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Maternal Postpartum Behavior and the Emergence of Infant–Mother and Infant–Father Synchrony in Preterm and Full-Term Infants: The Role of Neonatal Vagal Tone

ABSTRACT: *Relations between maternal postpartum behavior and the emergence of parent-infant relatedness as a function of infant autonomic maturity were examined in 56 premature infants (birthweight = 1000–1500 g) and 52 full-term infants. Maternal behavior, mother depressive symptoms, and infant cardiac vagal tone were assessed in the neonatal period. Infant–mother and infant–father synchrony, maternal and paternal affectionate touch, and the home environment were observed at 3 months. Premature birth was associated with higher maternal depression, less maternal behaviors, decreased infant alertness, and lower coordination of maternal behavior with infant alertness in the neonatal period. At 3 months, interactions between premature infants with their mothers and fathers were less synchronous. Interaction effects of premature birth and autonomic maturity indicated that preterm infants with low vagal tone received the lowest amounts of maternal behavior in the postpartum and the least maternal touch at 3 months. Infant–mother and infant–father synchrony were each predicted by cardiac vagal tone and maternal postpartum behavior in both the preterm and full-term groups. Among preterm infants, additional predictors of parent–infant synchrony were maternal depression (mother only) and the home environment (mother and father). Findings are consistent with evolutionary perspectives on the higher susceptibility of dysregulated infants to rearing contexts and underscore the compensatory mechanisms required for social-emotional growth under risk conditions for parent–infant bonding. © 2007 Wiley Periodicals, Inc.* Dev Psychobiol 49: 290–302, 2007.

Keywords: *maternal behavior; bonding; synchrony; mothering; fathering; cardiac vagal tone; touch; postpartum depression; HOME*

INTRODUCTION

In all mammals, including humans, the birth of an infant triggers a set of species-specific maternal behaviors aimed at assuring survival, promoting optimal growth, providing care, and soothing during times of distress (Carter & Keverne, 2002; Fleming, O'Day, & Kraemer, 1999; Leckman et al., 2004). The maternal behavior repertoire is genetically programmed, yet highly susceptible to epigenetic influences. Lesion studies have implicated specific brain structures and neurochemical systems in the

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initiation and maintenance of maternal behavior (Leckman & Herman, 2002), while cross-fostering studies have pointed to non-genomic transmission (Champagne & Meaney, 2001). Pedersen (1999) suggested that maternal behavior revolutionized child care not only by sustaining protection and nurturing of offspring but also by permitting a longer period of brain development, a prerequisite for higher intelligence. In support of this claim, research in animal models has demonstrated the profound effects of maternal postpartum behavior on brain morphology and physiology (Meaney, 2001; Modney & Hatton, 1994), on life-long propensity for stress reactivity (Vallee et al., 1997), and on the pup's ultimate capacity for social affiliation (Champagne, Diorio, Sharma, & Meaney, 2001; Insel & Young, 2001).

Authors applying the ethological framework to the study of maternal behavior across mammalian species and human cultural communities (Clutton-Brock, 1991; Hrdy, 1999) emphasize that the study of social bonds should begin with a meticulous documentation of discrete behaviors that emerge or intensify during bond formation as a prerequisite for theory building, thus advocating a micro-level observational approach. Fleming et al. (1999) suggest that bonding involves species-specific sequences of maternal behaviors that are coordinated with specific infant neurobehavioral sensitivities to maternal cues, including voice, touch, body rhythms, and odor. Over time, autonomic, neurological, and endocrinological systems in each partner are sensitized to the temporal patterns of the other, leading to the formation of a unique mother–infant bond. Hofer (1995), in an empirical program spanning over 30 years of careful observations, similarly pinpointed discrete components in the maternal physical presence and postpartum behavior that support specific bio-behavioral regulatory systems and promote the infant's social fittedness.

Studies documenting maternal behavior in humans typically enlist the mother's en-face gaze, smiling, "motherese" vocalization, and affectionate touch—a behavior akin to the licking-and-grooming of other mammals—as components of the maternal behavior repertoire in the postpartum period (Barratt, Roach, & Leavitt, 1992; Cohen & Beckwith, 1979; Feldman & Eidelman, 2003a; Feldman, Weller, Sirota, & Eidelman, 2002; Fleming, Steiner, & Corter, 1997; Goldberg, 1978; Keren, Feldman, Eidelman, Sirota, & Lester, 2003; Levy-Shiff, Sharir, & Mogilner, 1989; Miller & Holditch-Davis, 1992; Minde, Perrotta, & Marton, 1985). The amount of maternal postpartum behavior, including gaze, smile, vocalizations, and affectionate touch, has been shown to predict the infant's neurobehavioral maturation (Feldman & Eidelman, 2003a), cognitive growth (Cohen & Beckwith, 1979; Feldman, Eidelman, & Rotenberg, 2004), and attachment security (Goldberg, Perrotta, Minde, & Corter, 1986), as well as to reflect the mother's readiness for motherhood (Keren et al., 2003), social support networks (Zarling, Hirsch & Landry, 1988), and psychological well-being (Minde, 2000).

