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AUTHOR	Schore, Allan N.
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ABSTRACT

The interactive creation of an attachment bond of affective communication between the psychobiologically attuned primary caregiver and the infant is central to human emotional development. These emotional transactions directly influence the experience-dependent maturation of the infant's early developing right hemisphere, which is in a growth spurt in the first year-and-a-half of life and is dominant for the first 3 years of life. This paper examines attachment processes and emotional communications, the neurobiology and psychobiology of attachment, and the organization of an attachment regulatory system in the right brain. The paper notes that, as opposed to a secure attachment, early misattuned interactional environments generate an insecure attachment and a right brain regulatory system that is limited in its capacity to cope with stress. This neurodevelopment outcome represents a high risk for later-forming emotional disorders. It is suggested that Early Head Start interventions that focus on social-emotional development would thus have enduring effects on the adaptive coping capacities of the individual throughout the lifespan. (Contains 96 references.) (Author/KB)

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PLENARY ADDRESS: PARENT-INFANT COMMUNICATION AND THE NERUOBIOLOGY OF EMOTIONAL DEVELOPMENT

ALLAN N. SCHORE

DEPARTMENT OF PSYCHIATRY AND BIOBEHAVIORAL SCIENCES UNIVERSITY OF CALIFORNIA AT LOS ANGELES SCHOOL

Parent-infant communications and the neurobiology of emotional development

Allan N. Schore

University of California at Los Angeles School of Medicine

Abstract

The interactive creation of an attachment bond of affective communication between the psychobiologically attuned primary caregiver and the infant is central to human emotional development. These emotional transactions directly influence the experience-dependent maturation of the infant's early developing right hemisphere, which is in a growth spurt in the first year-and-a-half of life and is dominant for the first 3 years of life. In the following I discuss attachment processes and emotional communications, the neurobiology and psychobiology of attachment, and the organization of an attachment regulatory system in the right brain. As opposed to a secure attachment, early misattuned interactional environments generate an insecure attachment and a right brain regulatory system that is limited in its capacity to cope with stress. This neurodevelopment outcome represents a high risk for later forming emotional disorders. Early Head Start interventions that focus on social-emotional development would thus have enduring effects on the adaptive coping capacities of the individual throughout the lifespan.

At this point in time, although "the decade of the brain" has ended, it is clear that we are in the midst of a remarkable period in which dramatic new brain technologies continue to concentrate their focus upon certain basic problems of human psychology. And so, current brain imaging studies are giving us a more comprehensive picture of how the mature brain performs it essential function - detecting changes in both the environment and in the body, so that internal alterations can be made in order to adapt to different contexts. This research can do more than just detail the physical structure of the brain, it can delve directly into how changes in brain structural organization are associated with various normal and abnormal functional states, thereby linking biological and psychological models of the brain/mind/body.

It is undoubtedly true that by far the greatest amount of current research is on the adult rather then the developing brain, and most of it is not on normal but abnormal brain function. Even so, neuroscience is now becoming very interested in the early development of the brain. And so neurobiology is currently exploring "early beginnings for adult brain pathology" (Altman, 1997) and describing "alteration[s] in the functional organization of the human brain which can be correlated with the absence of early learning experiences" (Castro-Caldas et al., 1998). But this same time period of expansion of developmental neuroscience has also seen an explosion of interdisciplinary infant research, as developmental studies are now actively exploring not just the origins of cognitive, language, and sensory motor functions, but also the early development of social and emotional processes.

The question of why the early events of life have such an inordinate influence on literally everything that follows is one of the fundamental problems of science. How do early experiences, especially emotionally charged attachment experiences with other humans, induce and organize the patterns of structural growth that result in the expanding functional capacities of a developing individual? Using an arsenal of different methodologies and studying different levels of analysis, investigators are now inquiring into the fundamental mechanisms that underlie developmental processes. We now know that the concept of "early experiences" connotes much more than an immature individual being a passive recipient of environmental stimulation. Rather, these events represent active transactions between the infant and the early environment. The most important aspect of the environment is the social environment, the relationship the infant has with its caregivers.

In current thinking development is "transactional", and is represented as a continuing dialectic between the maturing organism and the changing environment. This dialectic is embedded in the infant-maternal relationship, and emotion (affect) is what is transacted in these interactions. This very efficient system of emotional exchanges is entirely nonverbal, and it continues throughout life as the intuitively felt affective communications that occur within intimate relationships. Human development cannot be understood apart from this affect-transacting relationship. Indeed, it now appears that the development of the capacity to experience, communicate, and regulate emotions may be the key event of human infancy.

Neuroscientists and developmental psychologists are now converging on the common principle that "the best description of development may come from a careful appreciation of the brain's own self-organizing operations" (Cicchetti & Tucker, 1994, p. 544). There is widespread agreement that the brain is a self-organizing system, but there is perhaps less of an appreciation of the fact that "the self-organization of the developing brain occurs in the context of a relationship with another self, another brain" (Schore, 1996, p. 60). This relationship is between the developing infant and the social environment, and is mediated by affective communications and psychobiological transactions.

