Developmental Psychology

Family Nurture Intervention for Preterm Infants Facilitates Positive Mother–Infant Face-to-Face Engagement at 4 Months

Beatrice Beebe, Michael M. Myers, Sang Han Lee, Adrianne Lange, Julie Ewing, Nataliya Rubinchik, Howard Andrews, Judy Austin, Amie Hane, Amy E. Margolis, Myron Hofer, Robert J. Ludwig, and Martha G. Welch

Online First Publication, October 4, 2018. http://dx.doi.org/10.1037/dev0000557

American Psychological Association

Developmental Psychology

0012-1649/18/$12.00

http://dx.doi.org/10.1037/dev0000557

Family Nurture Intervention for Preterm Infants Facilitates Positive Mother–Infant Face-to-Face Engagement at 4 Months

Beatrice Beebe
New York State Psychiatric Institute

Michael M. Myers
Columbia University Medical Center

Sang Han Lee
The Nathan S. Kline Institute for Psychiatric Research, Orangeburg, New York, and New York University School of Medicine

Adrianne Lange, Julie Ewing, and Nataliya Rubinchik
New York State Psychiatric Institute

Howard Andrews and Judy Austin
Columbia University Medical Center

Amie Hane
Columbia University Medical Center and Williams College

Amy E. Margolis, Myron Hofer, Robert J. Ludwig, and Martha G. Welch
Columbia University Medical Center

Although preterm infants are at risk for social deficits, interventions to improve mother–infant interaction in the neonatal intensive care unit (NICU) are not part of standard care (SC). Study participants were a subset from a randomized controlled trial of a new intervention for premature infants, the Family Nurture Intervention (FNI), designed to help mothers and infants establish an emotional connection. At infants' 4 months corrected age, mother–infant face-to-face interaction was filmed and coded on a 1-s time base for mother touch, infant vocal affect, mother gaze, and infant gaze. Time-series models assessed self- and interactive contingency. Comparing FNI to SC dyads, FNI mothers showed more touch and calmer touch patterns, and FNI infants showed more angry-protest but less cry. In maternal touch self-contingency, FNI mothers were more likely to sustain positive touch and to repair moments of negative touch by transitioning to positive touch. In maternal touch interactive contingency, when infants looked at mothers, FNI mothers were likely to respond with more positive touch. In infant vocal affect self-contingency, FNI infants were more likely to sustain positive vocal affect and to transition from negative to positive vocal affect. In maternal gaze interactive contingency, following infants' looking at mother, FNI mothers of male infants were more likely to look at their sons. In maternal gaze self-contingency, following mothers' looking away, FNI mothers of male infants were more likely to look at their sons. Documentation of positive effects of the FNI for 4-month mother–infant face-to-face communication is useful clinically and has important implications for an improved developmental trajectory of these infants.

Keywords: prematurity, NICU Family Nurture Intervention, mother–infant communication, self- and interactive contingency

Supplemental materials: http://dx.doi.org/10.1037/dev0000557.supp

Beatrice Beebe, Department of Psychiatry, New York State Psychiatric Institute; Michael M. Myers, Department of Psychiatry, New York State Psychiatric Institute, Columbia University Medical Center; Sang Han Lee, The Nathan S. Kline Institute for Psychiatric Research, Orangeburg, New York, and Department of Child and Adolescent Psychiatry, New York University School of Medicine; Adrianne Lange, Julie Ewing, and Nataliya Rubinchik, Department of Psychiatry, New York State Psychiatric Institute; Howard Andrews, Department of Psychiatry, New York State Psychiatric Institute, Columbia University Medical Center; Judy Austin, Heilbrunn Department of Population and Family Health, Columbia University Medical Center; Amie Hane, Department of Pediatrics, Columbia University Medical Center, and Department of Psychology, Williams College; Amy E. Margolis, Department of Psychiatry, New York State Psychiatric Institute, Columbia University Medical Center; Myron Hofer, Department of Psychiatry, Columbia University Medical Center; Robert J. Ludwig, Department of Pediatrics, Columbia University Medical Center; Martha G. Welch, Department of Psychiatry, and Department of Pediatrics, Columbia University Medical Center.

This work was funded through grants from the Bernard and Esther Besner Infant Research Fund (Beatrice Beebe), the Einhorn Family Charitable Trust, the Fleur Fairman Family, the Mary Stephenson Fund, and the Irving Institute for Clinical and Translational research (Michael M. Myers, Amie Hane, Judy Austin, Robert J. Ludwig, Martha G. Welch), as well as National Institute of Environmental Health Sciences Grant K23ES026239 (Amy E. Margolis). The content is solely the responsibility of the authors and does not necessarily reflect the official views of the National Institute of Environmental Health Sciences. We thank the research assistants who contributed to this work, especially Nidhi Parashar, Zach Neumann, Daisy Bear, Daniel Vigliano, Maeva Schlienger, Daniella Polyak, Greer Raggio, Jessica Latack, Meghan Loeser, Mina Dailami, Elliana Sherwin, Nur Emanet, Emily Hersch, Danruo Zhong, Molly Rappaport, Kristen Kim, Natalie Buchinsky, Sarah Pinson, Julia Reuben, Brianna Hailey, Anielle Fredman, and Kaitlin Walsh.

Correspondence concerning this article should be addressed to Beatrice Beebe, Department of Psychiatry, New York State Psychiatric Institute #108, 1051 Riverside Drive, New York, NY 10032. E-mail: beatrice.beebe@nyspi.columbia.edu

Preterm infants are at increased risk for adverse neurodevelopmental outcomes in infancy, childhood, and adolescence (Feldman, Rosenthal, & Eidelman, 2014; Johnson et al., 2012). Early maternal deprivation is associated with multiple deficits later in life in animals and humans (Haller, Harold, Sandi, & Neumann, 2014). The Family Nurture Intervention (FNI) was designed to overcome negative effects of maternal deprivation in the neonatal intensive care unit (NICU) by fostering mother–infant emotional connection (Welch, 2016b; Welch et al., 2012, 2013). This study tests the hypothesis that by 4 months (corrected age [CA]), the FNI improves multiple aspects of mother–infant social engagement associated with emotional connection.

Maternal postpartum nurturing is critical for mother–infant social development but is compromised following preterm birth due to prolonged maternal separation that occurs in the NICU, disrupting mother–infant emotional connection (Flacking et al., 2012; Welch & Myers, 2016). Maternal nurturing provides the context for the infant's repertoire of social contingencies. Mother–infant interaction is characterized by second-by-second shifts of gaze, affect, vocalization, and touch that require contingent coordination by both partners. Mothers and infants reciprocally coordinate communication behaviors from infants' birth (Lavelli & Fogel, 2005). Early patterns of mother–infant coordination establish the foundation for infant development in socioemotional, cognitive, and regulatory domains (Beebe et al., 2010; Feldman, 2007a, 2007b, 2007c; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Tronick, 1989).

Physical separation of mother and infant in the NICU impairs the early mutual physiological−emotional connection necessary for optimal coregulated social contingencies (Feldman, Weller, Sirota, & Eidelman, 2002; Welch, 2016b). With underdeveloped neurobehavioral systems, premature (vs. full-term) infants can be difficult to read and less socially responsive (Feldman & Eidelman, 2007; Malatesta, Culver, Tesman, & Shepard, 1989). Mothers of premature (vs. full-term) infants look at, talk to, and touch their infants less frequently (Davis & Thoman, 1988) and are less able to coregulate cycles of attention and affect with their infants (Lester, Hoffman, & Brazelton, 1985). Recent studies have also shown deficits in preterm infant−mother dyads during face-to-face and still-face paradigms (Feldman & Eidelman, 2007; Jean & Stack, 2012; Montirosso, Borgatti, Trojan, Zanini, & Tronick, 2010). These difficulties predict suboptimal infant biosocial outcomes (Feldman & Eidelman, 2006; van Baar, van Wassenaer, Briët, Dekker, & Kok, 2005). Specifically, these dyads are at risk for dysregulated self- and interactive processes during social interaction, the focus of our study.

Despite a number of promising NICU interventions, there is no consensus on which interventions are of greatest benefit (Symington & Pinelli, 2006). NICU intervention studies often lack randomization and blind assessments (Hussey-Gardner & Famuyide, 2009), and many interventions commence after the period of isolette confinement, depriving the infant of critical maternal involvement during the first weeks of life.

Family Nurture Intervention

Here we assess whether the Family Nurture Intervention (FNI) in the NICU improves mother–infant face-to-face communication at 4 months CA. FNI facilitates emotional connection and autonomic coregulation between mother and infant, starting with isolette confinement and continuing throughout the NICU stay (Welch et al., 2012). The FNI is not didactic but rather involves direct participation in nurturing activities facilitated by a nurture specialist, with several new constructs (Welch, 2016a):

1. The FNI aims to create *emotional connection* and *autonomic coregulation* between mother and infant through *calming sessions,* which include scent cloth exchange, skin-to-skin care, holding, comfort touch, eye contact, vocal soothing, and listening;
2. The FNI aims to utilize autonomic conditioning via repeated calming sessions to counter adverse NICU experiences and strengthen attraction between mother and infant; and
3. Mother and infant are equal agents of the FNI.

Previous analyses showed that FNI (vs. standard care [SC]) mothers exhibited increased maternal sensitivity during caregiving behavior in the NICU (Hane et al., 2015) and fewer anxiety and depressive symptoms when infants were 4 months CA; by 18 months, FNI (vs. SC) infants had improved cognitive and language scores (Bayley, 2006), fewer attention problems (Achenbach, 1999), and decreased risk for autism spectrum disorders (Welch et al., 2015). Because these improved outcomes were independent of specific components of amount of holding and skin-to-skin care, emotional connection may be an aggregate construct that is greater than the sum of the component parts.

The foundation of the FNI was first developed to overcome negative consequences of separations such as those that occur with preterm birth or maternal depression (Welch, 1988). Although the subcomponents of the FNI—olfaction, touch, calming, and vocal expression—are analogous to Feldman's (2012) regulatory framework and Hofer's hidden regulator subprocesses (Hofer, 1994), Welch argued that Pavlovian autonomic coconditioning governs these hidden regulators (Welch, 2016a). Hidden regulators are coconditioned in the viscera−autonomic nervous systems of fetus and mother during gestation. With normal birth, the coconditioning triggers attraction behaviors and physiological calming, facilitating emotional connection and visceral−autonomic coregulation. With preterm birth (or other adverse events), coconditioning can be interrupted. Repeated calming sessions restore emotional connection and physiological coregulation. We hypothesized that the FNI paved the way for the dyad to achieve more optimal patterns of self- and interactive contingency at the 4-month CA follow-up.

