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Preterm Infant Contingent Communication in the Neonatal Intensive Care Unit With Mothers Versus Fathers

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Very few studies have assessed infant capacity for bidirectional, contingent communication at birth, and to our knowledge there are none with preterm infants in the neonatal period. Presence versus absence of such interactive contingency makes a difference for our theories of development. We examined whether preterm infants can contingently coordinate behaviors with mothers and fathers in spontaneous communication in the Neonatal Intensive Care Unit (NICU), and whether mother–infant versus father–infant engagement and contingency differ. Twenty Italian preterm infants (60% girls, born 27–33 weeks, largely middle-class families) lying in a heated cot in the NICU were videotaped at 35 weeks with mothers, and fathers (counterbalanced), in face-to-face communication. Videotapes were coded on a 1-s time-base with parent and infant engagement scales. Multilevel time-series models evaluated self-contingency (auto-correlation) and interactive contingency (lagged cross-correlation). Mothers (vs. fathers) showed higher levels of engagement, interpreted as more arousing. Fathers (vs. mothers) showed more midrange engagement, interpreted as less "demanding" of infant engagement. Infants were more gaze-on-parent's-face and gaze-on-environment with mothers than fathers. Fathers interacted contingently with infants, whereas mothers did not. However, infants interacted contingently with mothers, but not fathers. When infants were in lower engagement levels 1 s prior, fathers stayed in lower engagement levels in the current second, closer to infants than mothers. We suggest that fathers were more coordinated because fathers were more able to join the infant's dampened state. We suggest that infants were more coordinated with mothers because mothers were more socially stimulating, and more familiar. We conclude that preterm infants, shortly after birth, are capable of contingent communication.

Keywords: preterm infants, NICU, face-to-face communication, mother–infant vs. father–infant, interactive contingency

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Early parent-infant face-to-face communication is characterized by second-by-second shifts of gaze, facial affect, vocalization, and touch in a continuous process of mutual adjustment that requires bidirectional contingent coordination by both partners, also known as "co-regulation" (Beebe et al., 2016; Fogel, 1993; Lavelli & Fogel, 2013; Tronick, 1989). From birth onward, co-regulated processes provide the foundation for developing patterns of parent–infant communication (Hsu & Fogel, 2003; Lavelli et al., 2019), infant attachment and cognition (Beebe et al., 2010; Jaffe et al., 2001), emotion regulation (Feldman, 2007), and childhood social/emotional/cognitive competence (Feldman & Eidelman, 2009).

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Only a few studies have assessed infant second-by-second co-regulation with parent/adult during face-to-face communication at birth (Dominguez et al., 2016; Kato et al., 1983; Lavelli & Fogel, 2005, 2013; Peery, 1980). No work to our knowledge has assessed this co-regulation with preterm infants and parents in the neonatal period during spontaneous face-to-face interaction, using a temporal dynamics approach to moment-by-moment bidirectional contingent coordination. The presence or absence in the neonatal period of such *interactive contingency*, that is, moment-to-moment adjustments in response to the partner's prior behavior, makes a difference for our theories of development. If preterm neonates, who are neurologically immature, can participate in co-regulated processes from birth, this capacity for interpersonal coordination is a robust capacity with which we are born. And prematurity cannot knock it out. Thus, this study aims to evaluate whether preterm infants and their mothers and fathers participate in interactive contingency during the infant's stay in the neonatal intensive care unit (NICU).

Moreover, because of their neurological immaturity, preterm infants are particularly dependent on mutually regulating interactions for optimal growth (Feldman & Eidelman, 2007). They are more vulnerable but also more likely to be affected by their first social experiences. Thus, a better understanding of whether and how preterm infants participate in interactive contingency with their parents in NICU is important not only for our understanding of early development, but also for our capacity to design appropriate interventions.

Full-Term Infant–Parent Communication in the Neonatal Period

Human newborns are sociable from birth. They selectively interact with other humans (Ammaniti & Gallese, 2014) and display remarkable capacities of perception and appropriate expression of social cues (Murray et al., 2016). Shortly after birth, newborns display heightened interest and attention not only toward social stimuli, but to stimuli signaling readiness to interact. They prefer to look at faces that engage them in mutual gaze (Farroni et al., 2002). They recognize a face that previously spoke to them with direct gaze (Guellaï & Streri, 2011). They prefer faces with happy rather than fearful expressions (Farroni et al., 2007). They distinguish and prefer infant-directed speech over adult-directed speech (Cooper & Aslin, 1990). This selective social activation correlates with age in hours over the first few days after birth, suggesting that even very limited experience with face-to-face interaction with other humans may be sufficient to activate relevant cortical regions (Farroni et al., 2013).

Most remarkable, newborns as young as a few hours old can imitate facial, hand, and finger movements, and vocalizations (Field et al., 1982; Meltzoff et al., 2018; Meltzoff & Moore, 1977; Nagy et al., 2014; Nagy & Molnar, 2004), although some questions about neonatal imitation are still open (Anisfeld et al., 2001; Jones, 2006; Meltzoff et al., 2018; Nagy et al., 2014).

We have more limited evidence that shortly after birth, full-term healthy newborns engage in interactive contingency with an adult partner. Using frame-by-frame analysis of 16 mm film, Peery (1980) showed that 1-day-old newborns can participate in a coordinated pattern of approach and withdrawal during face-to-face interaction with an experimenter. Kato et al. (1983) assessed the interactive contingency of adult speech (of mother, pediatrician, and nurse) in relation to infant body movement at 1–6 days with a computerized microanalysis, documenting that healthy full-term newborns can move their bodies synchronously with adult speech, and that mothers/adults vocally responding to their movements. Dominguez et al. (2016) instructed mothers to speak to their 2- to 4-day-old full-term newborns during face-to-face interaction and analyzed vocal turn-taking sequences. Two thirds of the newborn vocalizations that followed a maternal vocalization occurred within one second of maternal offset, suggesting that infant capacity for co-regulation with the caregiver may be present at birth.

Of the few studies in this area, only one analyzed spontaneous communication between parents and full-term infants in the neonatal period, Lavelli and Fogel (2013). They used weekly observations and sequential analysis (GSEQ, Bakeman & Quera, 1995) of mother–infant behaviors to examine how co-regulation processes unfold from birth to 3 months. Already in the first weeks of life, mother–infant face-to-face communication functions as a mutually regulated system characterized by a bidirectional sequential link of infant attention to the mother's face, followed by maternal affectionate talking, and vice versa; and a significant sequence of mother stimulating followed by infant gazing elsewhere.

Parent–Preterm Infant Communication as a Challenge in the NICU

While preterm infants have a high need for co-regulated interactions with their parents (White-Traut et al., 2013), establishing such interactions is challenging for both infants and parents because of the infant's neurobiological immaturity and other difficult conditions of premature birth and NICU hospitalization. Preterm infants in the NICU are exposed to physical and psychosocial stressors, including excessive light and noise levels (Lahav & Skoe, 2014), painful procedures (Ranger & Grunau, 2014), and early and prolonged separations from parents (Latva et al., 2007). These stressors can affect the immature, vulnerable brain of preterm infants and contribute to neuro-developmental risk (Maroney, 2003; Mooney-Leber & Brummelte, 2017). Physical separation of parents and infant in the NICU, in particular, disrupts the establishment of the early parent–infant physiological/emotional connection (Flacking et al., 2012; Welch & Ludwig, 2017) that plays a crucial role in regulating the stress response and that provides the context for optimal contingent coordination (Beebe et al., 2018). Preterm infants, therefore, facing the challenges of underdeveloped neurobehavioral systems and stressful environmental conditions, might not participate in early interpersonal coordination shortly after birth.