Furthermore, these early socioemotional events are imprinted into the biological structures that are maturing during the brain growth spurt that occurs in the first two years of human life, and therefore have far-reaching and long enduring effects. The stupendous growth rate of brain structure in the first year of life is reflected in the increase of weight from 400g at birth to over 1000g at 12 months. The human brain growth spurt, which begins in the last trimester and is at least 5/6 postnatal, continues to about 18 to 24 months of age (Dobbing & Sands, 1973). Furthermore, interactive experiences directly impact genetic systems that program brain growth. DNA production in the cortex increases dramatically over the course of the first year (see Schore, 1994). We now know that the genetic specification of neuronal structure is not sufficient for an optimally functional nervous system - the environment also powerfully affects the structure of the brain.

Thus, very current models hold that development represents an experiential shaping of genetic potential, and that genetically programmed "innate" stuctural systems require particular forms of environmental input.

> The traditional assumption was that the environment determines only the psychological residuals of development, such as memories and habits, while brain anatomy matures on its fixed ontogenetic calendar. Environmental experience is now recognized to be critical to the differentiation of brain tissue itself. Nature's potential can be realized only as it is enabled by nurture." (Cicchetti & Tucker, 1994, p. 538).

Neurobiology has now established that the infant brain "is designed to be molded by the environment it encounters" (Thomas et al., 1997, p. 209). The brain is currently thought of as a "bioenvironmental" or "biosocial" organ (Gibson, 1996), and investigators are exploring the unique domains of the "social brain" (Brothers, 1990) and are speaking of "the social construction of the human brain" (Eisenberg, 1995) It is known that the accelerated growth of brain structure occurs during "critical periods" of infancy, is "experience-dependent," and is influenced by "social forces." Neuroscience is, however, unclear as to the nature of these "social forces." In fact, developmental psychology has much to say about the "social forces" that influence the organization of the baby's brain. The brain growth spurt exactly overlaps the period of attachment so intensely studied by contemporary researchers (Schore, 1998c, d, e; 1999d). And so it is now thought that

> ...within limits, during normal development a biologically different brain may be formed given the mutual influence of maturation of the infant's nervous system and the mothering repertory of the caregiver (Connelly & Prechtl, 1981, p. 212).

My work integrates developmental psychology and infant psychiatry with neuroscience in order to formulate models of normal and abnormal emotional development. I have written, "The beginnings of living systems set the stage for every aspect of an organism's internal and external functioning throughout the lifespan" (Schore, 1994, p. 3). The central thesis of my ongoing work is that the early social environment, mediated by the primary caregiver, directly influences the final wiring of the circuits in the infant's brain that are responsible for the future socioemotional development of the individual. The "experience" that is required for the "experience-dependent" growth of the brain in the first two years of human life is specifically the social-emotional experiences embedded in the attachment relationship between the infant and the mother. Attachment is thus the outcome of the child's genetically encoded biological (temperamental) predisposition *and* the particular caregiver environment.

Since the book I have expanded this psychoneurobiological model and continue to cite a growing body of interdisciplinary studies which suggests that these interpersonal affective experiences have a critical effect on, specifically, the early organization of the limbic system (Schore, 1994, 1996, 1997a, 1998a, 1999a, in press d, e), the brain areas specialized for not only the processing of emotion but for the organization of new learning and the capacity to adapt to a rapidly changing environment (Mesulam, 1998). The emotion processing limbic system is expanded in the right brain (Tucker, 1992; Joseph, 1996), or what the neuroscientist Ornstein (1997) calls "the right mind." Most importantly, this right hemisphere, the neurobiological substrate of the emotional brain, is in a growth spurt in the first year and a half (see Figure 1).

About here insert Figure 1. Hemispheric brain growth cycles continue asymmetrically throughout childhood, showing early growth spurt of the right hemisphere. Adapted from Thatcher, 1994.

According to attachment theory, the dominant theory of emotional development in international developmental psychology, the limbic system is the site of developmental changes associated with the rise of attachment behaviors (Schore, 2000). But this theory also proposes that the mother directly influences the maturation of the infant's emerging coping capacities. In a number of writngs I offer evidence that attachment experiences specifically influence the experience-dependent maturation of the infant's right hemisphere (Schore, 1994, 1997a, in press a, b, c, d, e). The right brain acts "a unique response system preparing the organism to deal efficiently with external challenges," and so its adaptive functions mediate the stress coping mechanisms (Wittling, 1997, p. 55). This psychoneurobiological conception thus highlights the critical role of attachment experiences in the development of life-long coping capacities. The finding that the right hemisphere is dominant in human infants, and indeed, for the first 3 years of life, thus has significant implications for Head Start, and particularly Early Head Start.