Mother–Infant Communication

A dyadic systems view of face-to-face communication, in which both partners contribute to the face-to-face exchange through a bidirectional coregulation, informed the study. Because each person regulates ongoing behavior and at the same time coordinates with the partner, all dyadic interactions simultaneously reflect self- and interactive processes (Beebe et al., 2016; Gianino & Tronick, 1988). Fogel (1993) described all behavior as unfolding in the individual, while at the same time modifying and being modified by the changing behavior of the partner. Both self- and interactive processes are essential to face-to-face communication. Both intrapersonal and interpersonal behavioral rhythms provide ongoing temporal information necessary to coordinate with one's partner, so that each can anticipate how the other will proceed (Beebe et al., 2010; Feldman, 2016).

In this and past studies we quantified self- and interactive processes by coding behavior second-by-second and generating measures of *contingency,* a term we use interchangeably with *predictability* and *coordination*. Contingencies are quantified using time-series methods. *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 prior behavior predicts current behavior: the degree of stability−variability within an individual's own rhythms of behavior (in the presence of a particular partner; Beebe et al., 2016; Messinger, Ekas, Ruvolo, & Fogel, 2012). Prior research on full term samples found that both heightened and lowered degrees of mother and infant contingency may be associated with maternal distress and infant insecure attachment (Beebe et al., 2007, 2008, 2010; Jaffe et al., 2001; Malatesta et al., 1989).

Approach

Mothers and premature infants participated in a randomized controlled trial of the FNI. We aimed to specify the self- and interactive contingency patterns of these infants and mothers during videotaped mother–infant face-to-face communication at 4 months CA.

We chose to study 4 months because it is the age at which infant social capacities flower (Beebe et al., 2016; Tronick, 1989). We chose to assess mother–infant face-to-face communication because it provides critical inputs for maturation of the social brain and sensitizes infants to temporal and emotional resonances that underlie human relationships (Feldman, 2007b, 2015; Jaffe et al., 2001). By 4 months, face-to-face communication taps the infant's most advanced social capacities (Tronick, 1989).

Videotaped interactions were coded for mother gaze (MG) and infant gaze (IG), mother touch (MT), infant vocal affect (IVA), and maternal touch. Mother and infant gaze patterns generate greater−lesser likelihood of mutual gaze, the foundation of face-to-face engagement (Stern, 1985). Attention to, and contingent coordination with, the partner's direction of gaze at and away from one's own face provide a foundation for coordination in other modalities and are compromised with infant prematurity (Feldman, Weller, et al., 2002). Lower maternal gaze coordination with infant gaze is associated with higher maternal self-criticism and maternal depression (Beebe et al., 2007, 2008). Less predictable maternal gaze patterns predict infant insecure (vs. secure) attachment (Beebe et al., 2010).

Maternal touch may be the most basic mammalian maternal behavior (Feldman, 2012). Less affectionate and more intrusive maternal touch is associated with infant prematurity (Feldman & Eidelman, 2003, 2007) and maternal depression (Beebe et al., 2008). Lower maternal coordination of touch with infant touch patterns is associated with maternal depression (Beebe et al., 2008) and disorganized attachment (Beebe et al., 2010). Mothers of premature infants who participate in kangaroo care provide more affectionate touch (Feldman, Eidelman, et al., 2002; Feldman, Weller, et al., 2002).

Infant vocal affect measures positive to distressed affect. Infant vocal distress predicts social−cognitive risk (NICHD Network, 2004) and disorganized infant attachment (Beebe et al., 2010). Positive infant vocalization is associated with greater maternal attunement (Markova & Legerstee, 2006).

The specificity of the behavioral coding approach and data-analytic strategy allowed evaluation of the following dimensions of the 4-month interaction, which may be influenced by the FNI: (a) partner (mother−infant), (b) type of measure (behavioral frequency−contingency), (c) type of contingency (self−interactive), and (d) modality of behavior (attention, affect, touch).

We hypothesized that the FNI would optimize mother–infant social development assessed at 4 months (CA). Because prior studies have shown lower social coordination in premature infant−mother dyads, we predicted that the FNI would increase maternal and infant coordination with the partner's behavior as evidenced by increased interactive contingency. Lacking sufficient prior literature, we made no specific hypotheses regarding self-contingency.

Method

FNI Trial Design and Intervention

Participants were enrolled in a single-center, parallel group, randomized controlled trial. The study design is published (Welch et al., 2012, 2013) and was registered (ClinicalTrials.gov: NCT01439269). We excluded mothers who did not speak English or had a history of drug addiction or mental illness, as well as infants with birth weight below the third percentile for gestational age or significant congenital defect. A total of 115 mothers and 150 infants (35 sets of twins, 80 singletons, delivered 26–34 weeks gestation) were enrolled.

As soon after delivery as possible, mothers provided consent, completed baseline assessments, and were randomly assigned to standard care (SC) or the FNI. A research assistant drew a sealed envelope containing a group indicator from a box holding a numbered sequence of such envelopes, prepared using block randomization. Mothers assigned to the FNI met with nurture specialists, former NICU nurses trained in implementing the intervention, who guided mothers and families throughout the study regarding all aspects of the intervention. Mothers and infants assigned to the SC condition received standard NICU care: (a) parent education by the bedside nurse in infant touch, handling, skin-to-skin care, feeding, bathing, and diapering (skin-to-skin care and breast feeding were determined by the mother's preferences) and (b) availability of a social worker, infant mental health psychologist, and parent groups led by a social worker.

Initial FNI activities took place when infants were in incubators. As soon as possible after birth, two small cotton cloths were given to the mother, one worn in her bra and the other placed under her infant's head. Each day, the cloths were exchanged. Mothers were encouraged to sniff the cloth suffused with their infant's smell when going home at night; the cloth suffused with the mother's smell was placed by the infant's head. As infants became more stable, nurture specialists facilitated FNI mothers in making contact with their infants through the ports of the incubator, using firm and sustained touch, speaking and singing emotionally to their infants in their native language, and making eye contact as often as possible. Later, mothers were encouraged to engage in holding (skin-to-skin or non-skin-to-skin). FNI mothers engaged in these activities ~6 hr per week until discharge (Welch et al., 2012, 2013).

Procedures at Infant Age 4 Months Corrected Age

At 4 months CA, 80 ($n = 37$ SC and 43 FNI) of the original 115 mothers returned with their infants for face-to-face play with split-screen filming. The New York State Psychiatric Institute Institutional Review Board approved study procedures for "Data Analysis 4 Months: NICU Follow Up" (No. 6718; expiration January 21, 2019). Of $N = 115$ dyads, 30 were lost at term due to the following: transfer to other facilities (SC 4, FNI 4), infant death (SC 1, FNI 1), withdrawal (SC 0, FNI 4), or loss to follow-up (SC 10, FNI 6). An additional five were lost to follow-up by 4 months CA. Parents from dyads with 4-month video data were better educated, mother $\chi^2(1, N = 80) = 8.10$, $p = .017$; father $\chi^2(1, N = 80) = 6.78$, $p = .034$, and more likely to be married, $\chi^2(1, N = 80) = 5.48$, $p = .019$, but did not differ with respect to either parent's age and race−ethnicity or household income category.

Singletons and firstborn twins were filmed. Mothers (seated opposite infants seated in an infant seat on a table) were instructed to play with their infants as they would at home, but without toys, for approximately 10 min. A special-effects generator created a split-screen view from input of two synchronized cameras (mounted on opposite walls) focused on the head and upper torso of mother and infant. Of $N = 80$, nine recordings were lost due to poor film quality, camera angle inadequate for gaze coding, static audio, or failure to record audio. Thus, analyses on 71 dyads compared 39 FNI and 32 SC dyads.

By virtue of the intervention, FNI (vs. SC) mothers engaged in more hours of skin-to-skin contact per week (FNI = 3.6, SC = 1.5, $p < .001$). Infant gestational age at birth, birth weight, number of NICU visits per week, and hours of clothed holding per week did not differ for 39 FNI versus 32 SC dyads.

Behavioral Coding

The first 2.5 min[1] of uninterrupted mother–infant interaction were coded on a 1-s time base by coders blind to FNI−SC status. If more than one behavior occurred in the same second, the behavior occurring in the second half of the second was privileged (Beebe et al., 2010; Tronick & Weinberg, 1990). Behaviors were coded with ordinal scales from *high* to *low* except gaze, which was coded as on or off the partner's face. Infant vocal affect (vocal contour) was coded as *high positive, neutral/positive, none, fuss/whimper, angry-protest,* or *cry.*

Mother touch (MT) was coded from *affectionate* to *intrusive* for the following: affectionate (stroke, kiss), static (hold, provide finger for infant to hold), playful (tap, tickle), none, caregive, jiggle−bounce, infant-directed oral touch (e.g., put finger in infant's mouth), object-mediated, centripetal (body center: face, body, head), rough (scratch, push, pinch), and high intensity−intrusive (both rough touch and high intensity touch are considered intrusive). This coding considered type of touch, location, and intensity (mild−moderate vs. intense−intrusive); touch to the body periphery was considered less stimulating than was touch to the body center (Beebe et al., 2010; Stepakoff, 1999; Stepakoff, Beebe, & Jaffe, 2000). This maternal touch scale has yielded informative results (Beebe et al., 2007, 2008, 2010, 2016). For all coding details, see the online supplemental materials, Section A (or Beebe et al., 2010). Intercoder reliability estimates were conducted on 20% of the dyads and generated mean Cohen's kappa per modality as follows: infants (gaze .95; vocal affect .98), mothers (gaze .92; touch .90).

From these assessments, we generated four mother–infant modality pairings for analyses of self- and interactive contingency:

1. infant gaze–mother gaze,
2. infant gaze–mother touch,
3. infant vocal affect–mother touch, and
4. infant vocal affect–mother gaze.

Data Analysis

Analyses compared 39 FNI dyads and 32 SC dyads at 4 months CA, using all 150 s coded from the video for each individual. First we tested whether FNI versus SC dyads differed in means and frequencies of behavior. Then we created indices of self- and interactive contingency. Traditional time-series approaches model each dyad individually and enter model coefficients into analyses of variance. In contrast, multilevel time-series approaches model the group as a whole,[2] creating estimates of both fixed effects[3] in the sample (group level), and random effects (individual variation in those effects). Advantages of this approach include more appropriate statistical assumptions, more accurate estimates of parameters, and increased power. These 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).

SAS statistical software was used to estimate random and fixed effects on patterns of self- and self-with-other behaviors over 150 s. SAS PROC MIXED was used to examine ordinally coded mother

[1] A 2.5-min sample of behavior is standard in the literature (Beebe et al., 2010; Cohn & Tronick, 1988). Mother–infant face-to-face interaction has a relatively stable structure with robust session-to-session reliability (Cohn & Tronick, 1989; G. A. Moore, Cohn, & Campbell, 1997; Weinberg & Tronick, 1991; Zelner, Beebe, & Jaffe, 1982).

