Introduction

The basic premise that certain early experiences have important consequences for adult functioning has been a central feature of many developmental theories throughout the history of psychiatry, ethology, psychology, and anthropology. More than 100 years ago, Freud argued that events transpiring during an individual's first 3 years have lifelong influences on that individual's personality. One of the most critical contributions to our understanding of child development has been John Bowlby's attachment theory. In the 1960s and 1970s, Bowlby, borrowing concepts from both psychoanalytic and ethological frameworks, formulated a theory of social attachment which had as its most basic premise the notion that all of an individual's social relationships throughout life are influenced in fundamental ways by the initial attachment relationship with one's mother (or other primary caregiver) (Bowlby, 1977). Multiple developmental neuroscience approaches in the 1980s and 1990s expanded our understanding of this important relationship by focusing on long-term neurobiological changes associated with events experienced during early critical or sensitive periods. At the heart of these approaches has been the basic belief that "the child is the father of the man," that is, that early experiences can and do shape adult functioning (Rutter, 1989; Skeels, 1966).

Infant and child development is complex and multifactorial. Significant insights into the effects of early life environment on infants and children can be gained by cross-cultural investigations, especially among small-scale societies that share features with our environments of evolutionary adaptiveness (see chapters 5, 6, and 8). In addition to understanding the breadth and universalities of human development, the study of nonhuman animals provides additional insights. Animal models
afford opportunities that are not ethical, logistical, or plausible among human subjects. Experimental manipulation, pedigreed populations, and faster generation times allow for incredible leverage to unlock the genetic, epigenetic, hormonal, neurobiological, and behavioral contexts (and the interactions among them) that influence the biopsychological organization of individuals during early life (also see chapter 2). In the present chapter we review the role the rhesus macaque has played since the mid-19th century in shaping our understanding of maternal contributions, both behavioral and physiological, to infant development. Importantly, although we emphasize maternal and environmental effects in this chapter, infants and juveniles exert agency and are active contributors to their own development by eliciting and affecting the behavior of their caregivers (Fairbanks and Hinde, 2013). Here we summarize studies that showcase, in turn, some of the ways in which early environment influences behavior, cognition, and physiological regulation. We further expand the construct of early environment to include not just the mother’s behavioral care of the infant (or consequences of the absence of that caregiving) but also the role of physiological investment—mother’s milk. Collectively these studies emphasize the critical organizational effects of early life that shape long-term functioning in offspring.

The Rhesus Monkey

Some of the most compelling evidence in support of this proposition has come from extensive studies of rhesus monkeys (Macaca mulatta) carried out over the past half-century, beginning with the pioneering work of Harlow and colleagues (e.g., Harlow and Harlow, 1969). Rhesus monkeys are a highly successful, widely dispersed, and remarkably adaptable species of macaque monkeys. In the wild and in captive environments that provide sufficient space and resources, these monkeys reside in distinctive social groups (troops), each comprising between 2 dozen and 200 individuals. Each troop, large or small, is organized around several female-headed, multigenerational families, plus several immigrant adult males; this species-normative pattern of social organization is derived from the invariant tendency of females to remain in their natal troop for their entire lifetime, and that of males to emigrate from their natal troop around the time of puberty (Altmann, 1962). And yet, there are dramatic individual differences in the temperaments or personalities, as well as in their respective biological correlates, among the members of each rhesus monkey troop. For example, between 15% and 20% of troop members consistently appear to be unusually fearful or anxious in the face of novel or mildly challenging situations or circumstances, accompanied by significant arousal of a number of biological systems, notably the hypothalamic-pituitary-adrenal (HPA) axis (Suomi, 2004). Another 5% to 10% of troop members seem unusually impulsive or aggressive in many of their social interactions with other troop members. Individuals in this latter
subgroup tend to have chronically low levels of central serotonin metabolism (Suomi, 2004).

Rhesus monkey infants born in naturalistic social settings spend virtually all of their first postnatal month in intimate physical contact with their mother, during which time a strong and enduring social attachment bond is developed between mother and infant—one that is functionally equivalent to the attachment bonds that human infants in every culture form with their primary caregivers (Bretherton, 1992; Machado, 2013). As they mature, infants spend increasing amounts of time exploring their immediate physical and social environment, typically using their mother as a “secure base,” albeit with marked individual differences; for example, excessively fearful infants are reluctant to leave their mother’s side and tend to have low rates of exploration during this time, whereas the opposite is usually the case for excessively impulsive individuals (Suomi, 2005).

