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

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Abstract

Although preterm infants are at risk for social deficits, interventions to improve mother-infant interaction in the 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, *Family Nurture Intervention* (FNI), designed to help mothers and infants establish an emotional connection. At 4 months corrected age, mother-infant face-to-face interaction was filmed and coded on a 1-second 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 infant looking at mother, FNI mothers of male infants were more likely to look at their sons. In maternal gaze self-contingency, following mother looking away, FNI mothers of male infants were more likely to look at their sons. Documentation of positive effects of 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

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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). *Family Nurture Intervention* (FNI) was designed to overcome negative effects of maternal deprivation in the NICU by fostering mother-infant emotional connection (Welch, 2016b; Welch et al., 2012, 2013). This study tests the hypothesis that by four months (corrected age [CA]), 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 birth (Lavelli & Fogel, 2005). Early patterns of mother-infant coordination establish the foundation for infant development in socio-emotional, cognitive, and regulatory domains (Beebe et al., 2010; Feldman, 2007a, b, c; 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 co-regulated social contingencies (Welch, 2016b; Feldman, 2002). With underdeveloped neurobehavioral systems, premature (vs. full term) infants can be difficult-to-read and less socially responsive (Feldman & Eidelman, 2007; Malatesta, Grigoryev, Lamb, Albin, & Culver, 1986). 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 co-regulate cycles of attention and affect with their infants (Lester, Hoffman, & Brazelton, 1985). Recent studies also show 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 sub-optimal infant biosocial outcomes (Feldman & Eidelman, 2006; van Baar, van Waaenaer, Briet, 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 assessmemts (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 (FNI)

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

(1) FNI aims to create *emotional connection* and *autonomic co-regulation* 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) FNI aims to utilize autonomic conditioning via repeated calming sessions to counter adverse NICU experiences and strengthen attraction between mother and infant

(3) mother and infant are equal agents of 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 III), fewer attention problems (Child Behavioral Check List), 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 FNI was first developed to overcome negative consequences of separations such as those that occur with preterm birth or maternal depression (Welch, 1988). While the subcomponents of FNI, olfaction, touch, calming, and vocal expression are analogous to Feldman's regulatory framework and Hofer's 'hidden regulator' sub-processes (Hofer, 1994), Welch argues that Pavlovian autonomic co-conditioning governs these hidden regulators (Welch, 2016a). Hidden regulators are co-conditioned in the viscera/autonomic nervous systems of fetus and mother during gestation. With normal birth, the co-conditioning triggers attraction behaviors and physiological calming, facilitating emotional connection and visceral/autonomic co-regulation. With preterm birth (or other adverse events), co-conditioning can be interrupted. Repeated calming sessions restore emotional connection and physiological co-regulation. We hypothesize 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 bi-directional co-regulation, 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, Messinger, Bahrick, Margolis, Buck & Chen, 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 quantify 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). In prior research on full term samples, 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 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 underlies human relationships (Feldman, 2007, 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 and infant gaze, infant vocal affect, 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, Eidelman, Sirota & Weller, 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, Sirota & Eidelman (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 FNI: (1) partner (mother/infant), (2) type of measure (behavioral frequency/contingency), (3) type of contingency (self/interactive), and (4) modality of behavior (attention, affect, touch).

We hypothesized that 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 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, had a history of drug addiction or mental illness; 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 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 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; (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 languages, 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 hours/week until discharge (Welch, Hofer, Brunelli, Stark, Andrews, Austin, Myers, et al., 2012; Welch et al., 2013).

Procedures at Infant Age 4 Months Corrected Age

At 4 months CA, 80 (N = 37 SC, 43 FNI) of the original 115 mothers returned with their infants for face-to-face play with split-screen filming. New York State Psychiatric Institute Institutional Review Board approved study procedures for "Data Analysis 4 Months: NICU Follow Up" #6718 (expiration 1.21.19). Of N = 115 dyads, 30 were lost at term due to: 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 5 were lost to follow up by 4 months CA. Parents from dyads with 4-month video data were better educated (mother χ^2 = 8.10, p = .017; father χ^2 = 6.78, p = .034), and more likely to be married (χ^2 = 5.48, p = .019), but did not differ with respect to either parent's age and race/ethnicity, or household income category.

Singletons and first-born 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 minutes. A special-effects generator created a split-screen view from input of 2 synchronized cameras (mounted on opposite walls) focused on head and upper torso of mother and infant. Of N = 80, 9 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 vs. 32 SC dyads.