Preterm infants spend less time in alert states, show lower capacity for self-regulation, exhibit lower responsiveness during social exchanges, and send less clear communication signals than full-term infants (Bozzette, 2007; Eckerman et al., 1995). These behaviors make it more difficult for parents to interpret infants' signals, to help regulate their arousal, and to initiate and maintain interaction (Hall et al., 2015; Goldberg & Di Vitto, 2002). In addition, parents may experience heightened levels of stress, anxiety, and depressive symptoms related to the premature birth and physical separation from the infant (Howland et al., 2011; Lefkowitz et al., 2010). For example, Welch et al. (2016) reported that the prevalence of maternal depression following preterm birth is variously estimated to be between 28% and 70%. These difficult parental states can interfere with parental sensitivity to infant cues (Field, 2010; Zelkowitz et al., 2007), parental confidence, and the development of postnatal bonding (Feldman et al., 1999; Spinelli et al., 2016). As a consequence, caregiver–infant interactions with preterms have been found to be less mutually adaptive than those with full-term infants during the first 6 months of life (Forcada-Guex et al., 2011; Lester et al., 1985; Neri et al., 2015).

However, studies are not entirely consistent. Some studies reported no differences in quality of parent–infant interaction after full-term versus preterm birth, suggesting that the quality of parental behaviors with their preterm infants could be partly due to the support parents receive in the NICU (Hall et al., 2015; Korja et al., 2012). During the last decade, infant- and family-centered developmental-care interventions have increasingly been adopted by NICUs to reduce the stress experienced by preterm infants and parents, facilitating parent–infant proximity and parental involvement in daily care (Roué et al., 2017; Westrup, 2007). Studies of the effectiveness of developmental-care strategies show that parent–preterm infant physical and emotional closeness during hospitalization, particularly skin-to-skin contact and parental involvement in infant care and holding during painful procedures, enhance the infant's neurobehavioral outcomes (O'Brien et al., 2018; Reynolds et al., 2013), reduce parental stress, and mental health risk (O'Brien et al., 2018; Xie et al., 2019), and improve mother–infant face-to-face communication by 4 months corrected age (CA; Beebe et al., 2018).

To foster opportunities for proximity between parent and infant in the incubator, an increasing number of early interventions have used maternal voice (recorded in most studies) as a way to create more emotional connection (Filippa et al., 2017). Exposure to maternal voice increased preterm infant quiet alert state and attending behaviors, which are known to foster early parent–infant communication from as early as 32 weeks gestational age (GA) (Bozzette, 2008; Filippa et al., 2013; Keller et al., 2008). This exposure also increases later visual and auditory orientation at 3 months CA (Picciolini et al., 2014). Recent reviews show that exposure to maternal voice (Filippa et al., 2017; Provenzi et al., 2018), and more generally to human voice (Saliba et al., 2018), has beneficial effects on physiological and behavioral stability of preterm infants, and may offer an earlier opportunity for sensory enrichment when tactile stimulation is avoided due to medical instability (Provenzi et al., 2018). However, early sensory stimulation can have also detrimental effects (Lejeune et al., 2019), particularly when stimuli are not live and not contingent on infant behavior, as in the case of recorded voice (see Filippa, 2019).

These results raise central questions about what preterm infants in the NICU really need and the most appropriate way to intervene. They suggest that parental multimodal contingent communication can be a natural beneficial source of stimulation. Nevertheless, few studies have focused on parents' *spontaneous* face-to-face communication with their preterm infants in the NICU, assessing parent–infant interaction prior to discharge. Moreover, previous studies have focused mainly on parent/maternal behaviors, and not *infant* behaviors (Coppola & Cassibba, 2010; Feldman & Eidelman, 2007; Keren et al., 2003; Zelkowitz et al., 2007).

Feldman and Eidelman (2007) examined maternal coordination with infant readiness for social stimulation. They measured the proportion of time mothers provided any form of affiliative behavior (gaze at infant, facial positive affect, "motherese," affectionate touch) when the infant was in an alert state, comparing preterm infant–mother dyads at 37 weeks GA with full-term dyads at 39 weeks. Mothers of preterm (vs. full-term) infants were less able to coordinate affiliative behaviors with their infant's scant moments of alertness. However, this study did not assess the process of co-regulation, that is, whether each partner contingently altered her/his behavior with respect to the ongoing behavior of the other.

Although there is a large body of evidence that fathers, as well as mothers, contribute to child development (Cabrera et al.,2018), most studies of preterms have concentrated on infants and mothers; research on fathers' experience with their preterm infants and father–infant communication in the NICU is scarce (Stefana et al., 2018; Stefana & Lavelli, 2018). Fathers are known to become more involved when mothers are depressed, which is a key risk factor in prematurity (Goodman et al., 2014). Tactile stimulation by fathers has been found to stabilize preterm infants' physiological status (Kim et al., 2017). Yet comparison of the contributions of fathers versus mothers during *spontaneous face-to-face* communication with preterms is lacking. Zelkowitz et al. (2007) examined both fathers and mothers during feeding prior to NICU discharge, but father versus mothers were not directly compared. Saliba et al. (2020) asked mothers and fathers to talk to infants during the NICU stay. The voice of both parents increased infant quiet alert state, and no differences in the effects of father versus mother voice were identified. Since we know so little about father-infant interaction in the NICU, it is important to understand how mothers and fathers may make similar or different contributions at this stage.

A recent study from our group (Stefana et al., 2020) examined fathers (but not mothers) and their preterm infants. Sequential patterns of spontaneous face-to-face communication were explored between fathers and preterm infants (35 weeks GA) who were confined to the heated cot in the NICU. Sequential analysis (GSEQ, Bakeman & Quera, 2011) revealed significant bidirectional transitional probabilities between father's affiliative behavior and infant's gazing at the father's face, indicating the presence of bidirectional sequential patterns of communication.

We now deepen this interesting result to gain a better understanding of the process of co-regulation during parent–preterm infant interaction in the NICU, for several reasons. First, whereas the prior study focused only on father–infant communication, we now compare mother–infant and father–infant communication. The current analysis will provide more complete information on the possibility of interactive contingency between parents and preterm infants in the NICU, and on potential differences between mothers and fathers. Second, the method of sequential analysis is a conditional probability approach that focuses on associations between specific behaviors of partners, but not on the *temporal dynamics of the process of relating itself,* which is the approach of the current study, using time-series methods: the degree to which each individual coordinates behaviors *moment-by-moment* with behaviors of the partner, *over the course of the interaction.* Third, whereas the prior study focused exclusively on interpersonal sequential patterns, in contrast, we measure both intrapersonal (*self-contingency*) and interpersonal (*interactive contingency*) processes, both essential constituents of social interaction (Beebe et al., 2016; Gianino & Tronick, 1988; Messinger et al., 2012).

The Present Study

The main goal of the study is to evaluate whether and how preterm infants participate in interactive contingency with their mothers and fathers during spontaneous face-to-face communication in the NICU, and whether mother–infant versus father–infant interactive contingency differ.

Although both self and interactive processes provide core organizing principles of interaction (Sander, 1977; Trevarthen, 1993; Tronick, 1989), infant research on face-to-face communication has largely neglected self-organizing processes. As Sameroff (2010) notes, infants learn through a dyadic process that includes both their own behavior and that of their partners. In our dyadic systems view, self *and* interactive processes operate together as a system (Beebe et al., 2016). In this view, both partners contribute to the face-to-face exchange through a bidirectional, contingent process. Moreover, each partner's behavior unfolds in the individual (auto-correlation, termed self-contingency), while at the same time modifies and is modified by the ongoing behavior of the other (lagged cross-correlation, termed interactive contingency), (Fogel, 1993). Thus, all dyadic interactions simultaneously reflect self and interactive processes (Beebe et al., 2016; Gianino & Tronick, 1988). *Interactive contingency* assesses predictable moment-to-moment adjustments that each individual makes in response to the partner's prior behavior. *Self-contingency* measures the degree to which the individual's prior behavior predicts current behavior. Self-contingency taps *one dimension* of self-regulation, that is, the procedural anticipation of where one's own behavior is tending in the next second. It generates expectancies of the degree to which one can anticipate the rhythm of one's own behavior: how predictable, how stable, how variable one's behaviors are, from moment to moment, a process so basic it is rarely noticed, like breathing. In a series of studies examining how various risk conditions might alter mother–infant self- and interactive contingency at 4 months, self-contingency was often more sensitive than interactive in identifying disturbances, for example in risk conditions of maternal depression, anxiety, and infant prematurity (Beebe et al., 2008, 2011, 2018). We videotaped spontaneous mother–infant and father–infant face-to-face communication with preterm infants at 35 weeks postmenstrual age (born 27–33 weeks), who were confined to a heated cot in the NICU. We coded behavior second-by-second and quantified self- and interactive processes with measures of *self- and interactive contingency* using multilevel time-series models.

