EFFECTS OF A SECURE ATTACHMENT RELATIONSHIP ON RIGHT BRAIN DEVELOPMENT, AFFECT REGULATION, AND INFANT MENTAL HEALTH

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ABSTRACT: Over the last ten years the basic knowledge of brain structure and function has vastly expanded, and its incorporation into the developmental sciences is now allowing for more complex and heuristic models of human infancy. In a continuation of this effort, in this two-part work I integrate current interdisciplinary data from attachment studies on dyadic affective communications, neuroscience on the early developing right brain, psychophysiology on stress systems, and psychiatry on psychopathogenesis to provide a deeper understanding of the psychoneurobiological mechanisms that underlie infant mental health. In this article I detail the neurobiology of a secure attachment, an exemplar of adaptive infant mental health, and focus upon the primary caregiver's psychobiological regulation of the infant's maturing limbic system, the brain areas specialized for adapting to a rapidly changing environment. 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, and in this manner the attachment relationship facilitates the expansion of the child's coping capcities. This model suggests that adaptive infant mental health can be fundamentally defined as the earliest expression of flexible strategies for coping with the novelty and stress that is inherent in human interactions. This efficient right brain function is a resilience factor for optimal development over the later stages of the life cycle.

RESUMEN: En los últimos diez años el conocimiento básico de la estructura y función del cerebro se ha expandido considerablemente, y su incorporación como parte de las ciencias del desarrollo permite ahora tener modelos de infancia humana más complejos y heurísticos. Como una continuación a este esfuerzo, en este ensayo que contiene dos partes, se integra la actual información interdisciplinaria que proviene de los estudios de la unión afectiva en relación con comunicaciones afectivas en forma de díadas, la neurociencia en el desarrollo inicial del lado derecho del cerebro, la sicofisiología de los sistemas de tensión emocional, así como la siquiatría en cuanto a la sicopatogénesis, con el fin de presentar un conocimiento más profundo de los mecanismos siconeurobiológicos que sirven de base para la salud mental infantil. En este ensayo se explica con detalle la neurobiología de una relación afectiva segura, un modelo de salud mental infantil que se puede adaptar, y el enfoque del mismo se centra en la reglamentación sicobiológica que quien primariamente cuida del niño tiene del maduramiento del sistema límbico del infante, o sea, las áreas del cerebro especialmente dedicadas a la adaptación a un medio

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ambiente que cambia rápidamente. El temprano desarrollo del hemisferio cerebral derecho del infante presenta profundas conexiones en cuanto a los sistemas nerviosos límbico y autónomo, y es responsable por la respuesta humana a la tensión. De esta manera la relación afectiva facilita la expansión de las habilidades del niño de enfrentar diferentes situaciones. Este modelo sugiere que la salud mental infantil capaz de ser adaptada puede ser fundamentalmente definida como la expresión más temprana de estrategias flexibles para enfrentarse con lo novedoso y con la tensión inherente en las interacciones humanas. Esta efectiva función del lado derecho del cerebro es un factor de resistencia para el desarrollo óptimo en los niveles posteriores del ciclo vital.

RÉSUMÉ: Pendant ces dix dernières années la connaissance de base de la structure et de la fonction du cerveau s'est considérablement accrue, et son incorporation dans les sciences du développement autorise maintenant des modèles plus complexes et heuristiques de la petite enfance humaine. Dans un effort de poursuite de cet effort, j'intègre dans ce travail divisé en deux parties des données interdisciplinaires actuelles issues d'études sur l'attachement des communications affectives dyadiques, la neuroscience sur le développement précoce de l'hémisphère droit du cerveau, la psychophysiologie sur les systèmes de stress, et la psychiatrie sur la psychopathogénèse de façon à offrir une compréhension plus approfondie des mécanismes psychoneurobiologiques qui sous-tendent la santé mentale infantile. Dans cet article je détaille la neurobiologie d'un attachement solide, un modèle de santé mentale adaptative, et je mets l'accent sur la régulation psychobiologique que fait le mode de soin principal du système limbique arrivant à maturité du petit enfant, les régions du cerveau spécialisées dans l'adaptation à un milieu changeant rapidement. Le développement précoce de l'hémisphère droit du petit enfant a de profondes connexions dans les systèmes nerveux limbiques et autonomiques et l'emporte pour la réponse humaine au stress, et de cette manière la relation d'attachement facilite l'expansion des capacités à faire face de l'enfant. Ce modèle suggère que la santé mentale adaptive infantile peut être fondamentalement définie comme l'expression la plus précoce de stratégies flexibles pour faire face à la nouveauté et au stress qui sont inhérents aux interactions humaines. Cette fonction efficace de l'hémisphère droit du cerveau est un facteur de ressort pour le développement optimal lors des stades ultérieurs du cycle de vie.

ZUSAMMENFASUNG: In den letzten zehn Jahren hat sich die grundlegende Kenntnis der Gehirnstruktur und—funktion eindrucksvoll erweitert. Ihre Einbindung in die Entwicklungswissenschaften erlaubt es nun komplexere und erprobbare Modelle der menschlichen Kleinkindzeit zu entwickeln. In Fortsetzung dieser Anstrengungen integriere ich—in dieser zweiteiligen Arbeit—gegenwärtige interdisziplinäre Ergebnisse aus Bindungsstudien über dyadische, gefühlsgesteuerte Kommunikation, aus der Neurologie über die sich früh entwickelnde rechte Gehirnhälfte, aus der Psychophysiologie über Stresssysteme und aus der Psychiatrie zur Psychopathogenese, um ein tieferes Verständnis der psychoneurobiologischen Mechanismen, die der seelischen Gesundheit des Kleinkinds zugrunde liegen, zu ermöglichen.

In dieser Arbeit zeige ich die Neurobiologie der sicheren Bindung auf, ein Beispiel der Anpassung in der seelischen Gesundheit des Kleinkinds und ich beziehe mich auf die psychobiologische Regulation des kindlichen limbischen Systems durch die primäre Bezugsperson. Das limbische System ist jene Gehirnregion, die speziell für die Anpassung an eine sich schnell ändernde Umgebung zuständig ist. Die sich schnell entwickelnde rechte Hirnhälfte des Kleinkinds hat bedeutende Verbindungen zu dem limbischen und dem autonomen Nervensystem und ist bestimmend für die menschliche Stressreaktion, wodurch die Bindung die kindlichen Anpassungsleistungen erleichtert. Dieses Modell unterstell, dass die angepasste seelische Gesundheit des Kleinkinds im Grunde so definiert werden kann: Es ist das erste Auftauchen der flexiblen Strategien, um mit Neuem auszukommen und zeigt, dass Stress zur menschlichen Interaktion dazugehört. Diese effiziente Funktion der rechten Gehirnhälfte ist eine Bedingung für die optimale Entwicklung im weiteren Leben.

抄録：過去 10 年間、脳の構造と機能についての基礎的な知識は大きく広がり、それと発達科学の合体によっていまやより複雑で発見を助ける人間の乳児のモデルが可能になる。この努力の継続の中で、この二つの部分に分かれる仕事の中で、私は、乳幼児精神保健の基礎となる心理神経生物学的メカニ

ズムをより深く理解できるように、二者の感情コミュニケーションについて愛着研究から、早期の発達しつつある右脳について神経科学から、ストレスシステムについて精神生理学から、および精神病因論についての精神医学からの、最近の学際的データを統合する。

　この論文では、私は、適応的な乳幼児精神保健の典型として、安全な愛着の神経生物学を詳しく述べ、主要な養育者が乳児の成熟しつつある辺縁系へに与える心理生物学的制御に焦点付ける。辺縁系は急速に変化する環境に適応するために特化した脳の領域である。乳児の早期の発達しつつある右半球は、辺縁系および自律神経系と深い連絡があり、人間のストレス反応に優位であり、そしてこのやり方で愛着の関係性が子どもの対処能力の拡大を促進する。このモデルは、適応的な乳幼児精神保健は、人間の相互交流に内在する新奇性やストレスへの柔軟な対処戦略の再早期の表現として、基本的に定義できることを示唆する。この有効な右脳の機能は、後のライフサイクルの段階にわたって最適な発達への回復要素である。

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The fundamental importance of the psychological as well as the biological health of the infant has long been held as a cardinal principle by every clinical discipline that deals with young children — infant psychiatry, behavioral pediatrics, child psychology, developmental psychoanalysis, and more recently, the emerging fields of developmental psychopathology and infant mental health. And yet a more precise characterization of the concept of infant mental health, like the definition of "mental health" itself, has been elusive. Theoretically, it is clear that there must be links between infant and adult mental health, yet these too have been ill-defined. Although there is a large body of clinical knowledge in psychiatry, abnormal psychology, and psychoanalysis affirming the centrality of early relational experiences on enduring adaptive and maladaptive aspects of personality, there has been some question as to the structural mechanisms by which such events positively or negatively influence the process of development as it continues over the lifespan. In other words, how do the earliest interactions between a maturing biological organism and the social environment influence infant mental health, what are the central functions that define infant mental health, and how does it influence mental health at later stages of development?

The defined mission of the *Infant Mental Health Journal* is to focus upon infant social-emotional development, caregiver–infant interactions, contextual and cultural influences on infant and family development, and all conditions that place infants and/or their families at risk for less than optimal development. In this work I want to suggest that although the unique importance of "optimal development" has long been addressed by the psychological sciences, due to the advances of "the decade of the brain," developmental neuroscience is now in a position to offer more detailed and integrated psychoneurobiological models of normal and abnormal development. The incorporation of this information into developmental psychological models could forge closer links between optimal brain development and adaptive infant mental health, as well as altered brain development and maladaptive mental health.

A theoretical concept that is shared by an array of basic and clinical sciences is the concept of regulation (Schore, 1994, 1996, 1998d, 1999c, 2000b), and because it integrates both the biological and psychological realms, it can also be used to further models of normal and abnormal structure–function development, and therefore, adaptive and maladaptive infant mental health. Interdisciplinary research and clinical data are affirming the concept that in infancy and beyond, the regulation of affect is a central organizing principle of human devel-

opment and motivation. In the neuroscience literature Damasio asserts that emotions are the highest order direct expression of bioregulation in complex organisms (1998), and that primordial representations of body states are the building blocks and scaffolding of development (1994). Brothers argues that emotion occurs "in the context of evolved systems for the mutual regulation of behavior, often involving bodily changes that act as signals" (1997, p. 123). Emotions and their regulation are thus essential to the adaptive function of the brain, which is described by Damasio:

> The overall function of the brain is to be well informed about what goes on in the rest of the body, the body proper; about what goes on in itself; and about the environment surrounding the organism, so that suitable survivable accommodations can be achieved between the organism and the environment. (1994, p. 90)

In a number of works I have described the earliest ontogeny of these adaptive brain functions, and have argued that the essential events that allow for the emergence of the regulatory systems that control such functions occur during the brain growth spurt (Schore, 1994, 1996, 1997b, 1998a, 1998b, 2000b, 2000d). Moreover, I have offered data that suggest that the inceptive stages of development represent a maturational period of specifically the early maturing right brain, which dominant in the first three years of human life (Chiron, Nabbout, Lounes, Syrota, & Dulac, 1997; Schore, 1994). The right brain is centrally involved in not only processing social-emotional information, facilitating attachment functions, and regulating bodily and affective states (Schore, 1994, 1998a), but also in the control of vital functions supporting survival and enabling the organism to cope actively and passively with stress (Wittling & Schweiger, 1993).

Furthermore, in a series of contributions I have proposed that the maturation of these adaptive right brain regulatory capacities is experience dependent, and that this experience is embedded in the attachment relationship between the infant and primary caregiver (Schore, 1994, 1999b, 2000a, 2000b, in press c). But it is important to point out that this experience can either positively or negatively influence the maturation of brain structure, and therefore, the psychological development of the infant. This developmental psychoneurobiological model clearly suggests direct links between secure attachment, development of efficient right brain regulatory functions, and adaptive infant mental health, as well as between traumatic attachment, inefficient right brain regulatory function, and maladaptive infant mental health.

In an attempt to forge these conceptual links more tightly, in this two-part work I will address the problem of operationally defining adaptive and maladaptive infant mental health by integrating very recent data from attachment theory, developmental neuroscience, and developmental psychopathology. The primary goal of this latter field is to characterize the ontological processes whereby early patterns of individual adaptation evolve into later patterns of adaptation (Cicchetti, 1994), and thereby it investigates the early development of the individual's coping systems. In generating models of how early ontogenetic factors predispose high-risk individuals to later psychopathologies, this rapidly growing interdisciplinary approach is directly inquiring into the mechanisms that account for the continuity between infant mental health and mental health at later points in the lifespan.

An essential principle of the developmental psychopathology perspective is that atypical development can only be understood in the context of typical development, and so the focus is on underlying mechanisms common to both. This model suggests that any overarching conception of early development needs to integrate both the biological and psychological realms, and that it must incorporate models of both adaptive and maladaptive infant mental

health. It also implies that infant mental health cannot be defined solely as a "psychological" construct—rather, it is more precisely characterized as "psychobiological."

Utilizing such a perspective, in these two articles I will contrast the neurobiology of a secure attachment, an exemplar of adaptive infant mental, with the neurobiology of an insecure disorganized/disoriented ("type D") attachment, the most severe form of attachment pathology. This attachment category is associated with early trauma, and will be presented as a prototype of maladaptive infant mental health. Throughout, I shall underscore the effects of the caregiver's stress regulating and dysregulating psychobiological interactions on the infant's maturing coping systems that are organizing in the limbic circuitries of the early developing right hemisphere. An increasing body of evidence indicates that "maternal care during infancy serves to 'program' behavioral responses to stress in the offspring" (Caldji, Tannenbaum, Sharma, Francis, Plotsky, & Meaney, 1998, p. 5335).

So in the first of this two-part contribution I will offer an overview of an interdisciplinary perspective of development, outline connections between attachment theory, stress regulation, and infant mental health, describe the neurobiology of a secure attachment, present models of right brain, early limbic system, and orbital frontolimbic development, and suggest links between continued orbitofrontal and right brain development and adaptive mental health. In the second part of this sequenced work I will offer ideas about how early relational traumatic assaults of the developing attachment system inhibit right brain development, impair affect regulating capacities, and negatively impact infant and adult mental health. These models are presented for further experimental testing and clinical validation.

OVERVIEW OF AN INTERDISCIPLINARY PERSPECTIVE OF DEVELOPMENT

To date, infant mental health has mostly been described in terms of the presence or absence of certain psychological functions, but it should be pointed out that these functions are, in turn, the product of biological structural systems that are organizing over the stages of infancy. Such internal systems are clearly located in the developing brain, which mediates more complex functions, and it is known that the conditions and events occurring in "critical" or "sensitive" early periods of brain development have long-enduring effects. Brazelton and Cramer (1990) note that in critical phases energy is high in the infant and the parent for receptivity to each other's cues and for adapting to each other.

From late pregnancy through the second year the brain is in a critical period of accelerated growth, a process that consumes higher amounts of energy than any other stage in the lifespan, and so it requires sufficient amounts of not only nutrients, especially long-chain polyunsaturated fatty acids (Dobbing, 1997) but also regulated interpersonal experiences for optimal maturation (Levitsky & Strupp, 1995; Schore, 1994). The critical period concept, now firmly established in biology (Katz, 1999), prescribes that "specific critical conditions or stimuli are necessary for development and can influence development only during that period" (Erzurumlu & Killackey, 1982, p. 207). But it also suggests that during critical periods brain growth is exquisitely susceptible to adverse environmental factors such as nutritional deficits and dysregulating interpersonal affective experiences, both of which negatively impact infant mental health.