The parent–infant relational system is shaped not only by the amount parental behavior but by the degree of its coordination with the infant's state and signals. With the development of infant social responsiveness across the first 3 months of life, the parent's initial adaptation to the neonate's signals turns into a synchronous dialog where one partner responds to the social cues of the other within a lag of seconds (Feldman, 2003; Stern, 1985; Trevarthan, 1979; Tronick, 1989). The infant's ability to detect social contingencies is innate (Tarabulsy, Tessier, & Kappas, 1996). Neonates possess a remarkable capacity to alter their state and movement patterns in response to the caregiver's actions and mothers are innately attuned to coordinate their behavior with the newborn's scant moments of alertness (Minde, Marton, Manning, & Hines, 1981; Oehler, Eckerman, & Wilson, 1988). Lavelli and Fogel (2005) followed infants weekly from birth to 4 months and noted that already in the first days of life mother–infant communication functions as a mutually-adaptive dyadic system. At about 2 months, a developmental shift occurs and the maternal postpartum repertoire transforms into a bi-directional system where partners share gaze, affect, and interactive signals. At this age, gaze synchrony—the co-occurrence of social gaze between parent and child—becomes the most pronounced form of synchrony and provides an organizing framework for the emergence of coordinated behavior in other modalities, such as co-vocalization and the matching of affective states (Cohn & Tronick, 1988; Messer & Vietza, 1984; Pawlby, 1977; Tronick, Als, & Brazelton, 1977). This developmental shift in dyadic relatedness coincides with structural and functional maturation in neurobiological systems that support social engagement in infants (Leavitt, 2003; Porges, 2003).

Parent–infant synchrony evolves as a result of myriad parental, child, and contextual processes including the mother's initial interactive style during the bonding stage, the parents' personality, the infant's physiological regulation, and the nature of the home environment (Belsky, 1984; Feldman, 2007). The experience of synchrony, in turn, provides an important foundation for infant growth and shapes the child's cognitive, symbolic, self-regulatory, and social-emotional development (Feldman & Eidelman, 2004; Feldman, Greenbaum, & Yirmiya, 1999a; Feldman, Greenbaum, Mayes, & Yirmiya, 1996; Jaffee, Beebe, Feldstein, Crown, & Jasnow, 2002). A less researched area, however, is the nature of the synchrony that evolves between father and child, and very few studies examined the coordination of social behavior between father and child during the first months of life (Feldman, 2003; Feldman & Eidelman, 2004). Theoretical accounts on fathering, co-parenting, and family development (Belsky, 1981; Lamb, Pleck, Charnov, & Levine, 1987; McHale & Cowan, 1996) stress the importance of the initial bond between mother and child for the development of fathering, but little longitudinal research from the neonatal period exists to support such perspectives. To address this empirical gap, the present study examined the effects of maternal postpartum behavior on the development of both infant–mother and infant–father synchrony.

Premature birth disrupts the bonding process, decreases maternal behavior, and interferes with the emergence of parent–infant synchrony. Several factors may underlie the negative impact of prematurity on bonding. Prematurity interrupts the continuity of the mother–infant physical contact, which initiates a cascade of neurobiological changes and mental states required for bond formation (Feldman, Weller, Leckman, Kuint, & Eidelman, 1999; Klaus & Kenell, 1976). Mothers of premature infants tend to display less looking, vocalizing, and touch-and-contact behavior toward their infants and report lower levels of relationship-building behaviors and attachment representations in the postpartum period (Davis & Thoman, 1988; Feldman et al., 1999b; Minde, 2000). In addition, the infant's neurological immaturity decreases social responsiveness and premature infants are described as less rewarding social partners, spend less time in alert states, and send unclear and inconsistent social signals across the first year (Eckerman, Oehler, Hannan, & Molitor, 1995; Malatesta, Culver, Tesman, & Shpard, 1989). As a result, the dyadic system between parents and premature infants is less synchronous and mutually adaptive (Feldman, 2006; Lester, Hoffman, & Brazelton, 1985). Thus, premature infants who are the most dependent on mutually regulating interactions for optimal growth have the greatest difficulty eliciting such synchronous parenting. Greenberg and Crnic (1988), following preterm and full-term infants from birth to 2 years, found that maternal behavior and the home environment had a significantly greater impact on the cognitive development of preterm infants. These findings resonate with Belsky's (1998) notion on "differential susceptibilities to rearing environments", which postulates that the more dysregulated the child is, the more he or she would depend on attuned parenting to reach developmental milestones.

Among the physiological systems that support maternal behavior and infant social engagement is the autonomic system, particularly as it is mediated by parasympathetic pathways. Porges (1998, 2003) theorizes that the emergence of behaviors and mental states related to affiliation and parenting in mammals is linked with the development of the polyvagal system. This development marks an evolutionary shift from sympathetic-adrenal control of heart rate to a graded system that allows quick changes in metabolic inputs and outputs from the heart and facilitates complex behaviors such as attention, orientation, and the maintenance of calm states that are required for the formation of social bonds. The removal of the vagal brake through signals from the vagus via myelinated pathways that originate in the nucleus ambiguus allows for rapid increase in heart rate in response to external or internal stresses and to better adaptation to rapidly changing environmental inputs, hence to more competent coordination of micro-level changes in social signals that underlie interpersonal interactions. Neonatal resting vagal tone index (Vna) is a measure of autonomic maturity that has shown to predict the infant's neurobehavioral maturation (DiPietro & Porges, 1991; Feldman & Eidelman, 2003a), cognitive growth (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997), and social–emotional adaptation across infancy and up to 6 years of age (Doussard-Roosevelt, McClenny, & Porges, 2001). Neonatal vagal tone was also found to predict the degree of mother–infant synchrony at 3 months (Feldman, 2006), pointing to the role of neonatal physiological regulation in the emergence of parent–infant synchrony.

