Developmental Psychology
2016, Vol. 52, No. 4, 556–571

0012-1649/16/$12.00 http://dx.doi.org/10.1037/a0040085

A Systems View of Mother–Infant Face-to-Face Communication

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Principles of a dynamic, dyadic systems view of mother–infant face-to-face communication, which considers self- and interactive processes in relation to one another, were tested. The process of interaction across time in a large low-risk community sample at infant age 4 months was examined. Split-screen videotape was coded on a 1-s time base for communication modalities of attention, affect, orientation, touch, and composite facial-visual engagement. Time-series approaches generated self- and interactive contingency estimates in each modality. Evidence supporting the following principles was obtained: (a) Significant moment-to-moment predictability within each partner (self-contingency) and between the partners (interactive contingency) characterizes mother–infant communication. (b) Interactive contingency is organized by a bidirectional, but asymmetrical, process: Maternal contingent coordination with infant is higher than infant contingent coordination with mother. (c) Self-contingency organizes communication to a far greater extent than interactive contingency. (d) Self- and interactive contingency processes are not separate; each affects the other in communication modalities of facial affect, facial-visual engagement, and orientation. Each person's self-organization exists in a dynamic, homoeostatic (negative feedback) balance with the degree to which the person coordinates with the partner. For example, those individuals who are less facially stable are likely to coordinate more strongly with the partner's facial affect and vice versa. Our findings support the concept that the dyad is a fundamental unit of analysis in the investigation of early interaction. Moreover, an individual's self-contingency is influenced by the way the individual coordinates with the partner. Our results imply that it is not appropriate to conceptualize interactive processes without simultaneously accounting for dynamically interrelated self-organizing processes.

Keywords: mother–infant face-to-face communication, dynamic systems, self- and interactive contingency

Supplemental materials: http://dx.doi.org/10.1037/a0040085.supp

Interactive process remains a key issue in the study of mother–infant interaction, with implications for typical and atypical development. We offer a dynamic, dyadic systems view of mother–infant face-to-face communication at 4 months and test principles derived from this view. Our perspective is dynamic because it addresses the *temporal process* of relating from moment-to-moment (contingency). A system's organization emerges from the coordination of its components (Lickliter & Honeycutt, 2003; Piers, 2005; Thelen & Smith, 1994). We address the ways that the components (mother and infant) of a coupled system (the dyad) affect one another, moment-to-moment.

We examine each person's behavior in relation to his or her own prior behavior, *self-contingency*, and in relation to the partner's prior behavior, *interactive contingency*. Most research has investigated maternal contingent coordination with infant, less research has investigated infant contingent coordination with mother, and

This article was published Online First February 15, 2016.

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We thank Dafne Milne, Nataliya Rubinchik, Julie Ewing, Patricia Cohen, Howard Andrews, and Sang Han Lee. This work was partially supported by grants from NIMH RO1 MH56130, the Bernard and Esther Besner Infant Research Fund, the Fund for Psychoanalytic Research of the American Psychoanalytic Association and the Kohler Stiftung (Beebe); grants from NIH R01GM105004 and NSF BCS1052736 and BCS-1323927 (Messinger); grants from NICHD R01 HD05776 and K02 HD064943 (Bahrick).

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little research has addressed self-contingency. We aim to show that a consideration of self-contingency, one aspect of self-regulatory processes, enhances our understanding of mother–infant communication as a dynamic system; and that self-regulatory and other-regulatory processes are intimately related. We operationalize self- and other-regulatory processes using time-series methods, which examine the moment-to-moment process of interaction.

Systems views of mother–infant face-to-face communication have been described by various investigators. Sander (1977) argued that both partners generate complexly organized behavior that must be coordinated in a bidirectional process of mutual modification. Gianino and Tronick (1988) described interactive exchanges as a product of the integration of self- and interactive regulation, which are concurrent and reciprocal, each affecting the other. Fogel (1993) described all behavior as unfolding in the individual while at the same time continuously modifying and being modified by the changing behavior of the partner. Jaffe, Beebe, Feldstein, Crown, and Jasnow (2001) described each person's behavior as created in the process of joint coordination with the partner. In Sameroff's (1983, 2010) view, self-regulatory activity and other-regulatory activity are intimately related and should be considered elements of a single system.

Although systems views of communication provide an important perspective on infant social development, they remain relatively unexplored empirically. Studies of interactive regulation and of self-regulation have typically been conducted separately. These two aspects of regulation, however, constitute an integrated system, as each person must regulate her ongoing behavior and at the same time monitor and coordinate with the partner. Self- and interactive regulation are concurrent and reciprocal processes, each affecting the outcome of the other (Gianino & Tronick, 1988). This dyadic systems perspective takes into account both how the person is affected by his own behavior, as well as by that of the partner (Thomas & Malone, 1979; Thomas & Martin, 1976). Predictable processes within individuals provide the ongoing temporal information necessary to anticipate and coordinate with one's partner (Beebe et al., 2010; Tronick, 1989; Warner, 1992). Typically, self-regulation has been assessed through specific behaviors (Kopp, 1989), such as infant gaze aversion, which down-regulates arousal (Field, 1981), or infant self-touch, which facilitates gaze maintenance (Koulomzin et al., 2002). But any behavioral pattern in a face-to-face encounter, such as an individual's looking at and looking away from the partner, can be viewed as participating in both self- and interactive processes; that is, regulating the individual's own rhythms of looking, as well as communicating with the partner (Overton, 1998). Nevertheless, little research considers both self- and interactive processes and their interrelation, our central goal.

Contingency Processes

"Self- and interactive contingency" are used to provide more specific operationalization to the terms "self- and interactive regulation" (see e.g., Beebe et al., 2007, 2008, 2010, 2011). We define contingency as a temporal relation between the occurrence of two events (Tarabulsy, Tessier, & Kappas, 1996; Watson, 1985) that involves sequential coordination.

Contingency processes are essential to social communication. Infants are sensitive to the ways in which their behaviors are contingently responded to by social partners (Hains & Muir, 1996; Murray & Trevarthen, 1985; Tamis-LeMonda, Bornstein, & Baumwell, 2001). By 4 months, infants are adept at perceiving contingent relations, discriminating the strength of these relations, and generating expectancies (predictions) based on these contingencies (DeCasper & Carstens, 1980; Haith, Hazan, & Goodman, 1988; Harrist & Waugh, 2002; Tarabulsy et al., 1996; Watson, 1985). The prediction of events and the creation of expectancies about their time course is one foundation of the infant's communicative capacity, facilitating information processing, memory, and the procedural representation of interpersonal events (Fagen, Morrongiello, Rovee-Collier, & Gekoski, 1984; Hay, 1997; Lewis & Goldberg, 1969; Tronick, 1989).

Studies of interactive contingency in face-to-face communication have documented that by 3–4 months, mothers and infants contingently coordinate their behaviors. They coordinate gaze on/off the partner, yielding mutual gaze; facial expressions, often termed *facial mirroring*; vocal rhythms, such as speech rate and turn taking; orientation patterns, such as mutual approach or approach–avoid; and touch patterns (Beebe et al., 2010; Bigelow, 1998; Cohn & Tronick, 1988; Feldman, 2007; Jaffe et al., 2001; Lester, Hoffman, & Brazelton, 1985; Malatesta, Culver, Tesman, & Shepard, 1989; Stern, 1971; Tronick, 1989). A sophisticated understanding of interactive contingency has resulted, but self-contingency has been neglected. Only a few studies have addressed self-contingency as a variable in its own right (Beebe et al., 2007, 2010; Chow et al., 2010; Messinger, Ekas, Ruvolo, & Fogel, 2012).

Contingency has been measured in a variety of ways, depending in part on the type of coding used (Symons & Moran, 1994). One central distinction concerns event- versus time-based (continuous data) contingency methods. Event-based approaches assess contingent coordination from one discrete behavior to another. Within event-based approaches, and within a particular direction of influence, such as mother to infant, the dimensions of "responsiveness" (given mother smiles, infant smiles predictably follow) versus "dependency" (mother smiles must occur before an infant smile can be observed) may be distinguished (Bigelow & Power, 2014; Symons & Moran, 1994; Tarabulsy et al., 1996; Watson, 1985).

Whereas event-based approaches describe more detailed sequences of specific behaviors, time-based (here "time-series") approaches describe the overall picture of the interaction. Time-series approaches (Chen & Cohen, 2006) assess contingent coordination across the whole range of values being assessed. They require continuous sampling of equal time intervals and make assumptions about ordinalization of behavior, such as ordering degrees of positive to negative facial expressions. For example, in the current study maternal facial affect interactive contingency measures how closely mothers coordinate their entire range of facial expression changes with prior infant facial expression changes. Within time-series approaches, studies vary with respect to (a) whether coordination is assessed at the same moment for both partners, which does not distinguish direction of influence; (b) when direction of influence is assessed, whether it is assessed for both partners, that is, how each individual's prior moment of behavior predicts the partner's current moment of behavior; (c) and whether self-contingency (autocorrelation) is controlled statistically or, in addition, is used as a variable in its own right. In this study we use time-series approaches because they are designed to disembed self- and interactive processes.

Time-series approaches are used to identify the organization of a single time series, that is, how the series of one person's behaviors unfold in time; and the interrelatedness of two time-series, that is, whether and to what degree the series of behaviors of both partners influence each other as they progress in time. The individual's moment-to-moment adjustments to her own prior behavior define self-contingency (autocorrelation), and her adjustments to her partner's prior behavior define interactive contingency (lagged cross-correlation; Chen & Cohen, 2006). In a bivariate series, each partner may predict the other (bidirectional influence) or only one may predict the other (unidirectional influence). In assessing interactive process we differentiate direction of influence for both partners.

Autocorrelation accounts for a large amount of variance in a time series. Consequently, analysts have typically controlled for it statistically (Cohn & Tronick, 1988; Gottman, 1981) without considering it as a variable in its own right. But infants' moment-to-moment patterning of their social behaviors, and the degree to which current action is influenced by prior action, is fundamental to our understanding of their social competence. Our measure of self-contingency addresses this aspect of infant social capacity, which has been relatively neglected (for exceptions see Beebe et al., 2007, 2010; Chow, Haltigan, & Messinger, 2010; Messinger et al., 2012).

Self-contingency, the degree to which the prior state predicts the next observed state, is one form of self-regulatory process (Beebe et al., 2007, 2008, 2011; Chow et al., 2010; Thomas & Martin, 1976; Warner, 1992). It indexes the stability–variability of each person's own behavioral rhythms over time, in the presence of a particular partner. For example, infant facial affect self-contingency measures how predictably infant degrees of positive to negative facial expressions unfold from moment-to-moment.