In their second and third months, rhesus infants begin to develop distinctive social relationships primarily with peers—other infants of like age and comparable physical, cognitive, and social capabilities. Following weaning (usually in the fourth and fifth months), play with peers emerges as a predominant social activity for young monkeys and essentially remains so until puberty (Ruppenthal, Harlow, Eisele, and Harlow, 1974). Although play interactions develop in a species-typical pattern, (i.e., progressively more complex, increasingly sex-specific and sex-segregated; Harlow and Lauersdorf, 1974; Suomi, 2009), here too there are marked individual differences in the form and frequency of play behavior. For example, fearful youngsters appear to be shy in these social situations and tend to initiate relatively few playful exchanges with their peers, whereas impulsive individuals seem overly aggressive once they become involved in an initially playful exchange, eventually leading their peers to largely avoid them in the face of potential injury (Suomi, 1991).

Behavioral Consequences of Rearing Experiences and Environment

Individual differences notwithstanding, the general sequence of social development described above—an initial attachment to the mother, a transition involving both exploration increasingly at a distance from the mother and playful social interactions with peers—has consistently been observed in rhesus monkeys growing up either in naturalistic environments or in captive settings that provide unrestricted access to both their biological mothers and same-aged peers (MP rearing). However, when rhesus monkeys are experimentally raised from birth under conditions that prevent or limit access to either mothers or peers, there are significant behavioral and biological consequences. One such rearing condition that has been studied extensively over the past several decades is peer-only (PO) rearing. Here, rhesus infants are physically separated from their biological mothers at birth, hand-reared by human caregivers in a neonatal nursery for their first month of life, and then housed with
three or four other same-aged peers (cf. Harlow, 1969; Harlow and Harlow, 1969). Typically, after 6 or 7 months of PO rearing, these infants are placed in larger social groups containing both other same-aged PO-reared monkeys and MP-reared age mates, who have just been weaned from their mothers. In many studies both the PO- and MP-reared juveniles are kept together in these large social groups until puberty. Thus, any subsequent behavioral or biological differences between MP- and PO-reared monkeys can ultimately be traced to their experiences in the initial 6 to 7 months of life.

Virtually all PO-reared monkeys rapidly develop “hyperattachments” to one another within days of being placed together, attachments which are basically dysfunctional in that these infants spend significantly more time throughout their initial months clinging to one another than MP-reared monkeys spend clinging to their biological mothers (Suomi, 2009). Perhaps as a result, PO-reared infants tend to appear fearful, explore little, and play significantly less than their MP-reared counterparts during their initial months together. What little mutual play they do exhibit during this period tends to be rudimentary in nature and short-lived in duration, far less complex than routine play bouts among MP-reared monkeys of comparable age.

PO-reared monkeys as a group also exhibit more extreme behavioral and neuroendocrine (HPA) responses to social stressors that occur within the first year of life than do their MP-reared counterparts (Dettmer, Novak, Suomi, and Meyer, 2012; Suomi, 1997). In addition, perhaps because these PO-reared monkeys are essentially experiencing play deprivation even though they are in the continuous presence of potential playmates, as they grow older they become increasingly aggressive, far more so than most of their MP-reared fellow group members (Fahlke, Lorenz, Long, Champoux, Suomi, and Higley, 2000). Importantly, they also consistently exhibit significantly lower cerebrospinal fluid (CSF) 5-HIAA concentrations than MP-reared monkeys from early infancy to early adulthood (Higley, Chaffin, and Suomi, 2011; Shannon et al., 2005), as well as significantly different developmental trajectories of peripheral measures of the neurotrophic factors NGF and BDNF (Cirulli et al., 2011). Furthermore, as adolescents and young adults, they typically consume significantly more alcohol than MP-reared subjects in a “happy hour” situation (Fahlke et al., 2000; Higley, Hasert, Suomi, and Linnoila, 1991). In these respects PO-reared monkeys exhibit not only many of the same behavioral and biological patterns of response to environmental challenge and social stress that have been shown by excessively fearful monkeys but also those of overly impulsive and aggressive monkeys growing up in naturalistic settings (Higley et al., 2011); that is, they are comorbid for both these sets of behavioral and biological features (Suomi, 2009).