In this talk, I will present an overview of recent psychological studies of the social-emotional development of infants and neurobiological research on the maturation of the early developing right brain. I want to focus on the structure-function relationships of an event in early infancy that is central to human emotional development - the organization, in the first year, of an attachment bond of interactively regulated affective communication between the primary caregiver and the infant. These experiences culminate, at the end of the second year, in the maturation of a regulatory system in the right hemisphere. The failure of the dyad to create this system in the first two years is a developmental risk factor. These models are offered as heuristic proposals that can be evaluated by experimental and clinical research.

ATTACHMENT PROCESSES AND EMOTIONAL COMMUNICATIONS

As soon as the child is born it uses its maturing sensory capacities, especially smell, taste, and touch, to interact with the social environment. But by the end of the second month, with the myelination of occipital areas involved in the visual perception of a human face, there is a dramatic progression of its social and emotional capacities. In particular, the mother's emotionally expressive face is, by far, the most potent visual stimulus in the infant's environment, and the child's intense interest in her face, especially in her eyes, leads him to track it in space, and to engage in periods of intense mutual gaze. The infant's gaze, in turn, evokes the mother's gaze, thereby acting as a potent interpersonal channel for the transmission of "reciprocal mutual influences". It has been observed that the pupil of the eye acts as a nonverbal communication device and that large pupils in the infant release caregiver behavior (Hess, 1975).

Face-to-face interactions begin at about 2 months, in the first context of social play, and they are patterned by an infant-leads-mother-follows sequence. These are "highly arousing, affect-laden, short interpersonal events that expose infants to high levels of cognitive and social information. To regulate the high positive arousal, mothers and infants...synchronize the intensity of their affective behavior within lags of split seconds" (Feldman, Greenbaum, & Yirmiya (1999, p. 223). These authors observe that such experiences afford infants "their first opportunity to practice interpersonal coordination of biological rhythms, to experience the mutual regulation of positive arousal, and to build the lead-lag structure of adult communication" (p. 223).

A frame-by-frame analysis shows that this moment-to-moment state sharing represents an organized dialog occurring within milliseconds (see Figure 2). In contexts of "mutually attuned selective cueing", the infant learns to send specific social cues to which the mother has responded, thereby reflecting "an anticipatory sense of response of the other to the self, concomitant with an accommodation of the self to the other" (Bergman, 1999, p. 96). Thus the best description of this exchange is “affect synchrony.” According to Lester, Hoffman, and Brazelton, “synchrony develops as a consequence of each partner's learning the rhythmic structure of the other and modifying his or her behavior to fit that structure” (1985, p. 24).

About here insert Figure 2. Photographs of a "mirroring" sequence. Mother and infant are seated face to face, looking at each other. At point A, mother shows a "kiss-face," and infant's lips are partially drawn in, resulting in a tight, sober-faced expression. At point B, mother's mouth has widened into a slightly positive expression, and infant's face has relaxed with a hint of widening in the mouth, also a slighly positive expression. At point C, both mother and infant show a slight smile, further widened at point D. At point E, the infant breaks into a "full gape smile." At point F, the infant has shifted the orientation of his head further to his left, and upward, which heightens the evocativeness of the gape-smile. Total time under three seconds. (From Beebe & Lachmann, 1988).

This microregulation continues, as soon after the "heightened affective moment" of an intensely joyful full gape smile the baby will gaze avert in order to regulate the potentially disorganizing effect of this intensifying emotion (see Figure 3). In order to maintain the positive emotion the attuned mother takes her cue and backs off to reduce her stimulation. She then waits for the baby's signals for reengagement. In this way, not only the tempo of their engagement but also their disengagement and reengagement is coordinated. In this process of "contingent responsivity" the more the mother tunes her activity level to the infant during periods of social engagement, the more she allows him to recover quietly in periods of disengagement, and the more she attends to the child's reinitiating cues for reengagement, the more synchronized their interaction. The psychobiologically attuned caregiver thus facilitates the infant's information processing by adjusting the mode, amount, variability, and timing of the onset and offset of stimulation to the infant's actual integrative capacities. These mutually attuned synchronized interactions are fundamental to the healthy affective development of the infant.

About here insert Figure 3. Sequence of an attuned interaction : (A) the infant looks at the mother and the mother shows an exaggerated facial expression; (B) the infant and the mother smile; (C) the infant laughs, the mother relaxes her smile; and (D) the infant looks away, the mother ceases her smile and watches her infant. From Field and Fogel (1982).

Furthermore, in the visual and auditory emotional communications embedded within synchronized face-to-face transactions both members of the dyad experience a state transition as they move together from low arousal to a heightened energetic state of high arousal, a shift from quiet alertness into an intensely positive affective state. In physics, a property of resonance is sympathetic vibration, which is the tendency of one resonance system to enlarge and augment through matching the resonance frequency pattern of another resonance system. It is well established that the transfer of emotional information is intensified in resonant contexts, and that at the moment when a system is tuned at the "resonant" frequency it becomes synchronized. Such energy-infused moments allow for a sense of vitalization, and thereby increased complexity and coherence of organization within the infant (Schore, 1997a, in press a).