The human brain growth spurt, which is at least 5/6 postnatal, begins in the third trimester in utero and continues to about 18 to 24 months of age (Dobbing & Sands, 1973). During this period the brain is rapidly generating nucleic acids that program developmental processes at a rate that will never again be attained. This massive production of both nuclear and mitochondrial genetic material in the infant's brain is directly influenced by events in specifically the

social-affective environment (Schore, 1994). Indeed, the most recent conceptions of development utilize a "transactional model," which views development and brain organization as "a process of transaction between (a) genetically coded programs for the formation of structures and connections among structures and (b) environmental influence" (Fox, Calkins, & Bell, 1994, p. 681). So Sander (2000) formulates a key question for deeper understandings of infant mental health:

> To what extent can the genetic potentials of an infant brain be augmented or optimized through the experiences and activities of the infant within its own particular caregiving environment? (p. 8)

The interface of nature and nurture occurs in the psychobiological interaction between mother and infant, "the first encounter between heredity and the psychological environment" (Lehtonen, 1994, p. 28). According to Cicchetti and Tucker, "Environmental experience is now recognized to be critical to the differentiation of brain tissue itself. Nature's potential can be realized only as it enabled by nurture" (1994, p. 538). The evolution and specification of this potential is described in the current biological literature:

> [O]ne of the most fundamental strategies for biological adaptation in organisms is the ability of the central nervous system (CNS) to react and modify itself to environmental challenges. There is general agreement that the genetic specification of neuronal structure is not sufficient for an optimally functional nervous system. Indeed, a large variety of experimental approaches indicate that the environment affects the structure and function of the brain. (Gomez-Pinilla, Choi, & Ryba, 1999, p. 1051)

A large body of evidence supports the principle that cortical and subcortical networks are generated by a genetically programmed initial overabundant production of synaptic connections, which is then followed by an environmentally driven process of competitive interaction to select those connections that are most effectively entrained to environmental information. This parcellation, the activity-dependent fine tuning of connections and pruning of surplus circuitry, is a central mechanism of the self-organization of the developing brain (Chechik, Meilijson, & Ruppin, 1999; Schore, 1994). It is important to emphasize, however, that environmental experience can either enable or constrain the structure and function of the developing brain. In other words, early interpersonal events positively or negatively impact the structural organization of the brain and its expanding adaptive functional capacities. This clearly implies, in the broadest of terms, a direct relationship between an enabling socioemotional environment, an optimally developing brain, and adaptive infant mental health.

A major conclusion of the last decade of developmental neuroscience research is that there is now agreement that the infant brain "is designed to be molded by the environment it encounters" (Thomas et al., 1997, p. 209). The brain is thus considered to be a bioenvironmental or biosocial organ (Gibson, 1996), and investigators are now exploring the unique domains of the "social brain" (Brothers, 1990) and the central role of emotions in social communication (Adolphus, 2000). In applying this principle to social-emotional development, the connections between the neurobiological concept of "enriched environment" and the psychological concept of "optimal development" can now be more closely coupled in the psychoneurobiological construct of a "growth-facilitating" (as opposed to "growth-inhibiting") interpersonal environment (Greenspan, 1981; Schore, 1994) that positively (or negatively) effects the experience-dependent maturation of the brain.

This interdisciplinary model is compatible with very recent conceptions that emphasize that developmental processes can best be understood in terms of a context in which evolving biological systems are interacting with the social realm. As Cairns and Stoff describe:

It is necessary to go beyond the conventional notion that biological variables not only influence behavior and environment to the more modern notion that behavioral and environmental variables also impact on biology. Maturation and developmental processes may provide the common ground for understanding the process of biological social integration. On the one hand, it is virtually impossible to conceptualize developmental changes without recognition of the inevitable internal modifications that occur within the organism over time. On the other hand, it is misleading to focus on the individual's biology in the absence of detailed information about the interaction and social circumstances in which the behavior occurs. (1996, p. 349)

This integration of biology and psychology to understand development has a rich tradition in science. In *The Expression of Emotions in Man and Animals*, Darwin (1872) established the scientific study of emotions and proposed that movements of expression in the face and body serve as the first means of communication between the mother and her infant (Schore, 2000a, 2000b, 2000c). And in *The Project for a Scientific Psychology*, Freud (1895), in an attempt to link neurology and psychology, first presented both his models of early development and ideas on how early traumatic events could heighten the risk of later forming psychopathology (Schore, 1995, 1997a, 1997c). Although others have followed this line of integrating the biological and psychological realms, perhaps the most important scientist of the late twentieth century to apply an interdisciplinary perspective to the understanding of how early developmental processes influence later mental health was John Bowlby. Over two decades ago he asserted that attachment theory can frame specific hypotheses that relate early family experiences to different forms of psychiatric disorders, including the neurophysiological changes that accompany these disturbances of mental health. It is thus no coincidence that attachment theory, the dominant theoretical model of development in contemporary psychology, psychoanalysis, and psychiatry, is the most powerful current source of hypotheses about infant mental health.

ATTACHMENT, STRESS REGULATION, AND INFANT MENTAL HEALTH

In his classic work of developmental science Bowlby (1969) called for deeper explorations of how an immature organism is critically shaped by its primordial relationship with a mature adult member of its species, that is, more extensive studies of how an attachment bond forms between the infant and mother (Schore, 2000a, 2000b). In this conception, developmental processes are the product of the interaction of a unique genetic endowment with a particular "environment of adaptiveness, and especially of his interaction with the principal figure in that environment, namely his mother" (Bowlby, 1969, p. 180). Thus, the infant's emerging social, psychological, and biological capacities cannot be understood apart from its relationship with the mother.

More specifically, in *Attachment*, (1969) Bowlby inquired into the mechanisms by which the infant forms a secure attachment bond of emotional communication with the mother, and how this early socioemotional learning is then internalized in the form of an enduring capacity to regulate and thereby generate and maintain states of emotional security. He observed that

the mother–infant attachment relationship is "accompanied by the strongest of feelings and emotions, happy or the reverse," (p. 242), that this interaction occurs within a context of "facial expression, posture, tone of voice, physiological changes, tempo of movement, and incipient action," (p. 120), that attachment interactions allow for the emergence of a *biological control system* that functions in the organism's "state of arousal" (pp. 152–157), that the instinctive behavior that constitutes attachment emerges from the coconstructed environment of evolutionary adaptiveness has consequences that are "vital to the survival of the species" (p. 137), and that the infant's "capacity to cope with stress" is correlated with certain maternal behaviors (p. 344). These last two factors, adaptiveness and coping capacity, are obviously central components of infant mental health.

In recent writings I have contended that attachment theory is, in essence, a regulatory theory (Schore, 2000a, 2000b, 2000c). More specifically, in such attachment transactions the secure mother, at an intuitive, nonconscious level, is continuously regulating the baby's shifting arousal levels and therefore emotional states. Emotions are the highest order direct expression of bioregulation in complex organisms (Damasio, 1998), and attachment can thus be defined as the dyadic regulation of emotion (Sroufe, 1996). As a result of being exposed to the primary caregiver's regulatory capacities, the infant's expanding adaptive ability to evaluate on a moment-to-moment basis stressful changes in the external environment, especially the social environment, allows him or her to begin to form coherent responses to cope with stressors. It is important to note that not just painful experiences but novel events are stressors. This means that the capacity to orient towards not only the familiar but to approach, tolerate, and incorporate novelty is fundamental to the expansion of a developing system's adaptive capacity to learn new information and, therefore, to move towards more complexity.

Furthermore, because the maturation of the brain systems that mediate this coping capacity occurs in human infancy, the development of the ability to adaptively cope with stress is directly and significantly influenced by the infant's early interaction with the primary caregiver (Schore, 1994, 1997b, 2000b). In support of Bowlby's speculations on the association of attachment with coping mechanisms, recent interdisciplinary studies indicate that "even subtle differences in maternal behavior can affect infant attachment, development, and physical well-being" (Champoux, Byrne, DeLizio, & Suomi, 1992, p. 254), and that "variations in maternal care can serve as the basis for a nongenomic behavioral transmission of individual differences in stress reactivity across generations" (Francis, Diorio, Liu, & Meaney, 1999, p. 1155).

In other words, the same interactive regulatory transactions that cocreate a secure attachment bond also influence the development and expansion of the infant's regulatory systems involved in appraising and coping with stress, and therefore, essential to organismic survival. According to McEwen and Stellar, "A stressful stimulus results in a severe perturbation of an organism's physiological systems, and the degree of the perceived or real threat determines the magnitude of the stress response to an internal or extrernal challenge" (1993, p. 2093). In describing stress, a concept that lies at the interface of the biological and psychological realms, Weinstock (1997) states:

> The survival of living organisms depends upon the maintenance of a harmonious equilibrium or homeostasis in the face of constant challenge by intrinsic or extrinsic forces or stressors. Stress is a term that is widely used to describe both the subjective experience induced by a novel, potentially threatening or distressing situation, and the behavioral or neurochemical reactions to it. These are designed to promote adaptive response to the physical and psychological stimuli and preserve homeostasis. . . . Successful equilibrium is reflected by a

rapid neurochemical response to these stimuli which is terminated at the appropriate time, or gives way to counter-regulatory measures to prevent an excessive reaction. (p. 1)

There is now agreement that the these critical functions are mediated by the sympathetic–adrenomedullary (SAM) axis and the hypothalamo–pituitary–adrenocortical (HPA) axis. Furthermore, a growing body of studies indicates that the threshold for stimulation of the SAM axis is lower than that for stimulation of the HPA axis (Malarkey, Lipkus, & Cacioppo, 1995), and that the neurochemistry of the former is regulated by the major stress hormone, corticotropin releasing factor (CRF), that regulates catecholamine release in the sympathetic nervous system (Brown, Fisher, Spiess, Rivier, Rivier & Vale, 1982), and of the latter by the glucocorticoid, cortisol, the major "antistress" hormone (Yehuda, 1999). Yehuda points out that the greater the severity of the stressor, the higher the levels of these neurochemicals, and also that the actions of these two systems are synergistic: "whereas catecholamines facilitate the availability of energy to the body's vital organs, cortisol's role in stress is to help contain, or shut down sympathetic activation" (1999, p. 257).

In other words, the energy-expending sympathetic and energy-conserving parasympathetic components of the autonomic nervous system (ANS) regulate the autonomic, somatic aspects of not only stress responses but emotional states. This adaptive function is stressed by Porges (1997, p. 65):

Emotion depends on the communication between the autonomic nervous system and the brain; visceral afferents convey information on physiological state to the brain and are critical to the sensory or psychological experience of emotion, and cranial nerves and the sympathetic nervous system are outputs from the brain that provide somatomotor and visceromotor control of the expression of emotion.

But in addition to the ANS, there is now a growing appreciation of the role of the central nervous system (CNS) limbic circuits in coping capacities, because this emotion-processing system is specialized to appraise social information from facial expressions implicitly, without conscious awareness (Critchley et al., 2000a), to represent motivationally salient stimuli to adapt to a rapidly changing environment (Mesulam, 1998), and to alter the activity of brain stem neuromodulatory systems responsible for emotional states and arousal (Tucker, 1992). These subcortically produced neuromodulatory bioamines, especially the catecholamines dopamine and noradrenaline, regulate brain state (Flicker, McCarley, & Hobson, 1981), energy metabolism (Huang, Peng, Chen, Hajek, Zhao, & Hertz, 1994) and blood flow microcirculation (Krimer, Mully, Williams, & Goldman-Rakic, 1998). By activating cAMP-response element-binding protein (CREB; Walton & Dragunow, 2000), they also act as internal clocks to coordinate the timing of developmental processes (Lauder & Krebs, 1986) and mediate both trophic growth-promoting and stress-related functions (Morris, Seidler, & Slotkin, 1983; O'Dowd, Barrington, Ng, Hertz, & Hertz, 1994; Schore, 1994). The limbic system is involved in stress functions (Seyle, 1956), and various components of this system are responsible for appraising the salience of a stressor, and then initiating and organizing a psychobiological response.

Current developmental research indicates that individual differences in peripheral and central autonomic balance emerge in early development, and that these are reflected in the affective and cognitive domains (Friedman & Thayer, 1998). The "lower," subcortical sympathetic and parasympathetic components of the ANS, as well as the "higher" cortical limbic components of the CNS, are organizing pre- and postnatally, and their maturation is experience dependent (Schore, 1996, 2000d). In fact it is now thought that

(an) early postnatal period represents a "critical period" of limbic–autonomic circuit development, during which time experience or environmental events might participate in shaping ongoing synapse formation. (Rinaman, Levitt, & Card, 2000, p. 2739)

This organization is especially expressed in the early maturing (Chiron et al., 1997) right hemisphere, which, more so than the later developing left, deeply connects into both the limbic system (Tucker, 1992) and ANS (Spence, Shapiro, & Zaidel, 1996), and is therefore, dominant for the human stress response (Wittling, 1997) and organismic survival (Wittling & Schweiger, 1993). The environmental events that influence ANS–limbic circuit development are embedded in the infant's ongoing affect regulating attachment transactions. Bowlby suggested that the limbic system is intimately tied to attachment, an idea furthered by Anders and Zeanah (1984). But these circuits are emphasized in specifically the right brain, because compared to the left, "the right limbic system may be better connected with subcortical neurochemical systems associated with emotion" (Buck, 1994, p. 272).

It is now accepted that in a growth-facilitating social enviornment the attachment interactions the child has with its mediators influences the maturation of connections within her developing limbic system (Schore, 1994), and that cortical paralimbic networks are formed through "ontogenetic plasticity, that is, through a natural selection of those connections that match the data in the environment" (Tucker, 1992, p. 109). On the other hand, current developmental neurobiological research reveals that growth-inhibiting, adverse early rearing experiences "have longstanding and complex effects on a range of neurochemicals relevant to emotion regulation" (Coplan et al., 1998, p. 473). Severely compromised attachment histories are thus associated with brain organizations that are inefficient in regulating affective states and coping with stress (Schore, 1997b), and therefore, engender maladaptive infant mental health. This deficit is expressed in a failure to move away from homeostasis to turn on neurochemical stress responses when needed, and/or to turn them off and reestablish homeostasis when they are no longer needed.

As Emde (1988) has pointed out, a developmental orientation indictates that maladaptive functioning is specifically manifest as a lack of variability when an individual is faced with environmental demands that call for alternative choices and strategies for change. In light of the principle that the process of reestablishing homeostasis in the face of challenge allows for the adaptive capacity of "achieving stability through change" (Schulkin, Gold, & McEwen, 1998, p. 220), this deficit results in not just an unstable self-system but one with a poor capacity to change, a limited ability to continue to develop at later points in the life cycle. Crittenden and DiLalla describe:

Adaptive development can be considered a product of the interaction of a changing biological organism with its environment such that the organism is effective in using the resources of its environment to meet its present needs without jeopardizing its future development. Maladaptive developmental courses either do not meet the organism's present needs as well as others or they reduce the organism's responsiveness to future change. (1988, p. 585)

This relationship between events in early development and a later capacity for change is due to the fact that the early social environment directly impacts the experience-dependent maturation of the limbic system, the brain areas specialized for the organization of new learning and the capacity to adapt to a rapidly changing environment (Mesulam, 1998). Because limbic areas in the cortex and subcortex are in a critical period of growth in the first two years and

these same neurobiological structures mediate stress-coping capacities for the rest of the the lifespan, early interpersonal stress-inducing and stress-regulating events have long-enduring effects.

Indeed, recent developmental psychobiological studies suggest that:

> An individual's response to stressful stimuli may be maladaptive producing physiological and behavioral responses that may have detrimental consequences, or may be adaptive, enabling the individual to better cope with stress. Events experienced early in life may be particularly important in shaping the individual's pattern of responsiveness in later stages of life. (Kehoe, Shoemaker, Triano, Hoffman, & Arons, 1996, p. 1435)

This conception suggests direct links between infant and adult mental health.

Integrating these conceptualizations, I suggest that adaptive infant mental health can be fundamentally defined as the earliest expression of efficient and resilient strategies for coping with novelty and stress, and maladaptive infant mental health as a deficit in these same coping mechanisms. The former is a resilience factor for coping with psychobiological stressors at later stages of the life cycle, the latter is a risk factor for interruptions of developmental processes and a vulnerability to the coping deficits that define later-forming psychopathogies. Both are attachment outcomes, and so this formulation is congruent with Main's (1996) assertion that "disorganized" and "organized" forms of insecure attachment are primary risk factors for the development of mental disorders.

AFFECT SYNCHRONY, RESONANCE, AND ATTACHMENT COMMUNICATIONS

The ontogeny of adaptive infant mental health is positively correlated with the ongoing development of attachment experiences over the first year. This is due to the fact that the experience-dependent maturation of the baby's brain allows for the emergence of more complex functional capacities for coping with stressors, especially those from the social environment. This developmental advance is an outcome of the cocreation of a secure attachment bond of emotional communication between infant and mother. It has been said that "learning how to communicate represents perhaps the most important developmental process to take place during infancy' (Papousek & Papousek, 1997, p. 42). What do we know about the relationships between the earliest development of socio-emotional communication and the organization of adaptive brain systems?