Recent neuroimaging studies have demonstrated that PO-reared monkeys also differ significantly from their MR-reared counterparts in many aspects of both brain function and brain structure. For example, PO-reared juveniles exhibit lower serotonin transporter ligand binding potential and cerebral blood flow, as
determined by positron emission tomography, in raphe, thalamus, striatum, frontal, and parietal brain regions, than MP-reared monkeys (Ichise et al., 2006; Spinelli et al., 2010). Additionally, magnetic resonance imaging (MRI) studies have revealed larger stress-sensitive brain regions in PO-reared juveniles, particularly the vermis, dorsomedial prefrontal cortex, and dorsal anterior cingulated cortex (but no differences in corpus callosum thickness or hippocampal size; see Spinelli, Chefer, Suomi, Higley, Barr, and Stein, 2009).

Recent data also indicate major differences in susceptibility to adult disease risk in these differentially reared monkeys. Using microarray analyses of messenger RNA expression, Cole and colleagues (Cole, Conti, Arevalo, Ruggiero, Heckman, and Suomi, 2012) found that as early as 4 months of age, PO-reared infants showed enhanced expression of genes involved in inflammation and T-lymphocyte activation, and suppression of genes involved in antimicrobial defenses. Thus, adverse early life experiences appear to not only social behavior and neurobiology but also immunological functioning.

In sum, early life adversity in the form of PO rearing has profound consequences for rhesus monkeys, not only at the levels of behavioral expression and emotional regulation, but also in terms of neuroendocrine output, neurotransmitter metabolism, brain structure and function, and even genome-wide expression. At the phenotypical level, the behavioral and biological features of PO-reared infants resemble those of naturally occurring subgroups of excessively fearful and excessively impulsive or aggressive rhesus monkeys growing up in the wild, and many of these features persist long after the infants' period of exclusive exposure to peers has been completed and they have been living in more diverse social groups.

**Early Rearing Experience and Chronic Stress Outcomes**

It is well known that early life adversity, especially neglectful or abusive parenting, results in a host of mental and physical health disparities later in life, many of which are associated with exposure to chronic stress. The HPA axis represents the body's primary neuroendocrine stress response system, and as such is responsible for synchronizing the body's responses to perceived or actual stress. The endpoint of the HPA axis is cortisol, the primary stress response hormone in human and nonhuman primates. Cortisol feeds back negatively to the brain to inhibit further activation of the HPA axis, thereby placing a limit on the duration of the stress response. However, chronic activation of the HPA axis is implicated in the development of many diseases and disorders related to maladaptive parenting practices, including post-traumatic stress disorder and anxiety-related disorders, among others. Much research in animals and humans had demonstrated the detrimental yet often preventable role of adverse early experiences on dysregulated HPA activity and the resulting development of anxious behaviors. Most studied among these in nonhuman primates are differential rearing experiments examining the activity
and responsivity of the HPA axis. These experiments yield crucial information regarding the physiological and psychosocial consequences of suboptimal or even neglectful child rearing for the offspring, and offer insight into the nature of social relationships. In particular, nonhuman primate studies examining the physiological, cognitive, and behavioral development of infants reared with peers only (PO reared) versus those reared with their mothers in social groups (MP reared) give us an understanding of the evolution of current parenting practices, and what can result from the abandonment of evolved parenting practices, that is, rearing children with their families, surrounded by multi-aged relatives and embedded in cultural practices.