In light of the above, the goal of the present study was to examine maternal behavior in the postpartum as a function of infant autonomic maturity indexed by cardiac vagal tone. An additional goal was to assess the effects of infant vagal tone and maternal behavior in the postpartum period on the emergence of mother–infant and father–infant synchrony at 3 months, the period when infants are initiated into the social world and begin to take part in synchronous exchanges (Stern, 1985). The expression of parental behavior was assessed in two groups—full-term and preterm infants—to examine the consolidation of parenting under risk conditions for parent–infant bonding. We expected less optimal maternal postpartum behavior in the preterm group, in terms of lower frequencies of gaze, positive affect, vocalization, and affectionate touch, and less coordination of such behaviors with episodes of infant alertness. Similarly, lower levels of mother–infant and father–infant synchrony were expected between preterm infants and their parents at 3 months. Because parenting is highly dependent on the mother's initial style and sensitivity (Belsky, 1984), maternal postpartum behavior was expected to provide the foundation for the parent–infant communication and to predict the level of mother–infant as well as father–infant synchrony in both groups.

Infant autonomic maturity in the neonatal period was expected to shape the infant's capacity to partake in rapidly changing coordinated interactions at 3 months. Consistent with research on the relations of vagal tone and mother–infant synchrony (Feldman, 2006; Moore & Calkins, 2004), we expected that higher neonatal Vna would predict higher levels of synchrony with both parents among term and preterm infants. We were especially interested in gaze synchrony, which is the central mode of synchronous interactions at 3 months and provides a framework for coordinated interactions in other modalities (Fogel, 1977; Messer & Vietza, 1984). During the postpartum period, on the other hand, differential relations were expected between infant Vna and maternal behavior. It was hypothesized that following term birth, maternal behavior would evolve naturally regardless of individual variation in infant autonomic maturity. Following premature birth, as the natural course of bonding is disrupted and mothers are less disposed to engage in maternal behavior, the infant's skill at engaging maternal involvement was expected to have a greater impact. We thus hypothesized that preterm neonates with higher autonomic maturity would elicit more maternal postpartum behavior. We also examined whether such high-vagal tone preterm infants would receive more touch-and-contact from their mothers and fathers at 3 months. The mother's affectionate touch in early infancy is central for infant growth and predicts development in the neurobehavioral, cognitive, and symbolic domains (Feldman & Eidelman, 2003a; Feldman et al., 2004; Hertenstein, 2002) and we thus examined the relations between autonomic maturity and the mother's and father's touch during interactions. Consistent with previous research (Greenberg & Crnic, 1988), maternal and contextual factors were thought to have a greater impact on the development of premature infants and, thus, factors such as maternal depressive symptoms and the home environment were expected to predict parent–infant synchrony in the preterm group, above and beyond maternal behavior and infant vagal tone.

METHOD

Participants

One-hundred and eight mothers, fathers, and infants participated in the study in two groups. The first group included 52 infants and their parents born at full-term with no medical complications. The second group consisted of 56 Very Low Birthweight (VLBW) infants with a birthweight between 1000 and 1500 g and a gestational age (GA) of 29 to 33 weeks. Infants in the premature groups were relatively healthy and born at an appropriate weight for gestational age. Exclusion criteria included IVH grades III or IV, perinatal asphyxia, metabolic, genetic disease, or CNS infection. Families were recruited at the nursery (full-term) and the Neonatal Intensive Care Unit (preterm) to participate in a follow-up of infant development. Three mothers in the preterm group and two mothers in the full-term group refused, citing time constraints. No differences were observed between participating and declining families on family demographic or infant medical status.

Table 1. Family Demographic and Infant Medical Variables

	Preterm ($n = 56$)		Full-Term ($n = 52$)	
	M	*SD*	*M*	*SD*
Birthweight (g)	1278.13	234.12	3.321.87	457.12
CA (weeks)	30.38	2.50	38.82	2.98
Mother age (years)	29.14	4.33	29.63	5.86
Mother education (years)	14.37	2.18	14.82	2.42
Father age (years)	32.33	5.68	32.62	7.16
Father education (years)	14.53	2.38	14.82	3.33
M/F ratio	30/26		29/23	

Demographics and infant medical status are reported in Table 1 and the data show no group differences in infant gender, and maternal and paternal age and education. No differences were found in birth order (primaparous/multiparous) and maternal employment status (none, part-time, full-time) at 3 months. All families were considered middle-class by Israeli standards (Harlap et al., 1977), mothers were at least 20 years old, mothers were married to the child's father, and in all families at least one parent was employed.

Procedure and Measures

On the second post-partum day for the full-term group and the day prior to discharge in the preterm group (37 weeks GA), cardiac vagal tone was assessed, mother–infant interaction was observed, and maternal depressive symptoms were self-reported. At 3 months (corrected age for premature infants), trained research assistants visited the home for about 1.5 hr at a time both mother and father were present. The home environment was evaluated and infants were videotaped in infant–mother and infant–father interactions.

Neonatal Period

Premature infants were tested at a mean age of 37.3 weeks GA (range = 36.8 to 39.1 weeks) and full-term infants were tested at a mean age of 38.8 weeks GA. To account for the differences in the child's post-conceptual maturity, the infant's GA at the day of observation was entered for all preterm-full-term comparisons as a covariate.

Cardiac Vagal Tone. Approximately 10 min, the infant's heart rate was recorded when the infant was in a quiet sleep state from the cardiac monitor using a special analog-to-digital adaptor. The adaptor sampled heart rate and transferred the data into a special computerized system that registered the R waves and computed the inter-beat interval (i.e., heart period in ms). Vagal tone, defined as the amplitude of respiratory sinus arrhythmia, was quantified using Porges (1985) MXEdit system by a research assistant trained to reliability. After editing the inter-beat interval data to remove artifacts, the MXEdit system converts heart period data into time-based data sampled in 200 ms intervals, determines the periodicities of heart rate with a 21-point moving polynomial, filters the time-series to extract the heart period within the frequency band of spontaneous breathing of neonates, and calculates the vagal tone index (Vna).

