personality organization and must be of an essential quality as well as formed during the crucial early life. They are an important precondition for adequate creation of systems involved in the life-important complex neural regulations **(Figure 1).**

## Conclusions

Attachment theory is very complex and could be interpreted from various points of view. It has multiple neurobiological, neuroendocrine, neurophysiological, ethological, ontogenetic, genetic and epigenetic, developmental, psychological, psychotherapeutic, social and neuropsychiatric contributions and applications. To summarize the theory, early attachment to a primary caregiver could be considered as an important part of the human life continuum. This continuum begins at least two generations before the birth of a human individual because complex characteristics of his parents are formed in that period and consequently transferred to him. The next sequence of the continuum is prenatal life in the maternal uterus. There is evidence that important information is carried out by special proteins

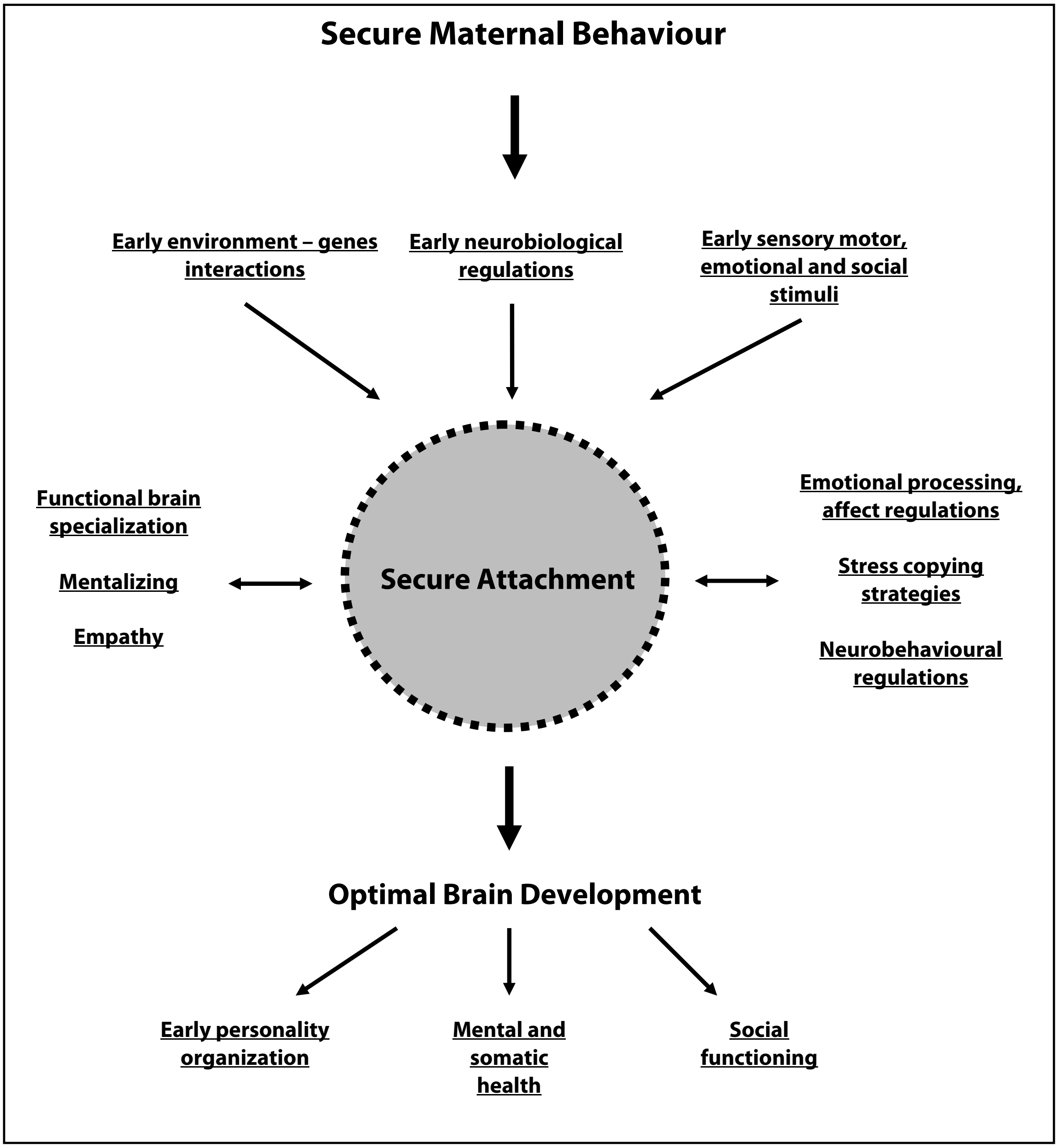


**Fig. 1.** Attachment and its importance for neurodevelopmental regulations.

(e. g. some hormones) and stored in the developing brain structures of the human foetus (e.g. by influencing the gene's expression) during the prenatal period. This information could be considered as important because these interactions are already taking place between the child and his environment in utero (Fedor-Freybergh 2008). These early interactions are markedly developing during the next postnatal period to create the crucial postnatal relationship to the mother (caregiver), which is of special importance for appropriate development, neural regulations and behavioural characteristics during life. They are critical for formation of attachment styles and relationships, stress copying strategies, social conformity and other important elements of human existence. The quality of these formations influences all the subsequent life periods (childhood, adolescence, adulthood, senility and death). These early attachment styles are passed to future generations to "preserve and be preserved" in the human life continuum. Moreover, they could serve as a preventive factor and if formed incorrectly, also as important elements in the pathogenesis of mental disorders. These important factors of early life development should be taken into account for the global interpretation of human psychological functioning.

The attachment, its influence on neural regulations, behaviour, emotional experiences, stress copying strategies, cognitive development, social interactions, mental


Copyright © 2011 Activitas Nervosa Superior Rediviva ISSN 1337-933X (print), e-ISSN 1338-4015 (online) **www.rediviva.sav.sk/**

health and well-being could be considered as an interdisciplinary field of special importance. It is an area in which ontogenetic, psychological, neurobiological, social and other factors interact in the unique constellation of every individual. Moreover, it is an excellent model showing the advancement of complex studies and sharing knowledge and principles of various scientific disciplines as the interpretation of **modern integrated neuroscience.**