Interactive contingency indexes moment-to-moment adjustments that each individual makes to the partner's prior behavior. Metaphorically interactive contingency measures expectancies of "how I affect you" and "how you affect me."

In our approach, contingency is a neutral concept. However, in relation to clinical issues, 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, 2011; Feldman, 2007; Jaffe et al., 2001; Leyendecker, Lamb, Fracasso, Scholmerich, & Larson, 1997; Malatesta et al., 1989). Here we step back from clinical distinctions to ask how the dyadic system functions generally across a large community sample.

Homeostatic Regulation

Although systems theories address both self- and interactive components, their interrelation is rarely empirically addressed. We propose below that this interrelation can be understood as a form of homeostatic regulation. Mother–infant interactions are mediated by homeostatic control "mechanisms" that affect the balance between behavioral excitation and inhibition, facilitating dyadic regulation (Feldman, 2007; Feldman & Greenbaum, 1997; Lester et al., 1985). Homeostatic refers to noncausal methods, which maintain a relatively stable state of equilibrium around a goal or set point. Whereas a positive feedback system amplifies deviations, a negative feedback system counteracts deviations in the system. Negative feedback systems typically show negative correlations (Beebe, Jaffe, Feldstein, Mays, & Alson, 1985; Jaffe et al., 2001). Jaffe et al. (2001) predicted secure attachment from midrange degrees of mother–infant interactive contingency of vocal rhythms at 4 months and insecure types from higher and lower degrees. They interpreted the findings as indexing a dyadic control system in which extremes of contingency are optimally counterbalanced, biasing the system toward a midrange set point. We anticipate that self- and interactive contingency will be organized through a homeostatic form of regulation, hence, negatively correlated.

Dynamic Dyadic Systems View: Predictions

We tested the following principles of mother–infant face-to-face dyadic interaction:

1. **Both self- and interactive contingency organize face-to-face communication.** We tested this principle by investigating the extent to which the prior behavior of each individual predicts the current behavior of the self (self-contingency) and of the partner (interactive contingency) in a variety of communicative modalities across a large sample of infant–mother dyads.

2. **Interactive contingency is organized by a bidirectional, but asymmetrical, process: Maternal contingent coordination with infant is higher than that of infant with mother.** Findings of bidirectional coordination are consistent with the literature (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008; Chow et al., 2010; Cohn & Tronick, 1988; Jaffe et al., 2001; Sameroff, 2010; Tronick, 1989). However, most prior research has documented bidirectionality dyad by dyad, finding evidence for bidirectionality for some proportion of dyads (see Cohn & Tronick, 1988; Jaffe et al., 2001). In contrast, we tested within-dyad processes for the group of dyads as a whole. Moreover, mothers have greater range, control, and flexibility than infants. We anticipate that mothers will be more responsive to infants than vice versa, consistent with the literature (Chow et al., 2010; Keller, Lohaus, Volker, Cappenberg, & Chasiotis, 1999; Van Egeren, Barratt, & Roach, 2001). As a consequence, infants would have more "influence" on mothers than vice versa.

3. **Self-contingency organizes face-to-face communication to a greater extent than interactive contingency.** We tested this principle by evaluating the respective weights of self- versus interactive contingency, an oft-ignored facet of interaction analyses (but see Beebe et al., 2007; Chow et al., 2010; Gottman, 1981; McCleary & Hay, 1980). We predict that self-contingency organizes the interaction to a greater degree than interactive contingency, consistent with the well-known large effects of self-contingency (measured as autocorrelation; see also Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998, in adult interaction).

4. **Face-to-face communication is characterized by a dynamic homoeostatic (negative feedback) balance between self- and interactive contingency.** We predict that the magnitudes of an individual's indices of self- and interactive contingency are negatively correlated, such

that the higher the self-contingency, the lower the interactive contingency, and vice versa. To our knowledge, this is the first such evaluation.

Approach

We study infants at 4 months because infant social capacities flower at 3–4 months. By this time infant ability to regulate states of arousal has matured, the capacity to engage and disengage social attention has developed, and a sustained face-to-face encounter is possible (Stern, 1985; Tronick, 1989). With others, we argue that 3–6 months is a "window of opportunity" for assaying infant social capacity (Feldman, Greenbaum, Yirmiya & Mayes, 1996; Stern, 1974, 1985; Tronick, 1989). Infant social interaction at 3–6 months robustly predicts later social and cognitive development (see e.g., Beebe et al., 2010; Field, 1995; Isabella & Belsky, 1991; Jaffe et al., 2001; Leerkes, Blankson, & O'Brien, 2009; Lewis & Feiring, 1989; Leyendecker, Lamb, Fracasso, Scholmerich, & Larson, 1997; Malatesta et al., 1989).

Face-to-face communication generates multiple simultaneous signals, but most research examines a single modality at a time, ignoring this multimodal reality (Bahrick & Lickliter, 2002). Because communication modalities are likely to differ (Kaye & Fogel, 1980; Keller et al., 1999; Van Egeren et al., 2001), we examine attention, affect, orientation, and touch. Few studies examine all these modalities. Doing so provides a far richer view of how the interaction is organized.

An alternative approach is that of a priori configurations of multiple modalities [Beebe & Gerstman's (1980) "engagement levels"; Tronick & Weinberg's (1990) "monadic phases"] which obscure unique contributions of different modalities but may capture more of the holistic "gestalt" of the interaction. We use this multimodal approach as well by constructing ordinalized facial-visual engagement scales (Beebe et al., 2010).

We code mother and infant videotaped behaviors separately on a 1-s time base and create ordinal scales of these behaviors. We use these ordinal scales to define separate communication modalities of *attention* (gaze on/off partner's face), *facial affect* (positive to negative facial expressions), *vocal affect* (positive to negative vocal contours), *spatial orientation* (mother sitting upright, leaning forward, or looming in; degrees of infant head orientation from enface to arch), and *touch* (mother touch from affectionate to intrusive; infant touch self, mother, object). We also create via algorithm a composite multimodal variable of facial-visual engagement, which combines these separate modalities of attention, orientation, facial, and vocal affect.

Attention and Affect

In face-to-face interactions, mothers are contingently responsive to infant vocalization, smile, and gaze behavior (Bigelow, 1998; Chow et al., 2010; Jaffe et al., 2001; Keller et al., 1999; Malatesta & Haviland, 1982; Stern, 1974; Van Egeren et al., 2001). By 3–5 months infants coordinate with maternal gaze shifts and are sensitive to variations in the form, intensity, and timing of maternal facial and vocal expressions (Kahana-Kalman & Walker-Andrews, 2001) and are capable of coordinating with them (Gusella, Muir, & Tronick, 1988; Haviland & Lelwica, 1987; Jaffe et al., 2001; Messinger, 2002; Muir & Hains, 1993; Murray & Cooper, 1997; Trevarthen, 1977; Tronick, 1989; Weinberg & Tronick, 1994, 1996).

Orientation

Maternal spatial orientation and infant head orientation organize dyadic approach-approach and approach-avoid patterns which regulate proximity (Beebe et al., 2010; Beebe & Stern, 1977; Stern, 1971). Infants detect, track and follow the trajectories of objects and their interactions in space and anticipate their speed and direction (Mandler, 1988).

Touch

Infant touch behaviors provide self-comfort. Infants increase self-touch during the still-face procedure (Weinberg & Tronick, 1996), when mother leaves the room or a stranger enters (Trevarthen, 1977), and during a "replay" experiment, in which infants view a noncontingent replay of the mother's behavior (Murray & Trevarthen, 1985). Infants who will be classified as disorganized (vs. secure) attachment decrease touch behaviors at 4 months (Beebe et al., 2010). Maternal touch compensates when facial/vocal communication is not available in the still-face experiment (Pelaez-Nogueras, Field, Hossain, & Pickens, 1996; Stack & Arnold, 1998). Less affectionate maternal touch is associated with maternal depression (Beebe et al., 2008; Cohn, Campbell, & Ross, 1991; Feldman & Eidelman, 2003; Field, 1995;). Van Egeren et al. (2001) documented bidirectional contingency between mother touch and infant vocalization, a pattern we investigate.

Facial-Visual Engagement

Observations of infants sustaining or disrupting the face-to-face play encounter led to the development of an infant engagement scale describing the various ways that infants combine their orientation to the mother, their visual attention to her, and subtle variations in their facial and vocal affect (Beebe & Gerstman, 1980, 1984; Beebe et al., 2010; Beebe & Stern, 1977).This variable captures a holistic gestalt characterizing the overall quality of mother–infant engagement. It is not created by human judgment but rather by a statistical algorithm combining separate modalities. In our prior work, engagement yielded useful information in relation to maternal depression and anxiety, and infant attachment (Beebe et al., 2008, 2010, 2011). Moreover, it was more fruitful in predicting attachment outcomes than the separate modality of facial affect (Beebe et al., 2010).

Communication Modality Pairings. Self- and interactive contingency were evaluated for each partner in the following modality-specific pairings:

1. infant attention– mother attention,
2. infant facial affect–mother facial affect,
3. infant vocal affect–mother facial affect,
4. infant facial-visual engagement—mother facial-visual engagement,
5. infant facial-visual engagement—mother touch,

6. infant vocal affect–mother touch,

7. infant touch–mother touch,

8. infant head orientation–mother spatial orientation.

We coded multiple modalities of mother–infant face-to-face communication, with the exception of maternal vocalization (we generated automated vocal rhythm data, reserved for a future report). Many possible combinations of communication modalities could be examined (6 infant variables × 5 mother variables = 30 interpersonal combinations). Consistent with the literature, we chose to limit our examination to the same behavior in both partners where possible: Pairings 1 (attention), 2 (facial affect), 4 (facial-visual engagement), 7 (touch), 8 (orientation). Guided by our research findings and prior literature, we also examined several further specific modality pairings. We examined infant vocal affect in relation to maternal facial affect (Pairing 3) because mothers have been found to use infant vocal affect to regulate their own emotional responses (Beebe et al., 2007, 2008, 2010, 2011; Hsu & Fogel, 2003). Because maternal touch was the most exploratory of our variables, we examined it in two additional pairings: In relation to infant engagement (Pairing 5) and vocal affect (Pairing 6), reasoning that infants may respond to intrusive maternal touch with combined facial-visual engagement behaviors, vocal distress, or increased touch (see Van Egeren et al., 2001).

