

Psychobiological Roots of Early Attachment

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ABSTRACT—*New laboratory research has revealed a network of simple behavioral, physiological, and neural processes that underlie the psychological constructs of attachment theory. It has become apparent that the unique features of early infant attachment reflect certain unique features of early infant sensory and motor integration, learning, communication, and motivation, as well as the regulation of biobehavioral systems by the mother–infant interaction. In this article, I will use this new knowledge to answer three major questions that have remained unsettled in our understanding of early human attachment: What creates an attachment bond? Why is early maternal separation stressful? How can early relationships have lasting effects? I will discuss the implications of these new answers for human infants and for the development of mental processes. Attachment remains useful as a concept that, like hunger, describes the operation of subprocesses that work together within the frame of a vital biological function.*

KEYWORDS—*attachment; separation; bond; maternal behavior; early experience; learning*

The word *attachment* has assumed new meanings as it has spread from literature to psychology, and most recently to biology. These changes have spanned the half century since the Second World War, when the vast numbers of displaced and orphaned children made the importance of a child's early tie to its mother evident to all. As different groups within psychology used the concept, there developed champions and detractors of one or another formulation. I think that a crucial change came when Bowlby's (1982) concept of attachment as a unique motivational system was gradually found to be incapable of generating testable

hypotheses that could explain several puzzling observations. Developmental psychobiology researchers focused instead on simpler processes at work within the interactions between infant and parent—such as orientation, nursing, early learning, thermoregulation, and sensorimotor-system development. There was a period between the early 1970s and late 1980s when *attachment* was seldom used by developmental psychobiologists. In the last decade, however, the word has found a new usefulness as a general descriptive term for the processes that maintain and regulate sustained social relationships, much the same way that *appetite* refers to a cluster of behavioral and physiological processes that regulate food intake.

The concept of attachment provides a good example of how a psychological construct can be analyzed at the level of the component processes that underlie it. This approach does not attempt to reduce psychological questions to the most basic units of biological organization. Rather, the focus is on the processes of behavioral and physiological regulation that closely underlie psychological constructs, providing a much-needed link between psychology and the cellular/molecular mechanisms of brain function. New knowledge at the level of behavior and integrative physiology promises to deepen our understanding of psychological constructs rather than eliminate the need for them.

In order to illustrate this point, I will describe how new research using animal models has helped resolve three questions left unanswered by psychological theories of attachment, and I will relate these findings to human psychology, as I see it.

WHAT CREATES AN ATTACHMENT BOND?

This question asks what processes are responsible for the development of the behaviors, and inferred mental states, that we refer to as the “bond” between infant and mother. Research has shown that predispositions can be created prenatally, in the fetus, to respond preferentially to specific maternal scents and sounds, and that these predispositions prepare the way for the next phase in the development of attachment.

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Regina Sullivan, Steve Brake, and I (Sullivan, Hofer, & Brake, 1986) discovered an experimental learning paradigm in newborn rats that revealed a rapid and powerful learning capacity by which neonates acquire the ability to discriminate, prefer, approach, and maintain proximity to their own mother. A specific neutral odor was presented to newborns while the pups were stroked with an artist's brush for 5 to 15 minutes. The odor was later applied to shavings under mesh in a two-compartment box. The neonates then turned preferentially to that odor and remained on the mesh over the scented compartment for the duration of testing. Control subjects were presented with the same stimuli but separated in time. They showed no later preference for the odor. Such rapid and specific associative learning had not been anticipated in rats of such an early age. Indeed Bowlby and others in the 1960s thought that even human newborns and young infants interacted with their mothers entirely through reflex and fixed-action-pattern behaviors (simple, rigidly stereotyped action sequences). We now know that human newborns also can distinguish their own mother's smell, apparently on the basis of prenatal experience, and add vocal and visual recognition postnatally—probably by similar early-learning systems (Winberg 2005).