## REFERENCES


1 Agrawai HR, Gunderson J (2004) Attachment Studies with Borderline Patients. A review. Harv Rev Psychiatry. **12**: 94–104.
2 Allen JG, Fonagy P, Bateman AW, editors (2008) Neurobiology. In: Mentalizing in Clinical Practice. Washington, London: American Psychiatric Publishing, Inc. p. 113–146.
3 Arrindell WA, Sanavio E, Aguliar G, Sica C, Hatzichristou CH, Eisemann M, Recinos LA, Gaszner P, Peter M, Battagliese G, Kállai J, Van der Ende J (1999) The development of a short form of the EMBU: Its appraisal with students in Greece, Guatemala, Hungary and Italy. Pers Individ Dif. **27**(4): 613–628.
4 Bieščad M, Hašto J (2010) Diagnostikovanie typov vzťahovej väzby (attachment) v dospelosti s použitím nástrojov dostupných v našich podmienkach. [(Assessment of the Adult Attachment Using the Questionnaires Available within the Slovak and Czech Area.) (In Slovak with English abstract.)] Psychiatrie. **14**(2): 68–74.
5 Blakemore SJ (2010) The Developing Social Brain: Implications for Education. Neuron. **65**: 744–747.
6 Bosch OJ, Neumann ID (2008) Brain vasopressin is an important regulator of maternal behavior independent of dams' trait anxiety. Proc Natl Acad Sci U S A. **105**(44): 17139–44.
7 Brennan KA, Clark CL, Shaver PR (1998) Self-report measurement of adult attachment: An integrative overview. In: Simpson JA, Rholes WS, editors. Attachment theory and close relationships. New York: The Guilford Press. p. 46–76.
8 Bowlby J. (1983). Attachment and Loss (Vol. 1, 2nd ed.). New York: Basic Books.
9 Bowlby J. (1995a). Elternbindung und Persönlichkeitsentwicklung: Therapeutische Aspekte der Bindungstheorie. Heidelberg: Dexter.
10 Bowlby J. (1995b). Bíndung: Historische Wurzeln, theoretische Konzepte und klinische Relevanz [Attachment: Historical roots, theory and dinical relevance]. In: G. Spangler & F. Zimmermann (Eds.), Die Bindungstheorie. Grundlagen, Forschung und Anwendung [Attachment theory]. Stuttgart: Klett-Cotta.
11 Bridges RS, Numan M, Ronsheim PM, Mann PE, Lupini CE (1990) Central prolactin infusions stimulate maternal behavior in steroid-treated, nulliparous female rats. Proc Natl Acad Sci U S A. 87(20): 8003–8007.
12 Broad KD, Curley JP, Keverne EB (2006) Mother–infant bonding and the evolution of mammalian social relationships. Phil Trans R Soc B. **361**: 2199–2214.
13 Buijs RM, De Vries GJ, Van Leeuwen FW, Swaab DF (1983) Vasopressin and oxytocin: distribution and putative functions in the brain. Prog Brain Res. **60**:115–22.
14 Burnett S, Blakemore SJ (2009) Functional connectivity during a social emotion task in adolescents and in adults. Eur J Neurosci. **29**: 1294–1301.
15 Caldji Ch, Diorio J, Meaney MJ (2003) Variations in maternal care alter GABA (A) receptor subunit expression in brain regions associated with fear. Neuropsychopharmacology : official publication of the American College of Neuropsychopharmacology. **28**(11):1950–9.
16 Dumontheil I, Apperly IA, Blakemore SJ (2010) Online usage of theory of mind continues to develop in late adolescence. Dev Sci. **13**(2): 331–338.
17 Fedor-Freybergh PG (2008) Psychosomatické charakteristiky prenatálneho a perinatálneho obdobia ako prostredia dieťaťa. [(Psychosomatic Characteristics of Prenatal and Perinatal Period as the Environment of Infant.) (In Slovak.)] Bratislava: Vysoká škola zdravotníctva a sociálnej práce sv. Alžbety.
18 Feldman R, Weller A, Zagoory-Sharon O, Levine A (2007) Evidence for a neuroendocrinological foundation of human affiliation: plasma oxytocin levels across pregnancy and the postpartum period predict mother-infant bonding. Psychol Sci. **18**(11): 965–70.