From birth onwards, the infant is using its expanding coping capacities to interact with the social environment. In the earliest proto-attachment experiences, the infant is utilizing its maturing motor and developing sensory capacities, especially smell, taste, and touch, to interact with the social environment. As described by Trevarthen (2000) and confirmed in very recent research on rhythmic discriminations in newborns (Ramus, Hauser, Miller, Morris, & Mehler, 2000), auditory stimuli are also impacting the infant's developing sensory systems. But by the end of the second month there is a dramatic progression of its social and emotional capacities. In two functional magnetic resonance imaging (fMRI) studies, Yamada et al. (1997, 2000) demonstrate a milestone for normal development of the infant brain occurs at about eight weeks. At this point a rapid metabolic change occurs in the primary visual cortex of infants. These authors interpret this rise to 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 emotionally expressive becomes the most potent stimulus in the infant's social 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." In the developmental psychological literature, Fogel and Branco (1997) characterize infant emotional metacommunication in parent–infant interaction expressed in nonverbal gaze direction, facial expression, posture, and body movements that are "mutually coordinated to create emergent social patterns" (p. 68). Writing in the neurobiological literature, Allman and Brothers assert, "When mutual eye contact is established, both participants know that the loop between them has been closed . . . and this is the most potent of all social situations" (1994, p. 61).

In very recent basic research on three-month-old infants, Feldman, Greenbaum, and Yirmiya (1999, p. 223) describe:

> Face-to-face interactions, emerging at approximately 2 months of age, 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.

These episodes of "affect synchrony" occur in the first expression of social play, and at this time they are patterned by an infant-leads-mother-follows sequence. This highly organized dialogue of visual and auditory signals is transacted within milliseconds, and is composed of cyclic oscillations between states of attention and inattention in each partner's play. In this interactive matrix both partners match states and then simultaneously adjust their social attention, stimulation, and accelerating arousal to each other's responses.

Feldman and her colleagues assert,

> Synchronicity is defined as a match between mother's and infant's activities that promotes positivity and mutuality in play. By synchronizing with the child's attentive states, mothers structure playful interactions, regulate infant attention, facilitate the development of verbal dialogue, and promote the infant's capacity for self-regulation . . . mutual synchrony exists when both partners simultaneously adjust their attention and stimulation in response to the partner's signals. (1996, p. 349)

These are critical events, because they represent a fundamental opportunity to practice the interpersonal coordination of biological rhythms. 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).

In this process of "contingent responsivity," not only the tempo of their engagement but also their disengagement and reengagement is coordinated. The more the psychobiologically attuned 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 period immediately after a "moment of meeting," when both partners disengage, provides "open space," in which both can be together, yet alone (autoregulating) in the presence of the other (Sander, 1988). The synchronizing 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 (Penman, Meares, & Milgrom-Friedman, 1983).

In these exchanges of affect synchrony, as the mother and infant match each other's temporal and affective patterns, each recreates an inner psychophysiological state similar to the partner's. Stern (1983b) describes moment-to-moment state sharing, feeling the same as the other, and state complementing, responding in one's unique way to stimuli coming from the other. In contexts of "mutually attuned selective cueing," the infant learns to preferentially send 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).

In describing the unique nature of an emotionally communicationg mother–infant dyad, a number of prominent theoreticians have been drawn to the concept of resonance. Trevarthen describes

> Corresponding generative parameters in . . . two subjects enable them to resonate with or reflect on one another as minds in expressive bodies. This action pattern can become "entrained," and their experiences can be brought into register and imitated. These are the features that make possible the kind of affectionate empathic communication that occurs, for instance, between young infants and their mothers. (1993, p. 126)

Simliarly, Sander (1991) emphasizes the critical importance of the context of a specifically fitted interaction between the infant and mother as a resonance between two systems attuned to each other by corresponding properties. Such energy-infused moments allow for a sense of vitalization, and thereby increased complexity and coherence of organization within the infant.

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 energy shifts are the most basic and fundamental features of emotion, 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 (Schore, 1997b, 2000d, in press a).

Resonances often have chaos associated with them, and thus they are characterized by nonlinear dynamical 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. In other words, when a psychobiologically attuned dyad cocreates 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.

In demonstration of this principle, emotion theorists describe "affect bursts," nonverbal expressions of synchronized facial and vocal activity triggered by an external stimulus (Scherer, 1994). And infant researchers refer to the delight the infant displays in reaction to the aug-

menting 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 that can "blast the infant into the next orbit of positive excitation," and generate "vitality affects." In these transactions the dyad is cocreating "mutual regulatory systems of arousal" (Stern, 1983a).

In this interactive context, the infant's attachment motivation synergistically interacts with the caregiver's maternal motivation. In current psychobiological models maternal motivation is conceptualized as the outcome of the interaction between external visual and auditory infant stimuli and the central state of maternal arousability (Pryce, 1992). To act as a regulator of the infant's arousal, she must be able to regulate her own arousal state. The burgeoning capacity of the infant to experience increasing levels of accelerating, rewarding arousal states 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.

Reciprocal facial signalling, mutual rhythmic entrainment, and dyadic resonance thus act as a psychobiological context for an open channel of social communication, and this interactive matrix promotes the outward expression of internal affective states in infants. Sander (1997) asserts that the parent expresses a behavior that is particularly fitted to catalyze a shift in the infant's state, and Tronick et al. (1998) state that the complexity of the infant's state is expandable with input from an external source—the caregiver. To enter into this communication, the mother must be psychobiologically attuned not so much to the child's overt behavior as to the reflections of the rhythms of his internal state.

Because affect attunements are "spontaneous, nonverbal responses to . . . children's expressed emotions" (Polan & Hofer, 1999, p. 176), the moment-to-moment expressions of the mother's regulatory functions occur at levels beneath awareness. Even so, the attuned mother can self-correct by accessing her reflective function whereby she monitors not only her infant's but her own internal signals and differentiates her own affective state. As a regulator of the infant's arousal levels, she also modulates nonoptimal high levels of stimulation that would induce supraheightened levels of arousal in the infant. Thus, she regulates not just the type but also the intensity of socioaffective information within the dyad's communication system.

But the primary caregiver is not always attuned—developmental research shows frequent moments of misattunement in the dyad, ruptures of the attachment bond. 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. Again, the key to this is the caregiver's capacity to monitor and regulate her own affect, especially negative affect. The regulation of her own affective state, as well as the child's, may be an emotionally demanding task.

In this essential regulatory pattern of "disruption and repair" (Beebe & Lachmann, 1994; Schore, 1994) the "good-enough" caregiver who induces a stress response in her infant through a misattunement, reinvokes in a timely fashion her psychobiologically attuned regulation of the infant's negative affect state that she has triggered. The reattuning, comforting mother and infant thus dyadically negotiate a stressful state transition of affect, cognition, and behavior. This recovery mechanism underlies the phenomenon of "interactive repair" (Tronick, 1989; Lewis, 2000), in which participation of the caregiver is responsible for the reparation of stressful dyadic misattunements.

If attachment is interactive synchrony, stress is defined as an asynchrony in an interactional sequence, but a period of synchrony following this allows for stress recovery (Chapple, 1970). It is now thought that the process of reexperiencing positive affect following negative expe-

rience may teach a child that negativity can be endured and conquered. Infant resilience emerges from an interactive context in which the child and parent transition from positive to negative and back to positive affect, and resilience in the face of stress is an ultimate indicator of attachment capacity and therefore adaptive mental health.

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 and the interactive mutual entrainment of physiological rhythms are fundamental processes that mediates attachment bond formation, and attachment can be defined as the regulation of biological synchronicity between organisms (Schore, 2000b; Wang, 1997). The mechanism of attachment dynamics is thus an example of the regulation of rhythm, which is a fundamental organizing principle of all living systems (Iberall & McCulloch, 1969).

To put this another way, the infant's developing regulatory and control systems create spontaneous physiological rhythms that are manifest in arousal fluctuations, which are in turn expressed in fluctuating psychobiological affective states, what Stern (1985) calls vitality affects. It is now accepted that affects reflect an individual's internal state and have an hedonic (valenced) dimension and an arousal (intensity) dimension. The crescendos and decrescendos of the infant's peripheral (ANS) and central (CNS) arousal systems underlie emotions, and so the mutual entrainment of affective states in attachment transactions can be defined as the dyadic regulation of emotion (Sroufe, 1996). Thus, Damasio (1998) is correct in characterizing emotions as the highest order direct expression of bioregulation in complex organisms, but it should be emphasized that the efficient bioregulation of internal emotional states can take the form of both interactive regulation and autoregulation.

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 (Schore, 1994; Grossman, Grossman, & Zimmerman, 1999). This ability is a marker of adaptive infant mental health.

ATTACHMENT AND THE INTERACTIVE REGULATION OF THE RIGHT BRAIN

In a number of contributions I have offered evidence that indicates that the emotional communications of evolving attachment transactions directly impact the experience-dependent maturation of the infant's developing brain. Trevarthen (1993) also observes that that the growth of the baby's brain literally requires brain–brain interaction, and occurs in the context of a positive affective relationship (see Figure 1). But in light of the fact that the early maturing right hemisphere is in a growth spurt in the first year-and-a-half, and that it is dominant for the first three (Chiron et al., 1997), I have contended that attachment experiences specifically impact the development of the infant's right brain. Confirming this model, Ryan, Kuhl, and Deci, using EEG and neuroimaging data, now report,
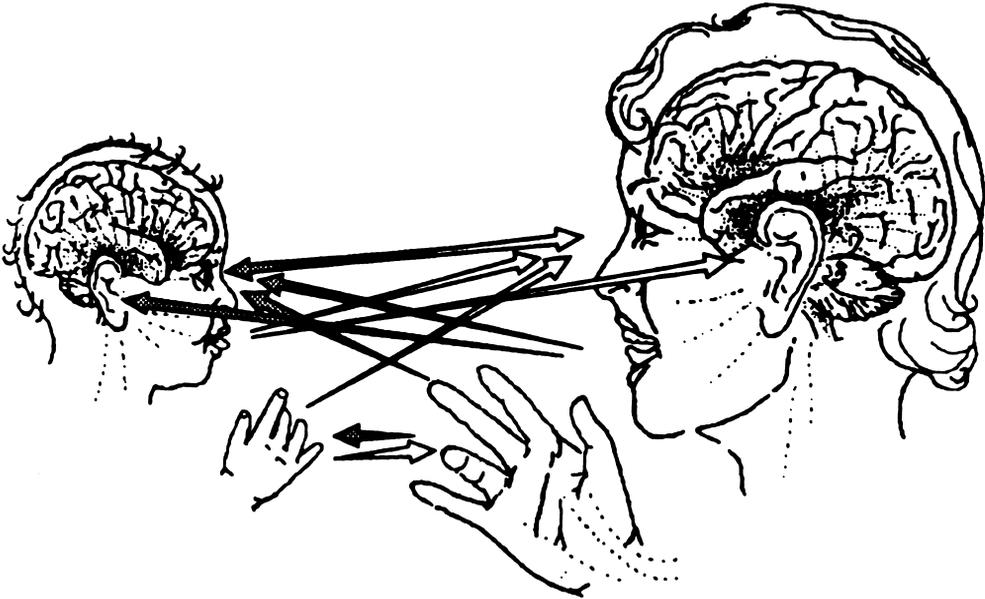
FIGURE 1. Brain–brain interactions during face-to-face communications of proto-conversation, mediated by eye-to-eye orientations, vocalizations, hand gestures, and movements of the arms and head, all acting in coordination to express interpersonal awareness and emotions. Adapted from Aitken & Trevarthen (1993) and used with permission of Cambridge University Press.

> 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. (1997, p. 719)

In an elegant phrase Trevarthen asserts 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). But again, I would amend this general statement to suggest that the regulators of both the infant and mother's brains are located in specifically the right limbic brain (Schore, 1994). Furthermore, Trevarthen's description of "emotional communication" as a traffic of visual, prosodic auditory, and gestural signals that induce instant emotional effects is paralleled by Buck's (1994) characterization of "spontaneous emotional communication":

> Spontaneous communication employs species-specific expressive displays in the sender that, given attention, activate emotional preattunements and are directly perceived by the receiver . . . The "meaning" of the display is known directly by the receiver . . . This spontaneous emotional communication constitutes a *conversation between limbic systems* . . . It is a biologically-based communication system that involves individual organisms *directly* with one another: *the individuals in spontaneous communication constitute literally a biological unit* . . . The direct involvement with the other intrinsic to spontaneous communication represents an attachment that may satisfy deeply emotional social motives. (p. 266, my italics)

Buck (1994) emphasizes the importance of the right limbic system, and localizes this biologically based spontaneous emotional communication system to the right hemisphere, in accord

with other research that indicates a right lateralization of spontaneous gestures (Blonder, Barns, Bowers, Moore, & Heilman, 1995) and emotional communication (Blonder, Bowers, & Heilman, 1991).

Recall Winnicott's (1971) description of 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." Winnicott contends that as a result of its transactions with the mother, the infant, through identification, internally creates a "subjective object." Recent research indicates that the right hemisphere is specialized for "the detection of subjective objects" (Atchley & Atchley, 1998), and for the processing and regulation of self-related information (Schore, 1994; Ryan et al., 1997; Kennan, Wheeler, Gallup, & Pascual-Leone 2001).

Furthermore, developmental neuroscientists have proposed that engrams related to emotional voices are more strongly imprinted into the early maturing, more active right hemisphere (Carmon & Nachson, 1973), and that particular areas of the right hemisphere are timed to be in a plastic and receptive state at the very time when polysensory information that emanates from faces is being attended to most intensely by the infant (Deruelle & de Schonen, 1998; de Schonen, Deruelle, Mancini, & Pascalis, 1993). These latter authors report that right hemisphere activation in face processing shows a significant structural advance at two to three months, in line with the previously cited work of Yamada et al. (1997, 2000) and Feldman et al. (1999). With ongoing episodes of affective synchrony, attachment functions mature later in the first year, and it has been suggested that "there is earlier maturation of right hemisphere inhibition over subcortically mediated emotional expressions in infancy, once cortical influences over this behavior come into play" (Best & Queen 1989, p. 273).

An accumulating body of evidence indicates that the infant's right hemisphere is involved in attachment and the mother's right hemisphere in comforting functions (Henry, 1993; Horton, 1995; Schore, 1994, 1998a, 1998b, 1999d, Shapiro, Jamner, & Spence, 1997; Siegel, 1999, Wang, 1997). Attachment represents the regulation of biological synchronicity between organisms, and imprinting, the learning process that mediates attachment, is defined as synchrony between sequential infant–maternal stimuli and behavior (Petrovich & Gewirtz, 1985). During the sequential signalling of play episodes mother and infant show sympathetic cardiac acceleration and then parasympathetic deceleration in response to the smile of the other (Donovan, Leavitt, & Balling, 1978). Imprinting is thus not a unidirectional learning process by which attachment experiences are passively absorbed into an empty template. Rather, it is an active dyadic process that occurs between two brains that are cogenerating synchronized emotional communications with each other.

I suggest that when two right brain systems are mutually entrained in affective synchrony they create a context of resonance, which is now thought to play a fundamental role in brain organization, CNS regulatory processes, and the organization of connectivity properties that are tuned by function (Salansky, Fedotchev, & Bondar, 1998). Earlier I described how in face-to-face contexts resonant amplification occurs when the frequency patterns of the mother's exogenous sensory stimulation coincides with the infant's own endogenous organismic rhythms. Trevarthen (1993) points out that the resonance of the dyad ultimately permits the intercoordination of positive affective brain states.

In current neuroscience, resonance refers to the ability of neurons to respond selectively to inputs at preferred frequencies, and "amplified resonance" or "amplifying currents" serve as a substrate for coordinating (synchronizing) patterns of network (circuit) activity. Basic research establishes that different behavioral and perceptual states are associated with different brain rhythms, that a resonant system evolves continuously into a spontaneously oscillatory system as the amplifying conductance is increased, and that amplified resonance can "tune networks to operate in frequency ranges of special biological meaning" (Hutcheon & Yarom, 2000, p. 220).

These general principles apply to face-to-face transactions, where patterns of information emanating from the caregiver's face, especially of low visual and auditory frequencies, are specifically processed by the infant's right hemisphere (Ornstein, 1997). The ventral stream (Ungerleider & Haxby, 1994) of this hemisphere is specialized to analyze low frequencies of visual perception that convey the general outlines of faces and low frequencies of auditory tones that express the emotional intonation of language, prime examples of biologically meaningful information. Fernald (1992) describes human maternal vocalizations to infants as "biologically relevant signals." Furthermore, these dyadically synchronized affectively charged transactions elicit high levels of metabolic energy for the tuning of right brain cortical–subcortical circuits involved in processing socioemotional information (Schore, 1994, 1997b, 2000d). An article in *Science* suggests "mothers invest extra energy in their young to promote larger brains" (Gibbons, 1998, p. 1346).