Next, Sullivan (reviewed in Moriceau and Sullivan, 2005) discovered that for the first 10 days after birth, an aversive level of stimulation (e.g., tail pinch, mild shock) that itself elicits vigorous escape behavior will paradoxically induce approach and preference for an odor previously associated with it. After those 10 days, such associative pairing results in avoidance of the odor. The unexpected early aversive-preference learning has an obvious parallel in the strong attachments frequently observed in abused human infants. In this animal model, Sullivan and coworkers have mapped out the critical period for the effect, have shown that the critical period can be extended in time by daily repetitions of the associative experience, and have related the normal close of this period to developmental transitions in specific brain systems that are regulated by circulating adrenocortical hormones.

In these studies, the questions of the nature of a psychological bond, its specificity, and how it is formed, can be answered in terms of an unexpected rapid early-learning process with properties that can be related to brain and hormone-system development. Experiments testing alternative hypotheses led us to a new way to understand the paradoxically close attachments of children to abusive parents.

WHY IS EARLY MATERNAL SEPARATION STRESSFUL?

In most conceptual formulations of attachment, the separation response is explained as deriving from the strong affective nature of the bond, which when severed or "ruptured" by separation results in a series of traumatic emotional reactions: the "biphasic protest–despair response," in which an initial burst of calling and active search behavior is followed by a long decline

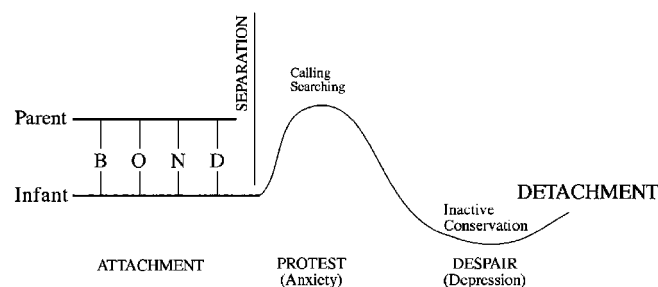


Fig. 1. Schematic representation of the dynamics of early-separation responses based on the concept of an attachment bond as described by John Bowlby (Bowlby, 1982).

in behavioral responsiveness (Bowlby, 1982; see Fig. 1). But there is circularity in this line of reasoning, as the evidence for the existence of the bond itself, and for its strength, lies in the dramatic response to its being broken by separation.

I was led to an entirely different way of thinking about separation by unexpected results in our laboratory (reviewed in Hofer, 1994). Initially, we did not believe that infant rats were capable of the complex cognitive-affective processes thought to underlie the separation response seen in infant monkeys and humans. But to our surprise, we found that, like primate infants, infant rats show a complex biphasic protest–despair response to maternal separation, as well as a number of other responses that were entirely unexpected. We found that these changes were not the expression of an integrated psychophysiological response (like the increase in heart rate and respiration during exercise) to the stressful event, but were the result of a novel mechanism I will now describe (see Fig. 2). Our experiments showed that each of the individual behavioral and physiological systems of the infant rat was responding to the loss of one or another of the components (e.g., nutrient, thermal/metabolic, or sensorimotor) of the infant's previous interaction with its mother and that the complex response to separation was due to the withdrawal of all these components at once.

For example, we found that providing one of these components, warmth, to a separated pup prevented the slow decline in

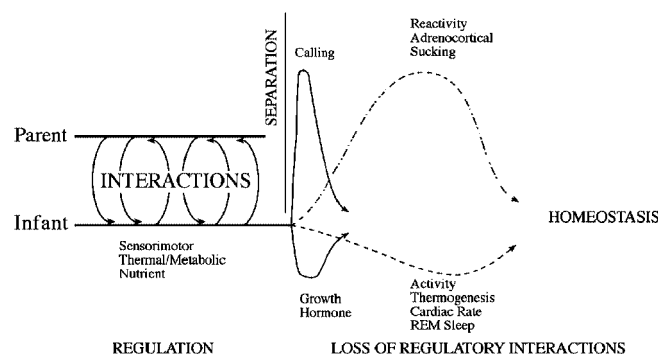


Fig. 2. Schematic representation of the dynamics of early-separation responses resulting from the loss of regulatory interactions within the mother–infant relationship.

the pups' general activity level (a response similar to Bowlby's "despair" phase), but this had no effect on responses in other systems. The pup's cardiac rate continued to fall by 40%, regardless of whether supplemental heat or tactile stimulation was provided. But we found that we could maintain cardiac rate in separated pups at normal levels by continuous infusion of milk to the pup's stomach. Supplying enough milk to prevent weight loss had no effect, but if enough was given to produce a normal range of weight gain, the cardiac rate at the end of a 24-hour separation was proportional to the amount of nutrient that had been infused. In other words, the supplied milk regulated the pups' heart rate. The physiological mechanism, we found, was not gastric distention or any effect of absorbed nutrients, but an effect of specific nutrients on receptors in the lining of the stomach that are connected to the brain.