Our main goal has two specific aims:

1. We compare the proportion of time spent in social engagement behaviors by mothers versus fathers, and by infants with mothers versus fathers. We expect that engagement will be higher in mothers, and in infants with mothers, because mothers spent more time with the infants in the NICU in the first weeks of life (see details below), and infants were likely more familiar with the mother, based on prenatal experience of maternal voice (Moon, 2017) and greater postnatal experience with the mother.

2. We assess differences in mother–infant and father–infant self- and interactive contingency of engagement behaviors in these preterm dyads. We conjecture that:

   a. Both parents will show interactive contingency with the preterm infant, but mothers' interactive contingency will be greater than that of fathers, for the same reason noted above in (1).

   b. Infants will show interactive contingency with both parents. Infants will show interactive contingency with mothers, based on the literature showing that preterm infants manifest increased attending when exposed to maternal voice (Bozzette, 2008; Filippa et al., 2013; Keller et al., 2008). Infants will show interactive contingency with fathers, based on prior work (Stefana et al., 2020) documenting significant infant transitional probabilities with fathers.

   c. In considering whether infants might show differences in interactive contingency with mothers versus fathers, we conjecture that infants will interact more contingently with mothers if, as we suppose, mothers will interact more contingently with infants than fathers.

   d. Self-contingency will be significant for all partner conditions, following Beebe et al. (2016), who found that self-contingency was significant in both mothers and infants. Lacking prior literature, we make no conjecture about specific differences in self-contingency in mother–infant versus father–infant dyads.

Method

Participants

Twenty very preterm infants (12 girls, eight boys) born 27–33 weeks GA and their mothers and fathers participated in the study. The fathers and preterm infants were the same as in (Stefana et al., 2020). All infants were healthy preterms hospitalized in the Level III NICU in Verona, Italy, and separated from the mother just after birth. The inclusion criterion was single or twin birth before 34 weeks GA, in line with other studies on maternal caregiving behavior during the NICU stay (Feldman & Eidelman, 2007; Welch et al., 2012) and on mother–preterm infant interaction after discharge (Beebe et al., 2018; Forcada-Guex et al., 2011; Muller-Nix et al., 2004). Exclusion criteria included perinatal asphyxia, neurologic pathologies (periventricular leucomalacia up to Stage I and/or intraventricular hemorrhage up to Stage II), malformation syndromes and/or major malformations, sensory deficits, and metabolic or genetic diseases. Parents were eligible if they were biological parents, with no psychiatric illness or habitual drug abuse, both Italian cultural background, and living together. The final sample recruited is described in Table 1. As noted in Table 1, four twin sets were included, consistent with the large representation of

Table 1
Infant and Parent Demographic and Clinical Characteristics

Characters	*M* (*SD*)	Range
Infant		
Gestational age (weeks)	31 (2.1)	27–33
Birth weight (kg)	1.450 (.411)	.650–2.100
Age (weeks) when videotaped	35.3 (.04)	34.7–35.9
Weight (kg) when videotaped	1.999 (.253)	1.530–2.290
PERI[a] score	6.20 (4.55)	1–16
% at risk	50%	
Twin sets	4	
Mother		
Age (years)	37.3 (4.8)	29–46
First-time parent %	63%	
CES-D[b] score	18.6 (11.0)	4–37
%depression	50%	
Father		
Age (years)	39.5 (4.7)	31–47
First-time parent %	69%	
CES-D score	15.1 (8.7)	5–32
%depression	38%	
Family		
Socioeconomic status[c]	3.0 (0.7)	1.8–4

[a] PERI = Perinatal Risk Inventory (Scheiner & Sexton, 1991); cut-off for risk ≥ 5. [b] CES-D = Center for Epidemiologic Studies-Depression (Fava, 1983); cut-off for depression ≥16; mothers' mean CES-D score was higher than that of fathers ($t = 2.05$, $p = .054$). [c] Socioeconomic status (SES) was coded combining education and professional status for both parents, using Pierrehumbert et al. (2003) 4-point scoring system derived from Hollingshead's Index.

twins in typical NICU samples in Italy (Basili et al., 2013). We note that mothers were more depressed (50% ≥ 16 on the Center for Epidemiological Studies–Depression Scale [CES-D], Fava, 1983) than fathers (38%).

Recruitment was challenging, and it took 15 months to involve 20 mother–infant and father–infant dyads. Families were recruited during the NICU stay and videotaped once the infant's medical condition was stabilized (32–34 weeks GA). The inclusion/exclusion criteria significantly reduced the number of families who could be contacted, because almost 40% of the families were immigrant or had at least one foreign parent, and some eligible preterm infants had sequelae. Moreover, over 50% of the families contacted refused to participate, likely due to the stressful conditions experienced by parents after preterm birth. Finally, several families who had originally agreed to participate were transferred to a Level II NICU closer to their homes (after improvement in the infant's medical condition) prior to data collection. None of the twins in our sample was transferred to a Level II NICU, because of their lower gestational age and slower medical improvement, contributing to the number of twins in our sample.

In the NICU open-bay wards, parents were admitted 8:00 a.m. to 8:00 p.m. However, mothers (vs. fathers) had more access to their infants. Mothers had Caesarean sections, were hospitalized the first week, and had more time to make contact with their infants in the incubator. Once infants were medically stabilized, ready for videotaping, mothers were at home. In Italy, although either mothers or fathers can receive paid leave, mothers (recovering from surgery) elected to receive it and stayed home; fathers could interact with infants only evenings/weekends.

The study (included in a larger research project titled "Parental Engagement and Early Interactions With Preterm Infants During the Stay in the Neonatal Intensive Care Unit") was approved by the Ethical Committee for Clinical Trials of the Verona and Rovigo Provinces (protocol no. 569CESC).

This study was not preregistered.

Procedure

Families were contacted by the second author who was present daily in the NICU (Stefana & Lavelli, 2017) to identify the best conditions for videotaping parent–infant face-to-face interaction with the preterm infant in a heated cot (e.g., according to parents' commitments and infant's behavioral state). Mothers and fathers together completed a questionnaire on sociodemographic information and separately completed the Italian version of the CES-D to assess symptoms of depression (Fava, 1983). Mothers and fathers were then videotaped during spontaneous face-to-face communication with their preterm infants when infants were (a) between 34 and 36 weeks GA (*M* 35.3 weeks, *SD* .4), and (b) transferred from incubators to open heated cots, having reached a weight of at least 1,600 g–1,800 g sufficient for thermoregulation. While in incubators, little interaction was possible, but once infants were moved to heated cots, a little more interaction was possible.

Videotaping

Each parent–infant dyad was videotaped for 5 min, beginning when the infant was in quiet alert state. The parent was face-to-face with the infant, standing beside or bent over the heated cot, and was asked to communicate with the infant freely; no specific instructions were given.[1] The order of videotaping mother–infant versus father–infant interaction was counterbalanced. The infant rested for at least 15 min without any social stimulation between the two interactions. The time of day for videotaping was organized around the father's work schedule.