Method

Participants

Recruitment. Within 24 hours of delivering healthy full-term singleton infants without major complications, 152 mothers were recruited from a major urban hospital for a study of infant social development involving a videotaped 4-month lab visit.[1] Subjects were primiparous women, 18 years or older, married (or living with partner), with home telephone. At 6 weeks, mothers were telephoned and invited to participate. When infants were 4 months, 132 mothers and infants visited the lab for face-to-face filming. No differences were found in ethnicity, education, or infant gender between the 152 recruited and the 132 who chose to participate.

Demographic description. Mothers had a mean age of 29 (*SD* 6.5, range 18–45), were 53% White, 28% Hispanic, 17.4% Black, 1.5% Asian, and well-educated (3.8% grade school, 8.3% high school, 28.8% some college, 33.3% college graduate, 25.8% some postgraduate). Of the 132 infants, 58 were female.

Procedure

Scheduling of 4-month videotaping took into account infant eating–sleeping patterns. Mothers (seated opposite infants 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 focused on head and upper torso of mother and infant.

Behavioral Coding

The first 2.5 uninterrupted continuous play minutes[2] of videotaped mother–infant interaction were coded on a 1-s time base, using Tronick and Weinberg (1990) timing rules. Behaviors were coded with *ordinalized scales* (required by time-series techniques), ordinalized from high to low (except gaze): *gaze* (attention): on-off partner's face; *mother facial expression* (facial affect): mock surprise, smile 3, smile 2, smile 1, "oh" face, positive attention, neutral, "woe" face, negative face (frown/grimace/tight compressed lips); *infant facial expression* (facial affect): high positive (smile), low positive (smile), interest/neutral, mild negative (frown/grimace), negative (precry/cry face); *infant vocal contour* (vocal affect): positive/neutral, none, fuss/whimper, angry protest/cry; *mother spatial orientation* (orientation): sitting upright, leaning forward, looming in; *infant head orientation* (orientation): en face, en-face-head-down, 30°–60° minor avert, 30°–60° avert + head-down, 60°–90° major avert, arch; *mother touch* (touch): affectionate (stroke, kiss), static (hold, provide finger for infant to hold), playful (tap, tickle), none, caregive, jiggle/bounce, infant-directed oral touch, 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); *infant touch* (touch): 2+, 1, or none of the following behaviors within the same second: touch/suck own skin, touch mother, touch object (Stepakoff, 1999; Stepakoff, Beebe & Jaffe, 2000, July). Ordinalized scales of mother touch and of mother and infant facial-visual engagement were constructed by an algorithm. *Infant Engagement* was anchored from high ("high positive engagement") to low ("cry"); *Mother Engagement* was anchored from "mock surprise" to "neutral/negative off."[3] For coding details which aid comprehension of the paper, see Beebe et al. (2010) Appendix A, or see the online supplementary materials, Appendix A, Coding of Ordinalized Behavioral Scales (http://nyspi.org/Communication_Sciences/index.html). Reliability estimates of or-

[1] This data set is distinct from that reported in Jaffe et al. (2001).

[2] A 2.5-min sample of behavior is standard in the literature (Beebe et al., 2010; Cohn & Tronick, 1988; Field et al., 1990). Mother–infant face-to-face interaction has a relatively stable structure with robust session-to-session reliability (Cohn & Tronick, 1988; Moore, Cohn, & Campbell, 1997; Weinberg & Tronick, 1991; Zelner, Beebe, & Jaffe, 1982). In past work, 2.5 min of mother–infant interaction at 4 months, coded on a 1-s time-base, was sufficient to identify communication disturbances associated with maternal depression (Beebe et al., 2008) and anxiety (Beebe et al., 2011), and 12-month insecure infant attachment patterns (Beebe et al., 2010). Ambady and Rosenthal's (1992) meta-analysis showed that accuracy in predicting interpersonal consequences did not differ among observations varying from 30 s to 5 min; samples of less than 5 min did not differ from those based on longer samples.

[3] Infant engagement (18 ordinalized levels) had 10 groupings: (1) gaze-on mother's face/oriented en face/positive facial expression and/or positive vocal contour; (2) gaze-on/oriented en face/negative facial expression and/or negative vocal contour; (3) look-angled-for-escape; (4) gaze-off/positive facial expression/positive vocal contour; (5) gaze-off/neutral facial expression/no vocalization; (6) gaze-at-object; (7) gaze-off/enface/negative facial expression/negative vocal contour; (8) gaze-off/avert/negative facial expression/negative vocal contour; (9) distress (facial/vocal); (10) cry. Mother engagement had 9 ordinalized levels: in the top seven levels mother is gaze on and ordinalized as mock surprise, smile 3, smile 2, smile 1, oh face, neutral/negative facial expression; in the lowest two levels mother is gaze off, ordinalized by positive facial expressions, then negative facial expressions.

dinalized scales[4] in 30 randomly selected dyads (tested in three waves to prevent "drift") generated mean Cohen's Kappa per scale as follows: *infants:* gaze .80, facial expression .78, vocal contour .89, head orientation .71, touch .75; *mothers:* gaze .83, facial expression .68, spatial orientation .89; touch .90. Mother facial affect with 9 degrees was difficult to code.

Data Analysis

To create indices of self- and interactive contingency, traditional time-series approaches model each dyad individually and enter model coefficients into analyses of variance. Multilevel time-series approaches model the group as a whole, creating estimates of both fixed effects in the sample and individual variation in those effects. Advantages of this approach include more appropriate statistical assumptions, more accurate estimates of parameters, and increased power.[5] The SAS PROC MIXED program (McArdle & Bell, 2000; Singer, 1998) was used to estimate "random" (individual differences) and "fixed" [6] (common model) effects on patterns of self- and interactive behavior over 150 s. The models generating indices of self- and interactive contingency examined eight modality pairings, including one mother gaze—infant gaze (on/off gaze) in which the dependent variable is dichotomous and analyzed by SAS GLIMMIX (Cohen, Chen, Hamigami, Gordon, & McArdle, 2000; Littell, Miliken, Stoup, & Wolfinger, 1996). For details of statistical models see Chen and Cohen (2006). These analyses used all 150 s coded from videotape for each individual. Repeated observations on individuals are the basic random data, just as in cross-sectional data single individuals are the basic units of analyses.

Self- and interactive contingency were calculated for the group of mothers and infants for all modality pairings (e.g., mother gaze - infant gaze). To determine optimum window size for calculating contingency estimates, preliminary analyses 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 the recent prior seconds, based on these analyses. Typically the prior 3 s sufficed to account for these lagged effects on the subsequent behavior (t_0).[7] The estimated coefficient for the effects of these lagged variables on current behavior (t_0) over the interaction indicates the level of contingency: the larger the standardized coefficient, the stronger the contingency. Each analysis included both self- and interactive contingency; thus, estimated coefficients of each form of contingency controlled for the other. Figure 1 illustrates this analysis.

Fixed effects indicate average effects over the full sample so that it is possible to estimate the extent to which a single overall model accounts for individual differences reflected in the random model, described below. Tests of hypotheses used fixed rather than random effects, with the exception of tests of conditional effects of self- and interactive contingency, which used the random model. For each model, data on individuals is considered the basic random model. The first step in these analyses examined between-subjects differences ("random effects") in mean level, linear slope over time, mean by time, and the interindividual difference term in the autoregression parameter. These random models were the basis for examination of fixed effects.

To calculate estimates of self- and interactive contingency across the group, we produced a "basic model" of fixed ("average") effects for each behavioral dependent variable. The modeling process for predicting the time-varying behavioral variable in question (e.g., mother facial affect) considered all demographic variables, effects of lagged variables as described above, and all possible two-way interactions between control variables and contingency. Effects of lagged variables on current behavior represent the average self- and interactive contingency across the subjects.

In calculating these "basic models," variables in the multilevel model were added in the following steps after the intercept of the dependent variable: (a) self- and partner lagged variables, (b) demographic variables (mother ethnicity, age, education, infant gender), (c) conditional effects between demographic variables, (d) conditional effects of demographic variables with lagged self

[4] Mother touch reliability was assessed on individual touch behaviors; the ordinalized touch scale was created through an algorithm.

[5] Multilevel models are designed to address patterns over time (here the course of behavior second by second). Compared with 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) control 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.

[6] A *random effect* is the term used for identifying the differences in a variable (function or association) among the study subjects. 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 autoregressive 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.

[7] Preliminary analyses estimated the number of seconds over which lagged effects were statistically significant. For each dependent variable, measures of prior self or partner behavior, termed "lagged variables," were computed. 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 the subsequent behavior. Across the modality pairings studied, mother was significant at 2–3 lags (2–3 s) for both self- and interactive contingency; evaluation of longer lags yielded nonsignificant results. Significant infant lags varied: for self-contingency, 4 lags (vocal quality), 3 (face, gaze), 2 (touch), and 1 (head orientation); for interactive contingency, 6 lags (mother gaze → infant gaze), 5 (mother face → infant face), 3 (M face → I vocal quality) and 0 (M spatial orientation → I head orientation). Although some of the above modality pairings showed infant lags longer than 3 s, the amount of variance accounted for was very small for lags longer than 3 s. Note that in the analyses, no more than 3 lags and no fewer than 2 were used in any weighted mean lag to maintain a 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.