[2] Compared to traditional time-series techniques, multilevel models (Singer & Willett, 2003) have more power, take into account error structures, and estimate individual effects with empirical Bayesian (maximum likelihood) techniques (rather than ordinary least squares), which take into account prior distributions. Because the prior probability of error is greatest for the extreme parameters, this method tends to pull in such extremes. Advantages of this approach include (a) multiple time series (in our case, self- and interactive contingency) can be modeled simultaneously, (b) an average effect of key parameters (e.g., infant behavior contingent on mother behavior) is estimated for the group and allows the investigator to ask how that group mean changes in the context of other factors (such as infant gender), (c) Standard Care variables and their conditional effects can be included as necessary, (d) potential nonlinear relations can be examined in the same analyses, and (e) more appropriate statistical model assumptions are made.

[3] *Random effect* is the term used for identifying the differences in a variable (function, or association) among the study participants. These always include variation in the mean of the dependent variable across observations, and variation in the variance of the dependent variable across observations; they usually include variation in the linear change in the dependent variable over time, and in our case it includes between-dyads variation in the autoregressive effect. *Fixed effect* is the average association across study units (in our case, dyads), just as it would be in an ordinary regression analysis. These average effects will account for some fraction of the random effects, just as in an ordinary regression analysis the predictors account for some fraction of the variance in the dependent variable.

touch and infant vocal affect behaviors (McArdle & Bell, 2000; Singer, 1998). SAS PROC GLIMMIX was used to evaluate mother and infant gaze behaviors (dichotomously coded; Cohen, Chen, Hamigami, Gordon, & McArdle, 2000; Goldstein, Healy, & Rasbash, 1994; Littell, Miliken, Stoup, & Wolfinger, 1996). Repeated second-by-second observations on individuals formed the basic random data, just as in cross-sectional data single individual variables are the basic units of analyses. For details of statistical models, see Chen and Cohen (2006). Self- and interactive contingency were first calculated for all mothers and infants for all modality pairings. A second set of analyses tested conditional effects of FNI versus SC group on self- and interactive contingency.

Two types of multilevel time-series models: Weighted lag and individual lags.

Weighted-lag time-series analysis. Consistent with procedures in previous studies, we used a weighted-lag approach (Beebe et al., 2007, 2010; 2016). Using a 4-s moving window,[4] we used the prior 3 s (Lags 1, 2, and 3 [L1, L2, and L3]) of behavior to predict t_0, the behavior at the current moment. All 3 prior seconds were condensed to one assessment ("weighted lag") by weighting each prior second by its relative association with t_0. For each dependent variable, standardized ($\bar{x} = 0$; $SD = 1$) measures of prior self or partner behavior ("lagged variables") were computed as a weighted average of the recent prior seconds, based on these analyses. Estimated coefficients for effects of these standardized lagged variables on current behavior (t_0) over the duration of the interaction (150 s) indicate the level of self- or interactive contingency: Larger coefficients reflect stronger contingencies. Each analysis included both self- and interactive contingency; thus, estimated coefficients of one form of contingency control for the other.

Individual-seconds (lags) time-series analysis. This approach is supplemental to the weighted-lag approach. Behaviors at each of the three prior lags were evaluated individually, with a separate model for each second's association with behavior at the current moment ($L1 \rightarrow t_0$; $L2 \rightarrow t_0$, $L3 \rightarrow t_0$). A key difference between the weighted-lag and individual-seconds analyses is that, in the latter, the values used in the analyses are simply those obtained at each of three lags; in the former, the values at the three lags are weighted by their respective correlations with t_0 and are then combined into a single value. Otherwise the models are identical. The individual-seconds approach applies a more precise lens to the identification of differences in FNI versus SC groups. For simplicity of interpretation, the individual-seconds approach does not accommodate the interaction terms of control variables with individual lags and group. The weighted-lag approach has more power in detecting differences between groups when each individual second of the 3 prior seconds is not sufficiently strong, but collectively the 3 prior seconds are sufficiently strong to detect differences. Reciprocally, the individual-seconds approach has more power when differences are primarily located in particular seconds of the 3 prior seconds. Nevertheless, where findings from the individual-seconds analyses are not consistent with those of the weighted-lag analyses, we present with caution.

Tests of hypotheses used fixed effects (FNI vs. SC groups). In addition to the intercept, fixed effects included (a) lagged effects of self- and partner behavior (self- and interactive contingency), (b) differences in behavioral frequencies (e.g., infant vocal affect) associated with group, and (c) differences in self- and interactive contingency associated with group. After we removed nonsignificant terms, the final model was the simplest consistent with the data. Significance level was set at $p < .05$. With 71 dyads (39 FNI, 32 SC) and 150 s of behavior per individual, the resulting 10,650 s for mother (or infant) per communication modality generated ample power to detect effects. In the weighted-lag models, we included maternal age, education, and ethnicity as covariates, but these were dropped because they did not contribute to the model; however, gender was significant and was retained as a covariate.

Analysis of predicted values: Illustrations of behavioral details of time-series models. Multilevel time-series analyses identify overall group differences in the level of self- and interactive contingency between FNI and SC groups but cannot explain where differences in specific behaviors lie. Further post hoc descriptive analyses are required to explicate specific patterns of behavioral predictors across L1, L2, and L3 that contribute to any significant group differences at t_0 identified by multilevel models. We used an approach termed *analysis of predicted values* to identify specific behavioral patterns that underlie significant group differences (see Searle & Gruber, 2016). Because the analysis of predicted values comes directly from the individual-seconds time-series models, it is more accurate (than, e.g., percentage time transition matrices) and represents the temporal dynamics.

Our analysis of predicted values derived predicted values at t_0 for FNI versus SC groups. For ordinal scales, the resulting value was the predicted level of the behavioral code at t_0. For gaze (binary variable), the resulting value was the predicted probability of being gaze-on at t_0. To locate sources of difference between FNI and SC contrasts identified by significant time-series models, we generated every possible combination of behavioral codes for mother at L1, L2, and L3 and infant at L1, L2, and L3 (within a particular modality pairing) in relation to a behavior predicted at t_0. We then computed estimated values (level of behavior or probability) at t_0 for FNI versus SC groups for the significant finding in question, using the equations generated by the individual-seconds time-series analyses. We identified absolute values of differences in predicted values at t_0 for the two groups, ranking the absolute differences from largest to smallest. To ascertain where FNI and SC groups differed the most, we examined the behavior combinations with the 10 highest differences in predicted value at t_0. For

[4] To determine optimum window size for calculating contingency estimates, in prior work (Beebe et al., 2007, 2010, 2016) we estimated the number of seconds over which lagged effects were significant and their magnitude for the pairs as a whole (fixed model estimates). For each dependent variable, measures of prior self- or partner behavior ("lagged variables") were computed as a weighted average of recent prior seconds, based on these analyses. The beta weight of each lag is divided by the sum of the significant beta weights (up to 3). Typically, the prior 3 s sufficed to account for these lagged effects on subsequent behavior (t_0). Across the modality pairings studied, mother was significant at two–three lags (2–3 s) for both self- and interactive contingency; evaluation of longer lags yielded nonsignificant results. Significant infant lags varied: for self-contingency, four lags (vocal affect), three (gaze); infant interactive contingency varied from six to three lags, but the amount of variance accounted for was very small for lags longer than 3 s. Note that in the weighted-lag analyses, no more than three lags, and no fewer than two, were used in any weighted mean lag, to maintain consistent sample size. By using a standard 3-s unit for both self- and interactive contingency, it is possible that there were subtle differences in the duration of the relevant prior window that we would not be able to determine in this model.

each combination of behaviors, the significant difference in predicted value of t_0 indicates that, although the FNI and SC dyads behaved in the same way over the prior 3s, they behaved differently at t_0.

In the individual-lags time-series approach, we could interpret relevant findings at each lag of L1, L2, and L3 for mother and for infant. But in the weighted-lag time-series approach, where the information of L1, L2, and L3 has been aggregated into one value, we used L1 to interpret effects in the analysis of predicted values approach, because we observed that L1 always had the largest association with t_0, as we expected.

Results

Descriptive Statistics

The first goal was a descriptive evaluation of differences between Family Nurture Intervention (FNI) and standard care (SC) groups. Comparing FNI and SC dyads in mean levels of behaviors using independent *t* tests, we found no differences (see the online supplemental materials, Section B1). Testing percentage of time spent in each behavior produced no group differences in mother gaze (MG), $\chi^2(1, N = 10{,}436) = .007$, $p = .931$, or infant gaze (IG), $\chi^2(1, N = 10{,}380) = 2.323$, $p = .128$, but did produce significant differences in mother touch (MT) patterns, $\chi^2(11, N = 10{,}582) = 197.272$, $p < .001$, and infant vocal affect (IVA) levels, $\chi^2(5, N = 10{,}540) = 81.166$, $p < .001$. FNI (vs. SC) mothers touched their infants a greater percentage of the time (less time coded as no touch: 16.5% vs. SC 20.7%); used more static touch, a more positive, calming pattern (43% vs. SC 36.5%); used less caregiving touch (which interrupts the ongoing communication; .7% vs. SC 1.9%); used more object-mediated touch (2.5% vs. SC .5%); and used more intrusive touch (1.2% vs. SC .6%). The latter two types of touch are rare. FNI (vs. SC) infants used more angry-protest (1.8% vs. SC .8%) but less cry (.4% vs. SC 1.8%).

Influenced by Feldman (2007b; Feldman & Eidelman, 2003, 2006), we pursued the possibility of other differences in gaze behavior in FNI versus SC dyads. However, we found no differences after testing the following variables: number and average length of mutual gaze episodes; proportion of time in mutual gaze; latency to, and duration of, first mutual gaze; which partner breaks the first mutual gaze; percentage of all mutual gaze episodes broken by mother or by infant; latency to first infant gaze aversion; likelihood of extensive infant gaze aversion (80% time or more); or co-occurrence within the same second of mutual gaze and mother positive touch (affectionate−static−playful patterns; see the online supplemental materials, Section B2).

Self- and Interactive Contingencies in FNI Versus SC Dyads

The second goal was to evaluate differences between the FNI versus SC groups in levels of self- and interactive contingency for four modality pairings: (a) infant gaze–mother touch, (b) infant vocal affect–mother gaze, (c) infant gaze–mother gaze, and (d) infant vocal affect–mother touch. For these analyses behavior in the current second is represented as t_0, behavior 1 s prior to the current second is represented as L1 (t_{-1}), behavior 2 s prior as L2 (t_{-2}), and behavior 3 s prior as L3 (t_{-3}).

Infant gaze–mother touch.

