Attachment and the regulation of the right brain*

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ABSTRACT   It has been three decades since John Bowlby first presented an over-arching model of early human development in his groundbreaking volume, *Attachment*. In the present paper I refer back to Bowlby's original charting of the attachment landscape in order to suggest that current research and clinical models need to return to the integration of the psychological and biological underpinnings of the theory. Towards that end, recent contributions from neuroscience are offered to support Bowlby's assertions that attachment is instinctive behavior with a biological function, that emotional processes lie at the foundation of a model of instinctive behavior, and that a biological control system in the brain regulates affectively driven instinctive behavior. This control system can now be identified as the orbitofrontal system and its cortical and subcortical connections. This 'senior executive of the emotional brain' acts as a regulatory system, and is expanded in the right hemisphere, which is dominant in human infancy and centrally involved in inhibitory control.

Attachment theory is essentially a regulatory theory, and attachment can be defined as the interactive regulation of biological synchronicity between organisms. This model suggests that future directions of attachment research should focus upon the early-forming psychoneurobiological mechanisms that mediate both adaptive and maladaptive regulatory processes. Such studies will have direct applications to the creation of more effective preventive and treatment methodologies.

KEYWORDS: affective processes – attachment theory – orbitofrontal system – psychobiological regulation – right hemisphere

In 1969, which was 29 years after his initial publication of an article in the *International Journal of Psycho-Analysis* on how the early environment could influence the development of character (1940), John Bowlby integrated his career-spanning observations and theoretical conceptualizations into the first of three influential books on *Attachment and loss*. This foundational volume, *Attachment*, was groundbreaking for a number of reasons. It focused upon one of the major questions of science: specifically, how and why do certain early ontogenetic events have such an inordinate effect on everything

that follows? Bowlby's scientifically-informed curiosity about this question envisioned the center stage of human infancy, on which is played the first chapter of the human drama, to be a context in which a mother and her infant experience connections and disconnections of their vital emotional communications. Bowlby presented his model in such a way that both a heuristic theoretical perspective and a testable experimental methodology could be created to observe, measure, and evaluate certain very specific mechanisms by which the early social environment interacts with the maturing organism in order to shape developmental processes (Schore, 2000).

But perhaps of even more profound significance was his carefully argued proposition that an interdisciplinary perspective should be applied to the study of developmental phenomena as they exist in nature. In such an approach the collaborative knowledge-bases of a spectrum of sciences would yield the most powerful models of both the nature of the fundamental ontogenetic processes that mediate the infant's first attachment to another human being, and the essential psychobiological mechanisms by which these processes indelibly influence the development of the organism at later points of the life-cycle.

In response to this classic volume Ainsworth observed that 'In effect what Bowlby has attempted is to update psychoanalytic theory in the light of recent advances in biology' (1967, p. 998). Bowlby's deep insights into the potential synergistic effects of combining the literatures of what appeared on the surface to be distantly related realms may now seem like a brilliant flash of intuition. In actuality it represented a natural convergence of his two most important intellectual influences, Charles Darwin and Sigmund Freud. In order to create a perspective that could describe critical events both in the external and in the internal world, concepts from both ethology (behavioral biology) and psychoanalysis are presented and interwoven throughout the volume. In essence, a central goal of Bowlby's first book is to demonstrate that a mutually enriching dialogue can be organized between the biological and the psychological realms, something attempted by Darwin (1872) in the first scientific treatise on the biology and psychology of emotion, *The Expression of Emotions in Man and Animals*, and by Freud (1895) in his endeavor to integrate neurobiology and psychology in order to create a 'natural science', *Project for a Scientific Psychology* (Schore, 1997a).

Although both Darwin and Freud emphasized the centrality of early development as an important part of their overall work, each primarily focused his observational and theoretical lens on the adaptive and maladaptive functioning of fully matured adult organisms. In the *Attachment* volume Bowlby (1969) argues that clinical observers and experimental scientists should intensively focus on the developing organisms that are in the process of maturing. More specifically, he calls for deeper explorations of the fundamental ontogenetic mechanisms by which 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 the mother. In this conception, Bowlby asserts that these developmental processes are the product of the interaction of a unique genetic endowment with a particular environment, and that the infant's emerging social, psychological, and biological capacities cannot be understood apart from its relationship with the mother.

BOWLBY'S ORIGINAL CHARTINGS OF THE ATTACHMENT LANDSCAPE

Much has transpired since the original publication of Bowlby's *Attachment*, and the ensuing explosion of attachment research over the last quarter of a century is a testament to the power of the concepts it contains. And yet a (re-) reading of this classic still continues to reveal more and more subtle insights into the nature of developmental processes, and to shine light upon yet to be fully explored areas of developmental research. In fact, in this seminal work of developmental science, the pioneering Bowlby presents a survey of what he sees to be the essential topographic landmarks of the uncharted territory of mother–infant relationally driven psychobiological processes. The essential guideposts of this dynamic domain – the central phenomena that must be considered in any overarching model of how the attachment relationship generates both immediate and long-enduring effects on the developing individual – are presented by Bowlby in not only the subject-matter but also the structural organization of the book. The reader will notice that the book is divided into four parts, 'The task', 'Instinctive behaviour', 'Attachment behaviour' and 'Ontogeny of human attachment', and that Bowlby devotes ten chapters to the first two parts, and seven to the last two parts.