A large body of literature exists on studies of acute stress with respect to early life rearing, but these studies are limited in their ability to assess the long-term physiological consequences of early parenting practices. Past studies have relied on measures of cortisol in blood plasma, saliva, CSF, urine, and feces. Each of these “point” measures provides a window into HPA activity, with blood plasma, saliva, and CSF reflecting activity within the past 15 minutes and urine and feces reflecting activity up to the past 24 hours. Owing in large part to the inherent qualities of these media for assessing cortisol—namely, their circadian variability, low long-term stability, and vulnerability to environmental disturbances (Meyer and Novak, 2012)—nonhuman primate studies examining the effects of early life stress on these measures of cortisol have been difficult to interpret. Early studies indicated that infant peer-reared (PR) monkeys aged 1 to 6 months exhibited similar basal plasma cortisol levels to mother-reared (MR) monkeys, but lower stress reactivity (Clarke, 1993). However, subsequent studies found the reverse, namely that PO-reared monkeys had lower basal plasma cortisol levels than MP-reared monkeys at 2 months of age (Capitanio, Mendoza, Mason, and Maninger, 2005; Shannon, Champoux, and Suomi, 1998), and larger cortisol increases after repeated stress (Higley, Suomi, and Linnoila, 1992). Finally, one study found that CSF basal or stress-related cortisol did not differ between PO- and MP-reared monkeys. Thus, although these studies have demonstrated differential effects of early parenting practices on later acute stress physiology, the overall impact has been difficult to ascertain. The inconsistency in HPA axis activity in PO-reared monkeys may be due in part to differing PR protocols across laboratories (Capitanio et al., 2005; Shannon et al., 1998; Winslow, Noble, Lyons, Sterk, and Insel, 2003), but they may also be due to the variability of cortisol samples. Additionally, repeated sampling, often invasive in nature, is required to provide a robust composite index of cortisol levels over time (Meyer and Novak, 2012). To address these limitations, in the Laboratory of Comparative Ethology, we have been studying the effects of differential rearing on chronic HPA axis activity and associated psychosocial development in rhesus monkeys.

Recently a new instrument has been developed for assessing HPA activity over long-term time scales. In 2006, an assay for measuring cortisol in the hair of rhesus monkeys was developed and validated (Davenport, Tiefenbacher, Lutz, Novak, and Meyer, 2006). This work demonstrated that cortisol was readily quantifiable in hair
and that hair cortisol levels were positively correlated with salivary cortisol values. Importantly, hair cortisol was significantly elevated compared with baseline after these monkeys were subjected to the major life stressor of relocation (Davenport, Lutz, Tiefenbacher, Novak, and Meyer, 2008). Since the development of this assay, hair cortisol has been assessed in many animal species, including humans, and has been related to levels of perceived stress (Kalra, Einarson, Karaskov, Van Uum, and Koren, 2007). Moreover, several studies in nonhuman primates (rhesus macaques, bonnet macaques, vervets) have demonstrated that hair cortisol is elevated in subjects undergoing significant stress (Davenport et al., 2006; Davenport et al., 2008; Fairbanks, Jorgensen, Bailey, Breidenthal, Grzywa, and Laudenslager, 2011; Laudenslager, Jorgensen, Grzywa, and Fairbanks, 2011; see Meyer and Novak, 2012, for a review). Human studies, too, have shown that hair cortisol is a reliable biomarker of chronic stress in neonates (Yamada et al., 2007), children (Vanaelst et al., 2013), and adults (Dettenborn, Tietze, Bruckner, and Kirschbaum, 2010; Karlén, Ludvigsson, Frostell, Theodorsson, and Faresjö, 2011; Russell, Koren, Riedel, and Van Uum, 2012). Thus, we can use the hair cortisol assay to determine the long-term physiological and psychosocial implications of adverse early rearing so as to better understand the effects of nonanesthral forms of parenting on child outcomes.