Mother–Neonate Interaction. Approximately 15 min of mother–infant interaction were videotaped and coded. Videotaping took place after the mid-morning feeding, to control for fluctuations in neonates' arousal due to feeding, and filming started when the infant was in an awake and calm state. Mothers sat in a comfortable chair in a quiet and empty room in the nursery and videotaping was conducted through a screening window. Mothers were asked to interact with the infant freely but no specific instructions were provided. Coding of all tapes was conducted at a central university laboratory by trained observers, unaware of the infant's group membership or the study's hypotheses. Coding was conducted using the Mother-Newborn Coding System of the Coding Interaction Behavior Manual (CIB, Feldman, 1998), a well-validated system for assessing mother–newborn interactions (Feldman & Eidelman, 2003a; Feldman et al., 2002a, 2004; Keren et al., 2003). For each 10-s epochs, four maternal categories and one infant category are coded and each category includes a set of mutually-exclusive codes. Two graduate students in psychology coded the videotapes. Training was conducted using a training tape of 15 mother–newborn interactions of full-term and preterm infants who were not part of the present study, and training continued until 90% agreement was achieved in all categories.

Categories, codes included in each category, and reliability for each category were as follows; *Maternal Gaze*: to infant's face, to infant's body, to object, gaze aversion (kappa = .84). *Maternal Affect*: positive, negative, neutral (kappa = .79). *Maternal Talk:* no talk, talk to infant, sing, "motherese" (kappa = .85). *Maternal Touch*: no touch, functional touch (e.g., wipe infant's mouth), loving touch (hug, caress, light pokes, or mother touch infant with clear positive affect and no functional purpose), rock, manipulate, and stimulate (*kappa* = .83). *Infant State*: fuss, cry, drowsy, sleep, alert to mother, alert to environment (*kappa* = .80). Reliability was conducted for 15 mother–infant dyads and reliability averaged 94%, *kappa* = .85. Two maternal composites and one infant code were used in the present study: *Maternal Affiliative Behavior*—included the sum proportions of Maternal Positive Affect, Maternal Gaze at infant face, "Motherse" vocalization, and Maternal Affectionate Touch (loving touch, hug, and cradle), *kappa* = .81. These variables have been described as the main components of the maternal post-partum repertoire in humans and predict positive outcomes (Barratt et al., 1992; Cohen & Beckwith, 1979; Feldman & Eidelman, 2003a; Goldberg, 1978; Levy-Shiff et al., 1989; Minde et al., 1981). Maternal *Stimulatory Touch*—considered the mother's active touch and included rock, manipulate, and stimulate, kappa = .77. These more active forms of proprioceptive touch are part of the maternal touch repertoire in the first months of life (Hertenstein, 2002). *Infant Alert*—the sum proportion of time the infant spent in an alert-scanning state to mother or to the environment was used to index the infant's participation in the interaction. Individual differences in infant alertness during social interaction are likely to be biologically based and predict cognitive development and the development of mothering (Feldman et al., 2002a; Keren et al., 2003).

To address the issue of social contingencies, we examined the coordination of maternal behavior with the infant's readiness for social stimulation. Conditional probabilities were computed to examine the time mothers provided any form of Maternal Affiliative Behavior—in the voice, touch, or affect communicative channels—during moments when the infant was in an alert state to mother or to the environment (the proportion of time out of the entire session maternal behavior was coordinated to infant "alertness" and social readiness) and the time mothers provided Maternal Affiliative Behavior, when the infant was in any other state (fuss, cry, drowsy, or sleep).

Maternal Depression. Maternal Depression was tested with the Beck Depression Inventory- BDI (Beck, 1978), a well-validated self-report instrument for the assessment of depression.

3 Months

Home Observation for Measurement of the Environment. (HOME, Caldwell & Bradley, 1978) evaluates the quality of the child's home environment and was administered at the home with both parents and child present. The HOME includes 55 items and information was noted during a 1.5-hr observation period in addition to direct questions of the parents. Six composites are computed and a total score is calculated by summing these composites. Separate scores were calculated for mothers and fathers on composites 1 (Emotional and Verbal Responsiveness), 2 (Avoidance of Restriction), and 5 (Parental Involvement with Child) and on the total HOME score. The same score for mother and father were used for composites 3 (Organization of Physical Environment), 4 (Provision of Appropriate Play Material), and 6 (Opportunities for Variety in Daily Life). The mothers' and fathers' total HOME scores were each used to predict the infant's synchrony with that parent. Research assistants were trained to 95% reliability and observed and questioned mother and father separately. Separate total scores were calculated for mothers and fathers and were averaged into a single score (alpha = .91).