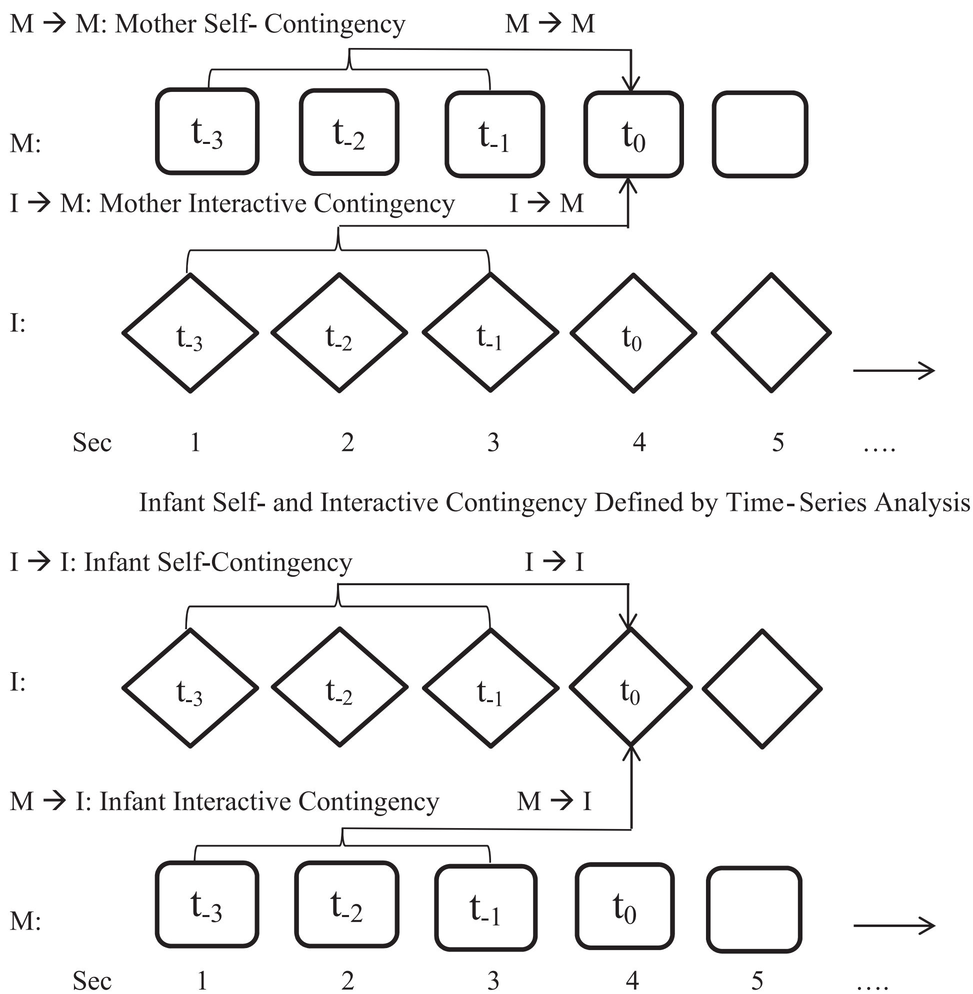

Figure 1. Illustrations of Mother and Infant Self- and Interactive Contingencies Defined by Time-Series Analysis. *Note*. This figure illustrates the calculation of self- and interactive contingency. The first row of squares represents the secs of the mother's ongoing stream of behavior; the second row of diamonds represents that of the infant. The prior three secs (t-1, t-2, t-3) are used to predict the current sec (t0), across secs 1-4. In the mother's stream of behavior (squares), t0 identifies the predicted second. A weighted average of secs t-1, t-2, and t-3 in the mother's behavioral stream identifies the "weighted lag," which is used to predict t0, generating mother self-contingency. To calculate mother interactive contingency, a weighted average of secs t-1, t-2, and t-3 in the infant's behavioral stream (diamonds) is used to predict t0 in the mother's behavioral stream. For both self- and interactive contingency, this is an iterative process in which sec 5 will then identify the new t0, and secs 2, 3, and 4 will identify the new "weighted lag."

and lagged partner behavior.[8] Because effects of demographic variables and their conditional effects were included as a check on the assumption that these would not alter the basic findings, when these effects were not statistically significant they were dropped from subsequent and final models. Main effects were retained in the model regardless of significance when any conditional effect involving that variable was statistically significant. The final model included the simplest model consistent with the data according to a goodness-of-fit test for these maximum likelihood estimates (Chen & Cohen, 2006).

Main effects of self- and interactive contingency, their relative effect sizes, and their conditional effects are presented for all modality pairings (see the online supplementary materials, Appendix C, Basic Model Tables, for 24 tables of self- and interactive contingency, three for each of the eight modality pairings).

Conditional effects of self- and interactive contingency test for a negative (or positive) relation between self- and interactive contingency. Estimates of self- and interactive contingency consist of the effects of lagged self- or partner behavior on subsequent behavior, that is, the estimated coefficients of lagged behavior

[8] After modeling lagged effects for self- and interactive contingency, a second model included self- and interactive contingency variables, demographic variables, and their interactions. In this second model, all variables were entered simultaneously and were allowed to compete for variance explained.

Table 1
Main Effects of Self- and Interactive Contingency

Infant interactive contingency				Self-contingency			
Mother → Infant	B	*SE* B	β	Infant → Infant	B	*SE* B	β
(1) M Gze → I Gze	0.614[a]	.112	.025[b]	(1) I Gze → I Gze	3.587	.050	.619
(2) M FceA → I FceA	0.051	.008	.038	(2) I FceA → I FceA	0.634	.016	.602
(3) M FceA → I VcA	0.002	.0004	.030	(3) I VcA → I VcA	1.024	.046	.956
(4) M Eng → I Eng	0.069	.016	.024	(4) I Eng → I Eng	0.680	.006	.657
(5) M Tch → I Eng	NS	—	—	(5) I Eng → I Eng	0.692	.006	.670
(6) M Tch → I VcA	NS	—	—	(6) I VcA → I VcA	0.684	.012	.639
(7) M Tch → I Tch	NS	—	—	(7) I Tch → I Tch	0.715	.024	.710
(8) M Sptl → I Head	0.099	.027	.050	(8) I Head → I Head	0.661	.009	.620
Mother Interactive Contingency				**Self-contingency**			
Infant → Mother	B	*SE* B	β	Mother → Mother	B	*SE* B	β
(1) I Gze → M Gze	0.582	.074	.061	(1) M Gze → M Gze	2.477	.114	.302
(2) I FceA → M FceA	0.133	.007	.139	(2) M FceA → M FceA	0.555	.007	.529
(3) I VcA → M FceA	1.421	.136	.073	(3) M FceA → M FceA	0.700[c]	.029	.667
(4) I Eng → M Eng	0.063	.005	.136	(4) M Eng → M Eng	0.467	.009	.407
(5) I Eng → M Tch	0.010	.004	.016	(5) M Tch → M Tch	0.738	.008	.733
(6) I VcA → M Tch	0.072	.027	.015	(6) M Tch → M Tch	0.738	.005	.733
(7) I Tch → M Tch	0.179	.035	.035	(7) M Tch → M Tch	0.843	.030	.837
(8) I Head → M Sptl	−0.008	.002	.015	(8) M Sptl → M Sptl	0.793	.029	.788

Note. Interactive contingency (e.g., M → I = infant interactive contingency) and self-contingency (e.g., I → I = infant self-contingency) were evaluated for each partner in a set of modality-specific pairings listed (1) to (8); e.g. (1) M gaze - I gaze. Entries represent effects of self- and interactive contingency, presented as unstandardized (B) and standardized (β) beta coefficients (*SE* B = standard error of the beta), drawn from the basic models (see Web Appendix C). All effects are significant ($p < .02$) (except that infant coordination with mother touch M → I was not significant for any infant modality tested). To illustrate the coefficients, the finding for infant facial affect interactive contingency in pairing (2), M FceA → I FceA (mother facial affect → infant facial affect) indicates that the estimate (B) was .051; the finding for infant facial affect self-contingency in pairing (2) I FceA → I Fce A indicates that the estimate was .634; the finding for mother facial affect interactive contingency with infant facial affect in pairing (2) I FceA → M Fce A indicates that the estimate was .133; the estimate of mother facial affect self-contingency (M FceA → M FceA) was .555. Gze = gaze; FceA = facial affect; VcA = vocal affect; Eng = engagement; Tch = touch; Sptl = mother spatial orientation; Head = infant head orientation.
[a] Because gaze is a binary value, it was calculated by logistic regression (SAS Proc Mixed). [b] For the purpose of this table, to obtain standardized coefficients for gaze, we re-ran gaze as a multilevel linear regression rather than a logistic regression (Cohen, Cohen, Westin, & Aiken, 2003). We use linear regression here to make coefficients more comparable to other behavioral scale pairings, yet suggest caution in interpretation. All other analyses in this paper use logistic regression for gaze. [c] Because of unequal units in coding of mother face and infant vocal affect, the value of mother face self-contingency (.700) appears less than that of mother interactive contingency with infant vocal affect (1.421). Once these values are represented as standardized effect sizes, self-contingency is greater than interactive.

variables in the fixed effects of the multilevel models. Differences in lagged effects among subjects are reflected in the "random" effects of the multilevel model. The magnitude of the random variance occurring in such multilevel models indicates the extent of variation between participants in individual estimates of contingency. The covariance of self- and interactive contingency from the random effects was used to test for conditional effects of self- and interactive contingency. These analyses estimate differences between dyads in model parameters, including the values of these parameters, such as mean values of the dependent variable, as well as the covariances among these parameters. Because these random parameters include lagged effects of self- and partner behavior (self- and interactive contingency), the random effects also include the covariance between the estimates of these coefficients. A negative covariance indicates that greater influence from one source (i.e., self or partner) covaried with less influence from the other source.[9]

Unstandardized regression coefficients are presented (with standardized coefficients) in Table 1; all tests were two-tailed. One hundred thirty-two dyads × 150 s yielded 19,800 s per partner per communication modality.

Results

We present results of the 4 predictions testing the principles of our dyadic systems view.

Principle 1. Both Self- and Interactive Contingency Organize Face-to-Face Communication

We investigated the degree to which the prior behavior (in the prior 3 s) of each individual predicts the current second of behavior of the individual (self-contingency) and of the partner (interactive contingency). Table 1 summarizes the main effects as unstandardized beta coefficients (B) and standardized coefficients (β), taken from the eight sets of basic model tables (see online supplementary materials, Appendix B). Table 1 shows that interactive contingency was significant in all modality pairings, $p < .02$, with the

[9] We obtained the individual estimates of random effects coefficients in a two-step process to maintain a univariate modeling framework. Future research will explore a bivariate model where infant and mother variables are included simultaneously so the covariances or correlations among random effects can be incorporated directly.

exception of infant coordination with maternal touch (through infant engagement, vocal affect or touch). All signs were positive (with one exception, mother spatial orientation coordination with infant head orientation, described below). Table 1 also shows that *self-contingency* was significant in every analysis ($p < .02$) with a positive sign, indicating that mother and infant behaviors are organized by self-predictability.

Our conclusion was that Principle 1 was supported for seven of eight modality pairings.

Principle 2. Interactive Contingency Is Organized by a Bidirectional But Asymmetrical Process; Maternal Contingent Coordination With Infant Is Higher Than That of Infant With Mother

Table 1 shows that all modality pairings (except those involving maternal touch) are organized by bidirectional interactive contingencies, such that mothers and infants both coordinate with the other. The positive signs (except maternal spatial orientation) indicate a dyadic positive feedback system in which behavioral changes are mutually mirrored.

Mother touch generated unidirectional contingencies: mothers coordinated their touch patterns with infant engagement, vocal affect and touch, but infants did not reciprocally respond to maternal touch using these communicative modalities. Maternal interactive contingency of touch with infant touch indicated, for example, that as infants were more likely to touch (self, object or mother), mother touch was likely to be more affectionate (and vice versa).