It is now more than 30 years since Bowlby's call for 'a far-reaching programme of research into the social responses of man, from the preverbal period of infancy onwards' (p. 174). In the following, I want to briefly offer, from a psychoneurobiological perspective, not only my views of the original contents of Bowlby's guidebook, but also some thoughts about the current and future directions of the experimental and clinical explorations of attachment theory as they pass from one century into the next. In doing so, I will specifically attend to not so much the quality of attachment research, which has served as a standard in psychology, psychiatry, and psychoanalysis as a whole, or to the breadth of the research, which spans developmental psychology, developmental psychobiology, developmental neurochemistry, infant psychiatry, and psychoanalysis, but rather to the foci of current investigations, as measured against the original prescriptions that are offered here by Bowlby. And I will suggest that certain uninvestigated areas of this attachment domain, sketched out in Bowlby's cartographic descriptions in this book, are now ready to be explored by interdisciplinary research

programs. For a broad overview of the field at the end of century I refer the reader to two excellent edited volumes, *Attachment theory: Social, developmental, and clinical perspectives* (Goldberg, Muir & Kerr, 1995) and *Handbook of attachment: Theory, research, and clinical applications* (Cassidy & Shaver, 1999).

In the book most current readers are very familiar (or even perhaps only familiar) with the latter two sections on attachment, and most researchers continue to focus their investigation upon the concepts outlined in these later chapters. It is here, as well as in the introductory sections, that Bowlby presents his essential contributions on the infant's sequential responses to separation from the primary attachment figure – protest, despair, and detachment. In the context of emphasizing the importance of studying the infant's behavior specifically during the temporal interval when the mother returns, Bowlby introduces the recent methodology of Ainsworth, which will soon become the major experimental paradigm for attachment research, the incrementally stress-increasing 'strange situation'.

But in addition to theorizing on the nature of separation responses, stressful ruptures of the mother–infant bond, Bowlby also describes what he sees as the fundamental dynamics of the attachment relationship. In stating that the infant is active in seeking interaction, that the mother's maternal behavior is 'reciprocal' to the infant's attachment behavior, and that the development of attachment is related both to the sensitivity of the mother in responding to her baby's cues and to the amount and nature of their interaction, he lays a groundwork that presents attachment dynamics as a 'reciprocal interchange' (p. 346), a conceptualization that is perfectly compatible with recent advances in dynamic systems theory (Schore, 1997b, in press a; Lewis, 1995, 1999, in press).

At the very beginning of the section on 'Attachment behavior' Bowlby offers his earliest model of the essential characteristics of attachment – it is instinctive social behavior with a biological function, 'readily activated especially by the mother's departure or by anything frightening, and the stimuli that most efficiently terminate the systems are sound, sight, or touch of the mother', and is 'a product of the activity of a number of behavioural systems that have proximity to mother as a predictable outcome' (p. 179). Although the first three postulates remained unaltered in his later writings, in his second volume Bowlby (1973) attempted to define more precisely the set-goal of the attachment system as seeking not just proximity but access to an attachment figure who is emotionally available and responsive.

A further evolution of this concept is now found in transactional theories that emphasize the central role of the primary caregiver in co-regulating the child's facially expressed emotional states (Schore, 1994, 1998a, in press b) and that define attachment as the dyadic regulation of emotion (Sroufe, 1996) and the regulation of biological synchronicity between organisms (Wang, 1997). The development of synchronized interactions is fundamental to the healthy affective development of the infant (Penman, Meares, &

Milgrom-Friedman, 1983). Reite and Capitanio (1985) conceptualize affect as 'a manifestation of underlying modulating or motivational systems subserving or facilitating social attachments' (p. 248) and suggest that an essential attachment function is 'to promote the synchrony or regulation of biological and behavioral systems on an organismic level' (p. 235). In these rapid, regulated face-to-face transactions the psychobiologically attuned (Field, 1985) caregiver not only minimizes the infant's negative but also maximizes its positive affective states (Schore, 1994, 1996, 1998b). This proximate interpersonal context of 'affect synchrony' (Feldman, Greenbaum, & Yirmiya, 1999) and interpersonal resonance (Schore, 1997b; in press, b) represents the external realm of attachment dynamics.

But due to his interests in the inner world, Bowlby here presents a model of events occurring within the internal realm of attachment processes. And so he offers his initial speculations about how the developing child constructs internal working models 'of how the physical world may be expected to behave, how his mother and other significant persons may be expected to behave, how he himself may be expected to behave, and how each interacts with the other' (p. 354). This initial concept has currently evolved into 'process-oriented' conceptions of internal working models as representations that regulate an individual's relationship adaptation through interpretive/attributional processes (Bretherton & Munholland, 1999) and encode strategies of affect regulation (Kobak & Sceery, 1988; Schore, 1994). Current psychobiological models refer to representations of the infant's affective dialogue with the mother which can be accessed to regulate its affective state (Polan & Hofer, 1999).