Infant gaze self-contingency (controlling for mother touch). Testing across the prior 3 s with a weighted lag, Table 1 shows no difference between FNI and SC infants in gaze self-contingency (controlling for prior mother touch). Testing for the predictability of each individual second, Table 2 shows that gaze self-contingency of

Table 1
Infant Gaze−Mother Touch: Weighted-Lag Analysis for SC and FNI and Their Differences (Δ)

Variable	β	*SE*	*p*
Infant gaze			
SC			
IG → IG[a]	1.338	.055	<.001
MT → IG[b]	.029	.093	.755
IS[c]	−.091	.179	.613
IG × IS → IG[d]	.062	.061	.310
MT × IS → IG	.196	.084	.021
FNI			
IG → IG	1.412	.051	<.001
MT → IG	.061	.033	.064
Δ[e]			
GP	−.012	.180	.945
IG × GP → IG[f]	.074	.062	.232
MT × GP → IG	.032	.097	.738
Mother touch			
SC			
MT → MT	5.783	.154	<.001
IG → MT	.261	.120	.029
IS	−.185	.207	.376
MT × IS → MT	−.278	.139	.045
IG × IS → MT	−.403	.131	.002
FNI			
MT → MT	4.709	.086	<.001
IG → MT	.601	.111	<.001
Δ			
GP	.236	.208	.260
MT × GP → MT	**−1.074**	**.170**	**<.001**
IG × GP → MT	**.340**	**.132**	**.010**

Note. Models included time and intercept. Beta values (β) are represented as standardized effect sizes. We evaluated whether contingencies of FNI vs. SC dyads differed and determined the significance of baseline contingencies for SC dyads and the additional effect of being in the FNI group. To determine the significance of contingencies of the FNI group, we reversed the 0/1 coding of FNI vs. SC and reran the models. We include main effects for these models and show significance of baseline contingencies for the FNI group (without other terms in the model). We include terms for infant sex or three-way interaction terms, e.g. (MG × GP × IS) only where significant. Arrows indicate the direction of prediction, with the predicted variable to the right of the arrow and the weighted-lag term to the left of arrow. In these weighted-lag models, the weighted-lag term is calculated in relation to the outcome variable, whereas lags in the individual-seconds models are not. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IG = infant gaze; MT = mother touch; IS = infant sex; GP = group.
[a] Infant gaze self-contingency (the contingency term represents baseline effects for male infants). [b] Infant gaze interactive contingency with mother touch (the contingency term represents baseline effects for male infants). [c] Difference in level of infant gaze for female (vs. male) infants. [d] Additional effect of being female on contingency (female = 1, male = 0). [e] Difference between the FNI and SC groups. [f] Additional effect of being in the FNI group (FNI = 1, SC = 0).

Table 2
Infant Gaze−Mother Touch: Individual-Seconds Time-Series Analysis for SC and FNI and Their Differences (Δ)

Variable	Infant gaze β	Infant gaze *SE*	Infant gaze *p*	Variable	Mother touch β	Mother touch *SE*	Mother touch *p*
				SC			
IG L1 → IG	2.24	.098	<.001	MT L1 → MT	.725	.034	<.001
IG L2 → IG	.573	.112	<.001	MT L2 → MT	.090	.042	.031
IG L3 → IG	.336	.107	.002	MT L3 → MT	−.030	.034	.367
MT L1 → IG	−.017	.015	.257	IG L1 → MT	.120	.256	.640
MT L2 → IG	.016	.020	.429	IG L2 → MT	−.010	.281	.973
MT L3 → IG	−.002	.019	.918	IG L3 → MT	−.043	.253	.865
				FNI			
IG L1 → IG	2.47	.090	<.001	MT L1 → MT	.408	.011	<.001
IG L2 → IG	.276	.103	.008	MT L2 → MT	.115	.012	<.001
IG L3 → IG	.562	.093	<.001	MT L3 → MT	.147	.011	<.001
MT L1 → IG	.003	.005	.487	IG L1 → MT	1.246	.227	<.001
MT L2 → IG	.018	.005	<.001	IG L2 → MT	−.454	.256	.076
MT L3 → IG	−.015	.005	.002	IG L3 → MT	−.506	.224	.024
				Δ			
GP	−.037	.183	.840	GP	.263	.204	.202
IG L1 × GP → IG	.231	.133	.083	MT L1 × GP → MT	**−.317**	**.035**	**<.001**
IG L2 × GP → IG	**−.298**	**.152**	**.051**	MT L2 × GP → MT	.025	.043	.557
IG L3 × GP → IG	.226	.142	.112	MT L3 × GP → MT	**.178**	**.035**	**<.001**
MT L1 × GP → IG	.020	.016	.200	IG L1 × GP → MT	**1.127**	**.342**	**.001**
MT L2 × GP → IG	.002	.021	.927	IG L2 × GP → MT	−.445	.380	.242
MT L3 × GP → IG	−.013	.019	.513	IG L3 × GP → MT	−.463	.338	.171

Note. The model testing for MT L1, L2, and L3 also includes IG L1, L2, and L3; that is, each of the six terms controls for the other five. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IG = infant gaze; MT = mother touch; L1 = Lag 1 (1 s prior); L2 = Lag 2 (2-s lag); L3 = Lag 3 (3-s lag); GP = group.

FNI (vs. SC) infants was marginally significantly lower (more variable) from L2 (IG L2 → IG β = −.298, p = .051). The β is a standardized index of degree of contingency.

Analysis of predicted values was used to clarify the details of these results (see the online supplemental materials, Section C, Table C1). Given infant gaze-on at L2, both FNI and SC infants are likely to be gaze-off at t_0 (both probabilities of gaze-on are less than 50%), but this is significantly more likely for FNI than for SC infants (mean of the top 10 probability values at t_0 = .184 for FNI and .282 for SC).

In summary, given infants were gaze-on 2 s prior, both FNI and SC infants were likely to be gaze-off at t_0, but this was significantly more likely for FNI infants. FNI infants have a more variable gaze process when controlling for mother touch.

Infant gaze interactive contingency (mother touch predicting infant gaze). Testing with weighted-lag and individual-seconds approaches, Tables 1 and 2 show no differences between FNI and SC groups in degree of infant gaze coordination with mother touch (controlling for prior infant gaze).

Mother touch self-contingency (controlling for infant gaze). Testing with a weighted lag, Table 1 shows lowered (more variable) touch self-contingency in FNI (vs. SC) mothers (MT × Group → MT β = −1.074, $p < .001$, controlling for prior infant gaze). Testing the predictability of each individual second, Table 2 shows that FNI (vs. SC) mothers had more variable touch self-contingency from L1 (MT L1 → MT β = −.317, $p < .001$), and heightened touch self-contingency from L3 (MT L3 → MT β = .178, $p < .001$).

Analysis of predicted values (see the online supplemental materials, Section C, Table C2) showed that, given mother touch tending toward the most negative values at L1, or the most positive values at L3, FNI (vs. SC) mothers showed more positive touch (about four levels higher) at t_0 (mean of the top 10 probability values at t_0 = 6.804 for FNI; = 2.749 for SC).

In summary, FNI (vs. SC) mothers are more likely to sustain positive touch and to repair moments of negative touch into positive touch.

Mother touch interactive contingency (infant gaze predicting mother touch). Testing with a weighted lag, Table 1 shows heightened maternal touch coordination with prior infant gaze in FNI (vs. SC) mothers (IG × Group → MT β = .340, p = .010, controlling for prior maternal touch). Testing with an individual-seconds approach, Table 2 also shows heightened maternal touch coordination with infant gaze in FNI (vs. SC) mothers, from L1 (IG L1 → MT β = 1.127, p = .001). Because the β is standardized, it is a measure of effect size. We note that the effect size is over 3 times greater using the individual-seconds approach, from L1. Thus, mother's touch coordination with infant gaze primarily occurs in the next second (from mother touch t_{-1} → infant gaze t_0).

Analysis of predicted values (see the online supplemental materials, Section C, Table C2) showed that, given infant gaze-on at L1, mother touch was more positive (four levels higher) at t_0 in

FNI (vs. SC) mothers (mean of the top 10 probability values at t_0 = 6.804 for FNI and 2.749 for SC).

In summary, FNI (vs. SC) mothers showed a heightened positive touch response to infant gaze-on (vs. gaze-off) mother's face. When infants look, FNI mothers are likely to greet infants with much more positive forms of touch in the next second.

Infant vocal affect–mother gaze.

Infant vocal affect self-contingency (controlling for mother gaze). Testing with a weighted lag, Table 3 shows lowered (more variable) infant vocal affect self-contingency (IVA → IVA β = −2.424, $p < .001$; controlling for prior mother gaze). Testing for the predictability of each individual second, Table 4 shows lowered (more variable) FNI (vs. SC) infant vocal affect self-contingency from L1 (IVA L1 → IVA β = −.903, $p < .001$) and increased infant vocal affect self-contingency from L2 (IVA L2 → IVA β = .166, $p < .001$).

Analysis of predicted values (see the online supplemental materials, Section C, Table C3) showed that, as infant vocal affect tended toward the most negative level at L1 or toward the most positive at L2, FNI (vs. SC) infant vocal affect was more positive at t_0, by over four vocal affect levels (mean of the top 10 probability values at t_0 = 6.677 for FNI and 1.850 for SC).

In summary, FNI (vs. SC) infants are more likely to sustain positive vocal affect and to transition from negative to more positive vocal affect (controlling for mother gaze).

Infant vocal affect interactive contingency (mother gaze predicting infant vocal affect). Testing with a weighted lag, Table 5 shows no difference between FNI and SC infants (β = .089, p = .528). Testing with an individual-seconds approach, Table 4 shows that vocal affect of FNI (vs. SC) infants is more coordinated with prior mother gaze (controlling for prior infant vocal affect), from L1 (MG L1 → IVA β = .988, p = .041).

Analysis of predicted values (see the online supplemental materials, Section C, Table C3) showed that, given mother gaze-on at L1, FNI (vs. SC) infants are likely to show more positive vocal affect in the current moment, by over four vocal affect levels (mean of the top 10 probability values at t_0 = 6.677 for FNI and 1.851 for SC).

In summary, given mother gaze-on in the prior second, FNI (vs. SC) infants show more positive vocal affect in the current second. However, the weighted-lag approach generated no corresponding finding. Because this was the only significant infant interactive contingency finding of 12 possible equations using the individual-seconds approach, it was not pursued.

Mother gaze self-contingency (controlling for infant vocal affect). Testing with a weighted-lag approach, FNI versus SC differences in maternal gaze self-contingency (controlling for prior infant vocal affect) were a function of infant sex. The three-way interaction effect (MG × Group × Infant Sex → MG β = .303, p = .003) in Table 3 represents the interaction of being in the FNI (vs. SC) group and being mothers of female (vs. male) infants, above and beyond either alone, on maternal self-contingency. As shown in Table 3, footnote a, the self-contingency of FNI mothers of male infants (β = .428) was lower than that of SC mothers of male infants (β = .647) and significantly different (β = .220, p = .004), but the self-contingency of FNI versus SC mothers of female infants did not differ (β = −.084, p = .226). Thus, FNI versus SC differences in mother gaze self-contingency were seen in only mothers of male infants. Within the FNI group, the self-contingency of mothers of male infants was lower than that of female infants (β = −.212, p = .003); within the SC group, mothers of male versus female infants did not differ (β = .091, p = .225). Thus, differences in the effect of gender on mother gaze self-contingency were seen in only the FNI group. Testing for the predictability of each individual second, Table 4 shows no findings.