Resonances often have chaos associated with them, and thus they are characterized by non-linear dynamic factors - relatively small input amplitudes engender a response with a surprisingly large output amplitude. This amplification especially occurs when external sensory stimulation frequency coincides with the organism's own endogenous rhythms. The British pediatrician-psychoanalyst Winnicott (1971) describes the infant's expression of a "spontaneous gesture," a somato-psychic expression of the burgeoning "true self," and the attuned mother's "giving back to the baby the baby's own self."

In other words, when a psychobiologically attuned dyad co-creates a resonant context within an attachment transaction, the behavioral manifestation of each partner's internal state is monitored by the other, and this results in the coupling between the output of one partner's loop and the input of the other's to form a larger feedback configuration and an amplification of the positive state in both. Infant researchers refer to the delight the infant displays in reaction to the augmenting effects of his mother's playful, empathically attuned behavior, her mulitmodal sensory amplification and resonance with the child's feelings. Stern

(1985) describes a particular maternal social behavior which can "blast the infant into the next orbit of positive excitation," and generate "vitality affects." In these transactions the dyad is co-creating "mutual regulatory systems of arousal".

In this system of nonverbal emotional communcation the infant and mother co-create a context which allows for the outward expression of internal affective states in infants. In order to enter into this communication, the mother must be psychobiologically attuned not so much to the child's overt behavior as to the dynamic crescendos and decescendos of his internal states of arousal. She also must monitor her own internal signals and differentiate her own affective state, as well as modulating nonoptimal high levels of stimulation which would induce supra-heightened levels of arousal in the infant. The burgeoning capacity of the infant to experience increasing levels of accelerating, rewarding affects is thus at this stage amplified and externally regulated by the psychobiologically attuned mother, and depends upon her capacity to engage in an interactive emotion communicating mechanism that generates these in herself and her child.

But the primary caregiver is not always attuned - developmental research shows frequent moments of misattunement in the dyad, ruptures of the attachment bond. Although short term dysregulations are not problematic, prolonged negative states are toxic for infants, and although they possess some capacity to modulate low intensity negative affect states, these states continue to escalate in intensity, frequency, and duration. In early development an adult provides much of the necessary modulation of infant states, especially after a state disruption and across a transition between states, and this allows for the development of self regulation.

Studies of interactive attunement following dyadic misattunement, of "interactive repair", support a conception of the mother's "holding" or "containing" function as the capacity to "stay with" the child through its emotional / impulsive expressions, "to hold the situation in time". In this pattern of "disruption and repair" (Beebe & Lachmann, 1994), the "good enough" caregiver who induces a stress response in her infant through a misattunement, reinvokes in a timely fashion a reattunment, a regulation of the infant's negative state. If attachment is interactive synchrony, stress is defined as an *asynchrony* in an interactional sequence, and, following this, a period of re-established *synchrony* allows for stress recovery. The mother and infant thus dyadically negotiate a stressful state transition. Infant resilience emerges from the child and parent transitioning from positive to negative and back to positive affect. Again, the key is the caregiver's capacity to monitor and regulate her own arousal levels.

These arousal-regulating transactions, which continue throughout the first year, underlie the formation of an attachment bond between the infant and primary caregiver. An essential attachment function is "to promote the synchrony or regulation of biological and behavioral systems on an organismic level" (Reite & Capitanio, 1985, p. 235). Indeed, psychobiological attunement, interactive resonance, and the mutual synchronization and entrainment of physiological rhythms are fundamental processes that mediates attachment bond formation, and attachment can be defined as the interactive regulation of biological synchronicity between organisms. (Schore, 1994, 2000a, b, in press c, d)

To put this another way, in forming an attachment bond of somatically expressed emotional communications, the mother is synchronizing and resonating with the rhythms of the infant's dynamic internal states and then regulating the arousal level of these negative and positive states. Attachment is thus the dyadic (interactive) regulation of emotion (Sroufe, 1996). The baby becomes attached to the psychobiologically attuned regulating primary caregiver who not only minimizes negative affect but also maximizes opportunties for positive affect.

These data underscore an essential principle overlooked by many emotion theorists - affect regulation is not just the reduction of affective intensity, the dampening of negative emotion. It also involves an amplification, an intensification of positive emotion, a condition necessary for more complex self-organization. Attachment is not just the restablishment of security after a dysregulating experience and a stressful negative state, it is also the interactive amplification of positive affects, as in play states. Regulated affective interactions with a familiar, predictable primary caregiver create not only a sense of safety, but also a positively charged curiosity that fuels the burgeoning self's exploration of novel socioemotional and physical environments.

THE NEUROBIOLOGY AND PSYCHOBIOLOGY OF ATTACHMENT

According to Ainsworth attachment is more than overt behavior, it is "built into the nervous system, in the course and as a result of the infant's experience of his transactions with the mother" (1967, p. 429). This brings us to another level of analysis - the neurobiological level. In this "transfer of affect between mother and infant" how are developing brain systems influenced by these interactions with the social environment?