Interestingly, Bowlby also describes internal working models in the first part of the volume, the eight chapters devoted to 'instinctive behavior'. I repeat my assertion that a deeper explication of the fundamental themes of this section of the book represents the frontier of attachment theory and research. In these opening chapters, the aggregate of which represents the foundation on which the later chapters on attachment are built, Bowlby posits that internal models function as 'cognitive maps' in the brain, and are accessed 'to transmit, store, and manipulate information that helps making predictions as to how . . . set-goals (of attachment) can be achieved' (p. 80). Furthermore, he states that 'the two working models each individual must have are referred to respectively as his environmental model and his organismic model' (p. 82). This is because 'sensory data regarding events reaching an organism via its sense organs are immediately assessed, regulated, and interpreted . . . The same is true of sensory data derived from the internal state of the organism' (p. 109). Here Bowlby is pointing to the need for a developmental theoretical conception of attachment that can tie together psychology and biology, mind and body.

And so at the very onset of his essay, he begins 'The task' by describing a theoretical landscape that includes both the biological and social aspects of attachment, a terrain that must be described in terms of its structural

organization as well as its functional properties. Following the general perspective of all biological investigators, he attempts to elucidate the structure–function relationships of a living system, but with the added perspective of developmental biology he is specifically focusing on the early critical stages within which the system first self-organizes. Thus the form of the book is first to outline the general characteristics of the internal structural system, and then to describe this system's central functional role in attachment processes.

Bowlby begins the third chapter by quoting Freud's (1925) dictum that 'There is no more urgent need in psychology than for a securely founded theory of the instincts'. The attempt to do so in this book, an offering of an 'alternative model of instinctive behavior', in essence represents Bowlby's conviction that what Freud was calling for was the creation of a model that could explicate the biology of unconscious processes. Towards that end, in the first of eight chapters on the topic he proposes that attachment is instinctive behavior associated with self-preservation, and that it is a product of the interaction between genetic endowment and the early environment.

But immediately after a brief 5-page introduction, Bowlby launches into a detailed description of a biological control system that is centrally involved in instinctive behavior. This control system is structured as a hierarchical mode of organization that acts as 'an overall goal-corrected behavioral structure'. Bowlby also gives some hints as to the neurobiological operations of this control system – its functions must be 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' (p. 110). He even offers a speculation about its anatomical location – the prefrontal lobes (p. 156).

This control system, he says, is 'open in some degree to influence by the environment in which development occurs' (p. 45). More specifically, it evolves in the infant's interaction with an 'environment of adaptiveness, and especially of his interaction with the principal figure in that environment, namely his mother' (p. 180). Furthermore, Bowlby speculates 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' (p. 156). In fact he even goes so far as to suggest the temporal interval that is critical to the maturation of this control system – 9 to 18 months (p. 180).

In a subsequent chapter on 'Appraising and selecting: Feeling and emotion', Bowlby quotes Darwin's (1872) observation that the movements of expression in the face and body serve as the first means of communication between the mother and the infant. Furthering this theme on the communicative role of feeling and emotion, Bowlby emphasizes the salience of 'facial expression, posture, tone of voice, physiological changes, tempo of movement, and incipient action' (p. 120). The appraisal of this input is experienced 'in terms of value, as pleasant or unpleasant' (pp. 111–112) and the

movements 'may be actively at work even when we are not aware of them' (p. 110); in this manner feeling provides a monitoring of both the behavioral and physiological state (p. 121). Emotional processes thus, he says, lie at the foundation of a model of instinctive behavior.

In following chapters Bowlby concludes that the mother–infant attachment relation is 'accompanied by the strongest of feelings and emotions, happy or the reverse' (p. 242), that the infant's 'capacity to cope with stress' is correlated with certain maternal behaviors (p. 344), and that the instinctive behavior that emerges from the co-constructed environment of evolutionary adaptiveness has consequences that are 'vital to the survival of the species' (p. 137). He also suggests that the attachment system is readily activated until the end of the third year, when the child's capacity to cope with maternal separation 'abruptly' improves, due to the fact that 'some maturational threshold is passed' (p. 205).

CONTRIBUTIONS FROM NEUROSCIENCE TO ATTACHMENT THEORY

So the next question is, 30 years after the appearance of this volume, at the end of the 'decade of the brain', how do Bowlby's original chartings of the attachment domain hold up? In a word, they were indeed prescient. In fact his overall bird's-eye perspective of the internal attachment landscape was so comprehensive that we now need to zoom in not just for close-up views of the essential brain structures that mediate attachment processes but also for visualizations of how these structures dynamically self-organize within the developing brain. This includes neurobiological studies of Bowlby's control system, which I suggest may now be identified with the orbitofrontal cortex, an area that has been called the 'senior executive of the emotional brain' (Joseph, 1996) and that has been shown to mediate 'the highest level of control of behavior, especially in relation to emotion' (Price, Carmichael, & Drevets, 1996, p. 523). Keeping in mind Bowlby's previously presented theoretical descriptions, the following is an extremely brief overview of a growing body of studies on the neurobiology of attachment. (For more extensive expositions of these concepts and references see Schore, 1994, 1996, 1997b, 1998a, 1999, in press a, b, c, d, e in preparation).