Behavioral coding

The first 2.5 minutes[1] of uninterrupted mother-infant interaction were coded on a one-second 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*, coded on/off the partner's face. *Infant vocal affect* (vocal contour) was coded as high positive, neutral/positive, none, fuss/whimper, angry-protest, cry.

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[1]A 2.5 minute 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; Moore, Cohn, & Campbell, 1997; Weinberg & Tronick, 1991; Zelner, Beebe, & Jaffe, 1982).

Mother touch was coded from affectionate to intrusive: 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), 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 touch to the body-center (Stepakoff, 1999; Stepakoff, Beebe & Jaffe, 2000; Beebe et al., 2010). This maternal touch scale has yielded informative results (Beebe et al., 2007, 2008, 2010, 2016). For all coding details, see Web Appendix A (or Beebe et al., 2010). Inter-coder 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 0.92; touch .90.

From these assessments, we generated 4 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

(4)   infant vocal affect - mother gaze.

Data Analysis

Analyses compared 39 FNI dyads and 32 SC dyads at 4 months CA, using all 150 sec coded from video for each individual. First we tested whether FNI vs. 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, multi-level 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).

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[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) SC variables and their conditional effects can be included as necessary, (d) potential nonlinear relations can be examined in the same analyses, (e) more appropriate statistical model assumptions are made.
[3]A "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-dyad variation in the auto-regressive effect. A "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.

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

Two types of multi-level time-series models: Weighted lag and Individual lags Weighted lag time-series analysis.

Consistent with previous studies, we used a weighted lag approach (Beebe et al., 2007; 2010; 2016). Using a 4-second moving window,[4] the prior 3 seconds (lags 1, 2 and 3: L1, L2, L3) of behavior were used 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 seconds) 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 3 prior lags were evaluated individually with a separate model for each second's association with behavior at the current moment: (L1 → t_0; L2 → t_0, L3 → 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 3 lags; in the former, the values at the 3 lags are weighted by their respective correlations with t_0 and then are 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 vs. SC groups. For simplicity of interpretation, the individual seconds approach does not accommodate the interaction terms

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[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 seconds sufficed to account for these lagged effects on subsequent behavior (t_0). Across the modality pairings studied, mother was significant at 2–3 lags (2–3 seconds) for both self- and interactive contingency; evaluation of longer lags yielded non-significant results. Significant infant lags varied: for self-contingency, 4 lags (vocal affect), 3 (gaze); infant interactive contingency varied from 6 to 3 lags, but the amount of variance accounted for was very small for lags longer than 3 seconds. Note that in the weighted lag analyses, no more than 3 lags, and no fewer than 2, were used in any weighted mean lag, to maintain consistent sample size. By using a standard 3-second 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.

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: (1) lagged effects of self- and partner behavior (self- and interactive contingency); (2) differences in behavioral frequencies (e.g. infant vocal affect) associated with group; (3) differences in self- and interactive contingency associated with group. After removing non-significant terms, the final model was the simplest consistent with the data. Significance level was set at $p < .05$. All tests were 2-tailed. With 71 dyads (39 FNI, 32 SC) and 150 seconds of behavior per individual, the resulting 10,650 seconds 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

Multi-level time-series analyses identify overall group differences in the level of self- and interactive contingency between FNI and SC groups but cannot tell us 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 multi-level 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, for example, percent time transition-matrices) and represents the temporal dynamics.

Our *analysis of predicted values* derived predicted values at t_0 for FNI vs. 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, L3, and infant at L1, L2, 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 vs. 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 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 can interpret relevant findings at each lag of L1, L2, and L3, for mother and 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, as we observed that L1 always had the largest association with t_0, as we expect.

Results

Descriptive Statistics

The first goal was a descriptive evaluation of differences between FNI vs. SC groups. Comparing FNI and SC dyads in mean levels of behaviors using independent t-tests, we found no differences (see Web Appendix B1). Testing percent time spent in each behavior produced no group differences in mother gaze ($\chi^2 = 0.007$, $p = 0.931$), or infant gaze ($\chi^2 = 2.323$, $p = 0.128$); but did produce significant differences in mother touch patterns ($\chi^2 = 197.272$, $p < 0.001$) and infant vocal affect levels ($\chi^2 = 81.166$, $p < 0.001$). FNI (vs. SC) mothers touched their infants a greater percentage of 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) (0.7% vs. SC 1.9%); used more *object-mediated touch* (2.5% vs. SC 0.5%); and used more *intrusive touch* (1.2% vs. SC 0.6%). The latter two types of touch are rare. FNI (vs. SC) infants used more *angry-protest* (1.8% vs. SC 0.8%) but less *cry* (0.4% vs. SC 1.8%).