Analysis of predicted values (see the online supplemental materials, Section C, Table C4) showed that, given mother gaze-off at L1, FNI (vs. SC) mothers of male infants are more likely to be gaze-on in the current moment. The mean probability of the top 10 values at t_0 is .762 for FNI versus .436 for SC.

Table 3
Infant Vocal Affect−Mother Gaze: Weighted-Lag Analysis for SC and FNI and Their Differences (Δ)

Variable	β	*SE*	*p*
Infant vocal affect			
SC			
IVA → IVA	2.987	.228	<.001
MG → IVA	.033	.150	.824
IS	.777	.492	.119
IVA × IS → IVA	4.335	.240	<.001
MG × IS → IVA	.048	.162	.769
FNI			
IVA → IVA	.553	.224	.014
MG → IVA	.123	.138	.375
Δ			
GP	.110	.494	.824
IVA × GP → IVA	**−2.424**	**.257**	**<.001**
MG × GP → IVA	.089	.162	.582
Mother gaze			
SC			
MG → MG	.647	.055	<.001
IVA → MG	.140	.122	.251
IS	.029	.206	.890
MG × IS → MG	−.091	.075	.225
IVA × IS → MG	−.042	.096	.662
FNI			
MG → MG	.428	.053	<.001
IVA → MG	−.051	.082	.534
Δ			
GP	−.086	.207	.680
MG × GP → MG	−.219	.076	.004
IVA × GP → MG	−.190	.137	.165
MG × GP × IS → MG	**.303**	**.103**	**.003**
Male infant			
SC	.647		<.001
FNI	.428		<.001
SC vs. FNI	**.220**		**.004**
Female infant			
SC	.556		<.001
FNI	.640		<.001
SC vs. FNI	−.084		.226
Male vs. female			
SC	.091		.225
FNI	−.212		.003

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IVA = infant vocal affect; MG = mother gaze; IS = infant sex; GP = group.

Table 4
Infant Vocal Affect−Mother Gaze: Individual-Seconds Time-Series Analysis for SC and FNI and Their Differences (Δ)

	Infant vocal affect				Mother gaze		
Variable	β	*SE*	*p*	Variable	β	*SE*	*p*
			SC				
IVA L1 → IVA	.647	.030	<.001	MG L1 → MG	1.578	.109	<.001
IVA L2 → IVA	.046	.037	.213	MG L2 → MG	.604	.120	<.001
IVA L3 → IVA	.173	.033	<.001	MG L3 → MG	.435	.119	<.001
MG L1 → IVA	−.396	.361	.273	IVA L1 → MG	−.008	.013	.515
MG L2 → IVA	.014	.374	.970	IVA L2 → MG	.049	.055	.366
MG L3 → IVA	−.244	.360	.498	IVA L3 → MG	.010	.029	.739
			FNI				
IVA L1 → IVA	−.256	.012	<.001	MG L1 → MG	1.549	.099	<.001
IVA L2 → IVA	.212	.012	<.001	MG L2 → MG	.555	.108	<.001
IVA L3 → IVA	.205	.012	<.001	MG L3 → MG	.309	.109	.005
MG L1 → IVA	.592	.322	.066	IVA L1 → MG	−.005	.004	.282
MG L2 → IVA	−.533	.332	.109	IVA L2 → MG	−.008	.004	.068
MG L3 → IVA	.319	.319	.318	IVA L3 → MG	−.003	.005	.580
			Δ				
GP	.110	.494	.824	GP	−.086	.207	.680
IVA L1 × GP → IVA	**−.903**	**.032**	**<.001**	MG L1 × GP → MG	−.029	.148	.843
IVA L2 × GP → IVA	**.166**	**.039**	**<.001**	MG L2 × GP → MG	−.049	.162	.763
IVA L3 × GP → IVA	.032	.036	.375	MG L3 × GP → MG	−.127	.162	.434
MG L1 × GP → IVA	**.988**	**.484**	**.041**	IVA L1 × GP → MG	.003	.013	.795
MG L2 × GP → IVA	−.546	.500	.275	IVA L2 × GP → MG	−.057	.055	.295
MG L3 × GP → IVA	.563	.482	.242	IVA L3 × GP → MG	−.012	.030	.677

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IVA = infant vocal affect; MG = mother gaze; L1 = Lag 1 (1 s prior); L2 = Lag 2 (2-s lag); L3 = Lag 3 (3-s lag); GP = group.

In summary, given mothers' gazing away in the just prior second, FNI (vs. SC) mothers of male infants are more likely to look at their sons in the current second.

Mother gaze interactive contingency (infant vocal affect predicting mother gaze). Testing with weighted-lag and individual-seconds approaches, Tables 3 and 4 show no FNI versus SC differences in mother gaze coordination with prior infant vocal affect.

Infant gaze–mother gaze.

Infant gaze self-contingency (controlling for mother gaze). Testing with a weighted-lag approach, Table 5 shows no difference between FNI and SC groups ($\beta = .062$, $p = .322$). Testing with the individual-seconds approach, Table 6 shows that FNI (vs. SC) infants are less predictable in gaze-on and gaze-off mother's face, from L2 ($\beta = -.298$, $p = .05$, controlling for prior mother gaze).

Analysis of predicted values (see the online supplemental materials, Section C, Table C5) showed that, given infant gaze-off at L2, the probability of infant gaze-on in the current moment is higher in FNI (vs. SC) infants. The mean probability of the top 10 values at t_0 is .643 for FNI infants and .556 for SC infants.

In summary, FNI (vs. SC) infants are more likely to seek visual reengagement with their mothers. We note that there was no corresponding finding from the weighted-lag approach.

Infant gaze interactive contingency (mother gaze predicting infant gaze). Testing with weighted-lag and individual-seconds approaches, Tables 5 and 6 show no FNI (vs. SC) differences. Note that infant contingent gaze coordination with mother gaze is not significant in either FNI or SC dyads.

Mother gaze self-contingency (controlling for prior infant gaze). Testing with a weighted-lag approach, FNI (vs. SC) differences in maternal gaze self-contingency (controlling for prior infant gaze) were a function of infant sex. The three-way interaction effect (MG × Group × Infant Sex → MG $\beta = .371$, $p < .001$) in Table 5 represents the interaction of being in the FNI (vs. SC) group and being mothers of female (vs. male) infants, above and beyond either alone, on maternal self-contingency. As shown in Table 5, footnote d, the self-contingency of SC mothers of male infants ($\beta = .642$) was higher than that of FNI mothers of male infants ($\beta = .378$), and significantly different ($\beta = .264$, $p < .001$), but the self-contingency of FNI versus SC mothers of female infants did not differ ($\beta = -.107$, $p = .128$; see Figure 1). Thus, differences in the effect of FNI (vs. SC) on mother gaze self-contingency were present in only mothers of male infants. Within the FNI group, the self-contingency of mothers of male infants was lower (more variable) than that of mothers of female infants ($\beta = -.267$, $p < .001$); within the SC group, mothers of male versus female infants did not differ ($\beta = .104$, $p = .176$). Testing for the predictability of each individual second, Table 2 shows no findings.

Analysis of predicted values (the online supplemental materials, Section C, Table C6) showed that, given mother gaze-off at L1, FNI (vs. SC) mothers of male (vs. female) infants were more likely

Table 5
Infant Gaze−Mother Gaze: Weighted-Lag Analyses for SC and FNI and Their Differences (Δ)

Variable	β	*SE*	*p*
	Infant gaze		
SC			
IG → IG	1.365	.047	<.001
MG → IG	.067	.046	.148
FNI			
IG → IG	1.431	.041	<.001
MG → IG	.024	.042	.561
Δ			
GP	.005	.179	.979
IG × GP → IG	.062	.062	.322
MG × GP → IG	−.043	.062	.491
	Mother gaze		
SC			
MG → MG[a]	.642	.056	<.001
IG → MG[a]	.100	.082	.224
IS	.013	.206	.951
MG × IS → MG[b]	−.104	.077	.176
IG × IS → MG[b]	.161	.114	.159
FNI			
MG → MG	.378	.055	<.001
IG → MG	.358	.073	<.001
Δ			
GP	−.066	.206	.750
MG × GP → MG[c]	−.264	.078	<.001
IG × GP → MG[c]	.258	.110	.019
MG × GP × IS → MG[d]	**.371**	**.105**	**<.001**
Male infant			
SC	.642		<.001
FNI	.378		<.001
SC vs. FNI	.264		<.001
Female infant			
SC	.538		<.001
FNI	.645		<.001
SC vs. FNI	−.107		.128
Male vs. female			
SC	.104		.176
FNI	−.267		<.001
IG × GP × IS → MG[d]	**−.443**	**.152**	**.004**
Male infant			
SC	.099		.224
FNI	.358		<.001
SC vs. FNI	−.258		.019
Female infant			
SC	.260		.001
FNI	.075		.268
SC vs. FNI	.185		.076
Male vs. female			
SC	−.161		.159
FNI	.283		.005

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IG = infant gaze; MG = mother gaze; IS = infant sex; GP = group.
[a] Contingency term alone represents the baseline effect for male infants. [b] Effect of being female on contingency (female = 1, male = 0). [c] Effect of being in the FNI group (FNI = 1, SC = 0). [d] Three-way interaction between prior mother gaze, group, and sex, for mother self-contingency ($\beta = .371$, $p < .001$) and mother interactive contingency ($\beta = -.443$, $p < .001$).

to be gaze-on in the current second. The mean probability of the top 10 values at t_0 is .851 for FNI mothers of male infants, compared to .613 for SC mothers of male infants.

In summary, the findings for mother gaze self-contingency here, controlling for infant gaze, are similar to those for mother gaze self-contingency above, controlling for infant vocal affect. Given mother gaze-off in the prior second, FNI mothers of male infants are more likely to be gaze-on in the current second.

Mother gaze interactive contingency (infant gaze predicting mother gaze). Testing with a weighted lag, Table 5 shows that differences in FNI versus SC maternal interactive contingency (controlling for prior mother gaze) were a function of infant sex. Testing for the predictability of each individual second, Table 6 shows no findings. The three-way interaction effect (IG × Group × Infant Sex → MG $\beta = -.443$, $p < .004$) in Table 5 represents the interaction of being in the FNI (vs. SC) group and being mothers of female (vs. male) infants on maternal interactive contingency. As shown in Table 5, footnote d, the interactive contingency of SC mothers of male infants ($\beta = .099$) was lower than that of FNI mothers of male infants ($\beta = .358$) and significantly different ($\beta = -.258$, $p = .019$), but the interactive contingency of FNI versus SC mothers of female infants did not differ ($\beta = .185$, $p = .076$; see Figure 1). Thus, the effect of FNI (vs. SC) on mother gaze interactive contingency was seen in only mothers of male infants. Within the FNI group, the interactive contingency of mothers of male infants was higher than that of female infants ($\beta = .283$, $p = .005$); within the SC group, mothers of male versus female infants did not differ ($\beta = -.161$, $p = .159$).