According to Ainsworth (1967, p. 429) attachment is more than overt behavior, it is internal, 'being built into the nervous system, in the course and as a result of the infant's experience of his transactions with the mother'. Following Bowlby's suggestion, the limbic system has been suggested to be the site of developmental changes associated with the rise of attachment behaviors (Anders & Zeanah, 1984). Indeed the specific period from 7 to 15 months has been shown to be critical for the myelination and therefore the maturation of particular rapidly developing limbic and cortical association areas (Kinney, Brody, Kloman, & Gilles, 1988) and limbic areas of the human

cerebral cortex show anatomical maturation at 15 months (Rabinowicz, 1979). In a number of works I offer evidence to show that attachment experiences, face-to-face transactions of affect synchrony between caregiver and infant, directly influence the imprinting, the circuit wiring of the orbital prefrontal cortex, a corticolimbic area that is known to begin a major maturational change at 10 to 12 months and to complete a critical period of growth from the middle to the end of the second year. This time-frame is identical to Bowlby's maturation of an attachment control system that is open to influence from the developmental environment.

The co-created environment of evolutionary adaptiveness is thus isomorphic to a growth-facilitating environment for the experience-dependent maturation of a regulatory system in the orbitofrontal cortex. Indeed, this prefrontal system appraises visual facial information (Scalaidhe, Wilson, & Goldman-Rakic, 1997), and processes responses to pleasant touch, taste, smell (Francis, D., et al., 1999) and music (Blood, Zatorre, Bermudez, & Evans, 1999) as well as to unpleasant images of angry and sad faces (Blair, Morris, Frith, Perrett, & Dolan, 1999). But this system is also involved in the regulation of the body state and reflects changes taking place in that state (Luria, 1980).

This frontolimbic system provides a high-level coding that flexibly co-ordinates exteroceptive and interoceptive domains and functions to correct responses as conditions change (Derryberry & Tucker, 1992), processes feedback information (Elliott, Frith, & Dolan, 1997), and thereby monitors, adjusts, and corrects emotional responses (Rolls, 1986) and modulates the motivational control of goal-directed behavior (Tremblay & Schultz, 1999). So after a rapid evaluation of an environmental stimulus, the orbitofrontal system monitors feedback about the current internal state in order to make assessments of coping resources, and it updates appropriate response outputs in order to make adaptive adjustments to particular environmental perturbations (Schore, 1998a). In this manner, 'the integrity of the orbitofrontal cortex is necessary for acquiring very specific forms of knowledge for regulating interpersonal behavior' (Dolan, 1999, p. 928).

These functions reflect the unique anatomical properties of this area of the brain. Due to its location at the ventral and medial hemispheric surfaces, it acts as a convergence zone where cortex and subcortex meet. It is thus situated at the apogee of the 'rostral limbic system', a hierarchical sequence of interconnected limbic areas in orbitofrontal cortex, insular cortex, anterior cingulate, and amygdala (Schore, 1997b, in press a, in preparation). The limbic system is now thought to be centrally involved in the implicit processing of facial expressions without conscious awareness (Critchley et al., 2000) and in the capacity 'to adapt to a rapidly changing environment' and in 'the organization of new learning' (Mesulam, 1998, p. 1028). Emotionally focused limbic learning underlies the unique and fast-acting processes of imprinting, the learning mechanism associated with attachment, as this dynamic evolves over the first and second years. Hinde (1990, p. 162) points

out 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'.

But the orbitofrontal system is also deeply connected into the autonomic nervous system and the arousal-generating reticular formation, and due to the fact that it is the only cortical structure with such direct connections, it can regulate autonomic responses to social stimuli (Zald & Kim, 1996) and modulate 'instinctual behavior' (Starkstein & Robinson, 1997). The activity of this frontolimbic system is therefore critical to the modulation of social and emotional behaviors and the homeostatic regulation of body and motivational states, affect-regulating functions that are centrally involved in attachment processes. The essential aspect of this function is highlighted by Westin (1997, p. 542) who asserts that 'The attempt to regulate affect – to minimize unpleasant feelings and to maximize pleasant ones – is the driving force in human motivation'.

The orbital prefrontal region is especially expanded in the right hemisphere which is specialized for 'inhibitory control' (Garavan, Ross & Stein, 1999), and it comes to act as an executive control function for the entire right brain. This hemisphere, which is dominant for unconscious processes, computes, on a moment-to-moment basis, the affective salience of external stimuli. Keeping in mind Bowlby's earlier descriptions, this lateralized system performs a 'valence tagging' function (Schore, 1998a, 1999), in which perceptions receive a positive or negative affective charge, in accord with a calibration of degrees of pleasure–unpleasure. It also contains a 'nonverbal affect lexicon', a vocabulary for nonverbal affective signals such as facial expressions, gestures, and vocal tone or prosody (Bowers, Bauer, & Heilman, 1993). The right hemisphere is thus faster than the left in performing valence-dependent, automatic, pre-attentive appraisal of emotional facial expressions (Pizzagalli, Regard & Lehmann, 1999).

Because the right cortical hemisphere, more so than the left, contains extensive reciprocal connections with limbic and subcortical regions (Tucker, 1992; Joseph, 1996), it is dominant for the processing and expression of 'self-related material' (Keenan et al., 1999), and emotional information and for regulating psychobiological states (Schore, 1994, 1998a, 1999; Spence, Shapiro, & Zaidel, 1996). Thus the right hemisphere is centrally involved in what Bowlby described as the social and biological functions of the attachment system (Henry, 1993; Schore, 1994; Shapiro, Jamner, & Spence, 1997; Wang, 1997; Siegel, 1999).