We concluded from these surprising results that warmth provided by the mother normally maintained the pup's activity level and that her milk maintained her pup's heart rate. Maternal separation withdrew these regulatory influences that were hidden within the ordinary mother–infant interactions, resulting in slowed behavior and low heart rate. We began to look for other effects of separation and the specific regulators that could prevent them. We found that sufficient levels of tactile stimulation during a 24-hour separation period prevented the increase in the pup's behavioral response to being moved into a novel test chamber, a behavioral hyper-reactivity that we had found in separated pups with normal body temperatures. Graded levels of tactile stimulation during separation produced graded levels of quieting of pups. For the rate of sucking on an artificial teat and for the immediate vocal "protest" phase of vocalization (Hofer, 1996), both of which increased in separated pups, more specific types of sensorimotor experience were necessary to reduce these behaviors to normal levels. We also studied sleep/wake states using an electroencephalograph and found that the durations of bouts of sleeping and waking and the smooth transitions between them were maintained (regulated) by the periodicity or rhythm of maternal milk supply and tactile interactions, rather than simply by their level. After 24 hours of separation, the REM-sleep time of pups remaining in their home cage was sharply decreased and slow-wave sleep was fragmented by frequent short awakenings. Only scheduled periodic bouts of nutrient infusion and tactile stimulation prevented this. Soon, other investigators were able to define other maternal regulatory effects: Saul Schanberg for growth hormone and Seymour Levine for adrenocortical system control (reviewed in Hofer, 1994).

In thinking about the implication of these findings for human infants, one can suppose that these kinds of simple maternal regulators would be found early in a baby's postnatal period, but that soon more subtle and intricate interactions would become important. Reciprocity, imitation, attunement, and play are now being investigated for their roles in regulating the baby's affective state and his or her developing capacity to self-regulate and later engage in complex social interactions outside the parental

relationship. But we should be aware that regulatory interactions at the simpler levels of touch, warmth, and smell may continue to be important for humans (as well as other animals), even into adult life, with implications for human grief (Hofer, 1984).

In trying to understand responses to separation in infants (as well as in adults), we should look carefully for exactly what was lost, not simply regard separation as an affective response to stress. The discovery of numerous regulatory processes hidden within the mother–infant interaction provides a novel causative explanation for the response of infants to maternal separation that does not depend upon the metaphorical concept of a "bond" that is "broken." Furthermore, the discovery of these regulatory processes at work within an ongoing mother–infant relationship raises the question of whether, in addition, they might be responsible for regulating the course of development over time.

HOW CAN EARLY RELATIONSHIPS HAVE LASTING EFFECTS?

An immediate implication of our discovery of multiple hidden regulators within the mother–infant interaction was the possibility that different patterns of early parent–infant interaction might differentially shape the course of development of offspring. The first pattern that we investigated was the early termination of the relationship, before the usual time of weaning (reviewed in Hofer, 1994). We found that if rat pups are separated from their mothers at 15 days instead of the usual 21 to 30 days, they can survive, but they will have been deprived of maternal regulation during that period of their development. We assessed the effect of this early weaning on the vulnerability of adults to a known stressor, 24 hours of immobilization, which had been reported to produce gastric ulceration in about 50% of normally reared adult rats. We found that early weaning did not affect the expected percent vulnerability when rats were stressed in adulthood (120 days); but in early adolescence (25 and 35 days), 80% of the early-weaned rats developed ulcers, and these were larger and deeper than those occurring in adults; however, no normally reared rats developed ulcers at these ages. In the immediate aftermath of maternal separation, at 17 days of age, no rat ulcerated. Even more surprising, as rats matured into later adulthood (160 days), the early-weaned rats were actually less vulnerable than the normally reared ones were.