Trevarthen's work on maternal-infant protoconversations bears directly on this problem. Coordinated with eye-to-eye messages are auditory vocalizations (tone of voice, Motherese) as a channel of communication, and tactile and body gestures. A traffic of visual and prosodic auditory signals induce instant emotional effects, namely the positive affects of excitement and pleasure build within the dyad. But Trevarthen also focuses on internal structure-function events (see Figure 4), stating that "the intrinsic regulators of human brain growth in a child are specifically adapted to be coupled, by emotional communication, to the regulators of adult brains" (Trevarthen, 1990, p. 357).

About here insert **Figure 4**. Channels of face-to-face communication in protoconversation. Protoconversation is mediated by eye-to-eye orientations, vocalizations, hand gestures, and movements of the arms and head, all acting in coordination to express interpersonal awareness and emotions. Adapted from Trevarthen (1993).

According to Trevarthen (1993) the resonance of the dyad ultimately permits the intercoordination of positive affective brain states. His work underscores the fundamental principle that the baby's brain is not only affected by these transactions, it's growth literally requires brain-brain interaction and occurs in the context of an intimate positive affective relationship between mother and infant. This interactive mechanism requires older brains to engage with mental states of awareness, emotion, and interest in younger brains, and involves a coordination between the motivations of the infant and the subjective feelings of adults. These findings support Emde's idea that "It is the emotional availability of the caregiver in intimacy which seems to be the most central growth-promoting feature of the early rearing experience" (1988, p. 32).

There is a consensus that interactions with the environment during critical periods are necessary for the brain as a whole to mature. But we know that different regions of the brain mature at different times. Can we tell what specific parts of the growing brain are affected by these emotion transacting events? It is now thought that "The emotional experience of the infant develops through the sounds, images, and pictures that constitute much of an infant's early learning experience, and are disproportionately stored or processed in the right hemisphere during the formative stages of brain ontogeny" (Semrud-Clikeman & Hynd, 1990, p. 198). With regard to the unique nature of this memory store, it has been pointed out that "the infant relies primarily on its procedural memory systems" during "the first 2-3 years of life" (Kandel, 1999, p. 513). Recall the right hemsphere is dominant for the first 3 years.

These emotionally charged, psychobiologically attuned face-to-face interactions occur in the context of mother-infant play, and they increase over the second and third quarters of the first year. The learning mechanism of attachment, imprinting, is defined as *synchrony* between sequential infant maternal stimuli and behavior (Petrovich & Gewirtz, 1985). I suggest that in these interactive regulatory transactions the infant's right hemisphere, which is dominant for the infant's recognition of the maternal face, and for the perception of arousal-inducing maternal facial affective expressions, visual emotional information, and the prosody of the mother's voice, is synchronizing with and thereby regulated by the output of the mother's right hemisphere, which is dominant for nonverbal communication, the processing of emotional information, the expression of spontaneous gestures, and the maternal capacity to comfort the infant.

In these transactions the attuned caregiver is "downloading programs" into the infant's brain by an optimal "chunking" of bits of sociaffective stimulation that the child's developing right hemispheric socioaffective information processing system can efficiently process and store in memory. In particular, as a result of attachment experiences the infant develops a representation of the mother, especially her face. We now know that the infant's memory representation includes not only details of the learning cues of events in the external environment (especially those that from a face), but also of reactions in his internal arousal state to changes in the external environment. These attachment experiences are imprinted into the early imagistic, visceral, and nonverbal implicit-procedural memory system of the right brain (Henry, 1993; Schore, 1994, 2000b; Siegel, 1999).

Furthermore, Tronick and his colleagues (1998) are now describing how microregulatory social-emotional processes of communication generate expanded intersubjective states of consciousness in the infant-mother dyad. In such there is "a mutual mapping of (some of) the elements of each interactant's state of consciousness into each of their brains" (Tronick & Weinberg, 1997, p. 75). He argues that the infant's self-organizing system, when coupled with the mother's, allows for a brain organiztion which can be expanded into more coherent and complex states of consciousness. I suggest that Tronick is describing an expansion of what the neuroscientist Edelman (1989) calls primary consciousness, which relates visceral and emotional information pertaining to the biological self, to stored information processing pertaining to outside reality. Edelman lateralizes primary consciousness to the right brain.

In light of research showing the involvement of the right hemisphere in attentional processes (e.g., Sturm et al., 1999), interactive experiences of "joint attention" may act as a growth-facilitating environment for the experience-dependent maturation of right hemispheric attentional capacities (Schore, 2000a, in press d, e). Notice that during the heightened affective moment the child's attention is riveted on the mother's face. But this hemisphere is also concerned with the analysis of direct information received from the body. Thus, in attachment transactions the child is using the output of the mother's right cortex as a template for the imprinting, the hard wiring of circuits in his own right cortex that will come to mediate his expanding cognitive-affective capacities to adaptively attend to, appraise, and regulate variations in both external and internal information. In support of this, Ryan and his colleagues (1997, p. 719), using EEG and neuroimaging data, now report that "The positive emotional exchange resulting from autonomy-supportive parenting involves participation of right hemispheric cortical and subcortical systems that participate in global, tonic emotional modulation".