Confirming this model, Ryan, Kuhl, and Deci (1997, p. 719), using EEG and neuroimaging data, conclude that 'The positive emotional exchange resulting from autonomy-supportive parenting involves participation of right hemispheric cortical and subcortical systems that participate in global, tonic emotional modulation'. And in line with Bowlby's assertion that attachment behavior is vital to the survival of the species, it is now held that the right hemisphere is central to the control of vital functions supporting

survival and enabling the organism to cope with stresses and challenges (Wittling & Schweiger, 1993).

There is a growing body of studies which shows that the infant's early maturing (Geschwind & Galaburda, 1987) right hemisphere is specifically impacted by early social experiences (Schore, 1994, 1998b). This developmental principle is now supported in a recent single photon emission computed tomographic (SPECT) study by Chiron *et al.* (1997), which demonstrates that the right brain hemisphere is dominant in preverbal human infants, and indeed for the first 3 years of life. I suggest that the ontogenetic shift of dominance from the right to left hemisphere after this time may explicate Bowlby's description of a diminution of the attachment system at the end of the third year that is due to an 'abrupt' passage of a 'maturational threshold'.

Current neuropsychological studies indicate that 'the emotional experience(s) of the infant . . . are disproportionately stored or processed in the right hemisphere during the formative stages of brain ontogeny' (Semrud-Clikeman & Hynd, 1990, p. 198), that 'the infant relies primarily on its procedural memory systems' during 'the first 2–3 years of life' (Kandel, 1999, p. 513) and that the right brain contains the 'cerebral representation of one's own past' and the substrate of affectively laden autobiographical memory (Fink *et al.*, 1996, p. 4275). These findings suggest that early-forming internal working models of the attachment relationship are processed and stored in implicit-procedural memory systems in the right cortex, the hemisphere dominant for implicit learning (Hugdahl, 1995).

In the securely attached individual, these models encode an expectation that 'homeostatic disruptions will be set right' (Pipp & Harmon, 1987, p. 650). In discussing these internal models Rutter (1987) notes that 'children derive a set of expectations about their own relationship capacities and about other people's resources to their social overtures and interactions, these expectations being created on the basis of their early parent–child attachments' (p. 449). Such representations are processed by the orbitofrontal system, which is known to be activated during 'breaches of expectation' (Nobre, Coull, Frith & Mesulam, 1999) and to generate affect-regulating strategies for coping with expected negative and positive emotional states that are inherent in intimate social contexts.

The efficient operations of this regulatory system allow for cortically processed information concerning the external environment (such as visual and auditory stimuli emanating from the emotional face of the attachment object) to be integrated with subcortically processed information regarding the internal visceral environment (such as concurrent changes in the child's emotional or bodily self-state). The relaying of sensory information into the limbic system allows incoming information about the social environment to trigger adjustments in emotional and motivational states, and in this manner the orbitofrontal system integrates what Bowlby termed environmental and organismic models. Recent findings that the orbitofrontal cortex generates

nonconscious biases that guide behavior before conscious knowledge does (Bechara, Damasio, Tranel & Damasio, 1997) and codes the likely significance of future behavioral options (Dolan, 1999), and represents an important site of contact between emotional information and mechanisms of action selection (Rolls, 1996), are consonant with Bowlby's (1981) assertion that internal working models are used as guides for future action.

These mental representations, according to Main, Kaplan, and Cassidy (1985), contain cognitive as well as affective components and act to guide appraisals of experience. The orbitofrontal cortex is known to function as an appraisal mechanism (Pribram, 1987; Schore, 1998a) and to be centrally involved in the generation of 'cognitive-emotional interactions' (Barbas, 1995). It acts 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).

Orbitofrontal activity is associated with a lower threshold for awareness of sensations of both external and internal origin (Goldenberg *et al.*, 1989), thereby enabling it to act as an 'internal reflecting and organizing agency' (Kaplan-Solms & Solms, 1996). This orbitofrontal role in 'self-reflective awareness' (Stuss, Gow, & Hetherington, 1992) allows an individual to reflect on his or her own internal emotional states, as well as those of others (Povinelli & Preuss, 1995). According to Fonagy and Target (1997) the reflective function is a mental operation that enables the perception of another's state. The right hemisphere mediates empathic cognition and the perception of the emotional states of other human beings (Voeller, 1986) and orbitofrontal function is essential to the capacity of inferring the states of others (Baron-Cohen, 1995). This adaptive capacity may thus be the outcome of a secure attachment to a psychobiologically attuned, affect-regulating caregiver. A recent neuropsychological study indicates that the orbitofrontal cortex is 'particularly involved in theory of mind tasks with an affective component' (Stone, Baron-Cohen & Knight, 1998, p. 651).

Furthermore, the functioning of the orbitofrontal control system in the regulation of emotion (Baker, Frith & Dolan, 1997) and in 'acquiring very specific forms of knowledge for regulating interpersonal and social behavior' (Dolan, 1999, p. 928) is central to self-regulation, the ability to flexibly regulate emotional states through interactions with other humans – that is, interactive regulation in interconnected contexts – and without other humans – that is, autoregulation in autonomous contexts. The adaptive capacity to shift between these dual regulatory modes, depending upon the social context, emerges out of a history of secure attachment interactions of a maturing biological organism and an early attuned social environment.