Lewis (1995) points out that the best example of the flowthrough of energy in a developing system is the processing of relevant information in the presence of emotion. Thus, as a result of synchronized emotional transactions, the organization of the infant's right brain shows increased coherence, as the flow of energy between the hierarchically organized higher right cortical and lower right subcortical components increase their connectivity, allowing the right brain to act as a self-regulating integrated whole, and therefore, capable of increasing complexity. This conception is consonant with current models that emphasize that the brain is a self-organizing system (van Pelt, Corner, Uylings, & Lopes da Silva, 1994), and that age increases brain complexity (Anokhin, Birnbaumer, Lutzenberger, Nikolaev, & Vogel, 1996). In applying dynamic systems principles to attachment theory, Siegel (1999) proposes a similiar scenario.

The infant's right brain is tuned to dynamically self-organize upon perceiving certain patterns of facially expressed exteroceptive information, namely the visual and auditory stimuli emanating from the smiling and laughing joyful face of a loving mother. In face-to-face interactive affect-amplifying transactions, the relational context triggers facially expressed "affect bursts" in the infant. According to Scherer, these highly emotionally charged events lead to a "strong synchronization of various organismic subsystems, particularly the various expressive channels, over a very brief period of time" (1994, p. 181).

What psychoneurobiological mechanism could underlie this caregiver-induced organization of the infant's brain? In earlier work I have suggested that the appearance of the mother's face in dyadic play experiences generates high levels of dopaminergic-driven arousal and elation in the infant's right brain (Schore, 1994). Dopamine neurons in the ventral tegmental area of the anterior reticular formation are involved in reward and emotionality (Wise & Rompre, 1989), and they respond to visual, auditory, and tactile stimuli by switching from "pacemaker-like firing" to "burst firing" (Gonon, 1988; Overton & Clark, 1997) in response to an environmental stimulus that is "ethologically salient" (a good definition of sensory stimulation emanating from the mother). This pacemaker firing of a subnuclei of arousal-generating ventral tegmental dopamine neurons may represent an important component of the infant's genetically encoded endogenous organismic rhythms.

The bursting of these neurons to salient, arousing environmental stimuli contributes to an orienting response, the setting of a motivational state, and the onset of exploratory behavior (Horvitz, Stewart, & Jacobs, 1997). Furthermore, "electrical coupling among bursting dopamine neurons may provide a mechanism for further amplification of the effects of synchronously firing dopamine cells on their target areas" (Freeman, Meltzer, & Bunney, 1985, p. 1993). Evidence also indicates that the evaluation of an environmental stimulus as affectively positive is associated with dopaminergic activation of specifically the right brain (Besson & Louilot, 1995).

An integration of these data may give us a model of the critical right brain events by which psychobiologically attuned attachment communications generate amplified resonance that tunes reward circuits to certain forms of human visual and auditory patterns of stimulation. In affectively charged face-to-face transactions, the biologically significant information that emanates from the mother's face is imprinted into the infant's developing right interior temporal areas that process familiar faces (Nakamura et al., 2000), and thereby takes on "special biological meaning." The right hemisphere is also dominant for the perception of "biological motion." These psychoneurobiological events of mother–infant play sequences drive the "affective bursts" embedded within moments of affective synchrony, in which positive states of interest and joy are dyadically amplified. Panksepp (1998) contends that "play may have direct trophic effects on neuronal and synaptic growth in many brain systems" (p. 296), and suggests that play serves the adaptive role of organizing affective information in emotional circuits, a function also performed by rapid eye movement (REM) dream sleep. This fits nicely with current neuroscience conceptions of the important role of REM sleep in brain maturation (Marks, Shaffery, Oksenberg, Speciale, & Roffwarg, 1995) and imaging studies showing a preferential activation of limbic regions in REM sleep (Braun et al., 1997; Maquet et al., 1996).

How can we account for the trophic effects of early play episodes? Again, in a previous contribution (Schore, 1994) I have proposed that in these face-to-face emotional communications, the visual input of the mother's face is also inducing the production of neuorotrophins in the infant's brain, such as brain-derived neurotrophic factor (BDNF). Maternal care has been shown to increase N-methyl-D-aspartate (NMDA) receptor levels, resulting in elevated BDNF and synaptogenesis in the infant's brain (Liu et al., 2000). This trophic factor, which is regulated by visual input (Gomez-Pinilla et al., 1999), promotes synaptic plasticity during postnatal critical periods (Huang et al., 1999). BDNF is also a growth-promoting factor for mesencephalic dopamine neurons (Hyman et al., 1991), and dopamine, which activates NMDA receptors (Knapp, Schmidt, & Dowling, 1990), is known to perform a growth-promoting role in the postnatal development of the cortex (Kalsbeek, Buijs, Hoffman, Matthijssen, Pool, & Uylings, 1987), especially in corticolimbic areas that send axons down to the dendrites of these dopamine neurons, and thereby come to regulate their activity (Sesack & Pickel, 1992; Schore, 1994). Dopamine acts as a trophic agent via regulation of the developing blood brain barrier (Schore, 1994) and microcirculation (Krimer et al., 1998) of developing target areas.

Other psychobiological data may explicate the mechanisms that mediate attachment, the interactive regulation of biological synchronicity between organisms. Despite the intrinsic dyadic nature of the attachment concept, hardly any research has concurrently measured mother and infant in the process of interacting with each other. In one of the few studies of this kind, Kalin, Shelton, and Lynn (1995) show that the intimate contact between the mother and her infant is mutually regulated by the reciprocal activation of their opiate systems—elevated levels of beta endorphins increase pleasure in both brains. It is established that opioids enhance play behavior (Schore, 1994), and that endorphins increase the firing of mesolimbic dopamine neurons (Yoshida et al., 1993).

Furthering these ideas, the developmental principle of "reciprocal mutual influences" refers to more than mutual behavior changes; indeed, it specifically implies that there are simultaneous changes within the right brains of *both* members of the dyad. In terms of the self-organization theory, the mutual entrainment of their right brains during moments of affect synchrony triggers an amplified energy flow that allows for a coherence of organization that sustains more complex states within both the infant's and the mother's right brains. In this manner, "the self-organization of the developing brain occurs in the context of a relationship with another self, another brain" (Schore, 1996, p. 60).

Evidence is now appearing that supports the idea that the organization of the mother's

brain is also being influenced by these relational transactions. A neurobiological study of early mammalian mother–infant interactions, published in *Nature*, entitled "Motherhood improves learning and memory," reports increased dendritic growth in the mother's brain (Kinsley et al., 1999). The authors conclude that events in late pregnancy and the early postpartum period

> . . . may literally reshape the brain, fashioning a more complex organ that can accommodate an increasingly demanding environment. . . . To consider the relationship of a mother caring for her young as unidirectional disregards the potentially rich set of sensory cues in the opposite direction that can enrich the mother's environment. By providing such stimuli, (infants) may ensure both their own and their mother's development and survival. (p. 137)

Hofer's (1990) developmental psychobiological work also emphasizes the bidirectional brain events of the mother–infant interaction. He describes, in detailed fashion, how the infant's immature and developing internal homeostatic systems are coregulated by the caregiver's more mature and differentiated nervous system. In this "symbiotic" pleasurable state, the adult's and infant's individual homeostatic systems are linked together in a superordinate organization that 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" (Hofer, 1990, p. 71).

These matters bear upon the concept of symbiosis, which has had a controversial history in recent developmental psychoanalytic writings. This debate centers around Mahler, Pine, and Bergman's (1975) reference to a normal symbiotic phase during which the infant "behaves and functions as though he and his mother were a single omnipotent system—a dual unity within one common boundary" (p. 8). Although the symbiotic infant is dimly aware that the mother is the source of his pleasurable experiences, he is in a "state of undifferentiation, a state of fusion with the mother, in which the 'I' is not differentiated from the 'not-I'" (p. 9).

This latter defintion of symbiosis departs from the classical biological concept, and is unique to psychoanalytic metapsychology. Current evidence may not directly support any inferences about the limits of the infant's awareness, nor about an entire stage that describes the infant's behavior only with this characterization. However, moments of face-to-face affective synchrony do begin at two to three months, the advent of Mahler's symbiotic phase, they do generate high levels of positive arousal, and such mutually attuned sequences can be portrayed as what Mahler et al. (1975) call instances of "optimal mutual cueing."

But even more importantly, Hofer's work as well as recent brain research calls for a return of the definition of symbiosis to its biological origins. The Oxford dictionary offers the derivation from the Greek, "living together," and defines symbiosis as an interaction between two dissimilar organisms living in close physical association, especially *one in which each benefits the other* (my italics). An even more basic definition from biological chemistry suggests that "symbiosis is an association between different organisms that leads to a reciprocal enhancement of their ability to survive" (Lee, Severin, Yokuba Yashi, & Reza Ghadiri, 1997, p. 591). Recall Buck's (1994) description of an emotionally communicating dyad as "literally a biological unit," a conception that echoes Polan and Hofer's (1999) description of the dyad as a self-organizing regulatory system composed of mother and infant as a unit. These conceptions suggest that instances of secure attachment bonding are an example of biological symbiosis. Interestingly, the Oxford dictionary also defines symbiosis as "companion," which suggests that Trevarthen's concept refers to this same psychobiological phenomenon.

The construct of symbiosis is reflected in the conception of attachment as the interactive regulation of biological synchronicity between organisms. In discussing the central role of facial signalling in attachment, Cole asserts, "It is through the sharing of facial expressions that mother and child become as one. It is crucial, in a more Darwinian biological context, for the

infant to bond her mother to ensure her own survival" (1998, p. 11). Recall Bowlby's (1969) assertion that the development of attachment has consequences that are vital to survival and that the infant's capacity to cope with stress is correlated with certain maternal behaviors. The right hemisphere is dominant for both attachment functions and for the control of vital functions supporting survival and enabling the organism to cope actively and passively with stress. These capacities are surely critical indices of adaptive infant mental health.

ATTACHMENT TRANSACTIONS AND THE HIERARCHICAL ORGANIZATION OF THE LIMBIC SYSTEM

Mary Main concludes that "The formation of an attachment to a specified individual signals a quantitative change in infant behavioral (*and no doubt also brain*) organization" (1991, p. 214, my italics). As a result of advances in the "decade of the brain" can we now identify what specific brain areas mediate this function? In his initial outline of attachment theory, Bowlby speculated that a "succession of increasingly sophisticated systems" involving the limbic system and brain arousal-regulating areas mediate attachment processes (1969, p. 154). It is well established that regions of the brain mature in stages, so the question is, what parts of the postnatally developing brain are maximally impacted by emotionally charged attachment experiences? As previously mentioned, the emotion processing limbic system has been implicated in attachment functions.

Indeed the first 18 months of human life are critical for the myelination, and therefore, the maturation of particular rapidly developing limbic and cortical association areas and limbic areas of the human cerebral cortex show anatomical maturation at about 15 months. It has long been thought that the limbic system is fundamentally associated with emotional functions. But as I stated previously, recent conceptions emphasize that limbic system function underlies the organization of new learning and the capacity to adapt to a rapidly changing environment (Mesulam, 1998). This concept relates to Hinde's assertion that "the development of social behavior can be understood only in terms of a continuing dialectic between an active and changing organism and an active and changing environment" (1990, p. 162).

Within the first year perhaps no organismic system is changing as rapidly as the brain, especially a sequence of ontogenetically appearing limbic circuits. These systems are organized from the simplest to the most complex, and they onset in a fixed progression over the first year, with the later maturing hierarchical cortical structures adaptively regulating the earlier maturing subcortical systems. This general ontogentic principle is articulated by Werner (1948), who suggested that "the development of biological forms is expressed in an increasing differentiation of parts and an increasing subordination, or hierarchization . . . an ordering and grouping of parts in terms of the whole (1948, p. 44). This hierarchical model has been significantly advanced in the psychoanalytic literature in the groundbreaking work of Gedo (1999; Gedo & Wilson, 1993).

In the current neuroscience literature Toates describes the importance of hierarchical control systems in development:

Development is associated with gaining autonomy from sensory control and acquisition of top-down control over behavior that is organized at a lower level. Reflexes can become integrated into cortical control. Such control will be perhaps most usually inhibition, but excitation might also occur . . . acquisition of higher-level control is not merely a process of more inhibition being exerted since the new forms of reacting to the environment also emerge and it is assumed that these are mediated at the higher level. (1998, p. 73)

In classical ego psychology psychoanalytic writings, Hartmann (1939) proposed that adaptation is primarily a reciprocal relationship of the organism and its environment, and that development is a differentiation in which primitive regulatory systems are increasingly replaced or supplemented by more effective regulatory systems. The progression and reorganization of the infant's regulatory, control systems is described by Brazelton and Cramer:

> The central nervous system, as it develops, drives infants towards mastery of themselves and their world. As they achieve each level of mastery, they seek a kind of homeostasis, until the nervous system presses them on to their next level. Internal equilibrium is always being upset by a new imbalance created as the nervous system matures. Maturation of the nervous system, accompanied by increasing differentiation of skills, drives infants to reorganize their control systems (1990, p. 98).

Fischer and Rose (1994) conclude that the development of higher order control system allows for the emergence of "dynamic skills," that a developmental stage is a point at which a new level of control systems emerge, and that emotions fundamentally shape the ways that control systems develop.

These control systems can now be identified. In current neuroscience, the neuroanatomy of the limbic system is characterized as a hierarchical system of vertically organized circuits within the brain (see Figure 2). And so authors are now referring to the "rostral limbic system"

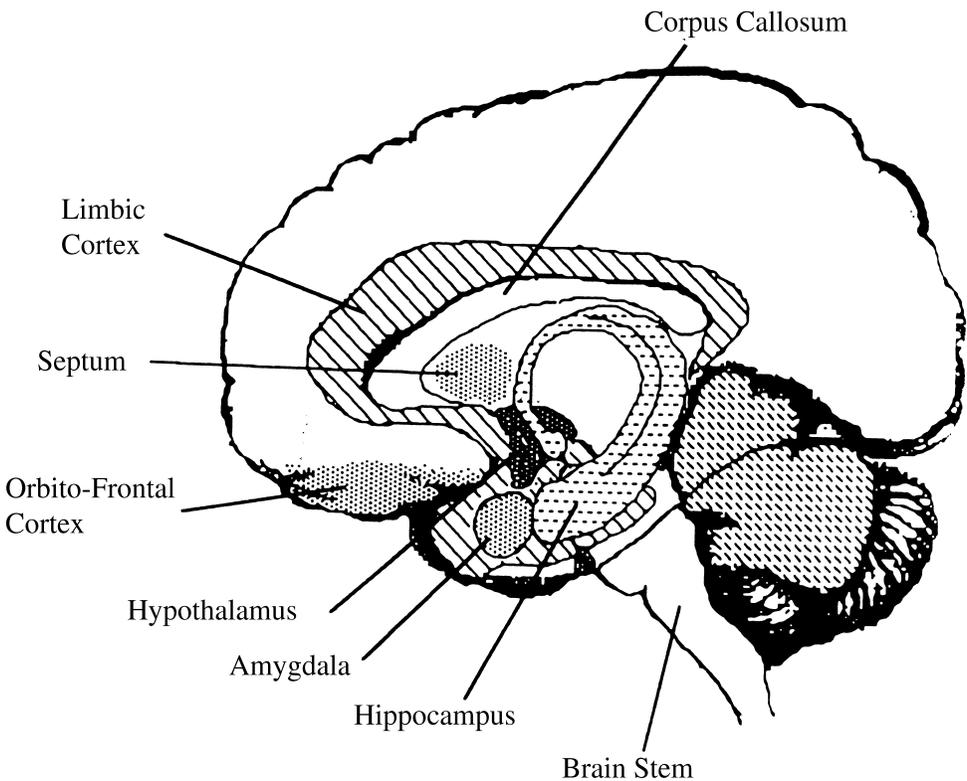

FIGURE 2.   Limbic structures of the right hemisphere, lateral view. Cingulate is labeled limbic cortex (from Trevarthen, Aitken, Papoudi, & Roberts, 1998, and used with permission of Jessica Kingsley Publishers).

a hierarchical sequence of interconnected limbic areas in orbitofrontal, insular cortex, anterior cingulate, and amygdala (Devinsky, Morrell, & Vogt, 1995), an "anterior limbic system" composed of orbitofrontal cortex, basal forebrain, amygdala, and hypothalamus (Schnider & Ptak, 1999), a "paralimbic circuit" containing orbitofrontal, insular, and temporopolar cortices (Mesulam & Mufson, 1982), an "anterior limbic prefrontal network" interconnecting the orbital and medial prefrontal cortex with the temporal pole, cingulate, and amygdala (Carmichael & Price, 1995), and a complex circuit of emotion regulation consisting of orbital frontal cortex, anterior cingulate, and amygdala (Davidson, Putnam, & Larson, 2000).