Influenced by Feldman and colleagues (Feldman, 2007b; Feldman & Eidelman, 2003, 2006), we pursued the possibility of other differences in gaze behavior in FNI vs. 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 co-occurrence within the same second of mutual gaze and mother positive touch (affectionate/static/playful patterns) (see Web Appendix B2).

Self- and Interactive Contingencies in FNI vs. SC Dyads

The second goal was to evaluate differences between the FNI vs. SC groups in levels of self- and interactive contingency for 4 modality pairings: (1) infant gaze - mother touch; (2) infant vocal affect - mother gaze; (3) infant gaze -mother gaze; (4) infant vocal affect - mother touch. For these analyses behavior in the current second is represented as **t_0**; behavior one second prior to the current second is represented as **L1** (t_{-1}); behavior two seconds prior as **L2** (t_{-2}); behavior three seconds prior as **L3** (t_{-3}).

(1) Infant Gaze – Mother Touch

(1a) Infant gaze self-contingency (controlling for mother touch).

Testing across the prior 3 seconds 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 FNI (vs. SC) infants was marginally significantly lower (more variable) from L2 (IG L2 → IG β = −.298, p = .051). The β is an index of degree of contingency.

Analysis of predicted values was used to clarify the details of these results (see Web Appendix 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 SC infants (mean of the top 10 probability values at t_0 = .184 for FNI; .282 for SC).

In summary, given infants were gaze-on 2 seconds 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.

(1b) 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).

(1c) 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 Web Appendix 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.

(1d) 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× 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 $t_{-1} \rightarrow$ infant gaze t_0).

Analysis of predicted values (see Web Appendix C, Table C2) showed that, given infant gaze-on at L1, mother touch was more positive (4 levels higher) at t_0 in FNI (vs. SC) mothers (mean of the top 10 probability values at t_0 = 6.804 for FNI; 2.749 for SC).

In summary, FNI (vs. SC) mothers showed a heightened positive touch response to infant gaze-on (vs. -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.

(2) Infant Vocal Affect - Mother Gaze

(2a) 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 Appendix 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 4 vocal affect levels (mean of the top 10 probability values at t_0 = 6.677 for FNI; 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).

(2b) 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 Web Appendix 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 4 vocal affect levels (mean of the top 10 probability values at t_0 = 6.677 for FNI; = 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.

(2c) Mother gaze self-contingency (controlling for infant vocal affect).

Testing with a weighted lag approach, FNI vs. SC differences in maternal gaze self-contingency (controlling for prior infant vocal affect) were a function of infant sex. The 3-way interaction effect (MG *Group*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 1, the self-contingency of FNI mothers of males (β = .428) was lower than that of SC mothers of males (β = .647), and significantly different (β = .220; p = .004); but the self-contingency of FNI vs. SC mothers of females did not differ (β = −.084; p = .226). Thus, FNI vs. SC differences in mother gaze self-contingency were seen only in mothers of male infants. Within the FNI group, the self-contingency of mothers of male infants was lower than that of females (β = −.212, p = .003); within the SC group, mothers of male vs. female infants did not differ (β = .091, p =.225). Thus, differences in the effect of gender on mother gaze self-contingency were seen only in the FNI group. Testing for the predictability of each individual second, Table 4 shows no findings.

Analysis of predicted values (see Web Appendix C, Table C4) showed that, given mother gaze-off at L1, FNI (vs. SC) mothers of males 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 vs. .436 for SC.

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

(2d) 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 vs. SC differences in mother gaze coordination with prior infant vocal affect.

(3)   Infant Gaze – Mother Gaze

(3a) Infant gaze self-contingency (controlling for mother gaze).

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

Analysis of predicted values (see Web Appendix 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} = .643 for FNI infants and = .556 for SC infants.

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

(3b) 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 FNI or SC dyads.

(3c) 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 3-way interaction effect (MG *Group*Sex → MG β = .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 4, the self-contingency of SC mothers of male infants (β = .642) was higher than that of FNI mothers of males (β = .378), and significantly different (β = .264; p < .001); but the self-contingency of FNI vs. SC mothers of females 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 only in mothers of male infants. Within the FNI group, the self-contingency of mothers of males was lower (more variable) than that of mothers of females ($\beta = -.267$; p < .001); within the SC group, mothers of male vs. 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 (Web Appendix C, Table C6) showed that, given mother gaze-off at L1, FNI (vs. SC) mothers of male (vs. female) infants were more likely to be gaze-on in the current second. The mean probability of the top 10 values at t_0 = .851 for FNI mothers of males, compared to .613 for SC mothers of males.