Exposure to chronic circulating glucocorticoids, whether by repeated exogenous administration or by exposure to repeated stressors, is detrimental to cognitive functioning in humans and animals alike (Lupien, McEwen, Gunnar, and Heim, 2009). In particular, the hippocampus, which functions in the formation of declarative and spatial memories, is particularly vulnerable to chronic stress (Conrad and Bimonte-Nelson, 2010). To determine whether hair cortisol serves as a reliable biomarker for cognitive development in developing rhesus monkeys, we assessed 32 infant monkeys beginning at 14 days of age on Piagetian object permanence tasks (which are reliable measures of emerging cognition: Sackett, Ruppenthal, Hewitson, Simerly, and Schatten, 2006; Wise, Wise, and Zimmerman, 1974). Testing continued through 3 to 4 months of life. Hair samples were collected at 14 days and again at 6 months of age; cortisol for the 6-month hair sample was assayed to provide a retrospective analysis of cumulative glucocorticoid exposure over the previous 5.5 months (which included object permanence testing). We found that hair cortisol concentrations significantly predicted object permanence performance in infant monkeys, such that infants with higher hair cortisol throughout the testing period required more test sessions to complete the tasks and were significantly older upon reaching criterion (Dettmer, Novak, Novak, Meyer, and Suomi, 2009). Since this study, others have also demonstrated a similar relationship between hair cortisol and cognitive functioning in adults (Saleem et al., 2013), indicating that hair cortisol is a reliable biomarker for stress-related cognitive performance. Importantly, the subjects in our study were all nursery-reared (NR) infants, suggesting that suboptimal early life experiences may have long-term consequences for cognitive development; however, we need to determine the relationship between chronic cortisol
levels and cognitive development in MP-reared monkeys to ascertain whether this relationship holds only for NR infants. Studies are underway in our laboratory to conduct cognitive testing on infant MP-reared monkeys in their social housing pens, as well as on NR infants, and we aim to elucidate the relationship between hair cortisol and emerging cognition in this more normative population.

Hair cortisol has also recently proved to be a reliable biomarker of some mental health disorders in adults (Stauflenbiel, Penninx, Spijker, Elzinga, and van Rossum, 2012; Steudte et al., 2013). In particular, higher hair cortisol has been associated with major depression and bipolar disorder (although this relationship only held for individuals with late age of onset), whereas generalized anxiety disorder, panic disorder, and post-traumatic stress disorder have been associated with lower hair cortisol (Stauflenbiel et al., 2012; Steudte et al., 2013). However, all of these studies have been conducted in adults, and thus far no studies have aimed to elucidate the relationship between hair cortisol and the emergence of mental health disorders. We studied 61 infant rhesus monkeys prospectively for the first 2 years of life to determine the influences of early life experience on (1) the development of anxious behaviors in adolescence after the imposition of the major life stress of housing relocation at 8 months of age, (2) chronic stress levels across development as assessed by hair cortisol, and (3) the ability of hair cortisol to predict anxious behavior. We studied three groups of monkeys exposed to different rearing conditions: MP-reared, PO-reared, and surrogate-peer (SP) reared. PO-reared monkeys were reared in a nursery together 24 hours per day, whereas SP-reared monkeys were reared in a nursery in single cages with cloth-covered surrogates and given 2-hour play sessions with three other peers per day. Hair samples were assessed at 6, 12, 18, and 24 months, and composite anxiety scores were calculated at the same time points to reflect total anxious behavior over the preceding 6 months. The effects of early life experience were striking. Across the first 2 years of life, PO-reared monkeys exhibited the most anxious behaviors, followed by SP-reared then MP-reared infants (Dettmer et al., 2012). Notably, PO-reared monkeys exhibited elevated anxiety for up to 1 year after the relocation stress (i.e., up to 18 months of age), whereas MP- and SP-reared monkeys did not differ at this age (Figure 3.1a). Different patterns of hair cortisol levels emerged for each rearing group. PO-reared monkeys exhibited the highest hair cortisol at 6 months (just before relocation), maintained elevated levels at 12 months (just after relocation), and saw cortisol levels gradually decrease over the next year. SP-reared infants’ hair cortisol was similar to that of MP-reared infants at 6 months (just before relocation) but sharply rose at 12 months (just after relocation), remained elevated at 18 months, and declined by 24 months to values indistinguishable from MP- and PO-reared infants. MP-reared infants seemed the most unaffected by the major life stress of relocation because their hair cortisol values showed no change from months 6 to 12. Further, their hair cortisol values decreased sharply from months 12 to 18 and remained low at 24 months, indicating that these animals experienced the lowest amounts of chronic stress across development and particularly after a major life stress (Figure 3.1b). These findings
Figure 3.1: Rearing differences in anxious behavior and hair cortisol concentrations across the first two years of life. (a) **PO > MP = SP (p < 0.001). (b) *PO > MP = SP (p < 0.05); **PO = SP > MP (p < 0.01). Data shown as mean + SEM.