A body of evidence shows that the orbitofrontal-insula, medial frontal anterior cingulate, and amygdala systems all interconnect with each other and with brain stem bioaminergic neuromodulatory and hypothalamic neuroendocrine nuclei (see Figure 3). Although each has reciprocal connections with dopamine neurons in the ventral tegmental area of the anterior reticular formation and noradrenaline neurons of the caudal reticular formation, each limbic subsystem maintains connections with different monoaminergic subnuclei (Halliday & Tork, 1986; Halliday et al., 1988).

Because they are all components of the limbic system, each processes and imprints a positive or negative hedonic charge on current exteroceptive information about changes in the external social environment, and then integrates it with interoceptive information about concurrent alterations in internal bodily states. Due to the facts that they each directly interconnect with the ANS (Neafsey, 1990), and that autonomic activity is controlled by multiple integrative sites within the CNS that are heirarchically organized (Lane & Jennings, 1995), all are involved in the regulation of bodily-driven affective states. Although all components process exteroceptive and interoceptive information, the later maturing systems in the cortex will process this information in a more complex fashion than the earlier subcortical components. The output of the lowest level limbic levels have the character of automatic innate reflexes, while higher processing produces more flexible intuitive responses that allow fine adjustment to environmental circumstances.

In optimal socio-emotional environments, each limbic level has bidirectional connections with the others, and in this manner information can both be forwarded up and down the limbic axis for further appraisal and hierarchical modulation. The earliest and simplest appraisals of exteroceptive and interoceptive affective stimuli would be hedonic and aversive affective core processes in the amygdala (Berridge, 2000), the later and most complex subjective experiences of pleasure and pain in the orbitofrontal areas (Blood, Zatorr, Bermudez, & Evans, 1999; Francis et al., 1999; Petrovic, Petersson, Ghatan, Stone-Elander, & Ingvar, 2000). These operations are primarily lateralized to the right limbic system, which is preferentially connected downward to the right neurochemical systems associated with emotion (Buck, 1994) and upward to the ipsilateral right neocortex (Wilson, Isokawa, Babb, Crandal, Levesque, & Engel, 1991).

The concept of a hierarchically organized brain that develops through an increasingly complex coordination of lower and higher levels was first introduced by the British neurologist Hughlings Jackson at the end of the nineteenth century. Jackson conceived of three levels of organization, including the lowest and most primitive, middle, and last to evolve, highest centers. Each of these levels is a representing system, with the highest level of integration and coordination dependent upon prefrontal activity that allows the organism as a whole to adjust to the environment (Jackson, 1931). A similar trilevel model is also seen in MacLean's (1990) triune brain. As applied to the developmental organization of the right limbic system of the right brain, this conception suggests a three-tiered self-organizing dynamic system. Increased interconnectivity (energy flow) among the three component circuits would allow for informa-

SCHORE'S RIGHT BRAIN DUAL CORTICOLIMBIC-AUTONOMIC CIRCUITS

RIGHT CORTEX

CNS Exteroceptive sensory input, visual, auditory, tactile, gustatory & olfactory

Mesocortical

3. Orbitofrontal:
•Online at 10-12 months
•Executive control system
•Expanded in the right
•Emotional regulation
•Joint Attention

VENTRAL TEGMENTAL CIRCUIT
Regulates positive emotions (approach)

Dopaminergic - Excitatory
•Active Coping
•Fight-flight
•To remove source of stress

Mesolimbic

LATERAL TEGMENTAL CIRCUIT
Regulates negative emotions (avoidance)

2. Cingulate
•Online at 3-9 months
•Responsive to social cues
•Shared pleasure states
•Separation anxiety

Noradrenergic - Inhibitory
•Passive Coping
•Immobility & Withdrawal
•To reduce effects of stress

1. Amygdala
•Functional at birth
•Startle response/passive avoidance
•Inhibited/disinhibited temperament

Hypothalamus

Neuroendocrine

Reticular Formation

Catecholamine Neuromodulator

Ventral Tegmental Dopamine Neurons

Sympathetic Nuclei

Parasympathetic Nuclei

Medullary Noradrenaline Neurons

Nucleus of solitary tract

ANS interoceptive information - Viscera regulation

RIGHT VAGUS NERVE

Mobilization or Calming input

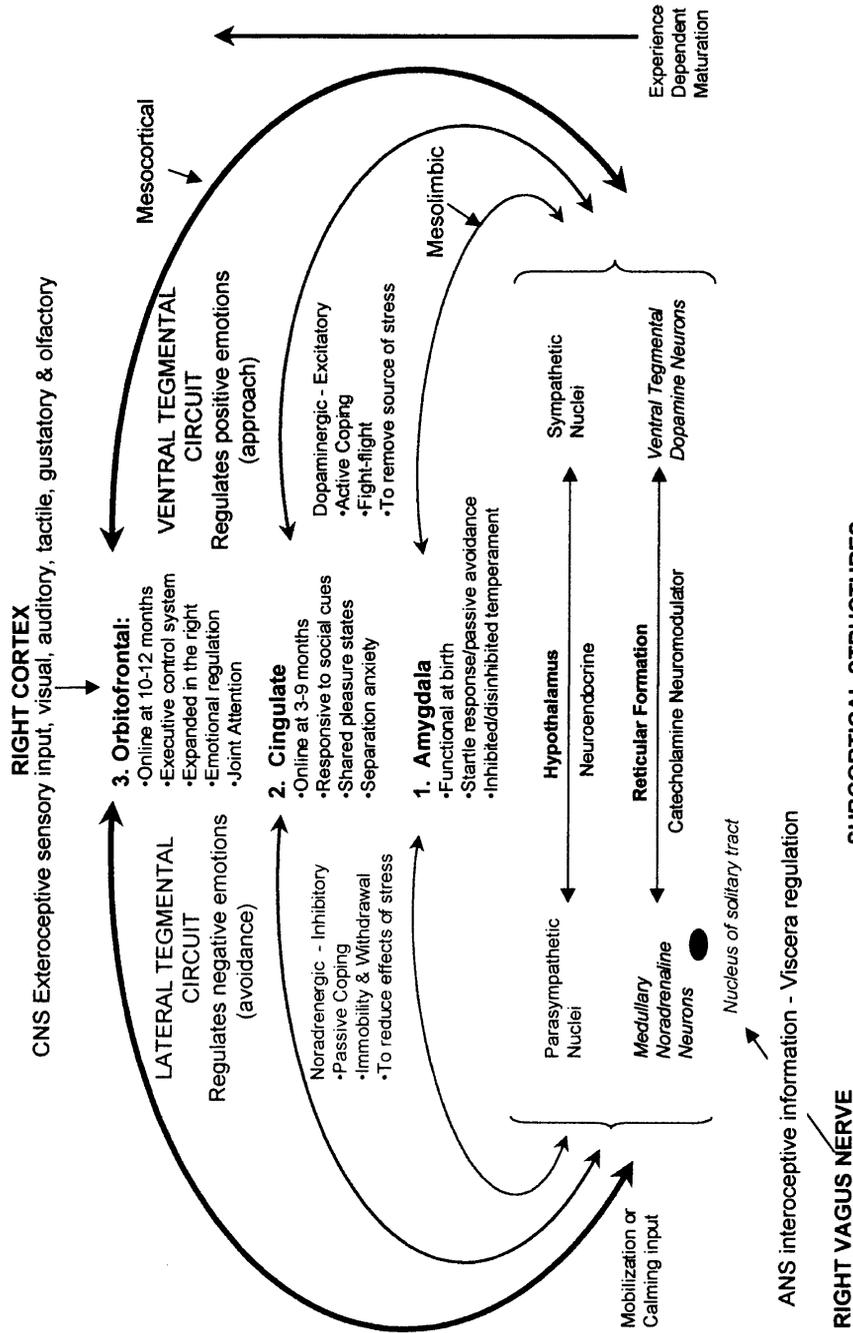Experience Dependent Maturation

SUBCORTICAL STRUCTURES

FIGURE 3.   Schematic of right brain dual cortical–limbic circuits.

tion stored at one level to be transferred to the others. The top level that receives feedback from the lower performs an executive function (Toates, 1998), and this allows for emergent properties, that is, novel combinations of more complex emotional states.

In line with the Jacksonian ontogenetic concept of vertical brain organization (Luu & Tucker, 1996) and the principle of caudal-to-rostral brain development, a model of the ontogeny of the limbic system can be offered. Keeping in mind that in humans this development continues postnatally, reversing the sequence of the rostral limbic system (amygdala, anterior cingulate, insular-orbitofrontal) could offer specific ideas about how a number of discrete limbic components could come on line in a defined sequence in the first year. Recall Bowlby's speculation that the limbic system is centrally involved in attachment and that the "upgrading of control during individual development from simple to more sophisticated is no doubt in large part a result of the growth of the central nervous system" (1969, p. 156).

The following sequence represents Bowlby's "succession of increasingly sophisticated systems" that mediates attachment development. I further propose that the ontogenetic progression of each of these limbic subsystems progresses from an initial sympathetic-dominant excitatory phase followed by a latter parasympathetic-dominant inhibitory phase and ultimately excitation-inhibition balance (see Schore, 1994).

At birth, only the amygdala (see Figure 2), a primitive limbic regulatory system that appraises crude information about external stimuli and modulates autonomic and arousal systems, is on line (Chugani, 1996). The right amygdala is known to be implicated in the processing of olfactory stimuli (Zald, Lee, Fluegel, & Pardo, 1998) within the mother and the perinatal infant relationship (Van Toller & Kendal-Reed, 1995). This suggests that right amygdala-driven processes underlie the infant's recognition of the mother's scent as well as the mother's recognition of neonates through olfactory cues (Porter, Cernoch, & McLaughlin, 1983).

Amygdala memorial systems also mediate the organization of the earliest representations of the infant maternal relationship that allow six-day-old infants to discriminate the scent of their mother's breast pad (MacFarlane, 1977) or axillary odor (Cernoch & Porter, 1985) from that of another woman. This early appearing subcortical limbic control system is thus a central component of the proto-attachment mechanisms that are driven by the unique salience of olfactory signals (Porter & Winberg, 1999). These data further suggest that dyadic "human olfactory communication" (Russell, 1976) occurs between the mother's and infant's right brains. Limbic areas of the right hemisphere are also centrally involved in human gustation (Small et al., 1999).

The fact that the processing of olfactory/gustatory information is dominant in the perinatal period is also documented by developmental researchers. The primary organ of the body that specializes in the latter function is, of course, the mouth. According to Hernandez-Reif et al. (2000, p. 205):

> The infant mouth, including the tongue, is a highly specialized multifunctional sensory-motor system designed to receive nutrients and to express discomfort, such as by varied cries that relay hunger or pain (van den Boom & Gravehurst, 1995). . . . Recent research revels that the newborn's mouth is also a well-developed perceptual organ. Upon contacting a non-nutritive object, the tactile receptors of the mouth generate positive presssure, presumably for the purpose of detecting object information. (Butterworth & Hopkins, 1988; Rochat, 1983)

These authors point out that newborns exhibit a transfer of learning from information detected by the mouth to other sensory modalities, citing studies which show that newborns

suck harder in order to see the visual (Walton, Bower, & Bower, 1992) and hear the auditory stimulation (DeCasper & Fifer, 1980) emanating from the mother's face. They also mention that at a later point of development (the second quarter of the first year; Morange-Majoux, Cougnot, & Bloch, 1997), exploration of objects shifts from the mouth to the hands (Bloch, 1998).

In the cerebral hemispheres only the primary somatosensory cortex is metabolically active at birth (Chugani, 1996), and this area is known to process tactile and kinesthetic sensations. If the olfactory and gustatory systems are connecting into the amygdala prenatally, I suggest that specifically somatosensory connections into the amygdala are also forming by the end of the first two months. Sufficient levels of tactile stimulation are provided by the maternal environment in the form of maternal contact comfort that releases early protoattachment behavior. Taylor (1987) notes, "The sensations impinging on the infant's skin presumably help regulate aspects of the infant's behavior and physiology" (p. 164). In accord with this, the classical work of Harlow (1958) demonstrates that skin-to-skin contacts come on-line early, and that the infant actively seeks to adhere to as much skin surface on the mother's body as possible.

Most human females cradle their infants on the left side of the body (Manning et al., 1997; Harris, Almergi, & Kirsch, 2000). This tendency is well developed in women but not in men, is independent of handedness, and is widespread in all cultures. 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). It also has been observed that "the language of mother and infant consist of signals produced by the autonomic, involuntary nervous system in both parties" (Basch, 1976, p. 766). This hemisphere, deeply connected into the ANS, is specialized for tactile perception on both sides of the body (Carmon & Benton, 1969) and for the perception and recall of spatial patterns of touch in nonverbal memory (Milner & Taylor, 1972). Again, the overt expressions of right hemisphere-to-right hemisphere communications are manifest from the very beginnings of infancy.

Neurobiological research indicates that "in early postnatal life, maintenance of critical levels of tactile input of specific quality and emotional content is important for normal brain maturation" (Martin, Spicer, Lewis, Gluck, & Cork, 1991, p. 3355). Indeed, the sensory input derived from contact with the mother during nursing has been suggested to shape dendritic growth (Greenough & Black, 1992). Infantile handling, tactile stimulation associated with comforting "holding" and "containing" experiences provided by the mother, induces permanent modifications of later hypothalamic CRF levels (Campbell, Zarrow, & Denenberg, 1973). Again, these experiences are right laterlized. Kalogeras et al. (1996) demonstrate that the right side of the human hypothalamus is dominant for neuropeptide secretion, including CRF activity.

I further propose that areas of the amygdala in the medial temporal lobe, especially the central and medial nuclei, are in a critical period of maturation that onsets in the last trimester of pregnancy and continues through the first two months of human life, the earliest period of bonding. In growth-facilitating perinatal environments, the experience-dependent maturation of interconnections between the infant's right amygdala and right paraventricular hypothalamic nuclei allow for coregulation of vasopressin and the antistress hormone oxytocin in early maternal–infant interactions (Panksepp, 1998). This is a critical period of organization of the amygdalar–hypothalamic system, in which sensory information processed by the amygdala receives a positive or negative hedonic charge and is then relayed to various hypothalamic nuclei (Fonberg, 1986). These events occur in what Bowlby (1969) calls the "preattachment phase" of the first two months, the same time period of the evolution of Stern's (1985) "emerging self," and the time-frame of the first-to-mature homeostatic control system described by Brazelton (2000) that is on-line in the first weeks of life.

I previously cited a finding of a milestone for normal development in a rapid change in brain maturation at eight weeks, reflecting the onset of a critical period during which synaptic connections in the primary visual cortex are modified by visual experience (Yamada et al., 1997, 2000). At this time infant visual preference behavior shifts from subcortical to cortical processing (Hoffmann, 1978), and face-to-face interactions, occurring within the primordial experiences of human play, first appear (Cohn & Tronick, 1987). Fogel and Branco observe

> Three-month old-infants signal their willingness to engage in play by both gazing at mother and smiling, and they use gaze away and the cessation of smiling or the onset of crying to indicate their desire to end a bout of play. Before three months, infants do not have the ability to do this. (1997, p. 76)

In these play sequences of affective synchrony, dyadically amplified elevations in sympathetic arousal occur in gaze engagements, followed by infant increases in parasympathetic activity (vagal nucleus ambiguus) in gaze aversion disengagements. The vagally controlled hormone, oxytocin, now is released by "sensory stimuli such as tone of voice and facial expression conveying warmth and familiarity" (Uvnas-Molberg, 1997, p. 42). Vagal tone (Porges, 1991) is undeveloped and weak in the first quarter of the first year, but increases significantly at two to four months (Kagan, 1994), a time when primary intersubjectivity and delight and laughter first appear (Sroufe, 1996).

This same interval represents the onset of a critical period for the development of the anterior cingulate areas (see Figure 2) of the medial frontal cortex, a region involved in play and separation behaviors, laughing and crying vocalizations, face representations, and modulation of autonomic activity (MacLean, 1993; MacLean & Newman, 1988; Paus, Petrides, Evans, & Meyer, 1993). MacLean (1987) provides evidence to show that this cortex is responsible for vocalizations that "maintain maternal–offspring contact." The anterior cingulate is also known to contribute to maternal behavior (Slotnick, 1967). A recent fMRI study reveals that the mother's cingulate and right orbitofrontal cortex respond to both pain and separation cries of an infant (Lorberbaum et al., 2000). With regard to the infant's expanding capacities, the right cingulate and parietal areas have been implicated in exploratory attentional movements (Gitelman et al., 1996) in the generation of a subjective prediction, and in the anticipation of being tickled (Carlsson, Petrovic, Skare, Petersson, & Ingvar, 2000).