Coding

The first 3 min uninterrupted by any videotaping adjustments were chosen for coding. Parent behaviors and infant behaviors were separately coded on a 1-s time-base with infant and parent ordinal engagement scales, devised specifically for this research project with preterm infants in the NICU (Lavelli & Beebe, 2016). The Parent Engagement Scale was comprised of eight mutually exclusive categories, ordered from the highest level of engagement, that is, the co-occurrence of gaze at infant, affectionate touch, affectionate talk, and positive facial affect, to the lowest level of engagement, gaze off. The Infant Engagement Scale was comprised of seven mutually exclusive categories, ordered from GazeOn+Smile, to negative expression. See Table 2 for detailed descriptions.

Reliability

Parent engagement behavior and infant engagement behavior were coded by two different sets of coders, trained by the first

[1] NICU routine practice provided parents with oral/written information about how to socially engage a preterm infant, according to infant gestational age. The "Parents Information Booklet" provided parents with information such as "At 30-32 weeks the infant will be able to see you at a distance of 20–30 centimeters," and "You must use a firm but gentle touch, without rubbing."

Table 2
Parent and Infant Engagement Scales

Parent Behavioral configuration	Description
8. Gaze On–Affectionate Touch–Affectionate Talk–Positive Facial Affect	Parent is gazing at the infant, touching and talking to her/him in an affectionate way. Affectionate Touch includes static touch,[a] stroking, and stroking combined with gentle tactile or gentle kinesthetic stimulation. Affectionate Talk includes "baby talk" vocalizations. Facial expression is positive.
7. Gaze On–Affectionate Touch–No Talk–Positive Facial Affect	Parent is gazing at the infant, touching her/him in an affectionate way (see above). Facial expression is positive.
6. Gaze On–No Touch–Affectionate Talk–Positive Facial Affect	Parent is gazing at the infant, without touching her/him, but talking to her/him in an affectionate way including "baby talk." Facial expression is positive.
5. Gaze On–Affectionate Touch–No Talk–Neutral Facial Affect	Parent is gazing at the infant, touching her/him in an affectionate way (see above). Facial expression is neutral
4. Gaze On–No Touch–No Talk–Positive Facial Affect	Parent is gazing at the infant, without touching and/or talking to her/him, but showing positive facial expression.
3. Gaze On–No Touch–Talk/No Talk–Neutral Facial Affect	Parent is gazing at the infant, without touching her/him. Parent could talk in a nonaffectionate mode including flat, adult-directed speech. Facial expression is neutral.
2. Gaze On–Non-Affectionate Caregiving Touch–Talk/No Talk–Neutral Facial Affect	Parent is gazing at the infant, touching her/him in a nonaffectionate way including caregiving or rough touch. Parent could talk in a nonaffectionate mode including flat, adult-directed speech. Facial expression is neutral.
1. Gaze Off	Parent is gazing away from the infant.
Infant Behavioral configuration	**Description**
7. Gaze On–Smile	The infant is gazing at the parent's face and smiling.
6. Gaze On–Neutral Facial Affect	The infant is gazing at the parent's face with no particular facial action (except for reflexes and vegetative movements).
5. Gaze On Environment	The infant is gazing at the surrounding environment.
4. Gaze Off–Neutral Facial Affect	The infant's gaze is oriented elsewhere from the parent's face but not active (i.e., eyes are open but gaze is vague); no particular facial action (except for reflexes and vegetative movements).
3. Gaze Off–Averted Head	The infant is keeping her/his head and gaze averted from the parent's face.
2. Eyes Closed	The infant's eyes are closed. Eyes closed for vegetative movements such as sneezing and yawning are included.
1. Negative Expression	The infant is showing any vocal and/or facial negative expression (grimace, precry, fussy, crying) and/or body negative expression (squirmy, agitated), either with gaze-on or off, and eyes open or closed.

Note. Upper part: Parent Behavioral configuration; lower part: Infant Behavioral configuration.
[a] In the NICU context, parental Static Touch (gently firm and sustained touch) is an effective way to be in contact with the preterm infant (Beebe et al., 2018), given the loss of physical contact with parents and the prolonged separation due to the NICU experience.

author. Intercoder reliability for behavioral configurations of mother and father, and infant with mother and father, was calculated on a random sample of 20% of the sessions, eight dyads: four infants with mother and four different infants with father. The average Cohen's kappa was .83 (range .79–.88) for mother behaviors, .82 (range .71–.91) for infant behaviors with mother, .79 (range .73–.84) for father behaviors, and .86 (range .80–.93) for infant behaviors with father.

Data Analysis

Aim 1

We tested whether mother–infant versus father-infant dyads differed in the proportion of time spent in engagement behaviors. The behavioral configurations of the Parent Engagement Scale were grouped into the following macrocategories: (a) high engagement: Configurations 8, 7, and 6; (b) midrange engagement: Configurations 5 and 4; (c) low engagement: Configurations 3 and 2; and (d) disengagement: Configuration 1 (see Table 3). The behavioral configurations of the Infant Engagement Scale were grouped into the following macrocategories: (a) engagement: Configurations 7, 6, and 5; (b) disengagement: Configurations 4, 3, and 2; and (c) negative expression: Configuration 1 (see Table 4). Mother versus father, and infant with mother versus father macrocategories of engagement levels were compared through paired t-tests.

Aim 2

Self- and interactive contingency were calculated for mother–infant versus father–infant groups, using multilevel time-series models. Parent and Infant Engagement Scales (see Method) were used as continuous variables in the time-series analyses and were standardized prior to data analysis. We first modeled the two groups as a whole, creating estimates of both *fixed effects* (group-level), and *random effects* (individual variation in those effects). Estimates of contingency for each partner in each group were then derived from the full model. Parents were dummy coded, mother = 0, father = 1.

Time-series models are designed to quantify patterns over time, here the course of behavior second-by-second within the individual (self-contingency), and between two individuals (interactive contingency). The SAS PROC MIXED program was used to estimate random and fixed effects on patterns of self- and self-with-other engagement behaviors over 180 seconds (Chen & Cohen, 2006).

Table 3
Sum Durations (in Seconds) of Mothers' and Fathers' Behaviors With the Preterm Infant (180 s)

	Mothers (N = 16)		Fathers (N = 16)				
Behavioral configuration	*M*	*SD*	*M*	*SD*	*t(df)*	*p*	*d*
High Engagement Levels (8 + 7+6)	127.20	39.08	109.80	43.81	2.43 (19)	.025	.54
8. GazeOn+AffTouch&Talk+PositFace	64.10	33.97	49.00	29.77			
7. GazeOn+AffTouch+PositFace	57.50	40.45	58.90	38.39			
6. GazeOn+AffTalk+PositFace	5.60	8.56	1.90	4.47			
Midrange Engagement Levels (5 + 4)	37.70	34.93	56.45	43.80	−2.60 (19)	.018	.58
5. GazeOn+AffTouch+NeutrFace	31.95	36.81	50.60	46.47			
4. GazeOn+PositFace	5.75	9.56	5.85	9.58			
Low Engagement Levels (3 + 2)	12.15	22.98	10.50	16.14	.39 (19)	.701	—
3. GazeOn+NeutrFace	4.80	15.57	3.85	5.52			
2. GazeOn+NonAffCarTouch+NeutrFace	7.35	18.86	6.65	13.65			
Disengagement					−.50 (19)		
1. GazeOff	3.05	3.93	3.75	4.09		.621	—

Note. AffTouch&Talk = affectionate touch & affectionate talk; AffTouch = affectionate touch; AffTalk = affectionate talk; PositFace = positive facial affect; NeutrFace = neutral facial affect; NonAffCarTouch = nonaffectionate caregiving touch.

Preliminary modeling of mother–infant and father–infant data evaluated the length of the temporal window (lag in seconds) to use in the final time-series models. We examined up to three prior lags (seconds), consistent with prior work (Beebe et al., 2016). Only a Lag 1 model (using the prior second t_{-1} to predict t_0, the current moment) was significant (using the *F* test) for both mother–infant and father–infant data. We thus chose the Lag 1 (L1) model because, in order to compare two groups, the lag structure must be the same (Cohen et al., 2000; McArdle & Bell, 2000; Singer, 1998).