In summary, the findings for mother gaze self-contingency (controlling for infant gaze) are similar to those in pairing (1) (controlling for infant vocal affect). Given mother gaze-off in the prior second, FNI mothers of males are more likely to be gaze-on in the current second.

(3d) Mother gaze interactive contingency (infant gaze predicting mother gaze).

Testing with a weighted lag, Table 5 shows that differences in FNI vs. 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 3-way interaction effect (IG*Group*Sex → MG β = −.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 4, the interactive contingency of SC mothers of male infants (β = .099) was lower than that of FNI mothers of males (β = .358), and significantly different (β = −.258; p = .019); but the interactive contingency of FNI vs. SC mothers of female infants did not differ (β = .185; p = .076) (see Figure 1). Thus, the effect of FNI (vs. SC) on mother gaze interactive contingency was seen only in mothers of male infants. Within the FNI group, the interactive contingency of mothers of male infants was higher than that of females (β = .283, p = .005); within the SC group, mothers of male vs. female infants did not differ (β = −.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 Web Appendix C, Table C6). Given male infants were gaze-on at L1, FNI (vs. SC) mothers of males 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 = .851 for FNI mothers of males, compared to .613 for SC mothers of males.

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

(4)   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 Web Appendix C, Tables C7 and C8. Because the results of this modality pairing were redundant with those presented above, we describe them in Web Appendix 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, 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, 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 NICU (compared to standard care) facilitated more optimal mother-infant face-to-face interaction at 4 months CA. Dyads who received FNI demonstrated: (a) greater frequency of maternal touch and more optimal maternal touch patterns; (b) greater frequency of more optimal (less extreme) infant expression of vocal distress; (c) more optimal maternal coordination of touch patterns with infant gaze patterns; (d) greater likelihood of *sustaining positive patterns*, specifically, maternal positive touch patterns and infant positive vocal affect patterns; (e) greater likelihood of *repair* patterns, whereby moments of negative maternal touch, or of negative infant vocal affect, transitioned into positive behavioral patterns; (f) greater likelihood of infant visual re-engagement after a moment of infant looking away; and (g) for mothers of male infants, greater likelihood of maternal visual re-engagement after a moment of mother looking away, and of maternal 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 et al., 2003), and interventions utilizing touch improve infant outcomes (Álvarez et al., 2017; Moore, Bergman, Anderson & Medley, 2016). 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 not only showed 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 a global coding scheme (CIB). Using a more detailed coding of infant vocal distress, our findings refine our 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 is 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 vs. 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 re-engagement. 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 re-engagement. When infants looked at their mothers, FNI (vs. SC) mothers of males were more likely to join their sons in looking, thus more contingently responsive. Intervening in the NICU with kangaroo care, Feldman, Weller et al. (2002) similarly found 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, Fornieles-Deu, Costas-Moragas, & Botet-Mussons, 2015), and 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 FNI would increase the capacity of infants and mothers to contingently coordinate with each other was upheld, in maternal touch coordination with infant gaze, and in maternal gaze coordination with infant gaze for mothers of males. However, the bulk of the findings concerned self-contingency.

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 re-engage. 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 co-regulation of the interactive system.

In prior work, self-contingency has frequently been a more sensitive variable than 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 co-constituted, with each process affecting the other. This co-constitution is consistent with Calming Cycle Theory (Welch, 2016a), which describes mother and infant as an open biobehavioral system of feedback loop co-regulation. We speculate that the self-contingency processes that we documented at 4 months stemmed from this co-regulation 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/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 Family Nurture Intervention in the NICU generated more positive forms of mother and infant engagement at 4 months CA. Our micro-level 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 our 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 FNI for 4-month mother-infant face-to-face communication has important implications for an improved developmental trajectory of these infants.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Mother Gaze Interactive Contingency

(Male infant: p = .019)