Recall the earlier depiction of mutually regulated states of maternal–infant high arousal, attention, and vocalizations occuring in play experiences that emerge at this time (Feldman et al., 1999). This is also the onset of the positive resonances that occur within the mother–infant "protoconversations" that induce what Trevarthen calls primary intersubjectivity (Trevarthen, Aitken, Papoudi, & Roberts, 1998). In this relational context the primary caregiver's anterior cingulate-driven maternal behavior would be socially tuning the infant's medial frontal cortex, thereby influencing the parcellation and final circuit wiring of the baby's developing anterior cingulate. During this critical period of the onset the infant's anterior cingulate-right temporal (Nakamura et al., 2000) sulcus face processing, which Mahler et al. (1975) call the symbiotic period, the infant forms a discriminate attachment to the mother's face.

The later occurring parasympathetic phase of the critical period of growth of this limbic component would occur in the third quarter, a time of cingulate-driven expressions of separation-anxiety (Joseph, 1992; MacLean, 1990), responses to attachment ruptures. At seven to ten months infants show fear (Sroufe, 1996) and stranger anxiety, in which they inhibit ongoing behavior and withdraw when exposed to novel and threatening situations and unfamiliar people.

The emergence of this more complex defensive behavior, inhibited approach, represents the parasympathetic maturation of the cingulate.

Furthermore, in light of the known role of the cingulate in consciousness (Kennard, 1955), it is tempting to speculate that the experience-dependent maturation of this limbic structure may be activated in moments of dyadically expanded states of consciousness that onset in the middle of the first year. Tronick et al. (1998) are now describing how microregulatory social-emotional processes of communication literally expand intersubjective states of consciousness in the infant–mother dyad. They argue that the baby's self-organizing system, when coupled with the mother's, allows for a brain organization that can be expanded into more coherent and complex states of consciousness. The interpersonal context of a coregulated dyadic system allows for "a mutual mapping of (some of) the elements of each partner's state of consciousness into the other partner's brain" (p. 296).

I suggest that Tronick is describing an expansion of what Edelman (1989) calls primary consciousness. Edelman states primary consciousness relates visceral and emotional information pertaining to the biological self to stored information pertaining to outside reality, and that it is lateralized to the right brain. Activity of limbic cingulate areas are known to be associated with primary consciousness (Denton et al., 1999). This developmental work supports the idea that consciousness is a product of that part of the brain that handles human relations, and is a property of a brain that is and has been in communication with other brains (Barlow, 1980; Schore, 1994). It also suggests that indices of the maturation of the infant's capacity for primary consciousness needs to be included in our models of infant mental health.

The critical period of anterior cingulate-driven limbic maturation thus overlaps Bowlby's (1969) phase of "attachment-in-the-making," and mediates what Stern (1985) terms, "the core self." Brazelton (2000) describes the emergence in the second quarter of the first year of a second homeostatic control system, one associated with a mutual reciprocal feedback system, although an advance of the former control system it is still "an immature psychophysiological system." I suggest this system can be identified as a maturing anterior cingulate which now hierarchically controls the earlier amygdala-dominated limbic configuration.

The right insula, a limbic structure involved in emotional and facial processing (Berthier, Starkstein, & Leiguarda, 1987), in integrating tonal structure with a speaker's emotions and attitudes (Riecker, Ackermann, Widgruber, Dogil, & Grodd, 2000), and in visceral and autonomic functions that mediate the generation of an image of one's physical state (Craig, Chen, Bandy, & Reiman, 2000) is also activated in primary consciousness (Denton et al., 1999). This limbic structure is implicated in pain processing and serves as an alarm center, "alerting the individual to potentially distressing interoceptive stimuli, investing them with negative emotional significance" (Banzett, Mulnier, Murphy, Rosen, Wise, & Adams, 2000, p. 2120). It is tempting to speculate that the experience-dependent maturation of this system is associated with both the more complex representation of body image and "stranger anxiety" that emerges in the second half year of life.

In the last quarter of the first year the quality of the infant's social relatedness changes dramatically (see Schore, 1994), due to the concurrent rapid myelination and maturation of developing limbic and cortical association areas. If earlier face-to-face interactions contain only spontaneous communication processes, after nine months the infant can engage in "joint attention," the ability to shift attention between an object and a person. In this form of nonverbal communication the infant coordinates his visual attention with that of the caregiver, and is now not only aware of an object but simultaneously aware of the mother's attention to the object. In such instances of what Trevarthen et al. (1998) call "secondary intersubjectivity," each member of the dyad coaligns separable, yet related forms of consciousness.

Joint attention occurs within highly affectively charged social referencing transactions, an

attachment process that mediates a resonance of positive affect (Schore, 1994). This dyadic mechanism allows the infant to appreciate that "the other person is a locus of psychological attitudes toward the world, that the other is 'attending' in such a way that shared experiences are possible" (Hobson, 1993, p. 267). In this manner the child comes to understand others "as intentional beings, that is, as subjects of experience possessing internal states such as interest and attention" (Tomasello & Camaioni, 1997, p. 20). To get an adult to tune into his attentional and intentional focus on the world the infant now uses an expanded repertoire of bidirectional communicative gestures, an important cognitive advance that communicates intention (Goldin-Meadow, 2000). It is also is in this period, the last quarter of the first year, when "the infant starts to adopt a mentalistic strategy to interpret and predict the behavior of other agents" and is "capable of taking the intentional stance" (Gergely, Nadasdy, Csibra, & Biro, 1995, p. 184). In developmental neurobiological research, Caplan et al. suggest that "the development of joint attention might reflect maturation of the prefrontal cortex" (1993, p. 589).

These critical advances represent a further maturation of the right hemisphere, because current research suggests it contributes to attention and intention (Mattingley, 1999; Sturm et al., 1999). Very recent studies of joint attention demonstrate that the right (and not left) hemisphere shifts attention to where someone is looking to follow the gaze of another (Kingstone, Friesen, & Gazzaniga, 2000). In fact, there is now evidence for "a special role for the right frontal lobe in sustaining attention over time" (Rueckert & Grafman, 1996, p. 952). Very recent reports now reveal that the right orbitofrontal and right anterior insula cortices are components of a neural circuit that "enables integration of adaptive bodily responses with ongoing emotional and attentional states of the organism" (Critchley, Elliott, Mathias, & Dolan, 2000b, p. 3033). But in addition this right prefrontal cortex is fundamentally involved in "regulating emotional responses" (Hariri, Bookheimer, & Mazziotta, 2000).

THE MATURATION OF AN ORBITOFRONTAL REGULATORY SYSTEM

In *Affect Regulation and the Origin of the Self* and continuing works I offer evidence to show that the orbital prefrontal cortex enters a critical period of growth that spans the last quarter of the first through the middle of the second year, an interval that corresponds with the beginnings of human socialization. The critical period of orbitofrontal-driven limbic maturation thus over-laps and mediates what Stern (1985) terms the developmental achievement of "the subjective self." This prefrontal limbic structure is reciprocally interconnected with other limbic areas in the insula (Augustine, 1996), anterior cingulate (Devinsky et al., 1995), and the amygdala (Barbas & de Olmos, 1990), and represents the hierarchical apex of the limbic system.

Brothers (1995, 1997) describes a limbic circuit of orbitofrontal cortex, anterior cingulate gyrus, amygdala, and temporal pole which functions as a social "editor" that is "specialized for processing others' social intentions" by appraising "significant gestures and expressions" (Brothers, 1997, p. 27) and "encourages the rest of the brain to report on features of the social environment" (p. 15). The editor acts as a unitary system "specialized for responding to social signals of all kinds, a system that would ultimately construct representations of the mind" (p. 27). Mesulam points out that the prefrontal areas involved in emotional modulation and attentional functions help to create "a highly edited subjective version of the world" (1998, p. 1013). This emergent subjective function is the outcome of a secure attachment.

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). Referring back
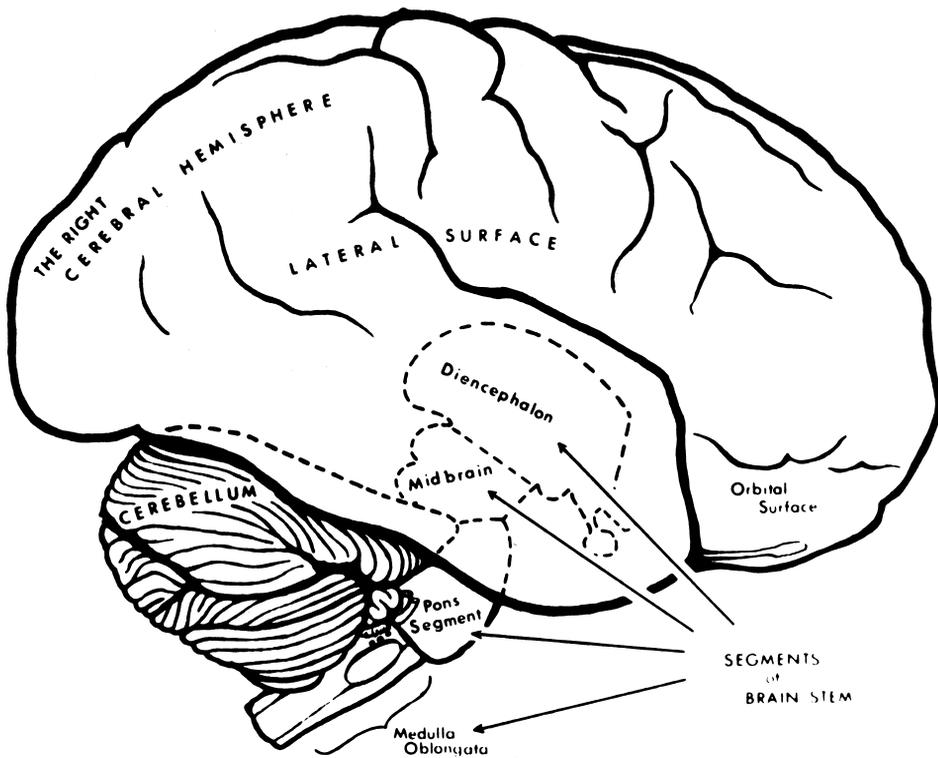
FIGURE 4. Relationships of the orbitofrontal cortex to subcortical structures of the right hemisphere (from Smith, 1981).

to Brazelton and Cramer's conception of the developmental reorganization of control systems, neurobiological studies show that the mature orbitofrontal cortex acts in "the highest level of control of behavior, especially in relation to emotion" (Price, Carmichael, & Drevets, 1996, p. 523). This prefrontal system, which functions in "emotional control" (Roberts & Wallis, 2000) and acts to "control autonomic responses associated with emotional events" (Cavada, Company, Tejedor, Cruz-Rizzolo, & Reinoso-Suarez-Suarez, 2000) is identical to Bowlby's control system of attachment (see Figure 4; for a further characterization of this prefrontal system, see Schore 1994, 1996, 1997a, 1997b, 1998a, 1998b, 1999a, 2000 b, 2000d, in press a, in press b).

This control system integrates the psychological and biological spheres of mind and body. The orbitofrontal cortex is known to play an essential role in the processing of interpersonal signals necessary for the initiation of social interactions between individuals (Schore, 1994). This cortex, along with the superior temporal sulcus and amygdala, comprises a circuit that mediates social gaze (Emery, 2000). Orbitofrontal neurons specifically process visual and auditory information associated with emotionally expressive faces and voices (Scalaidhe, Wilson, Goldman-Rakic, 1997; Romanski, Tian, Fritz, Mishkin, Goldman-Rakic, 1999). But this frontolimbic system is also involved in the representation of highly integrated information on the organismic state (Tucker, 1992). The systems that biochemically regulate all brain and bodily state phenomena are located in discrete groups of arousal-regulating bioaminergic neurons of the subcortical reticular formation that innervate wide areas of the brain through diffuse projections (Lydic, 1987). It now thought that the most basic level of regulatory process is the regulation of arousal (Tucker, Luu, & Pribram, 1995). The orbitofrontal cortex, especially in

the right hemisphere, "is involved in "both generation and afferent feedback representation of arousal" (Critchley et al., 2000b, p. 3037).

This prefrontal area regulates dopaminergic arousal (Iversen, 1977) via its direct reciprocal connections with dopamine neurons in the ventral tegmental area of the anterior reticular formation. It also projects to the ventral striatum and the core of the nucleus accumbens, a basal ganglia structure innervated by dopamine neurons and centrally involved in motivated behavior (Haber, Kunishio, Mizobuchi, & Lynd-Balta, 1995; Mogenson, Jones, & Yim, 1980), in the nonverbal decoding of positive facial expressions (Morris, Robinson, Raphael, & Hopwood, 1996), and in mechanisms of pleasant reward and motivation (Robbins & Everitt, 1996). The right nucleus accumbens (and the right cingulate) are activated in the encoding of pleasant emotional stimuli (Hamann, Ely, Graffton, Kilts, 1998).

This excitatory limbic circuit, the ventral tegmental limbic forebrain–midbrain circuit (Schore, 1994, 1996), is involved with the generation of positively valenced states associated with approach behavior, motivational reward, and active coping strategies. Recent neuroimaging data indicates that the lateral orbital prefrontal areas (which is irrigated by the middle cerebral artery) are specialized for regulating excitement (Elliot, Dolan, & Frith, 2000) and other positive emotional states (Northoff et al., 2000). Midbrain dopamine neurons are known to be preferentially activated by positively valenced appetitive rather than negatively valenced aversive stimuli (Mirenowicz & Schultz, 1996), and to exert an inhibitory influence on cortisol receptors (Casolini et al., 1993).

Phasic increases in dopamine activity allow the individual to immediately appraise the salience of biologically important stimuli in the environment (Berridge & Robinson, 1998). It is important to note, however, that there is an optimal range of stimulation of the dopamine (D_1) receptor that mediates working memory in the prefrontal cortex (Williams & Goldman-Rakic, 1995), and that dopamine levels that are either too low or too high impair its functional output (Arnstein & Goldman-Rakic, 1998; Zahrt, Taylor, Mathews, & Arnsten, 1997). Optimal activation of the ventral tegmental limbic forebrain–midbrain circuit is described not by a linear function but by an inverted "U" relationship. I suggest that an individual's unique narrow or broad optimal orbitofrontal ventral tegmental dopaminergic profile is set up during its critical period of development in positively valenced attachment transactions.

Orbitofrontal regions also have reciprocal connections with arousal-regulating noradrenergic neurons in the medulla oblongata solitary nucleus and the vagal complex in the brain stem caudal reticular formation, and onto subcortical targets in parasympathetic autonomic areas of the lateral hypothalamus, thereby completing the organization of another later maturing limbic circuit, the lateral tegmental limbic forebrain–midbrain circuit that activates the onset of an inhibitory state, regulates negative affect, and is associated with avoidance and passive coping (see Schore, 1994, 1996). Orbital-amygdala interactions allow the individual "to avoid making choices associated with adverse outcomes, without their first having to experience these adverse conditions" (Baxter, Parker, Lindner, Izquierdo, & Murray, 2000, p. 4317). Stimulation of orbitofrontal noradrenergic inhibitory circuits results in "behavioral calming" (Arnsten, Steere, & Hunt, 1996). Optimal activity is also described by an inverted "U" relationship, one organized in critical period attachment transactions of interactive repair of negative states. Neuroimaging studies show the medial orbitofrontal areas (irrigated by the anterior cerebral artery) are specialized for processing negative emotional states (Northoff et al., 2000; Paradiso, Chemerinski, Vazici, Tartaro, & Robinson, 2000).

The functioning of the two limbic circuits (see Figure 3) underlies the observation that emotions organize behavior along a basic appetitive-aversive dimension associated with either a behavioral set involving approach and attachment, or a set disposing avoidance, escape, and defense (see Schore, 1994, 1996, 1997b). A number of theorists have suggested that positive

and negative affect are mediated by different neural circuitries (e.g., Gray, 1990; Cacioppo & Berntson, 1994), and very recent neuroimaging data demonstrate that the neural activation pattern of happiness is "remarkably distinct" from sadness (Damasio et al., 2000).