In Pairing 8, mother spatial orientation–infant head orientation, the signs differ for mother and infant. Infant coordination is organized by a positive sign: As mothers move from sitting upright toward looming in ("chase"), infants move away from enface toward arch ("dodge"); and vice versa, as mothers move back toward upright, infants return toward en face. The maternal coordination, however, is organized by a negative sign: As infants orient away, from en face toward arch, mothers sit back, from loom toward upright, a mutual withdrawal; and vice versa, as infants orient back toward en face, mothers move forward or loom.

Table 2 reports confidence intervals around the beta weights of mother and infant interactive contingency. Estimates of maternal contingent coordination with infant are higher than those of infant with mother (except Pairing 8, mother spatial orientation—infant head orientation). We exclude pairings involving maternal touch (where infant estimates were not significant).

For Principle 2, we concluded that bidirectional interactive contingency was supported for all modality pairings except those involving mother touch; the prediction that maternal contingent coordination is higher than that of infant was supported for all modality pairings except maternal spatial orientation–infant head orientation.

Principle 3. Self-Contingency Organizes Face-to-Face Communication to a Greater Extent Than Interactive Contingency

We evaluate the respective weights of self-versus interactive contingency using the standardized coefficients of the betas for contingency presented in Table 1. For both partners, effect sizes of self-contingency are far greater than those of interactive contingency in all modality pairings (infant pairings involving maternal touch cannot be evaluated for this principle).

The relative magnitude of the self-contingency and interactive contingency effects can be illustrated with respect to standardized coefficients. For each 1 *SD* increase in the independent variable, the standardized coefficient represents the number of *SD* units that the dependent variable increases (or decreases). Illustrating with mother facial affect self-contingency, the standardized coefficient in Table 1 shows that as maternal facial affect in the prior moment (mean weighted lag) becomes more positive by 1 *SD*, maternal face in the current second increases 0.529 *SD*. In contrast, for maternal facial interactive contingency, as infant facial affect in the prior moment becomes more positive by 1 *SD*, mother face in the current second increases only 0.139 *SD*. Here, the effect of self-contingency is about four times that of interactive contingency, a ratio of 4:1. Calculating these relative effects of self- to interactive contingency for mothers yields the following ratios: gaze 5:1, touch 24:1, and spatial orientation 52:1. For infants, the ratios are as follows: head orientation 12:1, facial affect 16:1, and gaze 25:1. Thus, the effects of self-contingency are far greater than those of interactive contingency.

Table 2
Confidence Intervals for Comparisons of Interactive Contingency

Infant interactive contingency (M → I)			Mother interactive contingency (I → M)	
(1) M Gaze → I Gaze	.025 (.014, .036)	<	I Gaze → M Gaze	.061 (.045, .077)
(2) M Face → I Face	.038 (.026, .050)	<	I Face → M Face	.139 (.125, .153)
(3) M Face → I VcA	.030 (.018, .042)	<	I VcA → M Face	.073 (.059, .086)
(4) M Eng → I Eng	.024 (.013, .035)	<	I Eng → M Eng	.136 (.115, .157)
(5) M Tch → I Eng	.006[a] (−.005, .017)		I Eng → M Tch	.016 (.003, .028)
(6) M Tch → I VcA	.010[a] (−.002, .022)		I VcA → M Tch	.015 (.004, .026)
(7) M Tch → I Tch	−.005[a] (−.019, .008)		I Tch → M Tch	.035 (.021, .048)
(8) M Sptl → I Head	.050 (.023, .077)	≥	I Head → M Sptl	.015 (.004, .026)

Note. Entries are standardized coefficients (95% confidence interval) in a set of modality-specific pairings listed (1) to (8). The symbol < indicates that infant coordination with mother (M → I) is less than mother coordination with infant (I → M), based on the confidence intervals. Gaze = gaze; Face = facial affect; VcA = vocal affect; Eng = engagement; Tch = touch; Sptl = spatial orientation; Head = head orientation.
[a] not significant.

Table 3
Conditional Effects of Self- and Interactive Contingency

	Infant		Mother	
	I → I/M → I		M → M/I → M	
Modality pairings	*r*	*p*	*r*	*p*
(1) M Gaze → I Gaze	−.435	.336	.287	.361
(2) M FceA → I FceA	−.373	.013*	−.431	.030*
(3) M FceA → I Vocal Affect	−.062	.699	−.495	.011*
(4) M Engagement → I Engagement	−.075	.909	−.686	.001**
(5) M Touch → I Engagement	−.375	.049*	—	—
(6) M Touch → I Vocal Affect	.048	.805	−.824[a]	.056[a]
(7) M Touch → I Touch	−.464	.115	−.249	.158
(8) M Spatial → I Head	−.852	.001**	−.416	.011*

Note. Entries are conditional effects of dyad-by-dyad levels of self-contingency (e.g., M → M) and interactive contingency (e.g., I → M), in a set of modality-specific pairings listed (1) to (8). For ease of interpretations, conditional effects are presented as correlations, taken from the random effects model of the best-fit two-level multilevel models; *p*s are taken from tests of the covariance of these two effects. M → M/I → M indicates the correlation between self- and interactive contingency for mothers. For example, in the pairing M FceA → I FceA, the value −.431 represents the correlation of M FceA → M FceA self-contingency with I FceA → M FceA interactive contingency. All significant estimates of the conditional effects of self- and interactive contingency are negative, indicating a negative or inverse association between self and other contingency. Thus, for example above, mothers who had higher facial self-contingency tended to have lower contingency with infant facial affect, and vice versa. A long dash indicates the correlation could not be computed (the variance of I Eng → M Tch = zero). FceA = facial affect; Spatial = spatial orientation; Head = head orientation.
[a] The correlation of −.824 seems substantial, but it is not interpretable. Both self- and interactive contingency had such little variance that the correlation is not meaningful.
* $p < .05$. ** $p < .01$.

For Principle 3, we concluded that this principle was supported for all modality pairings tested.

Principle 4. Face-to-Face Communication Is Characterized by a Dynamic Homoeostatic (Negative Feedback) Balance Between Self- and Interactive Contingency

We evaluate whether, across the group, the magnitudes of an individual's respective indices of self- and interactive contingency—the influence of the self and the partner on the individual's own behavior—are associated with one another, with a negative sign. That is, do individuals who exhibit higher self-contingency exhibit lower interactive contingency (and vice versa)?

Table 3 presents conditional effects of self- and interactive contingency. For mothers, conditional effects are significant in four of eight analyses, for facial affect (paired with infant facial and vocal affect), facial-visual engagement, and spatial orientation. For infants, effects are significant in three of eight analyses, in facial affect, facial-visual engagement (paired with mother touch), and head orientation. Pairings involving gaze and/or touch are not significant for mothers or for infants. All conditional effects have negative signs: Individuals tend to have higher predictability in one form of contingency and lower in the other in these modality pairings. For example, those individuals who coordinate more strongly with the partner's facial affect tend to have lower (more variable) self-contingency of facial affect and vice versa.

For Principle 4, we concluded it was supported for all modality pairings tested except gaze and touch.

Discussion

We first discuss the results of our systems-based predictions of the structure of mother–infant face-to-face communication. We then address the importance of self-contingency, the homeostatic feedback process between self- and interactive contingency, and the implications of our findings for contingency processes across the first year. These results are based on analysis of 2.5 min of interaction at age 4 months, which is standard in the literature (Cohn & Tronick, 1988; Field et al., 1990), but which may nevertheless limit the generalizability of our findings. Although brief, in past work 2.5 min of mother–infant interaction at 4 months, coded on a 1-s time base, was sufficient to identify communication disturbances associated with maternal depression, anxiety, self-criticism, and dependency, and 12-month infant attachment patterns (Beebe et al., 2007, 2008, 2010, 2011).

Both Self- and Interactive Contingency Organize Dyadic Face-to-Face Communication at 4 Months

Across communication modalities of attention, affect, facial-visual engagement, orientation, and touch, our prediction that both self- and interactive contingency organize mother–infant face-to-face communication was largely confirmed across the group of 132 mothers and infants. In one exception, infants did not coordinate their vocal affect, facial-visual engagement, or touch frequency with maternal touch quality. Heretofore relatively unexplored, self-contingency was significant for mothers and for infants in every modality tested. Self-predictability of both partners is an important organizing feature of the dyadic system (Beebe et al., 2007, 2010; Chow et al., 2010).

Interactive Contingency at 4 Months Is Organized by a Bidirectional But Asymmetrical Process: Maternal Contingent Coordination With Infant Is Higher Than That of Infant Coordination With Mother

We documented bidirectional interactive contingency in all modality pairings except those associated with mother touch. Whereas Cohn and Tronick's (1988) landmark demonstration of bidirectional contingency obtained for a proportion of dyads, we documented it across the sample as a whole. Unlike Chow et al. (2010), bidirectional contingency was examined separately within the specific communicative modalities through which early interaction is organized.

Interactive contingency findings are interpreted as follows: In gaze, as infant and mother gaze at and away from the partner's face, each is likely to reciprocally follow the other's direction of gaze, at and away from the partner's face. In facial and vocal affect, partners show a mutual affective "mirroring," a shared direction of affective change. In facial-visual engagement, partners share direction of gaze and of affective change (replicating Beebe, Jaffe, Feldstein, Mays, & Alson, 1985). In orientation, examining mothers' influence on infants, as mothers move forward from upright toward loom, infants move away from en face toward arch: a "mother chase–infant dodge" pattern, replicating Beebe and Stern (1977; see also Beebe et al., 2010). Examining infants' influence on mothers, as infants orient away from en face toward arch (a "dodge"), mothers move back from loom toward upright, a stepping-back "repair" of the spatial intrusion, not previously documented.

Mothers coordinated their touch with infant behavior (touch, vocal affect, engagement), but infants did not reciprocate, a unidirectional interactive contingency. Thus, mothers are procedurally aware of infant touch patterns and use the frequency of infant touch behavior per second to inform the quality of their own touch. As infants were more likely to touch, mothers were likely to touch more affectionately (and vice versa, as infants touched less, mothers were likely to use more arousing forms of touch). Other studies have found infant coordination with maternal touch (Messinger, Mahoor, Chow, & Cohn, 2009; Van Egeren et al., 2001). This issue deserves further investigation. Similarly, as infants became more positive in vocal affect or facial-visual engagement, mothers were likely to touch more affectionately (and vice versa).