Further support the notion of maternal buffering and indicate that being reared in a family-like environment provides later physiological and behavioral coping benefits.

The second main finding from this study was that hair cortisol predicted the emergence of anxious behavior, but only for at-risk infants. PO-reared infants only, but not SP- or MP-reared infants, showed a strong positive correlation between hair cortisol taken at 6 months (just before relocation) and anxious behavior at 12 months (just after relocation; r_s = .75, p < .001). Furthermore, 6-month hair cortisol predicted anxious behavior through 18 months as well, but again only for PO-reared infants (r_s = .47, p < .05). Thus, it appears that hair cortisol is a useful biomarker for the development of anxious behavior for populations already at risk for developing such problems. Taken together, our studies using hair cortisol indicate that it is a reliable measure of chronic stress, particularly in individuals exposed to adverse early rearing conditions, and that it serves as a reliable predictor of cognitive and emotional development in young nonhuman primates. Hair cortisol is thus likely to become increasingly valuable in the search for valid biomarkers of stress-related and psychiatric disorders.

Mother’s Milk and Infant Behavioral Outcomes

Mothers provide not just the early postnatal social environment but also the postnatal physiological environment. This is most notably through the production of milk, which serves to provide nourishment, immunofactors, and hormonal signals (Hinde and German, 2012). There is a rich literature on how maternal behavioral care of the infant influences offspring behavior (Fairbanks and Hinde, 2013;
Machado, 2013; Vandeleest and Capitanio, 2012; see also chapter 2 of this volume), much less is understood about how mother’s milk contributes to offspring behavioral development (Hinde, 2013; Hinde and Capitanio, 2010). Mother’s milk contains building blocks for neurodevelopment, such as the fatty acids that are integral to neurodevelopment (Milligan, 2013). Mother’s milk also provides the calories infants use for their behavioral activity, which affords them the experiential learning that contributes to neuronal connectivity (Dauncey, 2013). Several studies have also demonstrated that “maternal-origin” hormones in milk, specifically glucocorticoids, bind to receptors in the neonate and exert influences on their neurobiology (Miller et al., 2013; reviewed in Hinde, 2013). These influences may persist into adulthood, although at this time long-term effects are only known from rodent models. Recent data from humans and rhesus monkeys show correlations between mother’s milk glucocorticoids and infant temperament, but substantially more research is needed to understand how mother’s milk programs infant behavior.

Since the 1980s, Angelucci, Catalani, and Casolini’s research group in the Department of Human Physiology and Pharmacology, University of Rome, has conducted a series of experiments on mother’s milk glucocorticoids and consequences for offspring. Their studies indicate that ingestion of glucocorticoids through mother’s milk contributes to the organization—and therefore regulation—of the HPA axis in offspring into juvenility and adulthood, with important implications for their behavior and cognition. In their study design, rat dams consumed glucocorticoids in their water, increasing glucocorticoids in their blood and their milk. As juveniles, individuals who ingested elevated glucocorticoids through their mother’s milk had better spatial memory as assessed by performance in a Morris water maze (Casolini, 1997; Catalani et al., 1993). Moreover, juvenile pups that ingested glucocorticoids engaged in more social play than did controls (Cinque, Zuea, Catalani, Giuli, Tramutola, and Scaccianoe, 2012). In adulthood, these individuals demonstrated less anxiety during stress challenges (Catalani, Casolini, Scaccianoe, Patacchioli, Spinozzi, and Angelucci, 2000; Catalani et al., 2002; Meerlo, Horvath, Luiten, Angelucci, Catalani, and Koolhaas, 2001). Individuals exposed to elevated glucocorticoids in mother’s milk showed better regulation of the HPA axis during these challenges, and in males this was apparently mediated by glucocorticoid receptor density in the hippocampus (Catalani et al., 2000). Although females showed similar behavioral and physiological effects as males, the neurobiological mechanism remains unknown—females exposed to glucocorticoids did not have higher density of glucocorticoid receptors in their hippocampus (Catalani et al., 2002). Taken together though, these rodent studies demonstrate empirically that hormones in mother’s milk shape behavioral outcomes in offspring, but that the neurobiological pathways may differ for sons and daughters. Notably, these studies did not investigate maternal behaviors that are implicated in offspring outcome, most specifically arched-back nursing and licking and grooming (see chapter 2).
Two studies from rhesus monkeys show some parallels with the rodent model (reviewed in detail in Hinde, 2013). In a sample of 44 rhesus monkey mothers, Sullivan and colleagues (Sullivan, Hinde, Mendoza, and Capitanio, 2011) found substantial individual variation in cortisol concentrations in mother's milk in the outdoor breeding colony at the California National Primate Research Center. Infants whose mothers produced higher concentrations of cortisol in milk were characterized as more “Confident,” a factor score derived from systematic ratings of confident, bold, active, curious, and playful trait adjectives (described in detail in Hinde and Capitanio, 2010). However, this main effect was due to a strong effect for sons—milk cortisol concentrations did not predict “Confident” factor scores for daughters (Sullivan et al., 2011). Assessment of milk cortisol concentrations and infant temperament ratings were conducted simultaneously. In another study in the same population, infant “Confident” temperament at 3 to 4 months of age was correlated with earlier available milk energy—the number of calories in the milk that mothers synthesized (Hinde and Capitanio, 2010). Mothers who produced higher available milk energy at 1 month postpartum, when rhesus infants show marked increases in behavioral activity and exploration, had sons and daughters who were characterized as more “Confident” months later. This result suggests that in rhesus monkeys, mother’s milk exerts an organizational effect on infant temperament reminiscent of the effects found in rodents.