19 Fleming AS, Corter C, Stallings J, Steiner M (2002) Testosterone and prolactin are associated with emotional responses to infant cries in new fathers. Horm Behav. 42 (4): 399–413.
20 Frith CD, Frith U (2005) Theory of mind. Curr Biol. **15**: R 644–R645.
21 Frith CD, Frith U (2006) The neural basis of mentalizing. Neuron. **50**: 531–534.
22 Gervai J, Novak A, Lakatos K, Toth I, Danis I, Ronai Z, Nemoda Z, Sasvari-Szekely M, Bureau JF, Bronfman E, Lyons-Ruth K (2007) Infant genotype may moderate sensitivity to maternal affective communications: attachment disorganization, quality of care, and the DRD4 polymorphism. Soc Neurosci. **2** (3–4): 307–19.
23 Gubernick DJ, Sengelaub DR, Kurz EM (1993) A neuroanatomical correlate of paternal and maternal behavior in the biparental California mouse (*Peromyscus californicus*). Behav Neurosci. **107**: 194–201.
24 Gunnar M (2005) Attachment and stress in early development. In: Carter CS, Ahnert L, Grossmann KE, Hrdy SB, Lamb ME, Porges SW, Sachser N, editors. Attachment and bonding: a new synthesis. Cambridge: The MIT Press. p. 245–255.
25 Hašto J (2006) Vzťahová väzba, pripútavacie správanie a psychiatria-psychoterapia. [(Attachment, Attachment Behaviour and Psychiatry-Psychotherapy.) (In Slovak with English abstract.)] Psychiatrie, **10**(1): 36–40.
26 Hašto J (2004) Vzťahová väzba. Ku koreňom lásky a úzkosti. [(Attachment. To the Roots of Love and Anxiety.) (In Slovak.)] Trenčín: Vydavateľstvo F.
27 Höschl C (2004) Poruchy nálady. [(Mood Disorders.) (In Czech.)] In: Höschl C, Libiger J, Švestka J, editors. Psychiatrie, druhé, doplněné a opravené vydání. Praha: Tigis, spol. s r. o. p. 420–465.
28 Höschl C (2004) Etologie a psychiatrie. [(Ethology and psychiatry.) (In Czech.)] In: Höschl C, Libiger J, Švestka J, editors. Psychiatrie, druhé, doplněné a opravené vydání. Praha: Tigis, spol. s r. o. p. 139–148.
29 Hsu FC, Zhang GJ, Raol YS, Valentino RJ, Coulter DA, Brooks-Kayal AR (2003) Repeated neonatal handling with maternal separation permanently alters hippocampal GABA A receptors and behavioral stress responses. Proc Natl Acad Sci U S A. **100**(21): 12213–8.
30 Champagne FA, Chretien P, Stevenson CW, Zhang TY, Gratton A, Meaney MJ (2004) Variations in Nucleus Accumbens Dopamine Associated with Individual Differences in Maternal Behavior in the Rat. J Neurosci. **24**(17): 4113–4123.
31 Jankowiak-Siuda K, Rymarczyk K, Grabowska A (2011) How we empathize with others: A neurobiological perspective. Med Sci Monit. **17**(1): RA18–24.
32 Johnson MH (2011) Interactive Specialization: A domain-general framework for human functional brain development? Dev Cogn Neurosci. **1**: 7–21.
33 Klaus M (1998) Research Perspectives: Mother and Infant: Early Emotional Ties. Pediatrics, Suppl. **102**(5): 1244–1246.
34 Krajčovičová L, Mikl M, Mareček R, Rektorová I (2010) Analýza "default mode" sítě u zdravých dobrovolníků. [("Default Mode" Network Analysis in Healthy Volunteers.) (In Czech with English abstract.)] Cesk Slov Neurol N. **73/106**(5): 517–522.
35 Leibenluft E, Gobbini MI, Harrison T, Haxby JV (2004) Mothers' Neural Activation in Response to Pictures of Their Children and Other Children. Biol Psychiatry. **56:** 225–232.
36 Lerch-Haner JK, Frierson D, Crawford LK, Beck SG, Deneris ES (2008) Serotonergic transcriptional programming determines maternal behavior and offspring survival. Nat Neurosci. **11**(9): 1001–3.