Infant–Mother and Infant–Father Interactions at 3 Months. Mothers and fathers were each videotaped in a 5-min free play session at home (counterbalanced for order) and coding was conducted offline on a computerized system. Instructions were: "play with your child as you normally do." No toys were provided. Micro-analysis of the parent–infant interactions was conducted using a computerized system (Noldus Co, Waggeniggen, The Netherlands) when the tape was running in normal speed switching to slow motion when a behavior change occurred. In this computerized system, initial state in each category is marked and change in behavior can be noted with a precision of milliseconds. Coding for parent and child were conducted in separate viewings. Several categories of parent and child behavior were coded and codes within each category were mutually exclusive. In the present study, only two measures were used; yet the coding scheme is presented in full for clarity. **Parent**: *Parent Gaze*—to infant, to object, gaze aversion. *Parent Affect*—positive, neutral, negative (kappa = .87), *Parent Vocalization*—none, adult-speech, "motherese" (kappa = .83). *Parent Touch*—affectionate, proprioceptive (e.g., pulling infant to sitting position), functional (e.g., wiping infant's mouth) (kappa = .85). *Proximity Position*—infant in arms, on lap, in infant-seat, and free (on sofa, carpet etc.) (kappa = .86). **Infant**: *Infant Gaze*: to partner, to object, gaze aversion (kappa = .81). *Infant Affect*: positive, neutral, negative, and fuss-cry (kappa = .79). *Infant Vocalization*—none, fuss-cry, positive vocalizations (kappa = .75). An uncodable code was added to all categories. Reliability was computed on 20 mother–infant and 20 father–infant interactions and exceeded 88% in all categories. Reliability averaged 93% kappa = .80 (range = .75–.87). Two variables were used in the present study: *Parent–infant synchrony*—Because gaze synchrony is the main mode of synchrony at 3 months of age and enables the coordination of affective behavior in other modalities (Messer & Vietza, 1984; Tronick, Als, & Brazelton, 1977), synchrony was measured in the domain of gaze, in line with previous research (Feldman & Eidelman, 2004). Gaze synchrony was indexed by two conditional probabilities: mother gaze at infant given the infant gazes at the mother and father gaze at infant given the infant gazes at the father. These probabilities address the co-occurrence of social gaze between the two partners and indicate the proportion of time out of the entire session when parent and infant synchronized their social gaze. *Parent Affectionate Touch*—was the sum proportion of mother's or father's affectionate touch and was selected due to its centrality for infant development (Hertenstein, 2002).

RESULTS

Group Differences between Preterm and Full-Term Infants

As a first step to data analysis, differences between full-term and preterm infants on all study variables were computed with analysis of Covariance, with the infant's GA at the day of observation entered for all infants as a covariate. These data are reported in Table 2.

As seen in Table 2, the vagal tone of premature infant at term age was lower than that of the full-term infants, pointing to the slower maturation of the autonomic system among preterm infants. Mothers of premature infants engaged in less maternal behavior and preterm infants spent less time in alert states during the interaction. Mothers of preterm infants also reported higher levels of depressive symptoms in the neonatal period. At 3 months, lower levels of mother–infant and father–infant gaze synchrony were observed between parents and preterm infants but no differences emerged in the mothers' or the fathers' affectionate touch. Comparisons between maternal and paternal interactive behavior showed that mothers engaged in more gaze synchrony with their infants, $t(df = 1, 107) = 9.33$, $p < .001$, and provided more affectionate touch, $t(df = 1, 107) = 4.23$, $p < .05$, than fathers.

In evaluating group differences in the coordination of maternal behavior with infant alertness, it was found that the co-occurrence of maternal behavior with the infant's alert state in the full-term group was, $M = .11$ of the interaction. This implies that out of the 17% of the entire session in which full-term neonates were in an alert state,

Table 2. Descriptive Statistics of Study Variables in Preterm and Full-Term Infants

	Preterm		Full-Term		
	M	*SD*	*M*	*SD*	*F*
Neonatal period					
Vagal tone (Vna)	1.73	1.09	2.28	1.46	4.54*
Maternal affiliative behavior[a]	.42	.34	.67	.27	4.67*
Maternal stimulatory touch[a]	.11	.16	.18	.15	NS
Infant alertness[a]	.11	.07	.17	.06	4.32*
Maternal depression	9.97	5.79	5.78	4.26	7.11**
3 Months					
HOME	52.95	5.98	52.75	6.24	NS
Mother-infant synchrony[a]	.24	.18	.38	.22	6.97**
Father-infant synchrony[a]	.12	.07	.20	.12	4.28*
Mother affectionate touch[a]	.13	.10	.16	.12	NS
Father affectionate touch[a]	.08	.06	.10	.07	NS

*$p < .05$.
**$p < .01$.
[a]Numbers represent proportions of time out of the interaction.

for 65% of that time mothers responded with some form of maternal behavior, in the gaze, vocalization, or touch modalities. A different profile emerged for the preterm group. The proportion of coordinated maternal behavior and infant alertness was, $M = .03$ of the entire interaction. Preterm infants were alert for 10% of the interaction, however, for only 33% of that time mothers responded to infant alertness with maternal behavior, χ^2 ($df = 1$, $N = 108$) $= 7.67$, $p < .01$. These findings suggest that premature birth exposes infants to a double risk. Not only maternal behavior and infant alert states decrease, but also mothers of preterm infants are less able to coordinate their affiliative behavior with the infant's scant moments of social readiness.

Interactive Effects of Group and Autonomic Maturity on Maternal Postpartum Behavior and Parents' Affectionate Touch at 3 Months

To examine the interaction effects of risk status and autonomic maturity on maternal postpartum behavior, vagal tone was divided at the median (Median Vna = 1.93) into a high- and low vagal tone groups. Median split is a common strategy in developmental research and has been used in studies of vagal tone in infancy (e.g., Arditi, Feldman, & Eidelman, 2006; Feldman, 2006). Analyses using the median split were supplemented by addressing the associations between the continuous variable of vagal tone with all study variables (Tab. 3).

Analysis of variance with group (preterm, full-term) and autonomic maturity (high, low Vna) revealed a main-effect for group, $F(df = 1, 105) = 4.34$, $p < .05$, and an interaction of group and autonomic maturity, F ($df = 1$, $105) = 3.96$, $p < .05$. Among full-term, no differences in maternal behavior was found between infants with high ($M = .71$) and low ($M = .63$) neonatal vagal tone. In the preterm group, on the other hand, maternal behavior was significantly higher ($M = .51$) among infants with high vagal tone as compared to those with low vagal tone ($M = .33$), $F(df = 1, 55) = 4.53$, $p < .05$. These data appear in Figure 1.