It is important to note that these dyadically synchronized affectively charged transactions elicit high levels of metabolic energy for the tuning of developing right brain circuits involved in processing socioemotional information. A recent article in *Science* suggests "mothers invest extra energy in their young to promote larger brains" (Gibbons, 1998, p. 1346). In terms of self-organization theory, the mutual entrainment of their right brains during moments of affect synchrony triggers an amplified energy flow which allows for a coherence of organization that sustains more complex states within both the infant's and the mother's right brains. In fact evidence now indicates that the organization of the mother's brain is also being influenced by these relational transactions. A study of early mammalian mother-infant interactions (Kinsley et al., 1999), published in *Nature*, entitled "Motherhood improves learning and memory," reports increased dendritic growth in the mother's brain.

Interactive transactions, in addition to producing neurobiological consequences, are also generating important events in the infant's bodily state, that is, at the psychobiological level. Winnicott (1986, p. 258) proposed that

"The main thing is a communication between the baby and mother in terms of the anatomy and physiology of live bodies." Developmental psychobiological research is revealing that when the dyad is in the mutually regulating "symbiotic" state, the adult's and infant's individual homeostatic systems are linked together in a superordinate organization which allows for mutual regulation of vital endocrine, autonomic, and central nervous systems of both mother and infant by elements of their interaction with each other. Psychobiologists are emphasizing the importance of "hidden" regulatory processes by which the caregiver's more mature and differentiated nervous system regulates the infant's "open," immature, internal homeostatic systems (Hofer, 1990).

These body-to-body communications also involve right brain to right brain interactions. Indeed, as you see here most human females cradle their infants on the left side of the body (controlled by the right hemisphere). This tendency is well developed in women but not in men, is independent of handedness, and is widespread in all cultures (Manning et al., 1997). It has been suggested that this left-cradling tendency "facilitates the flow of affective information from the infant via the left ear and eye to the center for emotional decoding, that is, the right hemisphere of the mother" (p. 327). As the neurologist Damasio (1994) indicates, this hemisphere contains the most comprehensive and integrated map of the body state available to the brain. Lieberman (1996) has written that current models of development are almost exclusively focusing on cognition. In an article in the *Infant Mental Health*

Journal she states, "The baby's body, with its pleasures and struggles, has been largely missing from this picture" (p. 289).

Even more specifically, psychobiological studies of attachment, the interactive regulation of biological synchronicity between organisms, indicate that the intimate contact between the mother and her infant is regulated by the reciprocal activation of their opiate systems - elevated levels of opiates (beta endorphins) increase pleasure in both (Kalin, Shelton, & Lynn, 1995). In these mutual gaze transactions, the mother's face is also inducing the production of not only endogenous opiates but also regulated levels of dopamine in the infant's brain, which generates high levels of arousal and elation. The expanding attachment mechanism thus sustains increased regulated synchronized positive arousal in play episodes, and in them, the mother, in a state of excitement, is also stimulating regulated levels of corticotropin releasing factor in the infant brain, which in turn increases ACTH and noradrenaline and adrenaline activity in the child's sympathetic nervous system (Schore, 1994, 1996, in press d).

And in her soothing and calming functions, the mother's also regulating the child's oxytocin levels. It has been suggested that oxytocin, a vagally-controlled hormone with antistress effects, is released by "sensory stimuli such as tone of voice and facial expression conveying warmth and familiarity" (Uvnas-Molberg, 1997, p. 42). In regulating the infant's vagal tone and cortisol level, activities regulated by the right brain, she's also influencing the ongoing development of the infant's postnatally maturing parasympathetic nervous system. The sympathetic and parasympathetic components of the ANS, important elements of the affect transacting attachment mechanism, are centrally involved in the child's developing coping capacities.

ORGANIZATION OF A REGULATORY SYSTEM IN THE RIGHT BRAIN

Attachment is "the apex of dyadic emotional regulation, a culmination of all development in the first year and a harbinger of the self-regulation that is to come" (Sroufe, 1996, p. 172). A psychoneurobiological perspective suggests that the infant's emerging social, psychological, and biological capacities can not be understood apart from its relationship with the mother. This is due to the fact that the maturation of the infant's right brain is experience-dependent, and that this experience is embedded in the affect regulating transactions between the mother's right brain and the infant's right brain. This hemisphere contains the major regulatory systems of the brain (Schore, 1994, 1997a, 2000b, in press d).