At the time of this chapter’s submission, to the best of our knowledge, only a single study of breast milk cortisol concentrations in humans and infant temperament has been published. Among 52 breastfeeding mothers, Grey and colleagues (Grey, Davis, Sandman, and Glynn, 2012) discovered that higher concentrations of cortisol in breast milk were associated with greater “Negative Affectivity” in the infant. This is a composite score of the infant’s tendency toward fear, sadness, discomfort, anger/frustration, and reduced soothability, as reported by the infant’s mother. These cross-sectional results were not explained by other factors such as maternal depression or perceived stress. And most interestingly, the effect was a result of an effect in daughters—the relationship between milk cortisol concentrations and negative affectivity was not present in sons. This result is particularly intriguing because the human results differ so markedly from the animal studies, both in that there are stronger effects in daughters than sons and that the effect is toward what could be considered a less confident temperament.

Taken together, the above studies on mother’s milk reveal that the physiological pathway from mother to infant is not restricted to the role of the placental interface during prenatal life (Rutherford, 2013), but rather continues postnatally in the form of mother’s milk. Moreover, given that this postnatal period is when the infant develops behaviorally and participates in contingent social interactions, mother’s milk may play a pivotal role in the organization of infant temperament. However, we must be exceedingly cautious in the interpretation of these studies to date. Importantly, the concentration of glucocorticoids in milk is correlated with nutritional aspects of milk—most notably concentrations of fat and protein.
(Sullivan et al., 2011)—and possibly also milk volume. However, most studies have investigated milk glucocorticoids in a vacuum from the other bioactives in milk, problematic for apportioning a programming role to glucocorticoids alone (Hinde, 2013). Future research should simultaneously investigate milk hormones and milk energy in concert as well as across time, identifying critical developmental windows. Lastly, a more holistic understanding of the mother–infant dyad is needed that integrates behavioral care and physiological investment to understand whether these have additive or multiplicative effects on infant outcomes.

**Conclusion**

Rhesus macaques provide an important bridge between the elegant experimental rodent work and the predominantly “epidemiological” research among humans. Results derived from research conducted in rhesus macaques are particularly translational because of our many shared features—an extended developmental time period characterized by the formation of close and long-lasting social bonds, within a complex community, in which the social dynamic requires nuanced social behavior and cognitive abilities. All together, recent research studies on the effects of early rearing experience on physiological, cognitive, and behavioral development inform the long-term consequences of child maltreatment and of parenting practices in general. Specifically, the results presented here demonstrate the superiority of practices in which infants are reared within family units embedded in a broader social context, in which they interact with both peers and nonparental adults and have exposure to family and societal cultural practices. Such a context is without doubt the “IEEA”—infant environment of evolutionary adaptedness.

**References**