Mother Gaze Self-Contingency
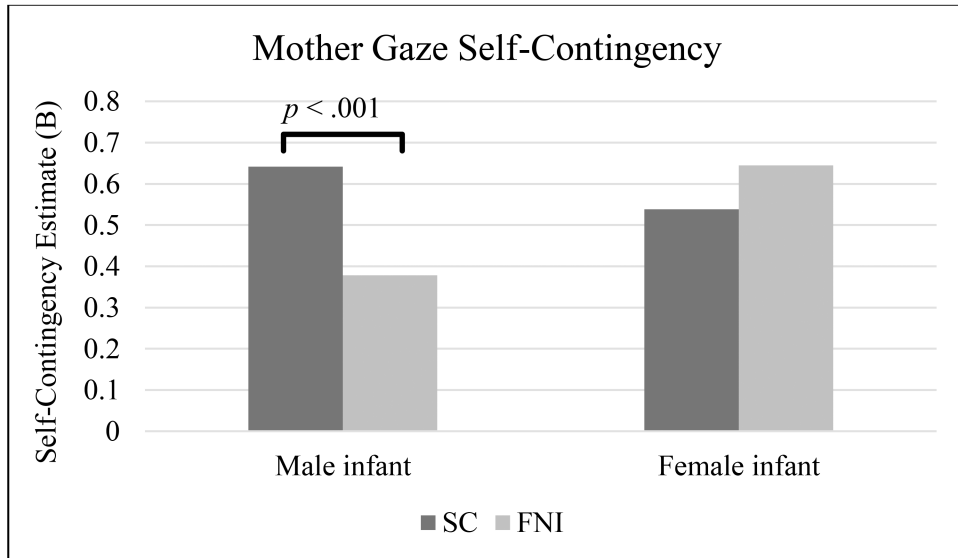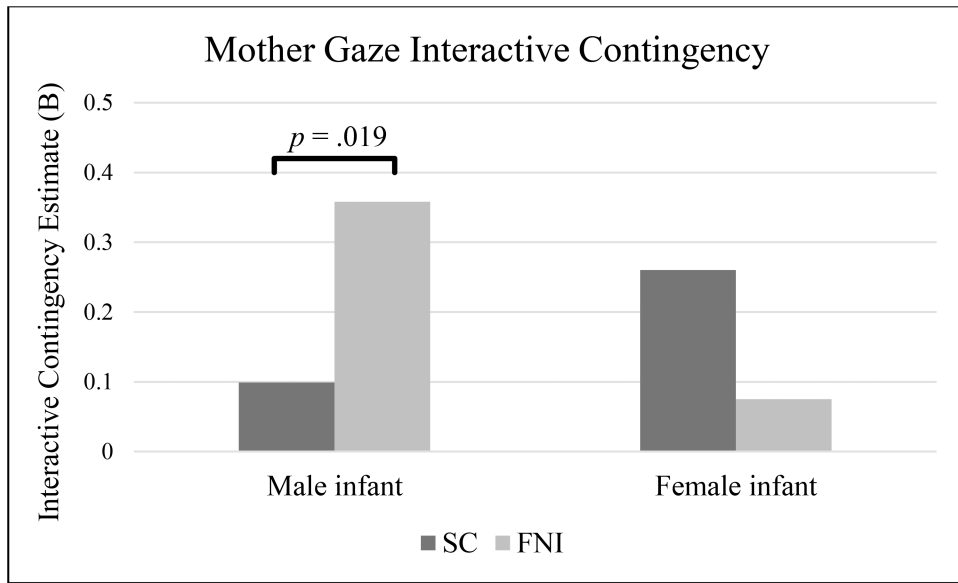
(Male infant: p < .001)

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.

Note For mothers of male infants: (1) mother gaze interactive contingency of FNI mothers was higher than that of SC mothers; (2) 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.

Table 1.

Infant Gaze - Mother Touch: Weighted Lag Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

	Infant Gaze	**β**	**SEβ**	**p**
SC	IG → IG[1]	1.338	.055	<.001
	MT → IG	.029	.093	.755
	I Sex[2]	−.091	.179	.613
	IG * Sex→ IG[3]	.062	.061	.310
	MT * Sex→ IG	.196	.084	.021
FNI	IG → IG	1.412	.051	<.001
	MT → IG	.061	.033	.064
[4]	Group	−.012	.180	.945
	IG * Group → IG[5]	.074	.062	.232
	MT* Group →IG	.032	.097	.738

	Mother Touch	**β**	**SEβ**	**p**
SC	MT → MT	5.783	.154	<.001
	IG → MT	.261	.120	.029
	I Sex	−.185	.207	.376
	MT * Sex→ MT	−.278	.139	.045
	IG * Sex→ MT	−.403	.131	.002
FNI	MT → MT	4.709	.086	<.001
	IG → MT	.601	.111	<.001
	Group	.236	.208	.260
	MT * Group → MT	**−1.074**	**.170**	**<.001**
	IG * Group → MT	**.340**	**.132**	**.010**

[1] IG → IG = infant gaze predicting infant gaze: infant gaze self-contingency; MT → IG = mother touch predicting infant gaze: infant gaze interactive contingency with mother touch; these contingency terms represent baseline effects for male infants. Arrow = direction of prediction; predicted variable is to the right of the arrow; weighted lag term is 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 (see Table 2) are not.