What are the unique functional capacities of this "nondominant" nonverbal right hemisphere? Right cortical areas contain a "nonverbal affect lexicon," a vocabulary for nonverbal affective signals such as facial expressions, prosody (the emotional tone of the voice), and gestures (Bowers et al., 1993). Very recent neuroimaging studies show that the right hemisphere is faster than the left in performing valence-dependent, automatic, pre-attentive appraisals of emotional facial expressions (Pizzagalli, Regard, & Lehmann, 1999). But in addition, the representation of visceral and somatic states and body sense is under primary control of the "non-dominant" hemisphere (Schore, 1998a).

Indeed, the right cortical hemisphere (see Figure 5), more so than the left, contains extensive reciprocal connections with limbic and subcortical regions, and so it is dominant for the processing and expression of emotional information (Schore, 1994). Authors are now referring to a "rostral limbic system," a hierarchical sequence of interconnected limbic areas in orbitofrontal, insular cortex, anterior cingulate, and amygdala (Devinsky, Morrell, & Vogt, 1995), and an "anterior limbic prefrontal network" interconnecting the orbital and medial prefrontal cortex with the temporal pole, cingulate, and amygdala (Carmichael & Price, 1995). These right limbic circuits allow for cortically processed information concerning the external environment (such as visual and auditory stimuli emanating from the emotional face of an attachment object) to be integrated with subcortically processed information regarding the internal visceral environment (such as concurrent changes in the bodily self state). This relaying of sensory information into the limbic system allows incoming social information to be associated with motivational and emotional states.

About here insert Figure 5. Relationships of brain stem structures to the orbital surface of the right hemisphere (from Smith, 1981).

A growing body of work now reveals that the right hemisphere is also more deeply connected into the ANS and that "right hemisphere control exists over both parasympathetic and sympathetic responses," the somatic components of all emotional states (Spence et al., 1996). There is data to show that the hypothalamus, the head ganglion of the ANS, is right-lateralized (Kalogeras et al., 1996). The hypothalamic nuclei are considerably larger on the right side of the human brain (Sowell & Jernigan, 1998), and the right hemisphere is dominant for the production of corticotropin releasing factor, and for cortisol (Wittling & Pfluger, 1990), the neurohormones that that mediate coping responses. For the rest of the lifespan the right brain plays a superior role in the regulation of physiological and endocrinological functions whose primary control centers are located in subcortical regions of the brain. The connections between the higher centers of this hemisphere and the hypothalamus are forged in infancy.

Since the hypothalamo-pituitary-adrenocortical axis and the sympathetic-adrenomedullary axis that mediate the brain's coping mechanisms are both under the control of the right cerebral cortex, the adaptive functions of this hemisphere mediate the human stress response (Wittling, 1997). It therefore is centrally involved in the vital functions that support survival and enable the organism to cope actively and passively with stress (Wittling & Schweiger, 1993). The attachment relationship thus directly shapes the maturation of the infant's right brain stress-coping systems that act at levels beneath awareness.

The right hemisphere contains an affective-configurational representational system, one that encodes self-and-object images unique from the lexical-semantic mode of the left. I suggest it stores an internal working model of the attachment relationship that determines the individual's characteristic approach to affect regulation. In the securely attached individual this representation encodes an expectation that homeostatic disruptions will be set right, allowing the child to self-regulate functions which previously required the caregiver's external regulation. For the rest of the lifespan these unconscious internal working models are used as guides for future action.

In a recent issue of the *American Psychologist,* Bargh and Chartrand asserted,

> most of moment-to-moment psychological life must occur through nonconscious means if it is to occur at all...various nonconscious mental systems perform the lion's share of the self-regulatory burden, beneficiently keeping the individual grounded in his or her current environment (1999, p. 462)..

These regulatory systems are not innate, but a product of the attachment experience-dependent maturation of the right brain. Since the right hemisphere is centrally involved in the unconscious processing of emotional stimuli (Wexler et al., 1992; Morris, Ohman, & Dolan, 1998), and in "implicit learning" (Hugdahl, 1995), this unconscious model is stored in right cerebral implicit-procedural memory. A body of studies reveal that the right hemisphere, "the right mind," is the substrate of affectively-laden autobiographical memory (Fink et al., 1996).

Implicit (procedural) learning is also a major mechanism for the incorporation of cultural learning, a process that initiates in infancy. Tucker

(1992) asserts that social interaction which promotes brain differentiation is the mechanism for teaching "the epigenetic patterns of culture," and that successful social development requires a high degree of skill in negotiating emotional communication, "much of which is nonverbal." Tucker concludes that such culturally transmitted social-emotional information engages specialized neural systems within the right hemisphere. I suggest that socialization is essential to not only advances in emotional-motivational development but to expansion of the self. A recent neuropsychological study concludes that "self-related material is processed in the right hemisphere" (Keenan et al., 1999, p. 1424).