The potentially asymmetrical nature of bidirectional coordination is often ignored. Moreover, there is a common assumption that greater socialization occurs in the direction of mother behavior influencing infant behavior, despite several studies which show the opposite (Chow et al., 2010; Keller et al., 1999; Van Egeren et al., 2001). Although interactive contingency was bidirectional with the exception of touch, infant behavior influenced mother behavior to a greater degree than the reverse. In the one exception of modality pairing infant head orientation-maternal spatial orientation, the magnitude of coordination was roughly equal for both partners. Thus, despite bidirectional effects, mothers coordinate and adjust their behaviors to their infants more than infants adjust to their mothers.

Self-Contingency Organizes Face-to-Face Communication at 4 Months to a Greater Extent Than Interactive Contingency

Strong effects of self-contingency (autocorrelation) led statisticians (Gottman, 1981; McCleary & Hay, 1980) to consider this variance "noise," which was routinely controlled for and ignored. In contrast, we consider self-contingency a construct in its own right. In our data, although interactive contingency was significant, self-contingency was far stronger (see also Schmidt et al., 1998). Thus, one's behavior in the current moment is far more predictable from one's own prior behavior than from the partner's prior behavior. In all modalities, the effects of self-contingency were substantially greater than the effects of interactive contingency. The relative effect of maternal prior behavior, compared with that of infant prior behavior, on maternal current behavior ranged from 4:1 (facial affect) to 53:1 (spatial orientation). Similarly, these relative effects for infants ranged from 12:1 (head orientation) to 25:1 (gaze).

Face-to-Face Communication at 4 months Is Characterized by a Dynamic Homoeostatic (negative feedback) Balance Between Self- and Interactive Contingency

The idea that self- and interactive contingency reciprocally affect one another tends to be metaphoric rather than empirically documented. As exceptions in the literature, examining vocal rhythms in adult conversations, Warner (1992) found a positive association between self- and interactive contingency, but Crown (1991) found no association. We documented reciprocal associations between self- and interactive contingency in mother–infant interaction in the modalities of facial affect, vocal affect, facial-visual engagement and orientation. All effects showed negative feedback patterns. For example, both mothers and infants who were less facially stable (more variable) were likely to coordinate more strongly with the partner's facial affect (follow the direction of affective change) and vice versa. More generally, individuals may have one of two patterns: (a) greater coordination with the partner and less self-stability, metaphorically more "socially-oriented"; (b) greater self-stability and less coordination with the partner, metaphorically more "self-directed" or "on one's own program," that is, behaving more relatively independently of one's partner.

Principle 4 holds across an interesting breadth of communication modalities: facial affect, facial-visual engagement, and orientation. Gaze does not conform to the homeostatic model, perhaps because gaze is a superordinate modality necessary to monitor the environment in case of danger, as well as serving a communicative function. Thus, one may need to use gaze in a more flexible way, irrespective of other conditions such as the degree of one's own self-contingency or how tightly one is coordinating with the partner. Touch does not conform to the homeostatic model, with the exception of one finding for infants in the modality pairing of infant engagement–mother touch: As infant engagement becomes less stable (more variable), infant engagement is more strongly coordinated with mother touch quality; that is, as mother touch becomes more affectionate, infant engagement is likely to become more positive (and vice versa). As infants increase their skill in different modalities across the first year, the particular modalities in which the homeostatic model may hold are likely to shift.

The Importance of Self-Contingency

Self-contingency is a fundamental aspect of mother–infant face-to-face communication that has received little consideration (but see Beebe et al., 2007, 2008, 2010, 2011; Messinger et al., 2012). Self-contingency taps one dimension of self-regulation, that is, the procedural (out of awareness) anticipation of where one's own behavior is tending in the next moment. It generates procedural expectancies of the degree to which one can anticipate one's behavior in the current moment from one's own behavior in the past few moments: how predictable, how stable, how variable one's behaviors are, from moment to moment. The process of self-contingency contributes to one's sense of temporal coherence over time (Beebe et al., 2008). Self-contingency is so basic that, like breathing, it may escape notice.

Within the dyadic face-to-face system at 4 months, self-contingency is far stronger than interactive contingency. This finding refines the mutual regulation model (Tronick, 1989). Both mother and infant are more "self-rooted" than coordinated with the partner. As Feldman (2007) noted, intrapersonal behavioral rhythms are a critical component of social interaction. We consider self-contingency to be one central self-organizing feature of the dyadic system. Nevertheless, our self-contingency findings do not imply that interactive contingency is any less important than previously supposed; both self- and interactive contingency are critical to understanding communication.

Departures from typical degrees of self-contingency are potentially markers of risk. For example, in predictions of 12-month disorganized attachment from the current 4-month data (Beebe et al., 2010), self-contingency could be too high, as in the overly stable infant touch patterns of future disorganized infants, stuck in states of no touch; or too low, as in the destabilized, lowered self-predictability of facial-visual engagement of these infants. However, Warner's (1992) study of face-to-face conversations between adult strangers showed that higher (more stable) self-contingency of vocal rhythms was associated with more positive evaluations of the interaction. We need more empirical work on the functions of self-contingency.

The Importance of Considering Self- and Interactive Contingency as a System

This study suggests that self-and interactive contingency affect one another, coconstituting the communication system. In facial and vocal affect, facial-visual engagement, and orientation, self- and interactive contingency processes were not independent. Rather each form of contingency affected the other, in a compensatory, negative feedback fashion. This association between an individual's self- and interactive contingency indicates that the process of regulating oneself (through one's moment-to-moment degree of self-contingency) is contingent on the way one responds to the partner and vice versa.

The implication is that the individual's self-organizing process (one's moment-to-moment degree of self-contingency) is not solely contained within the self; it is reciprocally bound up with the individual's coordination with the partner. Those mothers and infants who remain more loosely self-organized are more open to the influence of the partner; those who are more tightly self-organized, more on their own program or behaving relatively independently of the partner, are less open to the influence of the partner. Thus, the individual's own self-organizing process is more influenced by the individual's response to the partner than previously supposed.

These findings are consistent with Sander's (1977, 1995) idea of self-regulation (here self-contingency) as a "systems" competence. Within face-to-face communication, because self-contingency and interactive contingency are associated, the predictability of an individual's own behavioral stream is itself in part dyadic. In this compensatory process, the nature of the self- and interactive coordination can be construed as "emergent," in that the dyad discovers an organization that neither of the partners would reach on his or her own (Piers, 2005; Tronick, 2005).

Dynamic Homeostatic Balance Between Self- and Interactive Contingency

Negative feedback patterns pull the poles of the distribution back into midrange values, maintaining the system around a relatively stable solution (Weiner, 1948). In our findings, the negative feedback process provides a mechanism that shifts the system back toward midrange degrees of an individual's self- and interactive predictability. Lazlo (1972) considered such a negative feedback process a form of adaptive stabilization of the system (see also Sameroff, 1983). Changing conditions in relation to the environment (how tightly the individual coordinates with the partner) and changing conditions in internal variables (how stable the individual's own behavioral fluctuations are) can compensate for each other, reducing deviations, maintaining the system around a (momentarily) relatively stable solution. We infer that this momentary stabilization of the system facilitates social engagement: extremes of contingency, which are known to be associated with communication disturbance (Beebe et al., 2007, 2008, 2010; Jaffe et al., 2001; Gottman, 1979), are less likely.

Implications for Contingency Processes Across the First Year

Major behavioral reorganizations occur across the first year of life (Rochat, 2001). Particularly between 6 and 12 months, dyadic face-to-face interaction becomes less salient and triadic interactions involving joint attention to objects take center stage. Infants begin to understand symbolic gestures and they utter their first words (Tomasello, 1999). Infant initiation becomes more important in social interactions (Kaye & Fogel, 1980). Despite the implications of such behavioral reorganization for interpersonal engagement, stability and change in the organization of interpersonal contingency across the first year have not been extensively investigated. Summarizing over methodological differences and behavioral modalities assessed, across the first year, some studies suggest that interpersonal contingency effects increase (see e.g., Bigelow & Power, 2014; Crown et al., 1996; Feldman et al., 1996; Feldman, Greenbaum, & Yirmiya, 1999; Feldman, 2007; Lavelli & Fogel, 2013; Messinger et al., 2010); others suggest that contingency effects do not change (see e.g., Cohn & Tronick, 1988; Feldman, Granat, & Gilboa-Schechtman, 2005; Feldman & Greenbaum, 1997; Leyendecker et al., 1997; Symons & Moran, 1994); and still others suggest that contingency effects decrease (Cohn & Tronick, 1987). And no studies to our knowledge address stability of self-contingency across the first year as a variable separate from interactive contingency.

Because of this paucity of research on the stability and change in interpersonal contingency across the first year, we do not know whether the broad principles of the systems model we have defined at 4 months will hold across this period. Thus, our findings may only hold at the 4-month point. The fact that we examined only one age-point poses a limitation on the generalizability of the findings.

Our basic concepts are metaclaims about the system's organization. We speculate that the first three principles are sufficiently general that they may hold across the first year: (a) Both self- and interactive contingency organize face-to-face communication; (b) interactive contingency is organized by a bidirectional, but asymmetrical, process: maternal contingent coordination with infant is higher than that of infant with mother; and (c) self-contingency organizes face-to-face communication to a greater extent than interactive contingency. Because the Principle 4, face-to-face communication, is characterized by a dynamic homoeostatic (negative feedback) balance between self- and interactive contingency and is modality specific, we speculate that the modalities for which this principle holds may shift across age. Evaluating these principles longitudinally through one year of age and beyond is a topic for future investigation.

Conclusion

The results show how a consideration of self-contingency enhances our appreciation of the complexity of mother infant face-to-face interaction. Although documenting that early interactions are a simultaneous product of self- and interactive contingency, supporting theories of Fogel (1993), Gianino and Tronick (1988), and Sander (1977), we found that the interactive system is tilted substantially toward self-contingency. This new finding modifies the mutual regulation model of interaction. Moreover, there are contingencies between contingencies: An individual's self- and interactive contingency affect one another, in a homeostatic, negative feedback fashion. Thus, an individual's self-contingency is simultaneously self-organizing and influenced by the way the individual coordinates with the partner. In this sense, within face-to-face communication, an individual's behavior is itself partially dyadic, supporting the concept that the dyad is an irreducible unit of analysis. Our findings shift the picture of what an interaction is and what it means that two people are contingently coordinated. It is not appropriate to conceptualize interactive regulation without simultaneously accounting for related self-organizing processes.