Estimated coefficients for effects of L1 on t_0 over the course of the interaction (180 s) indicate the level of self- or interactive contingency. Each analysis included both self- and interactive contingency; thus, estimated coefficients of one form of contingency control for the other. Larger coefficients reflect stronger contingencies. Contingency estimates are standardized.

Tests of hypotheses used fixed effects (mother–infant vs. father–infant groups). In addition to the intercept, fixed effects included: (a) lagged effects of self- and partner engagement behavior (self- and interactive contingency); (b) differences in engagement frequencies associated with mother–infant versus father-infant groups; (c) differences in self- and interactive contingency associated with groups. After removing nonsignificant terms, the final model was the simplest consistent with the data. In each model we included as control variables (at the person-level): infant medical status (PERI), infant sex, twin status, mother depression and father depression, and mother age. Any covariate that did not contribute to the model was dropped; only mother age was significant and thus was retained in the model. Significance level was set at $p < .05$. All tests were two-tailed. With 40 dyads (20 mother–infant, 20 father–infant) and 180 s of behavior per individual, we were able to generate enough power to detect effects by greatly reducing the standard errors of estimates (Snijders & Bosker, 2012).

The equation of our model follows, using the example of predicting infant behavior:

$$I_{it} = b_i + \beta_0 MAge_i + \beta_1 MvF_i + \beta_2 I_{it-1} + \beta_3 P_{it-1} + \beta_4 P_{it-1} \times MvF_i + \epsilon_{it}$$

where I_{it} is infant's behavior at time t, b_i a random intercept, MvF_i is a binary indicator of mother (= o) or father (= 1), P_{it-1} represents either mother or father's behaviors (the same behavior) at time t_{-1} (one second prior), and $\epsilon_{it} \sim AR(1)$. Then, infant engagement difference with mother versus father from the

Table 4
Sum Durations (in Seconds) of Infants' Behaviors With Mothers and Fathers (180 s)

	I (N = 20) with mothers		I (N = 20) with fathers				
Behavioral configuration	*M*	*SD*	*M*	*SD*	*t(df)*	*p*	*d*
Infant engagement (7 + 6+5)	108.30	49.43	74.45	53.83	2.41 (19)	.026	.54
7. GazeOn+Smile	0.40	0.82	0.30	0.80			
6. GazeOn+NeutralFace	72.00	52.88	54.50	47.01			
5. GazeOnEnvironment	35.90	22.18	19.65	18.68			
Infant Disengagement (4 + 3+2)	63.70	45.60	104.40	54.61	−3.02 (19)	.007	.67
4. GazeOff+NeutralFace	24.45	26.31	31.80	26.57			
3. GazeOff+AvertedHead	9.00	23.09	7.40	15.49			
2. EyesClosed	30.25	31.73	65.20	63.81			
Infant NegativeExpression (1)	8.40	23.33	1.45	4.41	1.29 (19)	.214	—

equation becomes $\Delta(I, P) = \beta_1 + \beta_4 P$ where I and P are the variable of infant and parent's prior behavior code. Then, $|\Delta(I, P)|$ are ordered, and we focused on the highest 10 differences to seek behavioral details (the set of {I,P}) of the time-series models in the probability explications, described next.

Analysis of Predicted Values: Behavioral Details of Time-Series Models

Multilevel time-series analyses identify significant patterns of self- and interactive contingency, and group differences in levels of contingency between groups. However, these models cannot tell us where differences in specific behaviors lie. Further post hoc descriptive analyses are required to explicate specific behavioral predictors at L1 that contribute to any mother–infant versus father–infant group differences at t_0 identified as significant by the multilevel models. Consistent with prior literature, we used an analysis of predicted values to identify specific behavioral patterns that underlie significant group differences identified by the multilevel models (Beebe et al., 2018, 2020; Searle & Gruber, 2016).

Our analysis of predicted values is a post hoc illustration of the significant findings already documented in the time-series models; there is no additional significance testing. The structure of the predicted values analysis is as follows. It works with all dyads at all times. Based on the equation, it derives predicted engagement level values at t_0 for mother versus father (with infant), and infant with mother versus father $|\Delta(\text{I,P})|$, in relation to every possible combination of prior engagement levels in mother–infant versus father–infant dyads. We calculate predicted values at t_0, given that both parents are in the same prior engagement levels. The differences in predicted values between mother–infant and father–infant are then ranked from highest to lowest. We examine the 10 highest differences in an attempt to more precisely describe the behaviors which contribute to the contingency differences between mother–infant versus father–infant dyads. In past work (Beebe et al., 2020), the top 10 differences were sufficient to describe the pattern of findings. We interpret the probability explication values as tending toward low, middle, or high values, rather than interpreting specific concrete values of the engagement scale.

Power Analysis for Multilevel Time-Series Models

Snijders and Bosker (2012) formula for the calculation of power for multilevel models is $\frac{effect\,size}{standard\,error} \approx z_{1-\alpha} + z_{1-\beta}$, where $z_{1-\alpha}$, $z_{1-\beta}$ are z-scores associated with the cumulative probability values of Type I error (α) and power ($1-\beta$), with reasonably large degrees of freedom. Any effect sizes (beta) equal or greater than .075 in our findings will provide power of .80, $p = .05$, given that the estimated standard error of our estimate of interest is low, approximately .03; any effect size of .075 will provide power of .95, given that the standard error is low, approximately .023. Because we have many observation points (180 s), more accurate estimates of contingency (beta) are generated. Thus, we expect the standard error of the estimates to be low and accuracy to be high. To obtain differences between mothers versus fathers, we compare contingencies in 20 mother–infant versus 20 father–infant dyads, a total sample size of 40.

The data set and the study analysis code are available on request to first author.

Results

Comparing Engagement Levels in Mother–Infant Versus Father–Infant Dyads (Aim 1)

Comparisons of macrocategories of engagement levels of mother versus father, and infant with mother versus father, are seen in Tables 3 and 4, respectively, which present descriptive statistics and paired t-tests. Mothers spent a greater proportion of time in high engagement with their infants than fathers, particularly in the highest engagement configuration (GazeOn+ AffectionateTouch + AffectionateTalk+PositiveFacialAffect). In contrast, fathers spent a greater proportion of time in midrange engagement than mothers, particularly in the configuration of GazeOn+Affectionate Touch+NeutralFacialAffect, without vocalization. The preterm neonates, in turn, showed higher engagement, that is more alertness, with mothers than fathers. In particular, they spent more time gazing at mother's face than father's face, and more time gazing at the environment when interacting with mother versus father. In contrast, the proportion of time in which the preterm infants were disengaged, particularly with eyes closed, was greater with fathers than with mothers. We also evaluated father versus mother specific behaviors (e.g., AffectionateTalk, AffectionateTouch) that were combined in the engagement scales, to deepen our understanding of possible mother versus father differences in social stimulation. Mothers used AffectionateTalk and PositiveFacialAffect more than fathers (Supplemental Materials 2, Table S8).

Addressing the presence of four twin pairs, we reran the analyses including only one twin per family (16 mother–infant, 16 father–infant, $N = 32$ dyads).[2] The results remained the same (see Supplemental Materials 1, Tables S1, S2).

Self- and Interactive Contingencies in Mother–Infant and Father–Infant Dyads (Aim 2)

We evaluated differences in mother–infant versus father–infant self- and interactive contingency by multilevel time-series models, separately testing parents (with infants) and infants (with parents). We then derived individual estimates of contingency for mother versus father, and infant with mother versus father. We first consider self- and interactive contingency in parents, and then infants.