Furthermore, the activity of this "non-dominant" hemisphere, and not the later maturing "dominant" verbal-linguistic left, is instrumental to the perception of the emotional states of other selves, that is, for empathy (Schore, 1994; 1996, 1999a, 2000b). Current findings in neuroscience suggest that the right hemispheric biologically-based spontaneous emotional communications that occur within intimate interactions represent a "conversation between limbic systems" (Buck, 1994) and that "while the left hemisphere mediates most linguistic behaviors, the right hemisphere is important for broader aspects of communication" (Van Lancker & Cummings, 1999, p. 95).

The right brain contains a circuit of emotion regulation that is involved in "intense emotional-homeostatic processes" (Porges, Doussard-Roosevelt, & Maiti, 1994), and in the modulation of not only the biologically primitive negative emotions such as rage, fear, terror, disgust, shame, and hopeless despair, but also intensely positive emotions such as excitement and joy (Schore, 1994, 1996, 1997a, 1999a). Neuroimaging studies now show that the right hemisphere is particularly responsive to not only the positive aspects of touch, smell (Francis et al., 1999), music (Blood et al., 1999), facial expressions (Blair et al., 1999), and visual stimuli (Muller et al., 1999), but also for the negative emotional/motivational aspects of pain (Hsieh et al., 1995; Hari et al., 1997).

In securely attached individuals the highest levels of the right brain, the right orbitofrontal cortex (Schore, 1994; 1998a, in press d, e) acts as a recovery mechanism that efficiently monitors and autoregulates the duration, frequency, and intensity of not only positive but negative affect states. It's coping functions are most observable in contexts of uncertainty, in moments of emotional stress (Elliott et al., 2000). In a recent entire issue of *Cerebral Cortex* on "The mysterious orbitofrontal cortex," the editors conclude that "the orbitofrontal cortex is involved in critical human functions, such as social adjustment and the control of mood, drive and responsibility, traits that are crucial in defining the 'personality' of an individual" (Cavada & Schultz, 2000, p. 205). This right lateralized self system matures in the middle of the second year. The regulatory core of the self is thus nonverbal and unconscious.

The functioning of the "self-correcting" right hemispheric system is central to self-regulation, the ability to flexibly regulate emotional states through interactions with other humans - interactive regulation in interdependent, interconnected contexts, and without other humans - autoregulation in independent, autonomous contexts. The earliest cultural learning experiences, affective transactions in infancy, may influence the balance of these two modes within different cultures. On an individual basis however, the adaptive capacity to shift between these dual regulatory modes, depending upon the social context, emerges out of a history of secure attachment interactions of a maturing biological organism and an early attuned social environment. Researchers are now concluding "The attempt to regulate affect - to minimize unpleasant feelings and to maximize pleasant ones - is the driving force in human motivation" (Westen, 1997, p. 542).

In closing I want to point out that I have described an optimal developmental scenario, one that facilitates the experience-dependent growth of an efficient regulatory system in the right hemisphere that supports functions associated with a secure attachment. On the other hand, growth-inhibiting environments negatively impact the ontogeny of homeostatic self-regulatory and attachment systems. Social environments that provide less than optimal psychobiological attunement histories and generate prolonged episodes of unregulated interactive stress and heightened levels of negative affect retard the experience-dependent development of the highers levels of the right brain that are prospectively involved in affect regulating functions (Schore, 1994, 1997a, 1997b, 1998b, 1999b, c, in press, e).

There is now compelling evidence that all early forming psychopathology constitutes disorders of attachment and manifests itself as failures of autoregulation and/or interactive regulation. I propose that the functional indicators of this adaptive limitation are specifically manifest in recovery deficits of internal reparative coping mechanisms. This can take the form of either underregulation associated with externalizing psychopathologies, or overregulation and internalizing disturbances. Such coping deficits are most obvious under challenging conditions that call for behavioral flexibility and adaptive responses to socioemotional stress.

This conceptualization fits well with recent models which emphasize that loss of ability to regulate the intensity of feelings is the most far-reaching effect of early trauma and neglect, that this dysfunction is manifest in more intense and longer lasting emotional responses, and that defense mechanisms are forms of emotion regulation strategies for avoiding, minimizing, or converting affects that are too difficult to tolerate. I suggest that these functional vulnerabilities reflect structural weaknesses and defects in the organization of the right hemipsheric regulatory system that is centrally involved in the adjustment or correction of emotional responses.

The right hemisphere, the substrate of early attachment processes, ends its growth phase in the second year, when the left hemisphere begins one, but it cycles back into growth phases at later periods of the life cycle (Thatcher, 1994). This allows for the continuity of attachment mechanisms in subsequent functioning, and yet also for the potential continuing reorganization of the emotion-processing right brain throughout life. Future research of the continuing experience-dependent maturation of the right hemisphere could elucidate the underlying mechanisms by which certain attachment patterns can change from "insecurity" to "earned security" (Phelps, Belsky, & Crnic, 1998). However, this system is most plastic during the early critical periods of its maturation. Current brain research indicates that efficient right brain function is centrally involved in the control of vital functions supporting survival. Early interventions that focus on social-emotional development would have enduring effects on the adaptive coping capacities of a developing self throughout the lifespan.

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