ATTACHMENT THEORY IS FUNDAMENTALLY
A REGULATORY THEORY

Attachment behavior is currently thought to be the output of 'a neuro-biologically based biobehavioral system that regulates biological synchronicity between organisms' (Wang, 1997, p. 168). I suggest that the characterization of the orbitofrontal system as a frontolimbic structure that determines the regulatory significance of stimuli that reach the organism and regulates body state (Luria, 1980), bears a striking resemblance to the behavioral control system characterized by Bowlby over 30 years ago. The Oxford Dictionary defines control as 'the act or power of directing or regulating'.

Attachment theory, as first propounded in Bowlby's (1969) definitional volume, is fundamentally a regulatory theory. Attachment can thus be conceptualized as the interactive regulation of synchrony between psychobiologically attuned organisms. This attachment dynamic, which operates at levels beneath awareness, underlies the dyadic regulation of emotion. Emotions are the highest order direct expression of bioregulation in complex organisms (Damasio, 1998). Imprinting, the learning process it accesses, is described by Petrovich and Gewirtz (1985) as synchrony between sequential infant maternal stimuli and behavior (see Schore, 1994 and Nelson & Panksepp, 1998 for models of the neurochemistry of attachment).

According to Feldman *et al.* (1999), 'face-to-face synchrony affords infants their first opportunity to practice interpersonal coordination of biological rhythms' (p. 223) and acts as an interpersonal context in which 'interactants integrate into the flow of behavior the ongoing responses of their partner and the changing inputs of the environment' (p. 224). The visual, prosodic-auditory, and gestural stimuli embedded in these emotional communications are rapidly transmitted back and forth between the infant's and mother's face, and in these transactions the caregiver acts as a regulator of the child's arousal levels.

Because arousal levels are known to be associated with changes in metabolic energy, the caregiver is thus modulating changes in the child's energetic state (Schore, 1994, 1997b). These regulated increases in energy metabolism are available for biosynthetic processes in the baby's brain, which is in the brain growth spurt (Dobbing & Sands, 1973). In this manner, '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).

In addition, the mother also regulates moments of asynchrony, that is stressful negative affect. Social stressors can be characterized as the occurrence of an asynchrony in an interactional sequence (Chapple, 1970). Stress describes both the subjective experience induced by a distressing, potentially threatening, or novel situation, and the organism's reactions to a homeostatic challenge. It is now thought that social stressors are 'far more detrimental' than non-social aversive stimuli (Sgoifo *et al.*, 1999).

Separation stress, in essence, is a loss of maternal regulators of the infant's immature behavioral and physiological systems that results in the attachment patterns of protest, despair, and detachment. The principle that 'a period of synchrony, following the period of stress, provides a "recovery" period' (Chapple, 1970, p. 631) underlies the mechanism of interactive repair (Tronick, 1989; Schore, 1994). The primary caregiver's interactive regulation is therefore critical to the infant's maintaining positively charged as well as coping with stressful negatively charged affects. These affect regulating events are particularly impacting the organization of the early developing right hemisphere.

Bowlby's control system is located in the right hemisphere that is not only dominant for 'inhibitory control' (Garavan *et al.*, 1999), but also for the processing of facial information in infants (Deruelle & de Schonen, 1998) and adults (Kim *et al.*, 1999), and for the regulation of arousal (Heilman & Van Den Abell, 1979). Because the major coping systems, the hypothalamo-pituitary-adrenocortical axis and the sympathetic-adrenomedullary axis, 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). Basic research in stress physiology shows that the behavioral and physiological response of an individual to a specific stressor is consistent over time (Koolhaas *et al.*, 1999).

These attachment transactions are imprinted into implicit-procedural memory as enduring internal working models, which encode coping strategies of affect regulation (Schore, 1994) that maintain basic regulation and positive affect even in the face of environmental challenge (Sroufe, 1989). Attachment patterns are now conceptualized as 'patterns of mental processing of information based on cognition and affect to create models of reality' (Crittenden, 1995, p. 401). The 'anterior limbic prefrontal network,' which interconnects the orbital and medial prefrontal cortex with the temporal pole, cingulate, and amygdala, 'is involved in affective responses to events and in the mnemonic processing and storage of these responses' (Carmichael & Price, 1995, p. 639), and 'constitutes a mental control system that is essential for adjusting thinking and behavior to ongoing reality' (Schnider & Ptak, 1999, p. 680). An ultimate indicator of secure attachment is resilience in the face of stress (Greenspan, 1981), which is expressed in the capacity to flexibly regulate emotional states via autoregulation and interactive regulation. However, early social environments that engender insecure attachments inhibit the growth of this control system (Schore, 1997b) and therefore preclude its adaptive coping function in 'operations linked to behavioral flexibility' (Nobre *et al.*, 1999, p. 12).

In support of Bowlby's assertion that the child's capacity to cope with stress is correlated with certain maternal behaviors, current developmental biological studies are exploring 'maternal effects', the influence of the mother's experiences on her progeny's development and ability to adapt to

its environment (Bernardo, 1996). This body of research indicates 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), and that 'maternal care during infancy serves to "program" behavioral responses to stress in the offspring' (Caldji *et al.*, 1998. p. 5335).