The orbitofrontal system has been termed the "Senior Executive of limbic arousal" (Joseph, 1996). This is due to the fact that it has reciprocal connections with both dopaminergic neurons in the ventral tegmental area of the anterior reticular formation, as well as noradrenergic neurons in the solitary tract of the medullary areas of the caudal reticular formation (and serotonin neurons in the raphe nucleus). In the orbitofrontal areas dopamine excites and noradrenaline inhibits neuronal activity (Aou, Oomura, Nishino, Inokucki, & Mizuno, 1983). These opposing mechanisms of excitation and inhibition provide for rapid regulation of graded metabolic output and thereby functional activity. Subtle external perturbations would trigger changes in this control parameter, preferentially activating the excitatory lateral orbitofrontal subsystem and its connections into dopamine neurons that modulate large area of the brain and/or the inhibitory medial orbitofrontal subsystem and its connections into noradrenaline neurons that also innervate widely separated brain regions (Foote, 1987). In this manner small changes in the excitation-inhibition balance of the dual orbitofrontal system lead to large changes in the activity of state-regulating neuromodulators that regulate far-reaching neural networks.

The structural connections within and between the lateral and medial orbitofrontal subsystems and the excitation-inhibition balance between them are a product of both genetic and environmental factors, specifically the caregiver's attachment function as a regulator of the infant's arousal. Bowlby (1969) speculated that the functions of the attachment control system are associated with the organism's "state of arousal" that results from the critical operations of the reticular formation, and with "the appraisal of organismic states and situations of the midbrain nuclei and limbic system" (1969, p. 110).

Furthermore, due to the interconnections of the orbitofrontal system into the cervical, thoracic, lumbar, and sacral divisions of the spinal cord (Burstein & Potrebic, 1993) and into the vagal nerve that delivers autonomic information, it receives (like the amygdala and anterior cingulate) moment-to-moment interoceptive information from the entire body, especially information concerning changes in autonomic arousal and in bodily or "somatic" states. Because of its intimate connections with the hypothalamus (Ongur, An, & Price, 1998), the head ganglion of the ANS and the brain's major control center for energy expenditure (Levin & Routh, 1996), the orbital prefrontal area acts as a major center of CNS hierarchical control over the energy-expending sympathetic and energy-conserving parasympathetic branches of the ANS. The ANS is responsible for the somatic aspects of all affective states. In optimal early environments, a system emerges in which higher brain areas can modulate a flexible coping pattern of coupled reciprocal autonomic control, in which increases in one ANS division are associated with decreases in the other (Berntson, Cacioppo, & Quigley, 1991).

This frontolimbic system is particularly involved in situations in which internally generated affective representations play a critical role (Zald & Kim, 1996), and in the implicit processing (Critchley et al., 2000a; Rolls, 1996) and procedural learning (de Guise, del Pesce, Foschi, Quattrini, Papo, & Lussonde, 1999) of socioemotional information. The orbitofrontal system is now described as "a nodal cortical region that is important in assembling and monitoring relevant past and current experiences, including their affective and social values" (Cavada et al., 2000, p. 238). Orbitofrontal neurons are specialized for working memory, a sequential processing of information in real time, i.e., on a moment-to-moment basis (Goldman-Rakic, Muly, & Williams, 2000). These procedures include encoding a facially expressed affective stimulus, maintaining it "on-line," and directing an adaptive memory-guided response. As a result of such operations the orbitofrontal cortex is centrally involved in "acquiring very specific forms of knowledge for regulating interpersonal and social behavior" (Dolan, 1999, p. 928).

There is now evidence that the right inferior frontal regions mediate nonverbal memorial encoding and retrieval (Wagner, Poldrack, Eldridge, Desmond, Glover, & Gabrieli, 1998). The operations of the right orbitofrontal control system involve a rapid subcortical evaluation of the regulatory significance of an external environmental stimulus, a processing of feedback information about the current internal state to make assessments of coping resources, and an adaptive updating of context-appropriate autonomic response outputs to make adaptive adjustments to particular environmental perturbations (Schore, 1998a). In this manner the orbitofrontal areas are involved in the regulation of autonomic responses to social stimuli (Zald & Kim, 1996), the spontaneous gut feelings to others.

The orbitofrontal cortex is situated at the hierarchical apex of an "anterior limbic prefrontal network" that interconnects it with the temporal pole, cingulate, and amygdala, and through these linkages it plays an essential role in affect regulation (Davidson et al., 2000; Schore, 1994). The early maturing amygdala acts as a sensory gateway to the limbic system, but amygdala processing, although very rapid, is crude compared to the more complex processing of affective stimuli by later maturing corticolimbic areas. A recent fMRI study (Teasdale et al., 1999) demonstrates that while the subcortical amygdala responds to emotional stimuli at a direct perceptual level, its operations are less relevant to cognitively elicited emotions. In contrast, the ventromedial cortex is known as "the thinking part of the emotional brain." In optimal contexts the orbitofrontal cortex takes over amygdala functions (Rolls, 1996), and "provides a higher level coding that more flexibly coordinates exteroceptive and interoceptive domains and functions to correct responses as conditions change" (Derryberry & Tucker, 1992, p. 335).

Operating at levels beneath awareness, it is activated "when there is insufficient information available to determine the appropriate course of action" (Elliott, Dolan, & Frith, 2000, p. 308), but subsequently this regulatory system monitors, adjusts, and corrects emotional responses and regulates the motivational control of goal-directed behavior. It thus functions as a recovery mechanism that efficiently monitors and regulates the duration, frequency, and intensity of positive and negative affect states, from high intensity joy and excitement (Schore, 1994) to the affective-motivational aspects of pain (Gyulai, Firestone, Mintun, & Winter, 1997; Petrovic et al., 2000).

The functioning of this system thus allows for "the emotional modulation of experience" (Mesulam, 1998). Orbitofrontal areas function to "integrate and assign emotional-motivational significance to cognitive impressions; the association of emotion with ideas and thoughts" (Joseph, 1996, p. 427) and in "the processing of affect-related meanings" (Teasdale et al., 1999). A recent neuropsychological study indicates that the orbitofrontal cortex is "particularly involved in generating a theory of mind tasks with an affective component" (Stone, Baron-Cohen, & Knight, 1998, p. 651). These adaptive capacities are the outcome of a secure attachment.

The orbitofrontal system is specialized to act in contexts of "uncertainty or unpredictability" (Elliott et al., 2000, p. 308), an operational definition of stress. Its functions mediate affective shifts, the alteration of behavior in response to fluctuations in the emotional significance of stimuli (Dias, Robbins, & Roberts, 1996). In optimal frontolimbic operations, these shifts from one emotional state to another are are experienced as rhythms in feeling states and are fluid and smooth, a flexible capacity of a coherent dynamic system. Efficient orbitofrontal operations organize the expression of a regulated emotional response and an appropriate motivational state for a particular social environmental context, and in this fashion it contributes to "judicious, adapted behavior" (Cavada et al., 2000). These coping capacities define an efficient limbic system, the brain network responsible for the organization of new learning and the capacity to adapt to a rapidly changing environment. The right limbic system is centrally

involved in complex attachment functions and interpersonal coping strategies, and its operations are instrumental to adaptive infant mental health.

The efficient functioning of this frontolimbic cortex is thus manifest in its capacity to mediate between the external environment and the internal milieu. At 18 months, the time of orbitofrontal maturation, toddlers have been observed to have a "vastly enhanced capacity for experiencing the internal milieu" (Greenspan, 1979). Lieberman has emphasized that, "in the last two decades . . . efforts at understanding the subjective world of the infant have focused primarily on mental representations as the building blocks of inner experience. The baby's body, with its pleasures and struggles, has largely been missing from this picture" (1996, p. 289). These findings suggest that bodily intactness, somatic and physical functioning, mechanisms for coping with illness and pain, and general psychobiological integrity need to be included in operational definitions of infant mental health.

REGULATORY FUNCTIONS OF THE RIGHT BRAIN

The orbital prefrontal region, the "Senior Executive" of the social-emotional brain (Joseph, 1996), is especially expanded in the right cortex (Falk, Hildebolt, Cheverud, Vannier, Helmkamp, & Konigsberg, 1990), and, indeed, it comes to act in the capacity of an executive control function for the entire right brain. Because the early maturing and "primitive" right cortical hemisphere contains extensive reciprocal connections with limbic and subcortical regions (Tucker, 1992), it is dominant for the processing and expression of emotional information (Schore, 1994, 1999a, 2000a, in press a). The extensive reciprocal right frontal-subcortical connections, especially with bioaminergic and hypothalamic subcortical nuclei, account for the unique contribution of this hemisphere in regulating homeostasis and modulating physiological state in response to internal and external feedback.

It has been known for some time that arousal systems are right-lateralized (Heilman & Van Den Abell, 1979), and now there is data to show that the hypothalamus, the core brain system where hormonal control and visceral-emotional reactions are regulated (Kupferman, 1985), is also right-lateralized (Kalogeras et al., 1996). MRI research reveals that the right anterior temporal lobe is larger than the left from early infancy (Utsunomiya, Takano, Okazaki, & Mitsudome, 1999), and that the diencephalic hypothalamic nuclei are considerably larger on the right side of the human brain (Sowell & Jernigan, 1998). The right hemisphere, more so than the left, is deeply connected into the ANS (Erciyas, Topalkara, Topaktas, Akyuz, & Dener, 1999; Lane & Jennings, 1995; Yoon, Morillo, Cechetto, & Hachinski, 1997), and so the representation of interoceptive information, the dynamic flows of visceral and somatic states, is under primary control of this hemisphere.

But this hemisphere is also specialized for processing significant patterns of exteroceptive information. The right hemisphere is faster than the left in performing valence-dependent, automatic, preattentive appraisals of emotional facial expressions (Pizzagalli, Regard, & Lehmann, 1999) and in assessing visual or auditory emotional communicative signals (Nakamura et al., 1999). The right cortex is responsive to not only the positive aspects of facial expressions (Blair, Morris, Frith, Perrett, & Dolan, 1999), visual stimuli (Muller, Keil, Gruber, & Elbert, 1999), touch, smell (Francis et al., 1999), and music (Blood et al., 1999), but also for the negative emotional/motivational aspects of pain (Hsieh, Belfrage, Stone-Elander, Hansson, & Ingvar, 1995; Hari, Portin, Kettenmann, Jousmaki, & Kobal, 1997). In fact, this hemisphere plays an essential role in the nonconscious appraisal of the positive or negative emotional significance of social stimuli via a mechanism similar to Freud's pleasure–unpleasure principle (Schore, 1998a, 1998c, 1999a, 1999c, in press b). These findings are not consonant with earlier models that held that positive approach-related emotions are lateralized to the left hemisphere

and negative withdrawal-related emotions to the right (Davidson, Ekman, Saron, Senulis, & Friesen, 1990), a position not supported by recent brain imaging techniques (Canli, 1999). Citing only one example, Damasio's group (2000) reports a PET study revealing that happiness is associated with activation of the right orbitofrontal right indula, right somatosensory, right anterior cingulate, and right hypothalamus.

The coprocessing of exteroceptive and interoceptive information is possible when the higher cortical limbic regions of the right hemisphere are actively and bidirectionally communicating with the different levels of the right subcortical limbic regions. This organizational mode allows for the operation of right-lateralized (dual) circuit of emotion regulation that is involved in "intense emotional-homeostatic processes" and in the modulation of "primary" emotions (Porges, Doussard-Roosevelt, & Maiti, 1994). These authors describe a vagal circuit of emotion regulation lateralized on the right side of the brain.

Vagal tone is defined as "the amount of inhibitory influence on the heart by the parasympathetic nervous system" (Field, Pickens, Fox, Nawrocki, & Gonzalez, 1995, p. 227), and although it is present at birth, it evolves in an experience-dependent manner over the first two years. A functional progression in vagal tone occurs from the middle of the first to the middle of the second year (Sweet, McGrath, & Symons, 1999). The progressive postnatal assembly of this limbic–autonomic circuit (Rinaman et al., 2000) is reflected in a developmental shift from interactive regulation to autoregulation of negative affective states. This ontogenetic achievement represents the evolution, at 18 months, of the right lateralized orbitofrontal-dominated lateral tegmental limbic forebrain–midbrain parasympathetic inhibitory circuit.

Current studies indicate that "right hemisphere control exists over both parasympathetic and sympathetic responses" (Spence et al., 1996, p. 118), the autonomic somatic components of all emotional states. For the rest of the lifespan the right brain plays a superior role in the regulation of fundamental physiological and endocrinological functions whose primary control centers are located in subcortical regions of the brain. There is also now evidence to show that the right hemisphere is dominant for the production of cortisol (Wittling & Pfluger, 1990), CRF and ACTH (Kalogeras et al., 1996), and indeed for immune, neuroendocrine, and cardiovascular functions (Hugdahl, 1995; Sullivan & Gratton, 1999).

Because the hypothalamo–pituitary–adrenocortical axis and the sympathetic–adrenomedullary axis that mediate coping capacities are both under the main control of the right cerebral cortex, this hemisphere contains "a unique response system preparing the organism to deal efficiently with external challenges," and so its adaptive functions mediate the human stress response (Wittling, 1997, p. 55). It, therefore, is centrally involved in the vital functions that support survival and enable the organism to cope actively and passively with stress. The attachment relationship thus directly shapes the maturation of the infant's right brain stress-coping systems that act at levels beneath awareness. In line with Bowlby's description of a "control system" that regulates attachment behavior, the right hemisphere is dominant for "inhibitory control" (Garavan, Ross, & Stein, 1999).

Furthermore, the right brain stores an internal working model of the attachment relationship which encodes strategies of affect regulation that maintain basic regulation and positive affect even in the face of environmental challenge (Schore, 1994). Because this hemisphere is centrally involved in unconscious processes (Joseph, 1992b; Schore, 1998c, 1999a, in press a, in press b) and in "implicit learning" (Hugdahl, 1995), nonconsciously processed socio-emotional information is stored in right cerebral implicit-procedural memory. Neuropsychological studies reveal that this hemisphere, and not the later forming verbal–linguistic left, is the substrate of autobiographical memory (Fink, Markowitsch, Reinkemeier, Bruckbauer, Kessler, & Heiss, 1996).

Continuing these ideas, I suggest that the expansion of the earlier maturing ventral stream

(Ungerleider & Haxby, 1994) in the right hemisphere accounts for its role in "implicit," or "procedural" learning, while the predominance of the later maturing dorsal stream in the left underlies its emphasis in "explicit" or "declarative" functions. Zaidel, Esiri, and Beardsworth's (1998, p. 1050) proposal that "human memory systems in the two sides are wired up differently to support separate but complementary functional specialization in the hemispheres" suggests that the storage of right hemispheric implicit-procedural learning (Hugdahl, 1995) of affective information may be mediated by very different operations than explicit learning and memorial systems of the left (Gabrieli, Poldrack, & Desmond, 1998).

The right hemisphere contributes to the development of reciprocal interactions within the mother–infant regulatory system (Taylor, 1987), and mediates the capacity for biological synchronicity, the regulatory mechanism of attachment. In further support of its role in organismic synchronicity, the activity of this hemisphere is instrumental to the empathic perception of the emotional states of other human beings (Schore, 1994, 1999a, in press, a). The right hemisphere decodes emotional stimuli by "actual felt [somatic] emotional reactions to the stimuli, that is, by a form of empathic responding" (Day & Wong, 1996, p. 651). According to Adolphs, Damasio, Tanel, Cooper, & Damasio, "recognizing emotions from visually presented facial expressions requires right somatosensory cortices," and in this manner "we recognize another individual's emotional state by internally generating somatosensory representations that stimulate how the individual would feel when displaying a certain facial expression" (2000, p. 2683). The interactive regulation of right brain neuropsychology and attachment psychobiology is thus the substrate of empathy, another fundamental aspect of adaptive infant metal health.

CONTINUED ORBITOFRONTAL AND RIGHT BRAIN DEVELOPMENT AND ADAPTIVE MENTAL HEALTH

The orbital cortex matures in the middle of the second year, a time when the average child has a productive vocabulary of less than 70 words. The core of the self is thus nonverbal and unconscious, and it lies in patterns of affect regulation. This structural development allows for an internal sense of security and resilience that comes from the intuitive knowledge that one can regulate the flows and shifts of one's bodily-based emotional states either by one's own coping capacities or within a relationship with caring others. As a result of developmental neurobiological studies, Ryan and colleagues (1997) conclude that the operation of the right prefrontal cortex is integral to autonomous regulation, and that the activation of this system facilitates increases in positive affect in response to optimally challenging or personally meaningful situations, or decreases in negative affect in response to stressful events.

The activities of the "self-correcting" orbitofrontal system are central to self-regulation, the ability to flexibly regulate emotional states through interactions with other humans—interactive regulation in interconnected contexts via a two-person psychology, and without other humans—autoregulation in autonomous contexts via a one-person psychology. As Sander (1997) notes, in health both poles are primarily suffused with positive affects. 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 attuned social environment. The essential aspect of this function is highlighted by Westen,who asserts that "The attempt to regulate affect—to minimize unpleasant feelings and to maximize pleasant ones—is the driving force in human motivation" (1997, p. 542). The efficient functioning of the orbitofrontal system is thus necessary for adaptive infant (and adult) mental health.