A similar analysis of variance was computed for mother and father's affectionate touch at 3 months. An interaction of autonomic maturity and risk group was found for the mother's affectionate touch, $F(df = 1, 105) = 3.42$, $p < .05$. Significant differences were found in the preterm group between those in the low ($M = .08$) and high ($M = .18$) autonomic maturity, $F(df = 1, 55) = 4.21$, $p < .05$, whereas the difference in maternal touch between the low ($M = .15$) and high ($M = .17$) autonomic maturity group among full term infants was negligible. No associations were found between vagal tone and the fathers' affectionate touch. These findings are presented in Figure 2.

Bi-Variate Correlations between Study Variables

Correlations between study variables were tested separately for the preterm and full-term groups in order to assess whether different patterns of associations emerge under normative and high-risk conditions. These are reported in Table 3.

As seen in Table 3, several associations were found for both groups. Concurrent correlations were found between maternal behavior and infant alertness, between higher maternal depression and less maternal behavior, and between infant vagal tone and interactive alertness in the postpartum period. Longitudinal associations in both groups were found between maternal behavior and both mother–infant synchrony and father–infant synchrony at 3 months and between maternal depression and lower maternal, but not paternal touch. Other correlations were

Table 3. Bi-variate Correlations between Study Variables

	1	2	3	4	5	6	7	8	9	10
1. Vagal tone	—	.19	.18	.27*	−.29*	.21	.32*	.30*	.16	.19
2. Maternal affiliative behavior	.29*	—	.21	.30*	−.35*	.24	.30*	.28*	.25	.11
3. Maternal stimulatory touch	.05	.11	—	.29*	.18	−.21	−.18	−.08	−.22	−.18
4. Infant alertness	.30*	.28*	.07	—	−.17	.18	.32*	.28*	.21	.22
5. Maternal depression	−.34*	−.37*	.22	−.32*	—	−.09	−.28*	−.15	−.33*	−.09
6. HOME	.11	.30*	.13	.08	−.23	—	.21	.18	.18	.11
7. Mother–infant synchrony	.33*	.34*	−.32*	.17	−.30*	.23	—	.43***	.24	.12
8. Father–infant synchrony	.28*	.30*	−.24	.10	−.28*	.24	.45***	—	.28*	.15
9. Mother affectionate touch	.34*	.32*	.22	.16	−.29*	.21	.33**	.23	—	.30*
10. Father affectionate touch	.25	.19	.10	.14	−.22	.18	.24	.14	.47***	—

Note: Correlations below the line are for the preterm group; correlations above the line are for the full-term group.
*$p < .05$.
**$p < .01$.
***$p < .001$.

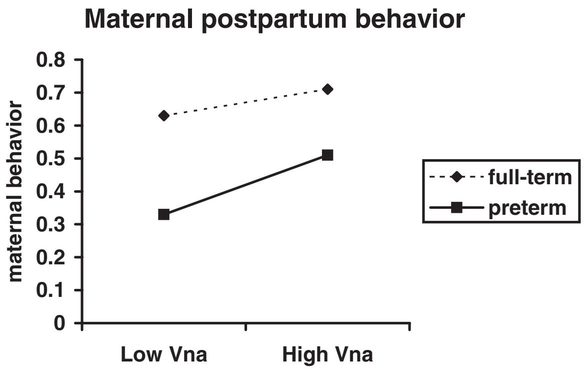

FIGURE 1 Maternal postpartum behavior among full-term and preterm infants with high and low neonatal vagal tone.

found only for the preterm group. Among preterm infants, vagal tone was related to more maternal behavior and to lower maternal depression and longitudinally, to mother affectionate touch. Maternal postpartum behavior was longitudinally related to the home environment at 3 months.

As expected, the contingency between maternal behavior and infant alertness in the neonatal period—the proportion of time out of the infant's alert state when mothers provided maternal behavior—was longitudinally related to both infant–mother, $r = .35$, $p < .01$, and infant–father, $r = .27$, $p < .05$ synchrony.

Predicting Infant–Mother and Infant–Father Synchrony in Full-Term and Preterm Infants

To examine the cumulative effects of maternal and infant postpartum behavior, infant autonomic maturity, maternal depression, and the home environment on the emergence of infant–mother and infant–father synchrony, four hierarchical regression equations were computed predicting mother–infant synchrony at 3 months for the full-term and preterm groups (Tab. 4) and father–infant synchrony at 3 months for the two groups (Tab. 5). Regressions were computed for each parent separately in order to assess the similarities and differences in the predictors of the infant's relationship with each parent. In each regression, variables were entered in six steps in a theoretically determined order. In the first step, infant vagal tone was entered to assess the contribution of infant's autonomic maturity to the emergence of parent–infant synchrony. The next three steps included interaction variables from the neonatal stage: Maternal behavior, maternal stimulatory touch, and infant alertness. The fifth and sixths blocks included the mother's depressive symptoms and the home environment indexed by the HOME score for that parent at 3 months. Table 4 presents the two regressions predicting mother–infant synchrony.

As seen in Table 4, vagal tone and maternal postpartum behavior predicted mother–infant synchrony in both the preterm and full-term groups. In the preterm group, in addition to these variables, maternal depressive symptoms and the home environment were each uniquely predictive of mother–infant synchrony above and beyond the infant's autonomic maturity and the mother's initial parenting style.

Table 5 presents the regressions for father–infant synchrony.

Results presented in Table 5 show that similar predictors; neonatal vagal tone and maternal post-partum behavior each explained unique variance in father–infant synchrony at 3 months in both the full-term and preterm groups. In the full-term group, vagal tone was only marginally related to father–infant synchrony. In the preterm group, the father's HOME score contributed to the prediction of synchrony above and beyond the infant's autonomic maturity and the mother's post-partum relational style, highlighting the associations between the caregiving context and the father's relational style.