Mother Versus Father Differences in Contingency With Infant

Parent differences in contingency with infants are shown in Table 5. The beta (β) is a standardized index of degree of contingency. Parent self-contingency, $P \to P$, represents the prediction of parent behavior at t_0 from parent behavior at 1 s prior (t_{-1}). Parent self-contingency ($P \to P$), testing mother versus father (MvF), summarized as $P \to P \times$ MvF in the table, differed. In other words, the interaction between lagged parent engagement and parent identity (father vs. mother), predicting parent, was significant. Parent interactive contingency, $I \to P$, represents the prediction of parent behavior at t_0 from infant behavior at 1 s prior (t_{-1}). Parent

[2] We dropped the twin with more time eyes closed and retained the twin with more time visually attending.

Table 5
Parent Difference Model: Testing Mother Versus Father (MvF) Differences in Contingency With Infant

Effect	Infant (I) → Parent (P) B	*SE* β	*P*
M Age	−.019	.012	.121
MvF	−.255	.028	<.001
P → P	1.170	.022	<.001
I → P	−.033	.023	.147
P → P × MvF	−.069	.030	.023
I → P × MvF	.116	.031	<.001

Note. → = direction of prediction: predicted variable is to the right of the arrow, predicting variable is to the left of the arrow; P → P = predicting parent behavior at t_0 from parent behavior at Lag1 (L1, 1s prior), across both parents; I → P = predicting parent behavior at t_0 from infant behavior at L1 (parent response to infant behavior), across both parents; P → P × MvF tests the difference in mother versus father self-contingency; I → P × MvF tests the difference in mother versus father interactive contingency. Models included time and intercept. β values are represented as standardized effect sizes. Mother is dummy-coded as 0, father as 1.

interactive contingency (I → P), testing mother versus father (MvF), summarized as I → P × MvF, in the table, differed. In other words, the interaction between lagged infant engagement and parent identity (father vs. mother), predicting parent, was significant.

Individual estimates of parent contingency were derived from the parent difference model and are presented in Table 6. Both mother and father self-contingency were significant, but mother self-contingency (M → M) was higher than that of father (F → F). Father interactive contingency (I → F) was significant, but mother interactive contingency (I → M) was not.

Analysis of predicted values was used to clarify the details of these results, presented in Table 7. We examined the top 10 combinations of parent and infant behaviors at L1 (Lag 1, 1 s prior) which resulted in the greatest absolute differences in mother versus father engagement at t_0, the current moment. Considering parent self-contingency, mother and father are both primarily at the high end (Configurations 6–8) of the Parent Engagement Scale at L1 (1 s prior). Given a high parent engagement level at L1, at t_0 mothers are likely to be higher than fathers. Thus, mothers are more likely to sustain high engagement levels, generating a higher, more stable self-contingency at higher engagement levels. Fathers are more likely to come down somewhat from high engagement levels, generating a lower, more variable self-contingency.

Considering parent interactive contingency (infant behavior predicting parent behavior), in the top 10 values of L1, the infant is primarily at the lower end (Configurations 1–3) of the Infant Engagement Scale, while parents are at the higher end of the scale at L1 (largely Configurations 5–7). Given infant behavior at lower engagement levels at L1 (1 s prior), at t_0 mothers are likely to be higher than fathers. Thus, as they respond, fathers are likely to stay somewhat closer to infant engagement levels, which generates a higher interactive contingency for fathers. If, however, infants have a higher engagement at L1, seen in the sixth and 10th top values (engagement Configuration 7), then fathers again are likely to match the infant more than mothers, that is, fathers also go higher with the infant than mothers.

We note that the only significant covariate in the time-series models was mother age. As mother is older (vs. younger), infant engagement is lower and mother engagement is also lower.

Table 6
Individual Estimates of Parent Contingency Derived From the Parent Difference Model

Effect	Infant (I) → Parent (P) B	*SE* β	*P*
M Age	−.019	.012	.121
MvF/ M	6.960	.438	<.001
MvF/ F	7.215	.438	<.001
M → M	1.170	.022	<.001
F → F	1.101	.022	<.001
I → M	−.033	.023	.147
I → F	.083	.023	.003

Note. M → M = predicting mother behavior at t_0 from mother behavior at Lag1, 1 s prior (mother self-contingency); F → F = predicting father behavior at t_0 from father behavior at Lag1 (father self-contingency); I → M = predicting mother behavior at t_0 from infant behavior at Lag1 (mother contingent response to infant behavior); I → F = predicting father behavior at t_0 from infant behavior at Lag1 (father contingent response to infant behavior).

Table 7
Probability Explication: Predicting Parent Engagement at t_0 From Parent Engagement and Infant Engagement at 1 s Prior (L1)

Parent L1	Infant L1	Predicted value of parent engagement t_0: Mother	Father	Absolute Diff
8	1	9.32,376	8.63,334	0.69,042
7	1	8.15,416	7.53,263	0.62,153
8	2	9.29,072	8.71,600	0.57,472
6	1	6.98,456	6.43,192	0.55,264
7	2	8.12,112	7.61,529	0.50,583
1	7	0.93,832	1.42,433	0.48,601
5	1	5.81,496	5.33,121	0.48,375
8	3	9.25,768	8.79,866	0.45,902
6	2	6.95,152	6.51,458	0.43,694
2	7	2.10,792	2.52,504	0.41,712

Note. Predicted values of the level of parent (P) engagement with infant at t_0 were generated by the time-series model and are ranked from highest to lowest absolute difference (Absolute Diff). values of parent engagement range from 1 (*lowest engagement*) to 8 (*highest*). This table includes the exemplars of the 10 combinations of parent and infant behaviors at L1 which resulted in the greatest absolute differences in mother versus father engagement at t_0. There were significant differences between parents at t_0 when predicting both from parent at L1, generating a parent self-contingency difference, and from infant at L1, generating a parent interactive contingency difference (see Tables 5 and 6). Considering *parent self-contingency*, given parent engagement tending toward the higher end of the scale (Configurations 5–8) at L1, the level of parent engagement at t_0 was higher in mothers than fathers, generating higher self-contingency in mothers: a greater likelihood of remaining at the higher end of the scale. Considering *parent interactive contingency*, given infant engagement tending toward the low end of the scale (Configurations 1–3) at L1, while parents are at the higher end of the scale at L1 (largely Configurations 5–7), mothers at t_0 are likely to be in a higher engagement level than fathers, generating significant interactive contingency for fathers only, who were more likely to be in engagement values closer to those of the infant.

Infant Differences in Contingency With Mother Versus Father

Infant differences in contingency with mother versus father (MvF) are shown in Tables 8 and 9. Infant self-contingency with mother versus father (I → I × MvF) differed. Infant interactive contingency with mother versus father (P → I × MvF) was not significantly different (p = .102).

Individual estimates of infant contingency were generated from the infant difference model and are presented in Table 9. Infant self-contingency was significant with both parents but was higher with father (I → I/F) than mother (I → I/M). Despite the fact that infant interactive contingency with mother versus father did not formally differ (p = .10) in the infant difference model (Table 8), we argue that this is an acceptable threshold for interpretation, especially considering the fact that once we derive the individual beta estimates, they show that the M → I estimate is clearly significant (p = .009), whereas F → I is not (p = .723).

Analysis of predicted values was used to clarify the details of these results, as seen in Table 10.

We examine the top 10 combinations of parent and infant behaviors at L1 which resulted in the greatest absolute differences in infant engagement at t_0 with mother versus father. Considering infant self-contingency, given infant engagement tending toward the lowest values (engagement Levels 1 and 2) at L1, the level of infant engagement at t_0 was higher with mother than father (mean of the top 10 infant engagement values with mother at t_0 = 3.268; with father at t_0 = 2.586), generating lower (more variable) infant self-contingency with mother.

Considering infant interactive contingency, given parent engagement tending toward values largely in the top half of the scale (5–8) at L1, while infants are still at the low end of the scale at L1, at t_0 infants are likely to be in a higher engagement level with mother than father. Thus, infants are more likely to follow mothers up into higher engagement levels.