[2] Sex = difference in level of infant gaze for female (vs. male) infants.

[3] IG * Sex → IG: additional effect of being female on contingency (female = 1, male = 0).

[4] = difference between FNI (Family Nurture Intervention) vs. SC (Standard Care) groups.

[5] IG * Group → IG: additional effect of being in FNI intervention group (FNI = 1, SC = 0).

Note. Models included time and intercept. Beta values 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 FNI group. To determine significance of contingencies of FNI group, we reversed the 0/1 coding of FNI vs. SC and re-ran the models. We include main effects for these models and show significance of baseline contingencies for FNI group (without other terms in the model). We include terms for sex, or 3-way interaction terms (*sex*group), only where significant.

Table 2.

Infant Gaze – Mother Touch: Individual Seconds Time Series Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

	Infant Gaze	β	SEβ	p	Mother Touch	β	SEβ	p
SC	IG L1 → IG [1]	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 [2]	−.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
	Group (GP)	−.037	.183	.840	Group (GP)	.263	.204	.202
	IGL1*GP→IG	.231	.133	.083	MT**L1***GP→MT	**−.317**	**.035**	**<.001**
	IG **L2*** GP→IG	**−.298**	**.152**	**.051**	MTL2*GP→MT	.025	.043	.557
	IG L3* GP→IG	.226	.142	.112	MT**L3***GP→MT	**.178**	**.035**	**<.001**
	MTL1*GP→IG	.020	.016	.200	IG **L1***GP→ MT	**1.127**	**.342**	**.001**
	MTL2*GP→IG	.002	.021	.927	IG L2*GP→ MT	−.445	.380	.242
	MTL3*GP→IG	−.013	.019	.513	IG L3*GP→ MT	−.463	.338	.171

[1] L1 = 1 sec lag (1 second prior); L2 = 2 sec lag; L3 = 3 sec lag.

[2] Model testing for MT L1, L2, L3 also includes IG L1, L2, L3; that is, of the six terms, all control for the other five.

Table 3.

Infant Vocal Affect - Mother Gaze: Weighted Lag Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

Infant Vocal Affect		β	SE β	p
	IV → IV	2.987	.228	<.001
	MG → IV	.033	.150	.824
SC	Sex	.777	.492	.119
	IV * Sex→ IV	4.335	.240	<.001
	MG * Sex → IV	.048	.162	.769
FNI	IV → IV	.553	.224	.014
	MG → IV	.123	.138	.375
	Group	.110	.494	.824
	IV * Group → IV	**−2.424**	**.257**	**<.001**
	MG * Group → **IV**	.089	.162	.582

Mother Gaze		β	SEβ	p
	MG → MG	.647	.055	<.001
	IV → MG	.140	.122	.251
SC	I Sex	.029	.206	.890
	MG * Sex → MG	−.091	.075	.225
	IV * Sex → MG	−.042	.096	.662
FNI	MG → MG	.428	.053	<.001
	IV → MG	−.051	.082	.534
	Group	−.086	.207	.680
	MG * Group → MG	−.219	.076	.004
	IV * Group → MG	−.190	.137	.165
	MG * Group* Sex → MG[1]	**.303**	**.103**	**.003**

MG*Group*Sex →MG	SC		FNI		SC vs. FNI	
	β	p	β	p	β	p
Male infant	.647	< .001	.428	<.001	**.220**	**.004**
Female infant	.556	<.001	.640	<.001	−.084	.226
Male vs. Female	.091	.225	−.212	.003		

Note. See Table 1 footnotes for explanation of terms. IV = infant vocal affect.

[1]The table below shows the betas, and significance tests of their differences, relevant to the 3-way interaction effect.

Table 4.