But this system is also necessary for later mental health. In a recent issue of the *American Psychologist*, Bargh and Chartrand assert,

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 mental systems care are not innate, but a product of the experience-dependent maturation of the orbitofrontal system that generates nonconscious biases that guide behavior before conscious knowledge does (Bechara, Damasio, Tanel, & Damasio, 1997). Such non-conscious regulatory mechanisms are embedded in implicit-procedural memory in unconscious internal working models of the attachment relationship that encode strategies of affect regulation. The orbitofrontal cortex is involved in procedural learning (de Guise et al., 1999), and the right cerebral hemisphere is dominant for implicit learning (Hugdahl, 1995), and so at all points of the lifespan this "Senior Executive of the social-emotional brain" is centrally involved in "emotion-related learning" (Rolls, Hornak, Wade, & McGrath, 1994). Current definitions of intuition as "the subjective experience associated with the we of knowledge gained through implicit learning" (Lieberman, 2000, p. 109) clearly suggest that intuitive thinking is a right brain process.

   Implicit learning is also a major mechanism for the incorporation of cultural learning, a process that initiates in infancy. Tucker (1992) asserts that social interaction that 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." He also states that the important brain systems in such functions are those that are involved in affective communication processes and mediate socialization. Tucker concludes that such emotional information engages specialized neural networks in humans, within the right hemisphere. Socialization is essential to advances in emotional – motivational development and to expansion of the self. A recent neuropsychological study concludes that "self-related material is processed in the right hemisphere" (Keenan, McCutcheon, Freund, Gallup, Sanders, & Pascual-Leone, 1999, p. 1424).

   The right hemisphere subsequently reenters into growth spurts (Thatcher, 1994) and ultimately forms an interactive system with the later maturing left (Schore, 1994; Siegel, 1999). This structural attainment, at 15 to 30 months, allows for the emergence of what Stern (1985) calls "the verbal self." The term "verbal self" connotes a purely left brain mechanism, and yet it may really be an emergent function of an early maturing and expanding right brain and it connections into the later maturing left.

   In describing a model of lingusitic development, Locke proposes

The first phase is indexical and affective; the infant is strongly oriented to the human face and voice, and learns caregivers' superficial characteristics. The second phase is primarily affective and social: its function is to collect utterances, a resposibility that is subserved largely by mechanisms of social cognition sited primarily in the right hemisphere. (1997, pp. 265 – 266)

Thus, both the first stage, which spans the last trimester of pregnancy to five to seven months, and the second, which continues to 20 – 37 months, are heavily driven by the right hemisphere. Although the left hemisphere begins a growth spurt at around 18 months, the right hemisphere is dominant through 36 months (Chiron et al., 1997).

   Indeed, despite a pervasive tendency for scientists and clinicians to automatically assume that language involves operations solely of the left hemisphere, there is now a growing body

of evidence underscoring the important roles of the early developing right hemisphere at later points in the lifespan for processing prosodic information in infants (Snow, 2000), children (Cohen, Branch, & Hynd, 1994), and adults (George et al., 1996; Schmitt, Hartje, & Willmes, 1997), for comprehension of language (Beeman & Chiarello, 1998), lexical emotional stimuli (Cicero et al., 1999), and communicative pragmatics (Van Lancker, 1997), and for emotional (Blonder et al., 1991) communication.

Current neurobiological studies indicate 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). Buck notes that "language is not simply a matter of 'cold cognition': strong motivational and emotional forces invigorate the learning of language and infuse its application with intensity and energy," and emphasizes the adaptive nature of right hemispheric "spontaneous emotional communication" (1994, p. 266). At all points of the lifespan nonverbal and verbal spontaneous emotional communications are outputs of the right brain attachment system.

It is important to point out that these communications are positively and negatively valenced, and so in addition to "satisfying" the attachment system, they can also stress it. In other words, they are also sources of interpersonal stressors and stress regulation, processes that tap directly into the unique functions of the right brain. Scherer (1994) describes facially and vocally expressed "highly emotionally charged affect bursts" associated with activation of the ANS. These events, although lasting for very brief periods, accommodate the needs of information processing and behavioral adaptation:

> One of the fundamental characteristics of an emotional episode . . . is the synchronization of the different components in the organism's efforts to recruit as much energy as possible to master a major crisis situation (in a positive or negative sense). (p. 186)

I suggest that this principle applies to the developmental crises that must be mastered as one moves along the lifespan. The continuing growth spurts of the right hemisphere (Thatcher, 1997) that mediates attachment, the synchronization of right brain activities between and within organisms, thus occur as the developing individual is presented with the stresses that are intrinsic to later stages of life, childhood, adolescence, and adulthood (Erikson, 1950; Seligman & Shahmoon-Shanok, 1995). The expanding ability of the individual to cope with interpersonal and bodily stressors is an important achievement in continuing human development, and it represents an expansion of the right brain, the hemisphere dominant for the human stress response. In terms of interpersonal stressors, this hemisphere is specialized for processing not only facially expressed auditory (Snow, 2000) but also visual emotional information in infants (de Schonen et al., 1993), children (de Haan, Nelson, Gunnar, & Tout, 1998), and adults (Kim et al., 1999). These right brain capacities are essential to all interactions between humans, including the social bonding between "companions" (Trevarthen, 2000). Panksepp (2000), notes that "the underlying neurobiological mechanisms for bonding are quite similar to those that sustain the affective side of friendships." Such interpersonal experiences facilitate future growth of the brain and therefore personality.

Attachment theory is fundamentally a theory of the development of the personality over the lifespan (Ainsworth & Bowlby, 1991). Weinfeld, Sroufe, Egeland, and Carlson (1999) offer a number of possible explanations for why early attachment experiences influence development at later stages of life: the early attachment relationship may serve as a foundation for learning affect regulation; it may influence subsequent development through behavioral regulation and behavioral synchrony; or through the continuing presence, over the course of the ensuing

developmental trajectory, of early forming internal representations. But these authors offer one other mechanism:

> [I]t is possible that the experiences within the early attachment relationship influence the developing brain, resulting in lasting influences at a neuronal level (Schore, 1994). This possibility . . . (is) compelling. (Weinfeld et al., 1999, p. 75)

In parallel writings in the neuroscience literature on the concept of development, Pandya and Barnes (1987, p. 66) assert the principle that:

> Each stage in development is marked by a more differentiated cytoarchitecture and a new set of connections, which together might reasonably be expected to subserve a new, and more advanced, behavior.

Thatcher (1994, 1997) has provided evidence to show that the right hemisphere, especially its frontal areas, continues subsequent growth spurts. I suggest that the ongoing maturational potential of an individual right brain is related to its attachment-influenced early organization, and that as in infancy, this further growth of right-lateralized cortical–subcortical systems is experience dependent.

For example, as the toddler becomes a young child, age-appropriate interactions with peers depend upon an efficient right hemispheric ability to engage in processes of affective synchrony with other children. This capacity involves the abilities to nonconsciously yet efficiently read faces and tones, and therefore, the intentionalities of peers and teachers, to empathically resonate with the states of others, to communicate emotional states and regulate interpersonal affects, and thus to cope with the novel ambient interpersonal stressors of early childhood. In light of the fact that both the right and left hemispheres enter into subsequent growth spurts from ages four through ten and that the frontal lobes continue to reorganize (Thatcher, 1997), the cognitive–emotional advances of late childhood reflect more complex connections within the right and between the emotional right and verbal–lingusitic left hemisphere.

In a recent chapter on attachment in adolescence, Allen and Land (1999) offer sections on "continuity in the meaning and status of attachment from infancy through adolescence" and on "emotion-regulating functions of adolescent attachment organization." In parallel writings in neuroscience, Spear (2000) presents a rapidly growing body of studies to show that the brain undergoes a significant reorganization during adolescence, and that this maturation contributes to the multiple psychological changes seen at this time of transition between childhood and adulthood. She notes, "adolescence is second only to the neonatal period in terms of both rapid biopsychosocial growth as well as changing environmental characteristics and demands" (p. 428), and that after a relatively long period of slowed growth during early childhood, the adolescent brain undergoes a prominent developmental transformation.

Indeed, overproduction and pruning of synapses, as in the postnatal period, is a hallmark of adolescence (Huttenlocher, 1984). It has been estimated that 30,000 synapses are lost per second in the primate cortex over the adolescent period, resulting in an ultimate reduction of almost one-half of the number of synapses per neuron in the preadolescent period (Rakic, Bourgeois, & Goldman-Rakic, 1994). During this time, as in human infancy, hypothalamic-regulated gonadal hormones reach very high levels, and Spear (2000) suggests that the reorganization of amygdala and prefrontal limbic areas that innervate the hypothalamus and modulate emotional reactivity, as well as alterations in the balance between mesocortical and mesolimbic dopamine systems involved in stress regulation, may drive the reorganization of

the adolescent brain. Indeed, an increase in the volume of the right hypothalamus (Sowell & Jernigan, 1998) is seen in late adolescence.

An fMRI study indicates that adolescents exhibit greater activation in the amygdala than in the frontal lobe during the identification of an emotional state from a facial expression, in contrast to adults, who show greater frontal over amygdala activation (Yurgelun-Todd, 1998). These data suggest that the right brain hierarchical dual corticolimbic–autonomic circuits that support self-regulation and stress coping mechanisms are significantly reorganized in adolescence (see Figure 3). This allows for early imprinted internal working models of attachment that encode strategies of affect regulation to become more complex over the course of the Eriksonian stages of the life cycle.

The stress literature clearly suggests that exposing the personality to learning from novel stressors and challenges is "pivotal for emotional and intellectual growth and development" (Chrousos, 1998, p. 312). Yet in addition to being potentially growth enhancing these same events can be emotionally overwhelming and disorganizing. However, during disequilibrating stage transitions when right lateralized autoregulatory systems are reorganizing, the child–adolescent with a secure attachment can access emotionally available parents for interactive regulation. In this manner, the original attachment objects can continue to scaffold the individual's developing nascent regulatory capacities.

This same principle is articulated in the neuropsychological literature by Lane, Kivley, Du Bois, Shamasundara, and Schwartz:

> [I]ndividuals who are naturally right hemispheric dominant may be better able to perceive and integrate emotion cues from the environment and thus take full advantage of an emotionally nurturing environment in promoting emotional development. (1995, p. 535)

Each of these ontogenetic continuations allows for more complex right and right–left representations, yet the earliest-forming strategies of affect regulation, cocreated in attachment transactions of affective synchrony, provide the coping mechanisms for dealing with the stressors inherent in these later novel, more challenging socioemotional environments. In securely attached individuals, or those in interaction with securely attached individuals who can act as interactive regulators, unconscious internal working models can become more complex.

The experience-dependent expansion of the right brain is reflected in the growth of the unconscious over the lifespan (Schore, 1999d). This reorganization is accompanied by more complex interconnections with the also expanding left brain, especially the anterior sections of the corpus callosum, which include axons of the orbitofrontal areas that "participate in interhemispheric integration on a broad scale" (Cavada et al., 2000). The orbitofrontal and amygdalar areas are the most plastic areas of the cortex (Barbas, 1995), and thus capable of future dendritic and synaptogenetic growth. This major stress coping system in the brain, activated in contexts of uncertainty, can potentially accrue more complexity.

During the transitions between later developmental stages the individual is presented with the challenge of retaining continuity while changing in response to environmental pressures. These challenges are associated with positive and negative affective states, and they call for a resilient right orbitofrontal regulated capacity that can read the facially expressed states of others, access a theory of mind, as well as cope with, regulate, and thereby tolerate the uncertainty and stress that are inherent in the attachment separation and exploratory dynamics of these transitional periods. Such regulated interpersonal and intrapersonal experiences allow for the further experience-dependent maturation of the emotion processing right brain at later stages of development. The evolutionary progression of the right lateralized frontolimbic "social ed-

itor" (Brothers, 1997) can now reedit more complex yet coherent and adaptive internal working models that can flexibly process greater amounts of information in more complex subjective states. The continuing ontogeny of this self-regulating and self-correcting dynamic system allows for an expansion of the boundaries of the emotion communicating self. The early right brain capacities of processing socioemotional information and bodily states are not only central to the origin of the self, they are required for the ongoing development of the self over the lifespan.

This evolution of the developmental trajectory allows for an elaboration and increased complexity of the known functions of the right brain: the storage of internal working models of the attachment relationship (Schore, 1994), the processing of socioemotional information that is meaningful to the individual (Schore, 1998a), the ability to empathize with the emotional states of other humans beings (Schore, 1996), the mediation of emotional-imagistic processes in moral development (Vitz, 1990), the appreciation of humor, a mechanism for coping with daily stress (Shammi & Stuss, 1999), the cerebral representation of one's own past and the activation of autobiographical memory (Fink et al., 1996), the establishment of a "personally relevant universe" (Van Lancker, 1991), and "the capacity to mentally represent and become aware of subjective experiences in the past, present, and future" (Wheeler, Stuss, & Tulving, 1997, p. 331).

On the most fundamental level, however, the emotion processing right hemisphere is dominant for the control of vital functions that support survival and enable the organism to cope with stressors (Wittling & Schweiger, 1993). There is now agreement that, fundamentally, "emotion is a mechanism that enables an organism to adapt psychologically, physiologically and behaviorally to meet organismic challenges" (Lane, Chua, & Dolan, 1999, p. 996). These stressors include interoceptive challenges, because it has been demonstrated that individuals express emotional responses to immunological stimuli like bacteria (Kusnecov, Liang, & Shurin, 1999). Recall, the emotion-processing right hemisphere is primarily involved with the analysis of direct information received from the body (Luria, 1973). But in addition, the ability of the right brain to process exteroceptive socio-emotional stimuli may underlie the mechanism by which an individual can recognize and respond to social support that beneficiently alters physiological processes (Uchino, Cacioppo, & Kielcolt-Glaser, 1996). In an earlier work I have proposed that the attachment relationship directly influences the development of right brain psychosocial–neuroendocrine–immune communications (Schore, 1994).

In very recent writings on the relationship between emotional states and physical health Salovey and his colleagues (2000) conclude,

> In general, negative emotional states are thought to be associated with unhealthy patterns of physiological functioning, whereas positive emotional states are thought to be associated with healthier patterns of responding in both cardiovascular activity and the immune system. (p. 111)

Salovey also contends that to mount an adaptive coping response to preserve mental (and physical) health, the individual must be able to access "emotional intelligence," defined as the processing of emotional information and accurate perception and appraisal of emotions in oneself and others, appropriate expression of emotion, and adaptive regulation of emotion in such a manner as to enhance living (Salovey & Mayer, 1989/1990).

This psychological description is echoed in current neuroscience, where Lane et al. conclude, "as right hemispheric dominance in the perception of facial emotion increases, the ability to perceive complexity during the processing of emotional information increases" (1995, p. 525). In a direct counterpart ot psychological "emotional intelligence," Brothers (1990) offers

the neurobiological concept of "social intelligence," a product of the "social brain" that is composed of limbic areas of the orbitofrontal cortex and amygdala, and face processing systems in the temporal lobe. This model is also advanced by Baron-Cohen et al. (2000, p. 355), who differentiates general intelligence from social intelliegence, the latter decribed as:

. . . our ability to interpret others' behaviour in terms of mental states (thoughts, intentions, desires and beliefs), to interact both in complex social groups and in close relationships, to empathize with others' states of mind, and to predict how others will feel, think, and act.

Recall that limbic circuits are emphasized in specifically the right brain, that the right limbic system is more directly connected with subcortical neuochemical systems associated with emotion, and that the limbic system is intimately tied to attachment functions. The data offered in this work suggest that emotional or social intelligence relies heavily upon right brain function, and that this capacity is an outcome of a secure attachment and a central component of adaptive infant, child, adolescent, and adult mental health.

In a related conception, Gardner (1983) speaks of "personal" intelligence, which has two forms, intrapersonal intelligence, the ability to access one's feeling life, and interpersonal intelligence, the ability to read the moods, intentions, and desires of others. These dual modes refer to, respectively, right brain autoregulatory and interactive regulatory capacities. As described above, these two abilities are available to the securely attached individual, and for this reason such early-appearing coping capacities of adaptive infant mental health are positive factors for "optimal development" and the ability to increase the complexity of the brain/mind/body self system and thereby enhance and vitalize the experience of being alive over all of the stages of the lifespan.

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