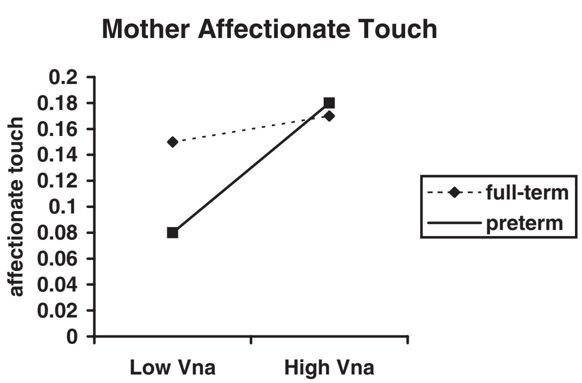

FIGURE 2 Parents' affectionate touch at 3 months among full-term and preterm infants with high and low neonatal vagal tone.

DISCUSSION

Maternal behavior—a uniquely mammalian phenomenon that accompanies bond formation and shapes neurological, physical, and adaptive growth of the young—provides an important foundation for the human infant's social–emotional and cognitive development. The present study addressed correlates of maternal behavior following natural and premature birth and explored its implications for the mother–infant and father–infant relationship. Results demonstrate that following premature birth, there is a significant decrease in maternal behavior and mothers of preterm infants tend to look, smile, vocalize, and touch their infants affectionately less often. In addition to the amounts of maternal behavior, mothers of premature

Table 4. Predicting Infant-Mother Synchrony at 3 Months in Preterm and Full-Term Infants

	Full-Term			Preterm		
	Beta	R^2 Change	F-Change	Beta	R^2 Change	F-Change
Vagal tone	.27*	.09	5.82*	.33*	.14	7.48**
Mother affiliative behavior	.28*	.07	4.74*	.27*	.07	4.57*
Mother stimulatory touch	−.10	.00	.67	−.15	.02	2.23
Infant alertness	.19	.03	2.76	.18	.02	2.72
Maternal depression	−.18	.02	2.14	−.29*	.05	3.87*
HOME	.16	.01	1.66	.27*	.05	4.01*
R^2 total	.22, $F(6, 50) = 2.97$, $p < .05$.			.35, $F(6, 48) = 3.95$, $p < .01$		

*$p < .05$.
**$p < .01$.

neonates were less competent at coordinating their social behavior with the infant's scant moments of alertness. The neonate's first encounter with a social partner affords a setting for the practice of social contingencies, and the experience of such contingencies is essential for bonding, social learning, and neurological maturation (Fleming et al., 1997; Eckerman et al., 1995). Premature neonates, therefore, are at a double risk for the experience of social contingencies, as both the infant's moments of alertness and the mother's capacity to coordinate the species-specific behavior with the infant's social readiness is reduced following a premature birth.

Maternal postpartum behavior emerged as a central predictor of the infant's relatedness with both mother and father. In each of the four regression models—predicting infant–mother and infant–father synchrony in the preterm and full-term groups—maternal postpartum behavior was found as an independent predictor. These findings underscore the formative, perhaps causal role of the initial mother–infant bond immediately after birth for the development of coordinated interactions in both the mothering and fathering systems, and are among the first to demonstrate the associations between postpartum maternal behavior and fathering in the human infant. The findings, therefore, are consistent with a ''sensitive period'' perspective on bonding and point to the critical role of the mother's postpartum behavior for shaping adaptation and social fittedness in mammals (e.g., Champagne & Meaney, 2001). Moreover, the coordination of maternal behavior with the infant's alertness was longitudinally related to synchrony with both mother and father, indicating that the neonate's initial experience in social contingencies is crucial for the formation of a mutually regulated parent–infant dialog. Unlike the mother's postpartum behavior, which is observed across mammalian species, parent–infant synchrony is an exclusively human experience that draws on the sharing of visual patterns and the matching of affective facial expressions. Possibly, the human mother's postpartum repertoire functions to sensitize infants to micro-level changes in facial signals, including the direction of gaze, tone of voice, and level of expressed affect, and afford

Table 5. Predicting Infant–Father Synchrony at 3 Months in Preterm and Full-Term Infants

	Full-Term			Preterm		
	Beta	R^2 Change	F-Change	Beta	R^2 Change	F-Change
Vagal tone	.16$^+$	.05	3.42$^+$	.25*	.08	4.64*
Mother affiliative behavior	.22*	.07	4.03*	.22*	.05	3.95*
Mother stimulatory touch	.03	.00	.66	−.07	.01	.47
Infant alertness	.15	.02	1.75	.14	.02	2.32
Maternal depression	−.11	.02	1.92	−.16	.03	3.42$^+$
HOME	.16	.02	2.11	.24*	.06	4.35*
R^2 total	.18, $F(6, 50) = 2.57$, $p < .05$.			.25, $F(6, 48) = 3.14$, $p < .05$		

$^+p < .10$.
*$p < .05$.

infants the first practice in reading and responding to contingencies during a social exchange.

Similar to maternal postpartum behavior, neonatal vagal tone predicted the level of infant–mother and infant–father synchrony across groups, albeit its contribution to father–infant synchrony in the full-term group was only marginal. According to the polyvagal theory (Porges, 2003), infant autonomic maturity as indexed by cardiac vagal tone provides the foundation for social engagement, particularly the capacity to adapt to rapidly changing social signals that occur during an interpersonal dialog. These findings are consistent with previous research on the relations between infant vagal tone and mother–infant synchrony in term and preterm infants (Feldman, 2006; Moore & Calkins, 2004), and extend these results to the father–child relationship. Higher autonomic maturity at birth may provide infants better neurobiological preparedness to adjust to the complex, second-by-second match of affective states during face-to-face play and these individual differences play a role regardless of initial risk conditions.