Recent developmental neurobiological findings support the idea that 'infants' early experiences with their mothers (or absence of these experiences) may come to influence how they respond to their own infants when they grow up' (Fleming, O'Day & Kraemer, 1999, p. 673). I suggest that the intergenerational transmission of stress-coping deficits occurs within the context of relational environments that are growth-inhibiting to the development of regulatory corticolimbic circuits sculpted by early experiences (see Schore in press e for a detailed discussion of the effects of early traumatic abuse and/or neglect on right brain development). These attachment-related psychopathologies are thus expressed in dysregulation of social, behavioral, and biological functions that are associated with an immature frontolimbic control system and an inefficient right hemisphere (Schore, 1994; 1996; 1997b, in press e). This conceptualization directly bears upon Bowlby's (1978) assertion that attachment theory can be used to frame the early etiologies of a diverse group of psychiatric disorders and the neurophysiological changes that accompany them.

FUTURE DIRECTIONS OF RESEARCH INTO REGULATORY PROCESSES

Returning to *Attachment*, Bowlby asserts that 'The merits of a scientific theory are to be judged in terms of the range of phenomena it embraces, the internal consistency of its structure, the precision of the predictions it can make and the practibility of testing them' (1969, p. 173). The republication of this classic volume is occurring at a point in time, coincident with the beginning of the new millennium, when we are now able to explore the neuropsychobiological substrata on which attachment theory is based. In earlier writings I have suggested that 'the primordial environment of the infant, or more properly of the commutual psychobiological environment shared by the infant and mother, represents a primal *terra incognita* of science' (Schore, 1994, p. 64). The next generation of studies of Bowlby's theoretical landscape will chart in detail how different early social environments and attachment experiences influence the unique microtopography of a developing brain.

Such studies will be projecting an experimental searchlight upon events occurring at the common dynamic interface of brain systems that represent the psychological and biological realms. The right-brain-to-right-brain psychobiological transactions that underlie attachment processes are bodily based, and critical to the adaptive capacities and growth of the infant. This

calls for studies that concurrently measure brain, behavioral, and bodily changes in both members of the dyad. Autonomic measures of synchronous changes to the infant's and the mother's bodily states need to be included in studies of attachment functions, and the development of co-ordinated interactions between the maturing central and autonomic nervous systems should be investigated in research on attachment structures.

It is now accepted that internal working models that encode strategies of affect regulation act at levels beneath conscious awareness. In a recent issue of the *American Psychologist* Bargh and Chartrand (1999, p. 426) assert that '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.' This characterization describes unconscious internal working models, and since their affective-cognitive components regulate and are regulated by the involuntary autonomic nervous system, these functions may very well be inaccessible to self-report measures that mainly tap into conscious thoughts and images.

The psychobiological mechanisms that trigger organismic responses are fast-acting and dynamic. Studying very rapid affective phenomena in real time involves attention to a different time dimension from usual, a focus on interpersonal attachment and separations on a microtemporal scale. The emphasis is less on enduring traits and more on transient dynamic states, and research methodologies will have to be created that can visualize the dyadic regulatory events occurring at the brain–mind–body interface of two subjectivities that are engaged in attachment transactions.

Since the human face is a central focus of these transactions, studies of right brain appraisals of visual and prosodic facial stimuli, even presented at tachistoscopic levels, may more accurately tap into the fundamental mechanisms that are involved in the processing of social-emotional information. And in light of the principle that dyadic regulatory affective communications maximize positive as well as minimize negative affect, both procedures that measure coping with negative affect – the Strange Situation – and those that measure coping with positive affect – play situations – need to be used to evaluate attachment capacities.

It is now established that face-to-face contexts of affect synchrony not only generate positive arousal but also expose infants to high levels of social and *cognitive* information (Feldman *et al.*, 1999). In such interpersonal contexts, including attachment-related 'joint attention' transactions (Schore, 1994), the developing child is exercising early attentional capacities. There is now evidence to show that 'intrinsic alertness', the most basic intensity aspect of attention, is mediated by a network in the right hemisphere (Sturm *et al.*, 1999). In light of the known impaired functioning of right frontal circuits in attention-deficit/hyperactivity disorders (Casey *et al.*, 1997), developmental attachment studies may elucidate the early etiology of these disorders, as well

as of right hemisphere learning disabilities (Semrud-Klikeman & Hynd, 1990; Gross-Tsur, Shalev, Manor & Amir, 1995).

Furthermore, although most attachment studies refer to 'infants' and 'toddlers,' it is well known that the brain maturation rates of baby girls are significantly more advanced than boys. Gender differences in infant emotional regulation (Weinberg, Tronick, Cohn & Olson, 1999) and in the orbitofrontal system that mediates this function (Overman, Bachevalier, Schuhmann & Ryan, 1996) have been demonstrated. Studies of how different social experiences interact with different female–male regional brain growth rates could elucidate the origins of gender differences within the limbic system that are later expressed in variations of social-emotional information processing between the sexes. This research should include measures of 'psychological gender' (see Schore, 1994). And in addition to maternal effects on early brain maturation, the effects of fathers, especially in the second and third years, on the female and male toddler's psychoneurobiological development can tell us more about paternal contributions to the child's expanding stress coping capacities.