References

Ambady, N., & Rosenthal, R. (1992). Thin slices of expressive behavior as predictors of interpersonal consequences: A meta-analysis. *Psychological Bulletin, 2,* 256–274. http://dx.doi.org/10.1037/0033-2909.111.2.256

Bahrick, L., & Lickliter, R. (2002). Intersensory redundancy guides early perceptual and cognitive development. In R. Kail (Ed.), *Advances in child development and behavior* (pp. 153–187). New York, NY: Academic Press.

Beebe, B., & Gerstman, L. (1980). The "packaging" of maternal stimulation in relation to infant facial-visual engagement. *Merrill-Palmer Quarterly, 26,* 321–339.

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., Feldstein, S., Mays, K., & Alson, D. (1985). Interpersonal timing: The application of an adult dialogue model to mother–infant vocal and kinesic interactions. In T. Field (Ed.), *Infant social perception* (pp. 217–248). New York, NY: Ablex.

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., Steele, M., Jaffe, J., Buck, K. A., Chen, H., Cohen, P., . . . Feldstein, S. (2011). Maternal anxiety and 4-month mother–infant self- and interactive contingency. *Infant Mental Health Journal, 32,* 174–206. http://dx.doi.org/10.1002/imhj.20274

Beebe, B., & Stern, D. (1977). Engagement-disengagement and early object experiences. In N. Freedman & S. Grand (Eds.), *Communicative structures and psychic structures* (pp. 35–55). New York, NY: Plenum Press. http://dx.doi.org/10.1007/978-1-4757-0492-1_3

Bigelow, A. (1998). Infants' sensitivity to familiar imperfect contingencies in social interaction. *Infant Behavior and Development, 21,* 149–162. http://dx.doi.org/10.1016/S0163-6383(98)90060-1

Bigelow, A., & Power, M. (2014). Effects of maternal responsiveness on infant responsiveness and behavior in the still-face task. *Infancy, 19,* 558–584.

Bornstein, M. H., Tamis-Lemonda, C. S., Hahn, C. S., & Haynes, O. M. (2008). Maternal responsiveness to young children at three ages: Longitudinal analysis of a multidimensional, modular, and specific parenting construct. *Developmental Psychology, 44,* 867–874. http://dx.doi.org/10.1037/0012-1649.44.3.867

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

Chow, S. M., Haltigan, J. D., & Messinger, D. S. (2010). Dynamic infant–parent affect coupling during the face-to-face/still-face. *Emotion, 10,* 101–114. http://dx.doi.org/10.1037/a0017824

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed). Hillsdale, NJ: Erlbaum.

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., Campbell, S., & Ross, S. (1991). Infant response in the still-face paradigm at 6 months predicts avoidant and secure attachments at 12 months. *Development and Psychopathology, 3,* 367–376. http://dx.doi.org/10.1017/S0954579400007574

Cohn, J., & Tronick, E. (1987). Mother–infant face-to-face interaction: The sequence of dyadic states at 3, 6, and 9 months. *Developmental Psychology, 23,* 68–77. http://dx.doi.org/10.1037/0012-1649.23.1.68

Cohn, J., & Tronick, E. (1988). Mother–infant face-to-face interaction: Influence is bi-directional 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

Crown, C. (1991). Coordinated interpersonal timing of vision and voice as a function of interpersonal attraction. *Journal of Language and Social Psychology, 10,* 29–46. http://dx.doi.org/10.1177/0261927X91101002

Crown, C., Flaspohler, D., Feldstein, S., Jaffe, J., Beebe, B., & Jasnow, M. (1996). Mathematical models for coordinated interpersonal timing in mother-infant interactions in the first year of life. *Journal of Psycholinguistic Research, 25,* 617–628. http://dx.doi.org/10.1007/BF01712412

DeCasper, A., & Carstens, A. (1980). Contingencies of stimulation: Effects on learning and emotion in neonates. *Infant Behavior and Development, 9,* 19–36.

Fagen, J. W., Morrongiello, B. A., Rovee-Collier, C., & Gekoski, M. J. (1984). Expectancies and memory retrieval in three-month-old infants. *Child Development, 55,* 936–943. http://dx.doi.org/10.2307/1130145

Feldman, R. (2007). 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., & 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., Granat, A., & Gilboa-Schechtman, E. (2005). *Maternal anxiety and depression, mother–infant synchrony, and infant regulation of negative and positive emotions*. Poster presented at the Biennial Meeting of the Society for Research in Child Development, Atlanta, GA.

Feldman, R., & Greenbaum, C. (1997). Affect regulation and synchrony in mother—Infant play as precursors to the development of symbolic competence. *Infant Mental Health Journal, 18,* 4–23. http://dx.doi.org/10.1002/(SICI)1097-0355(199721)18:1<4::AID-IMHJ2>3.0.CO;2-R

Feldman, R., Greenbaum, C., Yirmiya, N., & Mayes, L. (1996). Relations between cyclicity and regulation in mother–infant interaction at 3 and 9 months and cognition at 2 years. *Journal of Applied Developmental Psychology, 17,* 347–365. http://dx.doi.org/10.1016/S0193-3973(96)90031-3

Feldman, R., Greenbaum, C., & Yirmiya, N. (1999). Mother-infant affect synchrony as an antecedent of the emergence of self-control. *Developmental Psychology, 35,* 223–231. http://dx.doi.org/10.1037//0012-1649.35.1.223

Field, T. (1981). Infant gaze aversion and heart rate during face to face interactions. *Infant Behavior and Development, 4,* 307–315. http://dx.doi.org/10.1016/S0163-6383(81)80032-X

Field, T., Healy, B., Goldstein, S., & Guthertz, M. (1990). Behavior-state matching & synchrony in mother-infant interactions of nondepressed vs. depressed dyads. *Developmental Psychology, 26,* 7–14. http://dx.doi.org/10.1037/0012-1649.26.1.7

Field, T. (1995). Infants of depressed mothers. *Infant Behavior and Development, 18,* 1–13. http://dx.doi.org/10.1016/0163-6383(95)90003-9

Fogel, A. (1993). Two principles of communication: Co-regulation and framing. In J. Nadel & L. Camaioni (Eds.), *New perspectives in early communicative development* (pp. 9–22). London, England: Routledge.

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.

Gottman, J. (1979). *Marital interactions*. New York, NY: Academic Press.

Gottman, J. (1981). *Time-series analysis*. Cambridge, MA: Cambridge University Press.

Gusella, J. L., Muir, D., & Tronick, E. Z. (1988). The effect of manipulating maternal behavior during an interaction on three- and six-month-olds' affect and attention. *Child Development, 59,* 1111–1124. http://dx.doi.org/10.2307/1130278

Hains, S., & Muir, D. (1996). Effects of stimulus contingency in infant–adult interactions. *Infant Behavior and Development, 19,* 49–61. http://dx.doi.org/10.1016/S0163-6383(96)90043-0

Haith, M. M., Hazan, C., & Goodman, G. S. (1988). Expectation and anticipation of dynamic visual events by 3.5-month-old babies. *Child Development, 59,* 467–479. http://dx.doi.org/10.2307/1130325

Harrist, A., & Waugh, R. (2002). Dyadic synchrony: Its structure and function in children's development. *Developmental Review, 22,* 555–592. http://dx.doi.org/10.1016/S0273-2297(02)00500-2

Haviland, J. M., & Lelwica, M. (1987). The induced affect response: 10-week-old infants' responses to three emotion expressions. *Developmental Psychology, 23,* 97–104. http://dx.doi.org/10.1037/0012-1649.23.1.97

Hay, D. (1997). Postpartum depression and cognitive development. In L. Murray & P. Cooper (Eds.), *Postpartum depression and child development* (pp. 85–110). New York, NY: Guilford Press.

Hsu, H. C., & Fogel, A. (2003). Stability and transitions in mother–infant face-to-face communication during the first 6 months: A microhistorical approach. *Developmental Psychology, 39,* 1061–1082. http://dx.doi.org/10.1037/0012-1649.39.6.1061

Isabella, R., & Belsky, J. (l991). Interactional synchrony and the origins of infant-mother attachment: A replication study. *Child Development, 62,* 373–384. http://dx.doi.org/10.1111/j.1467-8624.1991.tb01538.x

Jaffe, J., Beebe, B., Feldstein, S., Crown, C., & Jasnow, M. (2001). Rhythms of dialogue in early infancy. *Monographs of the Society for Research in Child Development, 66*(2, Serial No. 264), 1–132. http://dx.doi.org/10.1023/A:1019573825857

Kahana-Kalman, R., & Walker-Andrews, A. S. (2001). The role of person familiarity in young infants' perception of emotional expressions. *Child Development, 72,* 352–369. http://dx.doi.org/10.1111/1467-8624.00283

Kaye, K., & Fogel, A. (1980). The temporal structure of face-to-face communication between mothers and infants. *Developmental Psychology, 16,* 454–464. http://dx.doi.org/10.1037/0012-1649.16.5.454

Keller, H., Lohaus, A., Volker, S., Cappenberg, M., & Chasiotis, A. (1999). Temporal contingency as an independent component of parenting behavior. *Child Development, 70,* 474–485. http://dx.doi.org/10.1111/1467-8624.00034

Kopp, C. (1989). Regulation of distress and negative emotions: A developmental view. *Developmental Psychology, 25,* 343–354. http://dx.doi.org/10.1037/0012-1649.25.3.343

Koulomzin, M., Beebe, B., Anderson, S., Jaffe, J., Feldstein, S., & Crown, C. (2002). Infant gaze, head, face and self-touch at 4 months differentiate secure vs. avoidant attachment at 1 year: A microanalytic approach. *Attachment & Human Development, 4,* 3–24. http://dx.doi.org/10.1080/14616730210123120

Lavelli, M., & Fogel, A. (2013). Interdyad differences in early mother–infant face-to-face communication: Real-time dynamics and developmental pathways. *Developmental Psychology, 49,* 2257–2271. http://dx.doi.org/10.1037/a0032268

Lazlo, E. (1972). *Introduction to systems philosophy: Toward a new paradigm of contemporary thought*. New York, NY: Gordon and Breach.

Leerkes, E. M., Blankson, A. N., & O'Brien, M. (2009). Differential effects of maternal sensitivity to infant distress and nondistress on social-emotional functioning. *Child Development, 80,* 762–775. http://dx.doi.org/10.1111/j.1467-8624.2009.01296.x

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

Lewis, M., & Feiring, C. (1989). Infant, mother, and mother–infant interaction behavior and subsequent attachment. *Child Development, 60,* 831–837. http://dx.doi.org/10.2307/1131024

Lewis, M., & Goldberg, S. (1969). Perceptual-cognitive development in infancy: A generalized expectancy model as a function of the mother–infant interaction. *Merrill-Palmer Quarterly, 15,* 81–100.