Infant Vocal Affect – Mother Gaze: Individual Seconds Time Series Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

	Infant Vocal Affect	β	SEβ	p	Mother Gaze	β	SEβ	p
	IV **L1** → IV	.647	.030	<.001	MG **L1** → MG	1.578	.109	<.001
	IV L2 → IV	.046	.037	.213	MG **L2** → MG	.604	.120	<.001
	IV **L3** → IV	.173	.033	<.001	MG **L3** → MG	.435	.119	<.001
SC	MG L1 → IV	−.396	.361	.273	IV L1 → MG	−.008	.013	.515
	MG L2 → IV	.014	.374	.970	IV L2 → MG	.049	.055	.366
	MG L3 → IV	−.244	.360	.498	IV L3 → MG	.010	.029	.739
	IV **L1** → IV	−.256	.012	<.001	MG **L1** → MG	1.549	.099	<.001
	IV **L2** → IV	.212	.012	<.001	MG **L2** → MG	.555	.108	<.001
FNI	IV L3 → IV	.205	.012	<.001	MG **L3** → MG	.309	.109	.005
	MG L1 → IV	.592	.322	.066	IV L1 → MG	−.005	.004	.282
	MG L2 → IV	−.533	.332	.109	IV L2 → MG	−.008	.004	.068
	MG L3 → IV	.319	.319	.318	IV L3 → MG	−.003	.005	.580
	Group (GP)	.110	.494	.824	Group (GP)	−.086	.207	.680
	IV**L1***GP → IV	**−.903**	**.032**	**<.001**	MGL1*GP→ MG	−.029	.148	.843
	IV**L2***GP → IV	**.166**	**.039**	**<.001**	MGL2*GP→ MG	−.049	.162	.763
	IVL3*GP → IV	.032	.036	.375	MGL3*GP→ MG	−.127	.162	.434
	MG**L1***GP → IV	**.988**	**.484**	**.041**	IVL1*GP → MG	.003	.013	.795
	MGL2*GP → IV	−.546	.500	.275	IVL2*GP → MG	−.057	.055	.295
	MGL3*GP → IV	.563	.482	.242	IVL3*GP → MG	−.012	.030	.677

Note. See Table 1 and 2 footnotes for explanation of terms.

Table 5.

Infant Gaze - Mother Gaze: Weighted Lag Analyses for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

Infant Gaze		β	SEβ	p
SC	IG → IG	1.365	.047	<.001
	MG → IG	.067	.046	.148
FNI	IG → IG	1.431	.041	<.001
	MG → IG	.024	.042	.561
	Group	.005	.179	.979
	IG * Group → IG	.062	.062	.322
	MG * Group → IG	−.043	.062	.491

Mother Gaze		β	SE6	p
SC	MG → MG[1]	.642	.056	<.001
	IG → MG[1]	.100	.082	.224
	I Sex	.013	.206	.951
	MG * Sex → MG[2]	−.104	.077	.176
	IG * Sex → MG[2]	.161	.114	.159
FNI	MG → MG	.378	.055	<.001
	IG → MG	.358	.073	<.001
	Group	−.066	.206	.750
	MG * Group → MG[3]	−.264	.078	<.001
	IG * Group → MG[3]	.258	.110	.019
	MG * Group * Sex → MG[4]	**.371**	**.105**	**<.001**
	IG * Group * Sex → MG[4]	**−.443**	**.152**	**.004**

MG*Group*Sex →MG	SC		FNI		SC vs. FNI	
	β	p	β	p	β	p
Male infant	.642	< .001	.378	<.001	.264	<.001
Female infant	.538	<.001	.645	<.001	−.107	.128
Male vs. Female	.104	.176	−.267	<.001		

MG*Group*Sex →IG	SC		FNI		SC vs. FNI	
	β	p	β	p	β	p
Male infant	.099	.224	.358	<.001	−.258	.019
Female infant	.260	.001	.075	.268	.185	.076
Male vs. Female	−.161	.159	.283	.005		

Note. See Table 1 footnotes for explanation of terms.

[1]MG → MG; IG → MG: contingency term alone represents the baseline effect for males.

[2]MG * Sex → MG; IG * Sex → MG: effect of being female on contingency (female 1, male 0).

[3]MG * Group → MG; IG * Group → MG: effect of being in FNI group (FNI = 1, SC = 0).

[4]MG * Group * Sex → MG; IG * Group*Sex → MG: 3-way interaction among prior mother gaze, group, and sex, for mother self-contingency (β = .371, p < .001), and mother interactive contingency (β = −.443, p < .001). Tables below show betas and significance tests of differences relevant to the 3-way interaction effects.

Table 6.