Analysis of predicted values showed that FNI (vs. SC) mothers of male infants coordinated to a greater degree with their infants (see the online supplemental materials, Section C, Table C6). Given male infants were gaze-on at L1, FNI (vs. SC) mothers of male infants were more likely to gaze at their sons in the current moment. The mean probability of mother gaze-on (for the top 10 values) in the current moment is .851 for FNI mothers of male infants, compared to .613 for SC mothers of males.

In summary, given infant gaze-on in the prior second, FNI (vs. SC) mothers of male infants are more likely to join their sons in gaze-on in the current second.

Infant vocal affect–mother touch. The results of these analyses are presented in Tables 7 and 8, and the analysis of predicted values can be found in the online supplemental materials, Section C, Tables C7 and C8. Because the results of this modality pairing were redundant with those presented earlier, we describe them in the online supplemental materials, Section D.

Across all equations, FNI (vs. SC) differences were documented in 50% of weighted-lag time-series equations and 25% of individual-seconds time-series equations. Differences were more evident in self-contingency processes than interactive contingency. Across weighted-lag models, self-contingency differences in FNI (vs. SC) were found in 50% of infant equations and 100% of mother equations; interactive contingency differences were found in no infant equations and in 50% of mother equations. Across individual-seconds models, self-contingency differences were found in 50% of infant equations and 33% of mother equations; interactive contingency differences were found in 8.3% of infant equations and 8.3% of mother equations.

Discussion

The Family Nurture Intervention (FNI) in the neonatal intensive care unit (NICU; compared to standard care) facilitated more

Table 6
Infant Gaze−Mother Gaze: Individual-Seconds Time-Series Analysis for SC and FNI and Their Differences (Δ)

	Infant gaze				Mother gaze		
Variable	β	*SE*	*p*	Variable	β	*SE*	*p*
				SC			
IG L1 → IG	2.278	.099	<.001	MG L1 → MG	1.548	.111	<.001
IG L2 → IG	.546	.113	<.001	MG L2 → MG	.565	.121	<.001
IG L3 → IG	.335	.108	.002	MG L3 → MG	.461	.121	<.001
MG L1 → IG	.187	.138	.175	IG L1 → MG	.286	.136	.036
MG L2 → IG	−.062	.142	.662	IG L2 → MG	.026	.148	.858
MG L3 → IG	.128	.137	.350	IG L3 → MG	.061	.136	.654
				FNI			
IG L1 → IG	2.449	.089	<.001	MG L1 → MG	1.506	.101	<.001
IG L2 → IG	.248	.012	.015	MG L2 → MG	.564	.110	<.001
IG L3 → IG	.604	.093	<.001	MG L3 → MG	.269	.112	.016
MG L1 → IG	.139	.122	.252	G L1 → MG	.439	.120	<.001
MG L2 → IG	−.099	.123	.422	IIG L2 → MG	−.299	.132	.024
MG L3 → IG	−.027	.120	.823	IG L3 → MG	.363	.119	.002
				Δ			
GP	−.037	.183	.841	GP	−.072	.211	.735
IG L1 × GP → IG	.171	.133	.199	MG L1 × GP → MG	−.042	.150	.780
IG L**2** × GP → IG	**−.298**	**.152**	**.050**	MG L2 × GP → MG	−.001	.164	.995
IG L3 × GP → IG	.269	.142	.059	MG L3 × GP → MG	−.192	.165	.244
MG L1 × GP → IG	−.048	.184	.795	IG L1 × GP → MG	.154	.182	.397
MG L2 × GP → IG	−.037	.188	.845	IG L2 × GP → MG	−.323	.198	.101
MG L3 × GP → IG	−.155	.182	.396	IG L3 × GP → MG	.301	.181	.096

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IG = infant gaze; MG = mother gaze; L1 = Lag 1 (1 s prior); L2 = Lag 2 (2-s lag); L3 = Lag 3 (3-s lag); GP = group.

optimal mother–infant face-to-face interaction at 4 months corrected age (CA). Dyads who received FNI demonstrated the following:

1. greater frequency of maternal touch and more optimal maternal touch patterns;
2. greater frequency of more optimal (less extreme) infant expression of vocal distress;
3. more optimal maternal coordination of touch patterns with infant gaze patterns;
4. greater likelihood of sustaining positive patterns, specifically, maternal positive touch patterns and infant positive vocal affect patterns;
5. greater likelihood of repair patterns, whereby moments of negative maternal touch, or of negative infant vocal affect, transitioned into positive behavioral patterns;
6. greater likelihood of infant visual reengagement after a moment of infant looking away; and
7. for mothers of male infants, greater likelihood of maternal visual reengagement after a moment of mother looking away and of mothers' joining infants in looking.

Together these findings document an improved social engagement reflective of greater emotional connection in the FNI preterm infants and their mothers at 4 months (CA).

Maternal Touch

Maternal touch is compromised in mothers of preterm infants (Davis & Thoman, 1988; Feldman & Eidelman, 2003), and interventions utilizing touch improve infant outcomes (Alvarez-Garcia, Fornieles-Deu, Costas-Moragas, & Botet-Mussons, 2015; E. Moore, Bergman, Anderson, & Medley, 2016). The FNI had an extensive impact on maternal touch patterns. Our findings extend the literature by specifying further dimensions of maternal touch at 4 months that changed with the FNI intervention. FNI (vs. SC) mothers showed not only a greater amount of touch and more positive touch patterns (particularly static, calming touch) but also the capacity to sustain positive touch and to repair negative touch patterns. Moreover, we documented increased maternal capacity to reciprocate infant gaze through heightened contingent touch responsivity, and with much more positive touch, in the very next second.

Infant Distress

The FNI (vs. SC) infants used less extreme forms of distress (angry-protest rather than cry). Feldman, Weller, et al. (2002) similarly found that infant distress at 3 and 6 months decreased with a NICU kangaroo care intervention, using the global coding

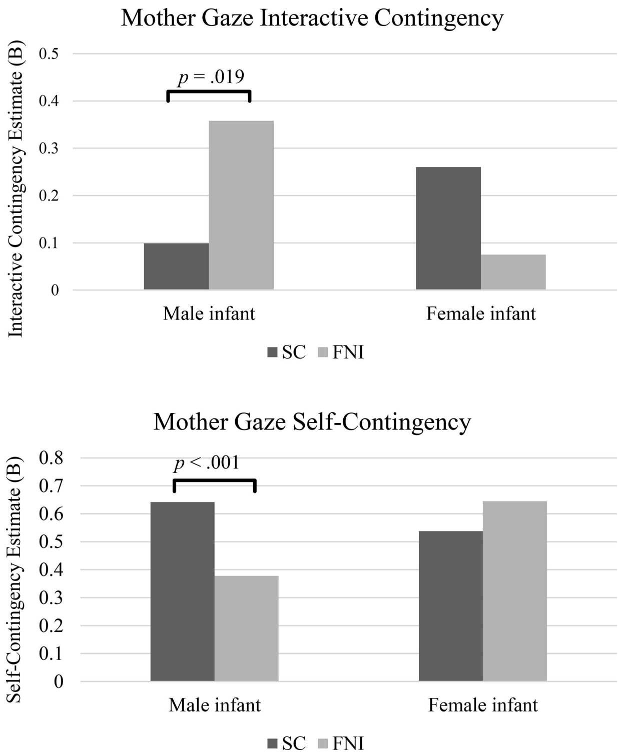

Figure 1. Differences in mother gaze interactive contingency and self-contingency between Family Nurture Intervention (FNI) and standard care (SC) groups for mothers of male infants and for mothers of female infants. For mothers of male infants, (a) mother gaze interactive contingency of FNI mothers was higher than that of SC mothers and (b) mother gaze self-contingency of FNI mothers was lower than that of SC mothers. For mothers of female infants, there were no significant group differences in mother gaze self- or interactive contingencies.

scheme, Coding of Interactive Behavior (CIB). Using a more detailed coding of infant vocal distress, our findings refine the understanding of how the FNI improved the premature infant's ability to engage in the face-to-face exchange at 4 months. The infant is not only less negative but also more likely to repair negative affect and to sustain positive affect. This is an important contribution of the infant to the improved emotional connection with the mother.

Infant Gaze

Testing FNI versus SC dyads with frequency and duration measures of mother and infant gaze behavior yielded no differences. In future studies, longer observations may yield differences. Instead, testing with time-series models, we documented differences in the process of relating through gazing and gazing away.

There were two infant gaze findings, interpreted with caution. Analyzing infant gaze controlling for maternal gaze, when infants gazed away, FNI (vs. SC) infants were more likely to look back, seeking visual reengagement. Analyzing infant gaze controlling for mother touch, when infants gazed at their mothers, both FNI and SC infants were then likely to gaze away, but this was more likely for FNI infants, indicating a more variable gaze process.

Mother Gaze

FNI (vs. SC) mothers of male infants were more visually engaged. When mothers looked away, FNI (vs. SC) mothers of male infants were more likely to look back, seeking visual reengagement. When infants looked at their mothers, FNI (vs. SC) mothers of male infants were more likely to join their sons in looking, thus being more contingently responsive. Feldman, Weller, et al. (2002) similarly found that intervening in the NICU with kangaroo care improved mother−infant shared attention at infant age 6 months.

Sex effects have been extensively documented in preterm infants. Preterm male (vs. female) infants are at greater risk for multiple deficits (Spinillo et al., 2009), perform less optimally on neonatal neurobehavioral tests Alvarez-Garcia et al. (2015), are less alert, and have more diffuse (immature) sleep states (Foreman, Thomas, & Blackburn, 2008). FNI mothers may have higher levels of gaze vigilance with their male (vs. female) infants due to the initial greater vulnerability of male infants.

Self-Contingency

Our hypothesis that the FNI would increase the capacity of infants and mothers to contingently coordinate with each other was upheld, in both maternal touch coordination with infant gaze and maternal gaze coordination with infant gaze for mothers of male infants. However, the bulk of the findings concerned self-contingency.

Table 7
Infant Vocal Affect−Mother Touch: Weighted-Lag Analysis for SC and FNI and Their Differences (Δ)

Variable	β	*SE*	*p*
Infant vocal affect			
SC			
IVA → IVA	2.638	.209	<.001
MT → IVA	.180	.236	.445
IS	.783	.552	.160
IVA × IS → IVA	4.124	.233	<.001
MT × IS → IVA	−.050	.174	.775
FNI			
IVA → IVA	.312	.219	.155
MT → IVA	.024	.102	.814
Δ			
GP	.149	.553	.792
IVA × GP → IVA	**−2.327**	**.247**	**<.001**
MT × GP → IVA	−.156	.249	.532
Mother touch			
SC			
MT → MT	5.593	.159	<.001
IVA → MT	.039	.128	.760
FNI			
MT → MT	4.286	.070	<.001
IVA → MT	.069	.084	.412
Δ			
GP	.187	.226	.411
MT × GP → MT	**−1.307**	**.174**	**<.001**
IVA × GP → MT	.030	.153	.844

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IVA = infant vocal affect; MT = mother touch; IS = infant sex; GP = group.