Leyendecker, B., Lamb, M., Fracasso, M., Scholmerich, A., & Larson, D. (1997). Playful interaction and the antecedents of attachment: A longitudinal study of Central American and Euro-American mothers and infants. *Merrill-Palmer Quarterly, 43,* 24–47. Retrieved from http://www.jstor.org/stable/23093726.

Lickliter, R., & Honeycutt, H. (2003). Developmental dynamics: Toward a biologically plausible evolutionary psychology. *Psychological Bulletin, 129,* 819–835. http://dx.doi.org/10.1037/0033-2909.129.6.819

Littell, R. C., Miliken, G. A., Stoup, W. W., & Wolfinger, R. D. (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, Serial No. 219). http://dx.doi.org/10.2307/1166153

Malatesta, C. Z., & Haviland, J. M. (1982). Learning display rules: The socialization of emotion expression in infancy. *Child Development, 53,* 991–1003. http://dx.doi.org/10.2307/1129139

Mandler, J. (1988). How to build a baby: On the development of an accessible representation system. *Cognitive Development, 3,* 113–136. http://dx.doi.org/10.1016/0885-2014(88)90015-9

McArdle, J., & Bell, R. (2000). An introduction to latent growth models for developmental data analysis. In T. Little, K. Schnabel, & J. Baumert (Eds.), *Modeling longitudinal and multilevel data: Practical issues, applied approaches, and specific examples* (pp. 69–107). Mahwah, NJ: Erlbaum.

McCleary, R., & Hay, R. (1980). *Applied time series analysis for the social sciences*. Beverly Hills, CA: Sage.

Messinger, D. (2002). Positive and negative: Infant facial expressions and emotions. *Current Directions in Psychological Science, 11,* 1–6. http://dx.doi.org/10.1111/1467-8721.00156

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

Messinger, D. S., Mahoor, M. H., Chow, S. M., & Cohn, J. F. (2009). Automated measurement of facial expression in infant–mother interaction: A pilot study. *Infancy, 14,* 285–305. http://dx.doi.org/10.1080/15250000902839963

Messinger, D. M., Ruvolo, P., Ekas, N. V., & Fogel, A. (2010). Applying machine learning to infant interaction: The development is in the details. *Neural Networks, 23*(8–9), 1004–1016. http://dx.doi.org/10.1016/j.neunet.2010.08.008

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

Muir, D., & Hains, S. (1993). Infant sensitivity to perturbations in adult facial, vocal, tactile, and contingent stimulation during face-to-face interaction. In B. DeBoysson-Bardies, S. de Schonen, P. Jusczyk, P. McNeilage, & J. Morton (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 171–185). Amsterdam, the Netherlands: Springer Netherlands. http://dx.doi.org/10.1007/978-94-015-8234-6_15

Murray, L., & Cooper, P. (1997). The role of infant and maternal factors in postpartum depression, mother–infant interactions, and infant outcome. In L. Murray & P. J. Cooper (Eds.), *Postpartum depression and child development* (pp. 111–135). New York, NY: Guilford Press.

Murray, L., & Trevarthen, C. (1985). Emotional regulation of interactions between two-month-olds and their mothers. In T. Field & N. Fox (Eds.), *Social perception in infants* (pp. 177–197). Norwood, NJ: Ablex.

Overton, W. F. (1998). Developmental psychology: Philosophy, concepts and methodology. In R. M. Lerner (Ed.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (pp. 107–188). New York, NY: Wiley.

Peláez-Nogueras, M., Field, T. M., Hossain, Z., & Pickens, J. (1996). Depressed mothers' touching increases infants' positive affect and attention in still-face interactions. *Child Development, 67,* 1780–1792. http://dx.doi.org/10.2307/1131731

Piers, C. (2005). The mind's multiplicity and continuity. *Psychoanalytic Dialogues, 15,* 229–254. http://dx.doi.org/10.1080/10481881509348830

Rochat, P. (2001). Dialogical nature of cognition. Commentary. *Monographs of the Society for Research in Child Development, 66* (2, Serial No. 264), 133–143. http://dx.doi.org/10.1111/1540-5834.00146

Sameroff, A. (1983). Developmental systems: Contexts and evolution. In W. Kessen (Ed.), *Mussen's handbook of child psychology* (Vol. 1, pp. 237–294). New York, NY: Wiley.

Sameroff, A. (2010). A unified theory of development: A dialectic integration of nature and nurture. *Child Development, 81,* 6–22. http://dx.doi.org/10.1111/j.1467-8624.2009.01378.x

Sander, L. (1977). The regulation of exchange in the infant-caretaker system and some aspects of the context–content relationship. In M. Lewis & L. Rosenblum (Eds.), *Interaction, conversation, and the development of language* (pp. 133–156). New York, NY: Wiley.

Sander, L. (1995). Identity and the experience of specificity in a process of recognition commentaries on Seligman and Shanok. *Psychoanalytic Dialogues, 5,* 579–593. http://dx.doi.org/10.1080/10481889509539095

Schmidt, R. C., Bienvenu, M., Fitzpatrick, P. A., & Amazeen, P. G. (1998). A comparison of intra- and interpersonal interlimb coordination: Coordination breakdowns and coupling strength. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 884–900. http://dx.doi.org/10.1037/0096-1523.24.3.884

Singer, J. D. (1998). Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. *Journal of Educational and Behavioral Statistics, 23,* 323–355. http://dx.doi.org/10.2307/1165280

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

Stack, D., & Arnold, S. (1998). Changes in mothers' touch and hand gestures influence infant behavior during face-to-face interchanges. *Infant Behavior and Development, 21,* 451–468. http://dx.doi.org/10.1016/S0163-6383(98)90019-4

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

Stepakoff, S., Beebe, B., & Jaffe, J. (2000, July). *Mother–infant tactile communication at four months: Infant gender, maternal ethnicity, and maternal depression*. Paper presented at the International Conference of Infant Studies, Brighton, England.

Stern, D. N. (1971). A micro-analysis of mother–infant interaction: Behavior regulating social contact between a mother and her 3 1/2-month-old twins. *Journal of the American Academy of Child Psychiatry, 10,* 501–517. http://dx.doi.org/10.1016/S0002-7138(09)61752-0

Stern, D. N. (1974). The goal and structure of mother–infant play. *Journal of the American Academy of Child Psychiatry, 13,* 402–421. http://dx.doi.org/10.1016/S0002-7138(09)61348-0

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

Symons, D., & Moran, G. (1994). Responsiveness and dependency are different aspects of social contingencies: An example from mother and infant smiles. *Infant Behavior and Development, 17,* 209–214. http://dx.doi.org/10.1016/0163-6383(94)90057-4

Tamis-LeMonda, C. S., Bornstein, M. H., & Baumwell, L. (2001). Maternal responsiveness and children's achievement of language milestones. *Child Development, 72,* 748–767. http://dx.doi.org/10.1111/1467-8624.00313

Tarabulsy, G. M., Tessier, R., & Kappas, A. (1996). Contingency detection and the contingent organization of behavior in interactions: Implications for socioemotional development in infancy. *Psychological Bulletin, 120,* 25–41. http://dx.doi.org/10.1037/0033-2909.120.1.25

Thelen, E., & Smith, L. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Thomas, E. A. C., & Malone, T. W. (1979). On the dynamics of two-person interactions. *Psychological Review, 86,* 331–360. http://dx.doi.org/10.1037/0033-295X.86.4.331

Thomas, E., & Martin, J. (1976). Analyses of parent-infant interaction. *Psychological Review, 83,* 141–156. http://dx.doi.org/10.1037/0033-295X.83.2.141

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.

Trevarthen, C. (1977). Descriptive analyses of infant communicative. In H. Schaffer (Ed.), *Studies in mother–infant interaction* (pp. 227–270). London, England: Academic Press.

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. (2005). Why is connection with others so critical? In J. Nadel & D. Muir (Eds.), *Emotional development* (pp. 292–315). Oxford, England: Oxford University Press.

Tronick, E. Z., Weinberg, M. K. (1990). *The infant regulatory scoring system* (*IRSS*). Unpublished manuscript, Children's Hospital and Harvard Medical School, Boston, Massachusetts.

Van Egeren, L. A., Barratt, M. S., & Roach, M. A. (2001). Mother–infant responsiveness: Timing, mutual regulation, and interactional context.

Developmental Psychology, 37, 684–697. http://dx.doi.org/10.1037/0012-1649.37.5.684

Warner, R. (1992). Sequential analysis of social interaction: Assessing internal versus social determinants of behavior. *Journal of Personality and Social Psychology, 63,* 51–60. http://dx.doi.org/10.1037/0022-3514.63.1.51

Watson, J. (1985). Contingency perception in early social development. In T. Field & N. Fox (Eds.), *Social perception in infants* (pp. 157–176). Norwood, NJ: Ablex.

Weinberg, M. K., & Tronick, E. (1991). *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, Washington.

Weinberg, M. K., & Tronick, E. Z. (1994). Beyond the face: An empirical study of infant affective configurations of facial, vocal, gestural, and regulatory behaviors. *Child Development, 65,* 1503–1515. http://dx.doi.org/10.2307/1131514

Weinberg, M. K., & Tronick, E. Z. (1996). Infant affective reactions to the resumption of maternal interaction after the still-face. *Child Development, 67,* 905–914. http://dx.doi.org/10.2307/1131869

Weiner, N. (1948). *Cybernetics*. New York, NY: Wiley.

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, NY.

Received April 1, 2014
Revision received September 30, 2015
Accepted November 11, 2015 ■

Correction to Duh et al. (2016)

In the article “Theory of Mind and Executive Function in Chinese Preschool Children” by Shinchieh Duh, Jae H. Paik, Patricia H. Miller, Stephanie C. Gluck, Hui Li, and Igor Himelfarb (*Developmental Psychology*, Advance online publication. February 4, 2016. http://dx.doi.org/10.1037/a0040068), there were two errors in Table 6. The coefficient between WM and Age was incorrectly set as −.46; it should have been .46. Further, the coefficient between WM and Gender should be .00 instead of −.00. The correct version is presented below.

Table 6
Pearson’s Coefficients for the Correlations between Theory of Mind (ToM), Gender, Conflict Inhibition (CI), and Working Memory (WM)

Predictor	ToM	Gender	Age	CI	WM
ToM	—	−.04	.42*	.30*	.33*
Gender		—	.00	−.01	.00
Age			—	.51*	.46*
CI				—	.33*
WM					—

* $p < .001$.

http://dx.doi.org/10.1037/dev0000129