37 Levine S, Huchton DM, Wiener SG, Rosenfeld P (1991) Time course of the effect of maternal deprivation on the hypothalamic-pituitary-adrenal axis in the infant rat. Dev Psychobiol. **24**: 547–558.
38 Madlafousek J (2004) Motivace. [(Motivation.) (In Czech.)] In: Höschl C, Libiger J, Švestka J, editors. Psychiatrie, druhé, doplněné a opravené vydání. Praha: Tigis, spol. s r. o. p. 172–176.
39 Marshall PJ, Meltzoff AN (2010) Neural mirroring systems: Exploring the EEG mu rhythm in human infancy. Dev Cogn Neurosci. doi:10.1016/j.dcn.2010.09.001
40 Meltzoff AN, Kuhl PK, Movellan J, Sejnowski TJ (2009) Foundations for a new science of learning. Science. **325**: 284–288.
41 Olazabal DE, Young LJ (2006) Oxytocin receptors in the nucleus accumbens facilitate 'spontaneous' maternal behavior in adult female prairie voles. Neuroscience. **141**: 559–568.
42 Rizzolatti G, Destro-Fabri M, Cattaneo L (2009) Mirror neurons and their clinical relevance. Nat Clin Pract Neurol. **5**(1): 24–34.
43 Rosenblum LA, Andrews MW (1994): Influences of environmental demand on maternal behavior and infant development. Acta Paediatr. Suppl **397**: 57–63.
44 Salomon R, Malach R, Lamy D (2009) Involvement of the Intrinsic/Default System in Movement-Related Self Recognition. PLoS ONE. **4**(10): e7527.
45 Shaver PhR, Mikulincer M (2009) An Overview of Adult Attachment Theory. In: Obegi JH, Berant E, editors. Attachment Theory and Research in Clinical Work with Adults. New York, London: The Guilford Press. p. 17–45.
46 Strathearn L, Fonagy P, Amico J, Montague PR (2009) Adult Attachment Predicts Maternal Brain and Oxytocin Response to Infant Cues. Neuropsychopharmacology. **34:** 2655–2666.
47 Schore AN (2000) Attachment and the regulation of the right brain. Attach Hum Dev. **2**(1): 23–47.
48 Schore AN (2001) Effects of a secure attachment relationship on right brain development, affect regulation, and infant mental health. Infant Ment Health J. **22**(1–2): 7–66.
49 Suomi SJ (1999) Attachment in Rhesus Monkeys. In: Cassidy J, Shaver PR, editors. Handbook of Attachment. Theory, Research, and Clinical Applications. New York: The Guilford Press. p. 181–197.
50 Thomas SA, Palmiter RD (1997) Impaired maternal behavior in mice lacking norepinephrine and epinephrine. Cell. **91**(5): 583–92.
51 Tully K, Bolshakov VY (2010) Emotional enhancement of memory: how norepinephrine enables synaptic plasticity. Mol Brain. **3**: 15.
52 Van Leengoed E, Kerker E, Swanson HH (1987) Inhibition of post-partum maternal behaviour in the rat by injecting an oxytocin antagonist into the cerebral ventricles. J Endocrinol. **112**(2): 275–282.
53 Wang Z, Ferris CF, De Vries GJ (1994) Role of septal vasopressin innervation in paternal behavior in prairie voles (Microtus ochrogaster). Proc Natl Acad Sci U S A. **91**(1): 400–4.
54 Zhang TY, Hellstrom IC, Bagot RC, Wen X, Diorio J, Meaney (2010) Maternal Care and DNA Methylation of a Glutamic Acid Decarboxylase 1 Promoter in Rat Hippocampus**.** J Neurosci. **24**(17): 4113–4123.
55 Ziabreva I, Schnabel R, Braun K (2000) Parental deprivation induces N-methyl-D-aspartate-receptor upregulation in limbic brain areas of Octodon degus: protective role of the maternal call. Neural Plast. **7**(4): 233–44.
56 Ziegler TE, Wegner FH, Snowdon CT (1996) Hormonal responses to parental and nonparental conditions in male cotton-top tamarins, *Saguinus oedipus*, a New World monkey. Horm Behav. **30**: 287–297.

 *Copyright © 2011 Activitas Nervosa Superior Rediviva ISSN 1337-933X (print), e-ISSN 1338-4015 (online)* ***www.rediviva.sav.sk/***