Addressing the power of these analyses, in general, we had 98% power to identify significant findings, thanks to the low standard errors in our data, around .02. For example, in Table 5, considering the difference model for parent interactive contingency, the beta is .116, and the SE is .031, generating power of .98. In Table 6, considering father interactive contingency, the beta is .083 and the SE is .023, generating power of .98.

Table 8
Infant Difference Model: Testing Infant Differences in Contingency With Mother Versus Father (MvF)

Parent (P) → Infant (I)			
Effect	β	*Se*β	*P*
M age	−.021	.007	.009
MvF	−.548	.020	<.001
I → I	1.277	.017	<.001
P → I	.042	.016	.009
I → I × MvF	.086	.023	.001
P → I × MvF	−.036	.022	.102[a]

Note. See Note Table 5.
[a] Despite (P → I × MvF) not being significantly different (p = .102), p = .10 is considered an acceptable threshold for interpretation (see text).

Table 9
Individual Estimates of Infant Contingency Derived From the Infant Difference Model

Parent (P) → Infant (I)			
Effect	B	*Se*β	*p*
M Age	−.021	.007	.009
MvF/M	5.302	.272	<.001
MvF/F	4.754	.272	<.001
I → I/ M1.362.017< .001	1.277	.017	<.001
I → I/ F	1.362	.017	<.001
M → I	.042	.016	.009
F → I	.006	.016	.723

Note. I → I/M = predicting infant behavior with mother at t_0 from infant behavior at Lag1, 1 s prior (infant self-contingency during mother-infant interaction); I → I/F = predicting infant behavior with father at t_0 from infant behavior at Lag1 (infant self-contingency during father-infant interaction); M → I = predicting infant behavior at t_0 from mother behavior at L1 (infant contingent response to mother behavior); F → I = predicting infant behavior at t_0 from father behavior at L1 (infant contingent response to father behavior).

Addressing the presence of four twin pairs in the models (N = 40 dyads), we reran the time-series models including only one twin per family (N = 32 dyads). The results remained largely the same (see Supplemental Materials 1, Tables S4, S5, S6, S7).

Discussion

We investigated whether preterm infants at age 35 weeks showed interactive contingency with their mothers and fathers during face-to-face interaction while in the NICU, and whether this interactive contingency might differ with mothers versus fathers. We also investigated whether mothers versus fathers differed in their interactive contingency with infants. Mothers and infants participated together in higher social engagement levels, and infants showed interactive contingency with mothers. However, mothers did not show interactive contingency with infants. Fathers showed interactive contingency with infants, but infants did not show interactive contingency with fathers. We discuss (a) the higher engagement levels in mothers and infants (vs. fathers and infants); (b) the presence of father, but not mother, interactive contingency with infants; (c) the presence of infant interactive contingency with mothers, but not fathers; (d) the implications for theories of development of the presence of preterm infant capacity for interactive contingency from birth; and (e) the implications of our findings for the roles of the father versus mother in early intervention in the NICU.

Preterm Infants and Mothers Showed Higher Engagement Levels Than Preterm Infants and Fathers

Both parents spent large proportions of time in the highest levels of engagement. However, mothers showed higher levels of engagement than fathers, as expected. The multiple co-occurring channels of affectionate social stimulation included in our measure of social engagement (gaze on, affectionate touch, affectionate talk, positive face) have previously been shown to be arousing and effective in increasing the likelihood of the preterm infant's engagement (Stefana et al., 2020). Likewise, as expected, infants

Table 10
Probability Explication: Predicting Infant Engagement at t_0 From Infant Engagement and Parent Engagement at 1 s Prior (L1)

Infant L1	Parent L1	Predicted value of infant engagement t_0 with mother	with father	Absolute diff
1	8	2.93,436	2.19,139	0.74,297
1	7	2.91,075	2.18,800	0.72,275
1	6	2.88,714	2.18,460	0.70,253
2	8	3.68,630	2.99,369	0.69,261
1	5	2.86,353	2.18,121	0.68,231
2	7	3.66,268	2.99,030	0.67,239
1	4	2.83,992	2.17,782	0.66,210
2	6	3.63,907	2.98,691	0.65,217
3	8	4.43,823	3.79,600	0.64,224
1	3	2.81,630	2.17,443	0.64,188

Note. Predicted values of the level of infant (I) engagement at t_0 with mother versus with father were generated by the time-series model and are ranked from highest to lowest absolute difference (Absolute Diff). Values of infant engagement range from 1 (*lowest engagement*) to 7 (*highest*). This table includes the exemplars of the 10 combinations of infant and parent behaviors at L1 which result in the greatest absolute differences in infant engagement with mother versus father at t_0. There were significant differences between infants with mothers versus fathers at t_0 when predicting both from infant at L1, generating a self-contingency difference, and from parent at L1, generating an interactive contingency difference (see Tables 8 and 9). Considering *infant self-contingency*, given infant engagement tending toward the lowest values (engagement Levels 1–2) at L1, the level of infant engagement at t_0 was higher with mother than father, generating lower (more variable) self-contingency with mother. Considering *infant interactive contingency,* given parent engagement tending toward higher engagement values largely in the top half of the scale (5–8) at L1, while infants are still at the low end of the scale, at t_0 infants are likely to be in a higher engagement level with mothers than fathers. Thus, infants are more likely to follow mothers into higher engagement levels, generating significant infant interactive contingency with mothers, but not fathers.

spent more time in higher engagement behaviors, such as gazing at the environment and at the parent's face with neutral facial affect, with mothers than fathers. This result is consistent with the literature showing preterm infants increased alert state and attending behavior when exposed to maternal voice (Bozzette, 2008; Filippa et al., 2013; Keller et al., 2008). In contrast, fathers (vs. mothers) spent a greater proportion of time in midrange engagement characterized by affectionate touch, but without talking, characterized as a less demanding interactive style; and infants reciprocally spent more time in lower engagement levels with fathers (vs. mothers), disengaged, or with eyes closed.

Although both parents were depressed, mothers were more depressed than fathers. Several of them felt responsible for the infant's preterm birth (Stefana et al., 2021). Moreover, mothers experienced the trauma of the preterm birth in their own bodies, and were subjected to a sudden separation from their infants. The early prolonged separation challenges postnatal mother–infant bonding (Flacking et al., 2012). These factors might contribute to a more urgent need in the mother (than the father) to be reassured by experiencing the infant as okay, as alive and alert, as responsive. The mothers might naturally want to bring the infant up to higher engagement levels. This result is consistent with other studies, such as Beebe et al. (2008), where the depressed mothers were more coordinated with infant facial and vocal affect; and Stefana et al. (2018), where the more depressed fathers had more affiliative behavior, and thus were more affectionately stimulating. Interestingly, the infant cooperates, rising up to higher engagement levels with mothers than fathers. However, older (vs. younger) mothers, as well as their infants, had lower engagement levels (identified because mother age was a significant covariate in the time-series models). We suggest that older (vs. younger) mothers may have a less demanding, more patient interactive style (Trillingsgaard & Sommer, 2018). They may feel a less urgent need to bring the infant up to higher engagement levels.

Mothers' (vs. fathers') higher engagement levels may also have to do with mothers' greater familiarity with the infants in the immediate postpartum period; they spent more time in the NICU close to the infant. Mothers were themselves hospitalized and did not have to return to work in this period. They might therefore have felt closer to their infants and they might have felt more natural talking to them than fathers. For their part, fathers did not experience the trauma of the preterm birth in their own bodies. Fathers were less physically close to the preterm infant in the immediate postpartum period. These factors might contribute to the possibility of a greater "psychological distance" in fathers, which allowed them to feel less emotionally pressured to "make it work," and allowed them to use more midrange engagement behaviors when interacting with their infants. These midrange engagement behaviors are less active, less arousing, and also less "demanding" of infant engagement.