What I believe this experiment illustrates is that when all maternal regulators are withdrawn early, a number of physiological and behavioral systems are altered in their developmental paths and in their relation to each other, creating a complex, changing pattern of vulnerability over the life span.

We then decided to study a more discrete form of change in the pattern of early mother–infant interactions by taking advantage of naturally occurring variations in the relative frequency of different maternal behaviors, what might be called different "qualities" of the relationship. Michael Myers, Harry Shair, and

I (Myers, Shair, & Hofer, 1992) were studying two strains of rats created by selective breeding, the spontaneously hypertensive strain and the normotensive-progenitor strain. We found a range of variation between litters in their mean adult blood pressure. We then observed a range of variation in the levels of 10 different maternal behaviors as we studied litters over the preweaning period. Within each strain, the offspring of mothers with high levels of three of these behaviors (licking-grooming, high-arched nursing posture, and time in contact) had significantly higher levels of blood pressure as adults than did offspring of mothers with low levels of those behaviors. (Since the animals in each strain had been inbred to the point that they were genetically identical, these differences could not be simply due to genetic covariation in maternal behavior and in blood pressure within each strain.) Furthermore, the mothers of the spontaneously hypertensive strain, as a group, showed higher levels of these maternal behaviors than did the mothers of the normotensive strain.

Finding such a strong correlation of levels of specific maternal behaviors with levels of offspring blood pressure in adulthood strongly supported our inference that certain components of the mother–infant interaction serve to regulate the later developmental paths of certain systems in their offspring. Subsequent research by Michael Meaney and his group, recently reviewed in this journal (Parent et al., 2005), found that two of these same behaviors (licking-grooming and high-arched nursing posture) predicted levels of adult offspring responses in a wide variety of other systems (e.g., adrenocortical and fear responses, cognitive function, and even maternal behavior in the next generation).

Variations in qualities of mother–infant relationships among humans thus appear to have deep biological roots in the form of their capacity to shape children’s psychological and biological responses to their environment—effects that extend into adulthood.

LINKS TO HUMAN MENTAL PROCESSES

In applying these experimental results to early human development, we can begin to see how the psychological constructs of the attachment “bond” and the “traumatic” effects of maternal separation originate, in one case, in an unusual form of rapid early learning and, in the other, in the unexpected developmental regulatory functions being carried out by specific mother–infant interactions. These processes can be thought of as “underlying” the psychological concepts that people have invented to help think about complex behaviors and mental experiences. In humans, the early-learning processes and the many different regulating interactions that I have described above are the first experiences out of which mental representations and their associated affects arise. It seems likely that these mental structures combine the infants’ newly developing capacities to remember and anticipate events and respond to symbolic cues with traces of the earlier functions of the maternal

regulatory interactions, through processes similar to the functional links involved in the associative conditioning of physiological responses. Thus, the “internal working model” of attachment theory is constructed as early biological regulatory interactions become linked to later-developing memories, expectations, and affect states by the many associations of physical and psychological events during this developmental transition period between infancy and childhood, in the same way that the salivation of Pavlov’s dogs became linked to the expectation of food through a series of prior associations. This may help explain the visceral sensations accompanying the vicissitudes of close human relationships even after the development of self-regulation of affect and motivation come to supplant the sensorimotor, thermal, and nutrient-based regulatory systems that are hidden within the observable interactions of younger infants with their mothers (Polan and Hofer, 1999).

The future directions of this research are, first, to extend our understanding of the actual links connecting specific mother–infant interactions (such as touch, voice, imitation) with developing psychological processes (on the one hand) and with cellular/molecular brain processes via neural and hormonal pathways (on the other); and, second, to find out how these interactions exert their effects on the developmental paths of behavior and biological systems, from infancy into adulthood.

Recommended Reading

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Acknowledgments—This work was supported by project grants and a Research Scientist Award from the National Institutes of Mental Health and by the Sackler Institute for Developmental Psychobiology at Columbia University.

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