We must also more fully understand the very early pre- and postnatally maturing limbic circuits that organize what Bowlby calls the 'building blocks' of attachment experiences (Schore, in press a, d). Bowlby (1969) refers to a succession of increasingly sophisticated systems of limbic structures that are involved in attachment (see Schore, in press a, d for an ontogenetic progression of amygdala, anterior cingulate, insula, and orbitofrontal cortex). Since attachment is the outcome of the child's genetically encoded biological (temperamental) predisposition *and* the particular caregiver environment, we need to know more about the mechanisms of gene-environment interactions. This work could elucidate the nature of the expression of particular genes in specific brain regions that regulate stress reactivity, as well as a deeper knowledge of the dynamic components of 'non-shared' environmental factors (Plomin, Rende & Rutter, 1991). It should be remembered that DNA levels in the cortex significantly increase over the first year, the period of attachment (Winick, Rosso & Waterlow, 1970).

A very recent report of an association between perinatal complications (deviations of normal pregnancy, labor-delivery, and early neonatal development) and later signs of specifically orbitofrontal dysfunction (Kinney *et al.*, 2000) may elucidate the mechanism by which an interaction of a vulnerable genetically-encoded psychobiological predisposition interacts with a misattuned relational environment to produce a high risk scenario for future disorders. Orbitofrontal dysfunction in infancy has also been implicated in a later appearing impairment of not only social but moral behavior (Anderson *et al.*, 1999).

Furthermore, developmental neuroscientific studies of the effects of attuned and misattuned parental environments will reveal the subtle but important differences in brain organization among securely and insecurely attached individuals, as well as the psychobiological mechanisms that mediate

resilience to or risk for later-forming psychopathologies. Neurobiological studies now indicate that although the right prefrontal system is necessary to mount a normal stress response, extreme alterations of such activity is maladaptive (Sullivan & Gratton, 1999). In line with the association of attachment experiences and the development of brain systems for coping with relational stress, future studies need to explore the relationship between different adaptive and maladaptive coping styles of various attachment categories and correlated deficits in brain systems involved in stress regulation. Subjects, classified on the Adult Attachment Inventory, could be exposed to a real-life, personally meaningful stressor, and brain imaging and autonomic measures could then evaluate the individual's adaptive or maladaptive regulatory mechanisms. Such studies can also elucidate the mechanisms of the intergenerational transmission of the regulatory deficits of different classes of psychiatric disorders (see Schore, 1994, 1996, 1997b).

In light of the fact that the right hemisphere subsequently re-enters into growth spurts (Thatcher, 1994) and ultimately forms an interactive system with the later maturing left (Schore, 1994, in press b; Siegel, 1999), neurobiological reorganizations of the attachment system and their functional correlates in ensuing stages of childhood and adulthood need to be explored. Psychoneurobiological research of the continuing experience-dependent maturation of the right hemisphere could elucidate the underlying mechanisms by which certain attachment patterns can change from 'insecurity' to 'earned security' (Phelps, Belsky & Crnic, 1998).

The documented findings that the orbitofrontal system is involved in 'emotion-related learning' (Rolls, Hornak, Wade & McGrath, 1994) and that it retains plasticity throughout later periods of life (Barbas, 1995) may also help us understand how developmentally-based, affectively-focused psychotherapy can alter early attachment patterns. A recently published functional magnetic resonance imaging study (Hariri, Bookheimer & Mazziotta, 2000) provides evidence that higher regions of specifically the right prefrontal cortex attenuate emotional responses at the most basic levels in the brain, that such modulating processes are 'fundamental to most modern psychotherapeutic methods' (p. 43), that this lateralized neocortical network is active in 'modulating emotional experience through interpreting and labeling emotional expressions' (p. 47), and that 'this form of modulation may be impaired in various emotional disorders and may provide the basis for therapies of these same disorders' (p. 48). This process is a central component of therapeutic narrative organization, of turning 'raw feelings into symbols' (Holmes, 1993, p. 150). This 'neocortical network', which 'modulates the limbic system' is identical to the right-lateralized orbitofrontal system that regulates attachment dynamics. Attachment models of mother–infant psychobiological attunement may thus be used to explore the origins of empathic processes in both development and psychotherapy, and reveal the deeper mechanisms of the growth-facilitating factors operating within the therapeutic alliance (see Schore, 1994, 1997c, in press, b, in preparation).

In a sense these deeper explorations into the early roots of the human experience have been waiting for not just theoretical advances in developmental neurobiology and technical improvements in methodologies that can noninvasively image developing brain-mind-body processes in real time, but also for a perspective of brain-mind-body development that can bridge psychology and biology. Such interdisciplinary models can shift back and forth between different levels of organization in order to accomodate heuristic conceptions of how the primordial experiences with the external social world alters the ontogeny of internal structural systems. Ultimately, these psychoneurobiological attachment models can be used as a scientific basis for creating even more effective early prevention programs.

In her concluding comments of a recent overview of the field, Mary Main, a central figure in the continuing development of attachment theory, writes 'we are currently at one of the most exciting junctures in the history of our field. We are now, or will soon be, in a position to begin mapping the relations between individual differences in early attachment experiences and changes in neurochemistry and brain organization. In addition, investigation of physiological "regulators" associated with infant-caregiver interactions could have far-reaching implications for both clinical assessment and intervention' (1999, pp. 881–882).

But I leave the final word to Bowlby himself, who in the last paragraph of this book, sums up the meaning of his work:

> The truth is that the least-studied phase of human development remains the phase during which a child is acquiring all that makes him most distinctively human. Here is still a continent to conquer.

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