Fathers, but Not Mothers, Showed Interactive Contingency With Preterm Infants

Partially confirming our hypothesis, the interactive contingency analyses via time-series models documented that fathers showed interactive contingency: They contingently coordinated their social engagement with infants. But partially disconfirming our hypothesis, mothers did not show interactive contingency. We suggest that the differences in mothers' versus fathers' engagement behaviors noted above affected these results.

Parent interactive contingency measures adjustments that the parent makes in response to the infant's prior behavior. When infants were in lower engagement levels in the prior second, fathers responded by staying in lower engagement levels in the current second, closer to infants, than mothers. This pattern can be dubbed joining the dampened state (Beebe et al., 2010; Cohen & Beebe, 2002). This paternal likelihood of staying closer to the infants' lower engagement levels generated a significant coordination in the fathers, which took place mainly in the middle to lower levels of the engagement scale.

In contrast, when infants were in lower engagement levels in the prior second, mothers responded with higher engagement levels than fathers in the current second, as if mothers were trying to arouse the infant or take the infant up into higher engagement. This pattern did not generate significant interactive contingency in the mothers.

Preterm Infants Showed Interactive Contingency With Mothers, Not Fathers

Infant interactive contingency measures adjustments that the infant makes in response to the parent's prior behavior. Partially confirming our hypothesis, infants showed interactive contingency with mothers. Partially disconfirming our hypothesis, infants did not show interactive contingency with fathers. This finding differs from our prior work (Stefana et al., 2020), which documented significant infant transitional probabilities with fathers, with a different statistical approach.

When parents were in more positive engagement levels, while infants were still in lower engagement levels, infants were then more likely to be in higher engagement levels with mothers than fathers. Thus, infants were more likely to follow mothers up into higher engagement levels.

Why Did Preterm Infants Show Interactive Contingency With Mothers (Not Fathers)? Why Did Fathers (Not Mothers) Show Interactive Contingency With Infants?

Mothers showed higher engagement behaviors than fathers, and particularly more affectionate talk and more positive facial expressions (see Supplemental Materials 2, Table S8). This higher, more positive level of social stimulation seems to have facilitated infant interactive contingency. In addition, the infants were likely more familiar with mothers, both from prenatal experience of voice (Moon, 2017), and greater postnatal experience. We suggest that the infant's familiarity with maternal voice is especially important. When exposed to maternal voices, preterm infants increase quiet alert state and attending behaviors (Bozzette, 2008; Filippa et al., 2013; Keller et al., 2008; Saliba et al., 2020). Moreover, vision is still unfocused in the early weeks of life (Candy, 2019).

Fathers stimulated the infants less than mothers, a less "demanding" style. We suggest that this style contributed to the father's significant interactive contingency with the infant. In this style fathers were able to join the infant's dampened state, rather than trying to shift the infant into a more positive state, a key parental capacity (Beebe et al., 2010). Moreover, fathers (compared with mothers) were less depressed, likely had somewhat more psychological "distance," and likely had a lesser need to demonstrate that the infant could respond.

Self-Contingency

As expected, all partners demonstrated significant self-contingency of engagement. Thus, preterm, medically stabilized infants, as well as their parents, were likely able to use this self-predictability to generate procedural expectancies of where one's behavior is tending in the next moment, contributing to a sense of temporal coherence. Whereas mothers maintained higher engagement levels over the course of the interaction, fathers were more variable. Fathers' greater variability in self-contingency may have contributed to their ability to contingently interact with the infant, able to move around to find the infant; and vice-versa, fathers' ability to contingently interact with their infants may have contributed to their greater variability.

Preterm infants were likely to remain in lower engagement levels with fathers, generating higher, more stable self-contingency; but they varied among lower and higher engagement levels with mothers, generating a more variable self-contingency process. Infant greater variability with mother may have contributed to infant ability to contingently interact with the mother; and vice-versa, the infant's ability to contingently interact with mother may have contributed to greater infant variability. This association between self- and interactive contingency is consistent with findings that demonstrate that self- and interactive contingency in the mother–infant dyadic system have a homeostatic feature: the lower the self-contingency, the higher the interactive contingency; and vice-versa (see Beebe et al., 2016).

Preterm Infant Capacity for Interactive Contingency From Birth: Implications for Theories of Development

Because very preterm infants contingently coordinated their behaviors with those of their mothers, we conclude that preterm infants, shortly after birth, are capable of interactive contingency. Our results constitute an "existence proof." That is, although we do not have a large sample, and we have not replicated our results in another sample, the fact that this group of premature infants showed significant interactive contingency is proof that this capacity can exist in premature infants. However, infant capacity for interpersonal coordination may be more vulnerable, requiring more specific conditions. In our study, the more affectionate talk, touch, and positive facial affect of mothers generated the facilitating conditions for infant interactive contingency.

The implication for theories of development is that infant capacity for interactive contingency is available from birth and prematurity does not knock it out. This finding expands to preterm infants the findings of other researchers such as Kato et al. (1983), Dominguez et al. (2016), and Peery (1980), who have shown that this interpersonal coordination exists at birth in term infants.

The Role of the Parents in Early Intervention in the NICU

Currently, many interventions are more focused on facilitating mother–infant emotional connection in the NICU (see e.g., Welch et al., 2012), although infant- and family-centered-developmental-care (IFCDC) interventions (Roué et al., 2017) have begun to involve both parents in infant care in the NICU. Our findings offer support for the cultural transition to family-centered care in the NICU and suggest that both parents can support preterm infants, but in different ways.

Fathers could be encouraged to be more involved in infant care, especially using their ability to join the infant's dampened state. The ability to join the infant where she is, rather than trying to shift her, is key to parental social capacity. For example, Beebe et al. (2010) documented that maternal inability to empathically join infants when distressed (and instead showing surprise, smiles, or overly stabilized facial "stone-walling" of infants) predicted disorganized attachment.

Mothers' ability to nurture the infant's capacity for interactive contingency, using affectionate voice and touch, can be supported and encouraged. Mothers could also monitor any tendency to need the infant to be "up" and positive. This may interfere with her ability to join the infant where she is, and thus contingently interact with the infant. Moreover, mothers and fathers could learn from each other: Mothers could learn to join the infant's dampened states, and fathers could learn to be more positively engaged and particularly vocally engaging.

Limitations

This study is limited by the small sample size and by the great difficulty recruiting this type of sample, which necessitated including a number of twins. However, an analysis excluding one twin of each pair gave the same result. The small sample size is counterbalanced by the multilevel time-series models where statistical power is enhanced by the large number of observations (seconds), which improve the accuracy of estimates by increasing the degrees of freedom and reducing the standard error of the estimates of interest. Moreover, the detailed microanalysis of behavior adds a rare specificity to the findings. Nevertheless, replication with a larger sample is needed.

Conclusion

This study makes a unique contribution to the scant literature on parent-preterm-infant co-regulated processes in the neonatal period in the NICU. It is the first study to evaluate the presence of bidirectional interactive contingency during spontaneous face-to-face communication in this period, by assessing the second-by-second self- and interactive dynamics with multilevel time-series methods, and the first to compare these processes in mother–infant versus father–infant dyads. We documented that 35-week-old preterm infants, lying on a heated cot in the NICU, contingently coordinated their social engagement behaviors with those of their mothers (but not their fathers). Fathers (but not mothers) also contingently coordinated with infants. Fathers' ability to join their infants' dampened state likely facilitated the fathers' interactive contingency.

This study provides new knowledge. From a theoretical perspective, it is the first evidence that the capacity for interpersonal coordination is present in the neonatal period in preterm infants. From a clinical perspective, our study suggests that mothers and fathers have different skills, and each could learn from the other. Fathers could be encouraged to play with their infants in the NICU more actively, with higher engagement levels. Mothers could be coached to join the dampened state of the preterm infant to facilitate their interactive contingency with their infants.

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