Table 8
Infant Vocal Affect−Mother Touch: Individual-Seconds Time-Series Analysis for SC and FNI and Their Differences (Δ)

Variable	Infant vocal affect β	*SE*	*p*	Variable	Mother touch β	*SE*	*p*
SC							
IVA L1 → IVA	.330	.022	<.001	MT L1 → MT	.714	.033	<.001
IVA L2 → IVA	.134	.033	<.001	MT L2 → MT	.093	.041	.022
IVA L3 → IVA	.236	.032	<.001	MT L3 → MT	−.026	.033	.430
MT L1 → IVA	−.049	.042	.241	IVA L1 → MT	.013	.017	.461
MT L2 → IVA	.082	.051	.107	IVA L2 → MT	−.012	.026	.644
MT L3 → IVA	−.028	.042	.509	IVA L3 → MT	.001	.025	.967
FNI							
IVA L1 → IVA	−.226	.011	<.001	MT L1 → MT	.437	.010	<.001
IVA L2 → IVA	.207	.012	<.001	MT L2 → MT	.060	.011	<.001
IVA L3 → IVA	.187	.012	<.001	MT L3 → MT	.145	.010	<.001
MT L1 → IVA	.005	.013	.669	IVA L1 → MT	.011	.008	.207
MT L2 → IVA	.011	.014	.444	IVA L2 → MT	.002	.008	.807
MT L3 → IVA	−.025	.013	.056	IVA L3 → MT	−.016	.009	.070
Δ							
GP	.221	.553	.691	GP	.213	.222	.342
IVA L1 × GP → IVA	**−.556**	**.025**	**<.001**	MT L1 × GP → MT	**−.277**	**.035**	**<.001**
IVA L2 × GP → IVA	**.073**	**.035**	**.038**	MT L2 × GP → MT	−.033	.042	.435
IVA L3 × GP → IVA	−.049	.034	.150	MT L3 × GP → MT	**.171**	**.035**	**<.001**
MT L1 × GP → IVA	.054	.044	.213	IVA L1 × GP → MT	−.002	.019	.903
MT L2 × GP → IVA	−.072	.053	.176	IVA L2 × GP → MT	.014	.028	.607
MT L3 × GP → IVA	.003	.044	.944	IVA L3 × GP → MT	−.017	.027	.525

Note. Bold type indicates significant effects. SC = standard care; FNI = Family Nurture Intervention; IG = infant gaze; MT = mother touch; IS = infant sex.

Whereas interactive contingency measures adjustments an individual makes in response to a partner's prior behavior, self-contingency measures the individual's likelihood of maintaining (or changing) behavior from moment to moment. Self-contingency generates procedural expectancies of how predictable (stable–variable) one's behaviors are and where one's behavior is tending in the next moment, contributing to a sense of temporal coherence. It is this aspect of relatedness that the FNI intervention substantially altered.

In touch self-contingency, FNI mothers were more likely to sustain positive touch and to transition from negative to positive forms of touch. In vocal affect self-contingency, FNI infants were more likely to sustain positive vocal affect and to transition from negative to more positive vocal affect. In gaze self-contingency, FNI mothers of male infants were more likely to visually reengage. We note that the effect sizes were twice as large for infant vocal affect self-contingency as for mother touch self-contingency. Thus, the intervention had a particularly large effect on infant vocal affect, pointing to the sensitivity of the infant to the intervention and to the importance of the infant's contribution to the coregulation of the interactive system.

In prior work, self-contingency has frequently been a more sensitive variable than has interactive contingency (Beebe et al., 2007, 2008, 2010). Beebe et al. (2016) documented that the effects of self-contingency are substantially greater than those of interactive contingency and that self- and interactive contingency are coconstituted, with each process affecting the other.

This coconstitution is consistent with the calming cycle theory (Welch, 2016a), which describes mother and infant as an open biobehavioral system of feedback loop coregulation. We speculate that the self-contingency processes that we documented at 4 months stemmed from this coregulation, which began in utero, continued after birth, and was shaped by FNI conditioning.

Clinical Implications

The specificity of our findings can inform NICU interventions and, more generally, clinical work with premature infants and their mothers. For example, our findings of maternal static touch, sustained positive forms of touch, the rapid repair of intrusive touch, and immediate positive maternal touch response to infant looking can generate specific intervention targets.

Limitations and Future Directions

Lacking sufficient prior literature, we made no specific hypotheses regarding self-contingency. We did not code maternal vocalization, because it will be coded by an automated method, reserved for a future report. A comparison of these preterm infants with a term sample is under way.

Conclusion

Our randomized control trial of the Family Nurture Intervention in the NICU generated more positive forms of mother and infant engagement at 4 months CA. Our microlevel behavioral coding and time-series approach revealed dimensions of maternal touch, infant vocal affect, and mother and infant gaze hitherto undetected by global coding methods. These results, suggesting greater positive emotional connection, add to the published findings showing immediate and long-term improvements for the FNI group. Because mother–infant coordination during face-to-face communication in the early months of life is a critical foundation for development, this documentation of positive effects of the FNI for 4-month mother–infant face-to-face communication has important implications for an improved developmental trajectory of these infants.

References

Achenbach, T. M. (1999). The Child Behavior Checklist and related instruments. In M. E. Maruish (Ed.), *The use of psychological testing for treatment planning and outcomes assessment* (pp. 429–466). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Alvarez-Garcia, A., Fornieles-Deu, A., Costas-Moragas, A., & Botet-Mussons, F. (2015). Neurobehavioral conditions and effects of gender, weight and severity in preterm infants according to the Neonatal Behavioral Assessment Scale. *Annals of Psychology, 31,* 818–824.

Bayley, N. (2006). *Bayley Scales of Infant and Toddler Development* (3rd ed.). San Antonio, TX: Harcourt Assessment.

Beebe, B., Jaffe, J., Buck, K., Chen, H., Cohen, P., Blatt, S., . . . Andrews, H. (2007). Six-week postpartum maternal self-criticism and dependency and 4-month mother-infant self- and interactive contingencies. *Developmental Psychology, 43,* 1360–1376. http://dx.doi.org/10.1037/0012-1649.43.6.1360

Beebe, B., Jaffe, J., Buck, K., Chen, H., Cohen, P., Feldstein, S., & Andrews, H. (2008). Six-week postpartum maternal depressive symptoms and 4-month mother-infant self- and interactive contingency. *Infant Mental Health Journal, 29,* 442–471. http://dx.doi.org/10.1002/imhj.20191

Beebe, B., Jaffe, J., Markese, S., Buck, K., Chen, H., Cohen, P., . . . Feldstein, S. (2010). The origins of 12-month attachment: A microanalysis of 4-month mother-infant interaction. *Attachment & Human Development, 12,* 3–141. http://dx.doi.org/10.1080/14616730903338985

Beebe, B., Messinger, D., Bahrick, L. E., Margolis, A., Buck, K. A., & Chen, H. (2016). A systems view of mother-infant face-to-face communication. *Developmental Psychology, 52,* 556–571. http://dx.doi.org/10.1037/a0040085

Chen, H., & Cohen, P. (2006). Using individual growth model to analyze the change in quality of life from adolescence to adulthood. *Health and Quality of Life Outcomes, 4,* 10. http://dx.doi.org/10.1186/1477-7525-4-10

Cohen, P., Chen, H., Hamigami, F., Gordon, K., & McArdle, J. (2000). Multilevel analyses for predicting sequence effects of financial and employment problems on the probability of arrest. *Journal of Quantitative Criminology, 16,* 223–235. http://dx.doi.org/10.1023/A:1007568606759

Cohn, J., & Tronick, E. (1988). Mother-infant face-to-face interaction: Influence is bidirectional and unrelated to periodic cycles in either partner's behavior. *Developmental Psychology, 24,* 386–392. http://dx.doi.org/10.1037/0012-1649.24.3.386

Cohn, J. F., & Tronick, E. (1989). Specificity of infants' response to mothers' affective behavior. *Journal of the American Academy of Child & Adolescent Psychiatry, 28,* 242–248. http://dx.doi.org/10.1097/00004583-198903000-00016

Davis, D. H., & Thoman, E. B. (1988). The early social environment of premature and fullterm infants. *Early Human Development, 17,* 221–232. http://dx.doi.org/10.1016/S0378-3782(88)80009-4

Demetri Friedman, D., Beebe, B., Jaffe, J., Ross, D., & Triggs, S. (2010). Microanalysis of 4-month infant vocal affect qualities and maternal postpartum depression. *Clinical Social Work Journal, 38,* 8–16. http://dx.doi.org/10.1007/s10615-010-0261-x

Feldman, R. (2007a). Mother-infant synchrony and the development of moral orientation in childhood and adolescence: Direct and indirect mechanisms of developmental continuity. *American Journal of Orthopsychiatry, 77,* 582–597. http://dx.doi.org/10.1037/0002-9432.77.4.582

Feldman, R. (2007b). Parent-infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry, 48,* 329–354. http://dx.doi.org/10.1111/j.1469-7610.2006.01701.x

Feldman, R. (2007c). Parent-infant synchrony: Biological foundations and developmental outcomes. *Current Directions in Psychological Science, 16,* 340–345. http://dx.doi.org/10.1111/j.1467-8721.2007.00532.x

Feldman, R. (2012). Parent-infant synchrony: A bio-behavioral model of mutual influences in the formation of affiliative bonds. *Monographs of the Society for Research in Child Development, 77,* 42–51. http://dx.doi.org/10.1111/j.1540-5834.2011.00660.x

Feldman, R. (2015). The adaptive human parental brain: Implications for children's social development. *Trends in Neurosciences, 38,* 387–399. http://dx.doi.org/10.1016/j.tins.2015.04.004

Feldman, R. (2016). The neurobiology of mammalian parenting and the biosocial context of human caregiving. *Hormones and Behavior, 77,* 3–17. http://dx.doi.org/10.1016/j.yhbeh.2015.10.001

Feldman, R., & Eidelman, A. I. (2003). Skin-to-skin contact (kangaroo care) accelerates autonomic and neurobehavioural maturation in preterm infants. *Developmental Medicine & Child Neurology, 45,* 274–281. http://dx.doi.org/10.1111/j.1469-8749.2003.tb00343.x

Feldman, R., & Eidelman, A. I. (2006). Neonatal state organization, neuromaturation, mother-infant interaction, and cognitive development in small-for-gestational-age premature infants. *Pediatrics, 118*(3), e869–e878. http://dx.doi.org/10.1542/peds.2005-2040

Feldman, R., & Eidelman, A. I. (2007). 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. *Developmental Psychobiology, 49,* 290–302. http://dx.doi.org/10.1002/dev.20220

Feldman, R., Eidelman, A. I., Sirota, L., & Weller, A. (2002). Comparison of skin-to-skin (kangaroo) and traditional care: Parenting outcomes and preterm infant development. *Pediatrics, 110,* 16–26. http://dx.doi.org/10.1542/peds.110.1.16

Feldman, R., Rosenthal, Z., & Eidelman, A. (2014). Maternal-preterm skin-to-skin contact enhances child physiologic organization and cognitive control across the first 10 years of life. *Biological Psychiatry, 75,* 56–64. http://dx.doi.org/10.1016/j.biopsych.2013.08.012

Feldman, R., Weller, A., Sirota, L., & Eidelman, A. I. (2002). Skin-to-skin contact (kangaroo care) promotes self-regulation in premature infants: Sleep-wake cyclicity, arousal modulation, and sustained exploration. *Developmental Psychology, 38,* 194–207. http://dx.doi.org/10.1037/0012-1649.38.2.194

Flacking, R., Lehtonen, L., Thomson, G., Axelin, A., Ahlqvist, S., Moran, V. H., . . . the SCENE group. (2012). Closeness and separation in neonatal intensive care. *Acta Paediatrica, 101,* 1032–1037. http://dx.doi.org/10.1111/j.1651-2227.2012.02787.x

Fogel, A. (1993). *Developing through relationships: Origins of communication, self, and culture*. Chicago, IL: University of Chicago Press.