Unlike the relations between vagal tone and parent–infant synchrony, the links between vagal tone and maternal postpartum behavior were group-specific; significant relationships emerged between vagal tone and maternal behavior in the preterm, but not in the full-term group. Possibly, when bonding occurs naturally, the mother's neuroendocrinological and mental systems are primed to bond with the infant and maternal behavior is expressed, regardless of individual variation in the infant's autonomic reactivity. When the bonding process is disrupted and the mother's neuroendocironological systems are not properly primed, as natural breastfeeding and full maternal–infant contact is prevented, the infant's innate capacity for social engagement and self-regulation plays a greater role. Under such conditions, infants who are able to elicit maternal attention are likely to receive more maternal behavior. Because maternal behavior provides an important foundation for the infant's neurobehavioral, cognitive, and social growth, the findings emphasize the high risk for premature infants with lower autonomic maturity who are less able to elicit the mother's engagement and therefore receive very low levels of maternal behavior. According to the "differential susceptibility" theory (Belsky, 1998), these are the infants who most rely on the mother's synchronous behavior to provides the extrauterine regulatory framework for neurological maturation (Hofer, 1995).

Maternal depressive symptoms were associated with lower frequencies of postpartum behavior and lower neonatal vagal tone, and were longitudinally related to less maternal affectionate touch at 3 months. Most research documenting the effects of maternal postpartum depression on mothering examined maternal behavior from 3 months an on (e.g., Field, 1992) and the present findings extend this literature by emphasizing the immediate impact of depression on the mother's postpartum behavior and the bonding process. The relation between maternal depression and lower infant vagal tone is consistent with previous research in full-term infants (Field et al., 2000), and the present data show such associations in premature infants as well. It is also possible that neurochemical changes in the mother related to depression during pregnancy impacted on the intrauterine maturation of parasympathetic control over heart rhythms in the fetus, but this hypothesis requires much further research. Research in genetic animal models for depression demonstrate that depressed dams engage in less maternal postpartum behavior, such as licking-and-grooming and arched back nursing, and the lower frequencies of maternal behavior are associated with disruptions to dopaminergic systems and the reward mothers received from the pups (Lavi-Avnon et al., 2005). The present findings demonstrate similar associations between maternal depressive symptoms and reduced maternal postpartum behavior in humans, and the links also extend to the maternal affectionate touch at 3 months. The relationship between maternal depression and reduced maternal touch in the postpartum has been previously noted (Feldman & Eidelman, 2003a) and the current findings point to the long-term impact of postpartum depression on the mother's affectionate touch. Thus, in accordance with the sensitive period perspective, the first postpartum days appear to play a crucial role in the formation of the mother–infant bond (Klaus & Kenell, 1976). Moreover, the results demonstrate the effects of maternal–infant bonding not only on the mother–child relationship but also on the development of fathering. The inter-relatedness of the aforementioned measures—maternal behavior, maternal depression, infant vagal tone, and premature birth—points to the cumulative risk for infants born prematurely to start their life on a non-optimal trajectory for social–emotional growth. As suggested by the dynamic systems' perspective (Fogel, 1993; Thelen & Smith, 1994), individual trajectories self-organize across development and even small variations in initial conditions may result in substantial disruptions to the parent–infant relational unit and the infant's ultimate development.

Results of the regression models demonstrate that maternal and environmental conditions had a greater impact on the development of infant–mother and infant–father relationship in preterm, compared to full-term infants. These findings are in line with previous research on the greater contribution of parental and contextual factors to the development of premature infants (Greenberg & Crnic, 1988; Minde, 2000). The mother's well-being and the provision of a sensitive and adequately stimulating home environment are especially needed for the premature infant to develop a mutually-regulated parent-infant system. Such findings resonate with Stern's (1995) theory on the ''ports of entry'' and with perspectives on the compensatory, self-righting mechanisms in early development (Gottlieb, 1991). Following the disruption to the parent–infant bonding caused by premature birth, there may be several entry-points to correct some of the negative effects of prematurity on infant development. Techniques that may be helpful include methods related to maternal–infant touch and contact—such as Kangaroo Care and massage—psychosocial interventions that educate parents on the need to provide an appropriately stimulating home environment, and extra support for parents to promote maternal psychological well-being. Interventions that focus on maternal-infant touch and contact have been shown to promote maternal behavior, increase the maturation rate of infant vagal tone, and contribute to mother-infant and father-infant reciprocity at 3 months in premature infants (Feldman & Eidelman, 2003b; Feldman, Weller, Eidelman, & Sirota, 2003; Goldstein-Ferber et al., 2005). Such methods should be applied in neonatal intensive care units as soon as the infant's medical condition reaches a stable state.

Limitation of this study relate to the fact that physiological measures, especially vagal tone were not assessed at 3 months. It would be important to know whether the high-vagal tone infants of the preterm group reached full maturity at that stage and whether there was some catch-up for the low-vagal tone group. Information on infant aspects of temperament at 3 months, particularly on reactivity and regulation, would have also contributed to a fuller picture of the parent–infant communication system.

Future research should focus on the effects of maternal postpartum behavior on infant development across childhood and address its interaction with other physiological and neurobehavioral systems as children grow and acquire new skills. Maternal behavior provides the most immediate and environmentally salient social milieu for the development of the human infant. Further study of its underlying genetic, neurological, biochemical, and mental correlates are important to elucidate the multiple ways by which specific mother-related regulatory experiences shape the infant's growth and development through repeated cycles of natural caregiving and responsivity.

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