Infant Gaze – Mother Gaze: Individual Seconds Time Series Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

	Infant Gaze	β	SEβ	p	Mother Gaze	β	Seβ	p
	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
SC	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
	IG L1 L IG	2.449	.089	<.001	MG L1 L MG	1.506	.101	<.001
	IG L2 L IG	.248	.012	.015	MG L2 L MG	.564	.110	<.001
FNI	IG L3 L IG	.604	.093	<.001	MG L3 L MG	.269	.112	.016
	MG L1 → IG	.139	.122	.252	IG L1 → MG	.439	.120	<.001
	MG L2 → IG	−.099	.123	.422	IG L2 → MG	−.299	.132	.024
	MG L3 L→ IG	−.027	.120	.823	IG L3 → MG	.363	.119	.002
	Group (GP)	−.037	.183	.841	Group (GP)	−.072	.211	.735
	IGL1*GP → IG	.171	.133	.199	MGL1*GP → MG	−.042	.150	.780
	IGL2*GP → IG	**−.298**	**.152**	**.050**	MGL2*GP → MG	−.001	.164	.995
	IGL3*GP → IG	.269	.142	.059	MGL3*GP → MG	−.192	.165	.244
	MGL1*GP → IG	−.048	.184	.795	IGL1* GP → MG	.154	.182	.397
	MGL2*GP → IG	−.037	.188	.845	IGL2* GP → MG	−.323	.198	.101
	MGL3*GP → IG	−.155	.182	.396	IGL3* GP → MG	.301	.181	.096

Note. See Tables 1 and 2 footnotes for explanation of terms.

Table 7.

Infant Vocal Affect - Mother Touch: Weighted Lag Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

Infant Vocal Affect		β	SEβ	p
	IV → IV	2.638	.209	<.001
	MT → IV	.180	.236	0.445
SC	I Sex	.783	.552	.160
	IV * Sex → IV	4.124	.233	<.001
	MT * Sex→ IV	−.050	.174	.775
FNI	IV → IV	.312	.219	.155
	MT → IV	.024	.102	.814
	Group	.149	.553	.792
	IV * Group → IV	**−2.327**	**.247**	**<.001**
	MT * Group→ IV	−.156	.249	.532

Mother Touch		*β*	*SEβ*	*p*
SC	MT → MT	5.593	.159	<.001
	IV → MT	.039	.128	.760
FNI	MT → MT	4.286	.070	<.001
	IV → MT	.069	.084	.412
	Group	.187	.226	.411
	MT * Group→ MT	**−1.307**	**.174**	**<.001**
	IV * Group → MT	.030	.153	.844

Note. See Table 1 footnotes for explanation of terms.

Table 8.

Infant Vocal Affect – Mother Touch: Individual Seconds Time Series Analysis for Standard Care (SC) and Family Nurture Intervention (FNI) and their Differences ( )

	Infant Vocal Affect	β	SE β	p	Mother Touch	β	Seβ	p
	IV L1 → IV	.330	.022	<.001	MT L1 → MT	.714	.033	<.001
	IV L2 → IV	.134	.033	<.001	MT L2 → MT	.093	.041	.022
SC	IV L3 → IV	.236	.032	<.001	MT L3 → MT	−.026	.033	.430
	MT L1 → IV	−.049	.042	.241	IV L1 → MT	.013	.017	.461
	MT L2 → IV	.082	.051	.107	IV L2 → MT	−.012	.026	.644
	MT L3 → IV	−.028	.042	.509	IV L3 → MT	.001	.025	.967
	IV L1 → IV	−.226	.011	<.001	MT L1 → MT	.437	.010	<.001
	IV L2 → IV	.207	.012	<.001	MT L2 → MT	.060	.011	<.001
FNI	IV L3 → IV	.187	.012	<.001	MT L3 → MT	.145	.010	<.001
	MT L1 → IV	.005	.013	.669	IV L1 → MT	.011	.008	.207
	MT L2 → IV	.011	.014	.444	IV L2 → MT	.002	.008	.807
	MT L3 → IV	−.025	.013	.056	IV L3 → MT	−.016	.009	.070
	Group (GP)	.221	.553	.691	Group (GP)	.213	.222	.342
	IV**L1***GP → IV	**−.556**	**.025**	**<.001**	MT**L1***GP → MT	**−.277**	**.035**	**<.001**
	IV**L2***GP → IV	**.073**	**.035**	**.038**	MTL2*GP → MT	−.033	.042	.435
	IVL3*GP → IV	−.049	.034	.150	MT**L3***GP → MT	**.171**	**.035**	**<.001**
	MTL1* GP → IV	.054	.044	.213	IVL1*GP → MT	−.002	.019	.903
	MTL2* GP → IV	−.072	.053	.176	IVL2*GP → MT	.014	.028	.607
	MTL3* GP → IV	.003	.044	.944	IVL3*GP ↔ MT	−.017	.027	.525

Note. See Tables 1 and 2 footnotes for explanation of terms.