Foreman, S. W., Thomas, K. A., & Blackburn, S. T. (2008). Individual and gender differences matter in preterm infant state development. *Journal of Obstetric, Gynecologic, and Neonatal Nursing, 37,* 657–665. http://dx.doi.org/10.1111/j.1552-6909.2008.00292.x

Gianino, A., & Tronick, E. (1988). The mutual regulation model: The infant's self and interactive regulation, coping and defense. In T. Field, P. McCabe, & N. Schneiderman (Eds.), *Stress and coping* (pp. 47–68). Hillsdale, NJ: Erlbaum.

Goldstein, H., Healy, M. J., & Rasbash, J. (1994). Multilevel time series models with applications to repeated measures data. *Statistics in Medicine, 13,* 1643–1655. http://dx.doi.org/10.1002/sim.4780131605

Haller, J., Harold, G., Sandi, C., & Neumann, I. D. (2014). Effects of adverse early-life events on aggression and anti-social behaviours in animals and humans. *Journal of Neuroendocrinology, 26,* 724–738. http://dx.doi.org/10.1111/jne.12182

Hane, A. A., Myers, M. M., Hofer, M. A., Ludwig, R. J., Halperin, M. S., Austin, J., . . . Welch, M. G. (2015). Family Nurture Intervention improves the quality of maternal caregiving in the neonatal intensive care unit: Evidence from a randomized controlled trial. *Journal of Developmental and Behavioral Pediatrics, 36,* 188–196. http://dx.doi.org/10.1097/DBP.0000000000000148

Hofer, M. A. (1994). Early relationships as regulators of infant physiology and behavior. *Acta Paediatrica, 83*(Suppl. 397), 9–18. http://dx.doi.org/10.1111/j.1651-2227.1994.tb13260.x

Hussey-Gardner, B., & Famuyide, M. (2009). Developmental interventions in the NICU. *NeoReviews, 10*(3), e113–e120. http://dx.doi.org/10.1542/neo.10-3-e113

Jaffe, J., Beebe, B., Feldstein, S., Crown, C. L., & Jasnow, M. D. (2001). Rhythms of dialogue in infancy: Coordinated timing in development. *Monographs of the Society for Research in Child Development, 66*(2), i–viii, 1–132.

Jean, A. D., & Stack, D. M. (2012). Full-term and very-low-birth-weight preterm infants' self-regulating behaviors during a still-face interaction: Influences of maternal touch. *Infant Behavior and Development, 35,* 779–791. http://dx.doi.org/10.1016/j.infbeh.2012.07.023

Johnson, M., Schmeid, V., Lupton, S. J., Austin, M. P., Matthey, S. M., Kemp, L., . . . Yeo, A. E. (2012). Measuring perinatal mental health risk. *Archives of Women's Mental Health, 15,* 375–386. http://dx.doi.org/10.1007/s00737-012-0297-8

Lavelli, M., & Fogel, A. (2005). Developmental changes in the relationship between the infant's attention and emotion during early face-to-face communication: The 2-month transition. *Developmental Psychology, 41,* 265–280. http://dx.doi.org/10.1037/0012-1649.41.1.265

Lester, B. M., Hoffman, J., & Brazelton, T. B. (1985). The rhythmic structure of mother-infant interaction in term and preterm infants. *Child Development, 56,* 15–27. http://dx.doi.org/10.2307/1130169

Littell, R., Miliken, G., Stoup, W., & Wolfinger, R. (1996). *SAS system for mixed models*. Cary, NC: SAS Institute.

Malatesta, C., Culver, C., Tesman, J., & Shepard, B. (1989). The development of emotion expression during the first two years of life. *Monographs of the Society for Research in Child Development, 54,* 1–2.

Markova, G., & Legerstee, M. (2006). Contingency, imitation, and affect sharing: Foundations of infants' social awareness. *Developmental Psychology, 42,* 132–141. http://dx.doi.org/10.1037/0012-1649.42.1.132

McArdle, J., & Bell, R. (2000). *An introduction to latent growth models for developmental data analysis*. Mahwah, NJ: Erlbaum.

Messinger, D., Ekas, N., Ruvolo, P., & Fogel, A. (2012). "Are you interested, baby?" Young infants exhibit stable patterns of attention during interaction. *Infancy, 17,* 233–244. http://dx.doi.org/10.1111/j.1532-7078.2011.00074.x

Montirosso, R., Borgatti, R., Trojan, S., Zanini, R., & Tronick, E. (2010). A comparison of dyadic interactions and coping with still-face in healthy pre-term and full-term infants. *British Journal of Developmental Psychology, 28,* 347–368. http://dx.doi.org/10.1348/026151009X416429

Moore, E., Bergman, N., Anderson, G., & Medley, N. (2016). Early skin-to-skin contact for mothers and their healthy newborn infants. *Cochrane Database of Systematic Reviews, 2016*(11), CD003519. http://dx.doi.org/10.1002/14651858.CD003519.pub4

Moore, G. A., Cohn, J. F., & Campbell, S. B. (1997). Mothers' affective behavior with infant siblings: Stability and change. *Developmental Psychology, 33,* 856–860. http://dx.doi.org/10.1037/0012-1649.33.5.856

NICHD Network. (2004). Affect dysregulation in the mother-child relationship in the toddler years: Antecedents and consequences. *Development and Psychopathology, 16,* 43–68.

Searle, S., & Gruber, M. (2016). *Linear models*. Chichester, United Kingdom: Wiley.

Singer, J. (1998). Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. *Journal of Educational and Behavioral Statistics, 24,* 323–355.

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. http://dx.doi.org/10.1093/acprof:oso/9780195152968.001.0001

Spinillo, A., Montanari, L., Gardella, B., Roccio, M., Stronati, M., & Fazzi, E. (2009). Infant sex, obstetric risk factors, and 2-year neurodevelopmental outcome among preterm infants. *Developmental Medicine & Child Neurology, 51,* 518–525. http://dx.doi.org/10.1111/j.1469-8749.2009.03273.x

Stepakoff, S. (1999). *Mother-infant tactile communication at four months: Effects of infant gender, maternal ethnicity, and maternal depression* (Doctoral dissertation). St. John's University, New York, NY.

Stepakoff, S., Beebe, B., & Jaffe, J. (2000, July). Infant gender, maternal touch, and ethnicity. *International Conference of Infant Studies*, Brighton, United Kingdom.

Stern, D. (1985). *The interpersonal world of the infant*. New York, NY: Basic Books.

Symington, A., & Pinelli, J. (2006). Developmental care for promoting development and preventing morbidity in preterm infants. *Cochrane Database of Systematic Reviews, 2006*(2), CD001814.

Tronick, E. Z. (1989). Emotions and emotional communication in infants. *American Psychologist, 44,* 112–119. http://dx.doi.org/10.1037/0003-066X.44.2.112

Tronick, E., & Weinberg, M. (1990). *The infant regulatory scoring system*. Unpublished manuscript, Children's Hospital, Harvard Medical School, Boston, MA.

van Baar, A. L., van Wassenaer, A. G., Briët, J. M., Dekker, F. W., & Kok, J. H. (2005). Very preterm birth is associated with disabilities in multiple developmental domains. *Journal of Pediatric Psychology, 30,* 247–255. http://dx.doi.org/10.1093/jpepsy/jsi035

Weinberg, K., & Tronick, E. (1991, April). *Stability of infant social and coping behaviors and affective displays between 6 and 15 months: Age-appropriate tasks and stress bring out stability*. Paper presented at the Society for Research in Child Development, Seattle, WA.

Welch, M. G. (1988). *Holding time: How to eliminate conflict, temper tantrums, and sibling rivalry and raise happy, loving, successful children*. New York, NY: Simon & Schuster.

Welch, M. G. (2016a). Calming cycle theory: The role of visceral/autonomic learning in early mother and infant/child behaviour and development. *Acta Paediatrica, 105,* 1266–1274. http://dx.doi.org/10.1111/apa.13547

Welch, M. G. (2016b). Nurture in the neonatal intensive care unit. *Acta Paediatrica, 105,* 730–731. http://dx.doi.org/10.1111/apa.13294

Welch, M. G., Firestein, M. R., Austin, J., Hane, A. A., Stark, R. I., Hofer, M. A., . . . Myers, M. M. (2015). Family Nurture Intervention in the neonatal intensive care unit improves social-relatedness, attention, and neurodevelopment of preterm infants at 18 months in a randomized controlled trial. *Journal of Child Psychology and Psychiatry, 56,* 1202–1211. http://dx.doi.org/10.1111/jcpp.12405

Welch, M. G., Hofer, M. A., Brunelli, S. A., Stark, R. I., Andrews, H. F., Austin, J., . . . Family Nurture Intervention (FNI) Trial Group. (2012). Family Nurture Intervention (FNI): Methods and treatment protocol of a randomized controlled trial in the NICU. *BMC Pediatrics, 12,* 14. http://dx.doi.org/10.1186/1471-2431-12-14

Welch, M. G., Hofer, M. A., Stark, R. I., Andrews, H. F., Austin, J., Glickstein, S. B., . . . the FNI Trial Group. (2013). Randomized controlled trial of Family Nurture Intervention in the NICU: Assessments of length of stay, feasibility and safety. *BMC Pediatrics, 13,* 148. http://dx.doi.org/10.1186/1471-2431-13-148

Welch, M. G., & Myers, M. M. (2016). Advances in family-based interventions in the neonatal ICU. *Current Opinion in Pediatrics, 28,* 163–169. http://dx.doi.org/10.1097/MOP.0000000000000322

Zelner, S., Beebe, B., & Jaffe, J. (1982, April). *The organization of vocalization and gaze in early mother-infant interactive regulation.* Paper presented at the International Conference Infant Studies, New York City, NY.

Received August 25, 2017
Revision received March 6, 2018
Accepted April 12, 2018 ■