# Social Emotions in Nature and Artifact

*Edited by Jonathan Gratch and Stacy Marsella*

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# Early Emotional Communication: Novel Approaches to Interaction

*Daniel S. Messinger, Mohammad H. Mahoor, Sy-Miin Chow, John D. Haltigan, Steven Cadavid, & Jeffrey F. Cohn*

This chapter is concerned with the emergence of emotional communication—transactional emotions—early in life. We review methodological and conceptual issues in research on early interaction and then present two studies of emotional communication. The first study uses computer vision to describe infant–mother interaction from a microanalytic perspective. It reveals evidence of changing infant–mother emotional dynamics during the course of interaction. The second study formally models these changing dynamics utilizing continuous ratings of affective valence. Each study utilizes a different approach for continuously measuring emotion during interaction that may resolve methodological impasses and shed new light on emotional transactions.

## Early Emotional Interaction

In this chapter, we describe a class of dyadic interactions characterized by intense emotional communication. These interactions regularly involve peals of laughter and, at times, tears of desperation. While one partner in the interaction often appears entirely devoted to the other, the second partner may appear relatively unconcerned with the expectations of the first. These patterns of behavior are not rare events that are coincident with infrequent happenings such as homecomings or relationship dissolution. They characterize the day-to-day interactions between infants and their parents.

## Emotional Interaction and Development

The infant–parent relationship is a prototype for social relationships throughout life. During interaction, infants and parents seem to respond to one another, and enter into and out of shared joyous states. Parent–infant interactions are characterized by nonverbal emotional communication. These are the infant's first experiences of feeling with another, a potential basis of emotional contagion and rapport. We study these interactions as a tractable model system for understanding communicative development.

The patterning of infant–parent interaction has a central role in early development. Synchronous interaction between infant and parent—high correlations between emotional engagement states—is predicted by the rhythmicity of infants' early physiological (e.g., sleep–wake) cycles (Feldman, 2006). The patterning of infant–parent interaction, likewise, predicts later developmental achievements. The predilection of parents to shift affective states to match those of their infants is related to increases in infants' self-control and cognitive performance at 2 years (Feldman & Greenbaum, 1997; Feldman, Greenbaum, & Yirmiya, 1999; Feldman, Greenbaum, Yirmiya, & Mayes, 1996). More generally, interaction patterns characterized by maternal responsivity and positive affect predict later toddler internalization of social norms (Feldman et al., 1999; Kochanska, 2002; Kochanska, Forman, & Coy, 1999; Kochanska & Murray, 2000).

Why is it the case that early parental positive affect and responsivity predict self-control and normative behavior? Normative behavior is implicitly interactive in two senses. First, it involves acting with respect to the expectations of a generalized other; second, it involves the expectation that one's actions affect others (Kochanska, 2002). We posit that young infants who act with the developing expectation of eliciting positive affect in the parent develop to be young children who regulate themselves to please their parents. It may also be the case that infants who are developing responsivity to their parents become increasingly responsive to the expectations of others.

As suggested by these explanations of the longitudinal predictions found by developmental psychologists, a fundamental question in infant–parent interaction concerns communicative influence. Do infant behaviors influence the parent? Do parent behaviors influence the infant? The converse of one partner's influence is the other partner's responsivity. Only if partners influence each other can we meaningfully refer to their interaction. Substantively, there is little attention in the infant–parent interaction literature to the possibility that interactive influence varies in time. Yet it appears possible that there are temporal variations in the responsivity of each partner to the other. Both empirical studies in this chapter tackle this issue. To place those studies in context, we begin by reviewing two conventional approaches to measuring influence during interactions—contingency analyses of discrete behaviors and time series analyses of ordinal rating scales.

## Contingency Analyses of Discrete Behaviors

One approach to the question of influence involves manually measuring discrete infant and parent behaviors (Kaye & Fogel, 1980; Van Egeren, Barratt, & Roach, 2001) such as facial expressions (Elias & Broerse, 1995; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001), and gazes and vocalizations (Crown, Feldstein, Jasnow, Beebe, & Jaffe, 2002). Interaction is conceptualized with respect to the sequencing of dyadic states. Contingency analyses are typically employed to examine the likelihood of one partner's discrete behavior (e.g., a smile or vocalization) predicting the onset of the partner's behavior (Fogel, 1988; Kaye & Fogel, 1980; Malatesta, Culver, Tesman, & Shepard, 1989; Symons & Moran, 1994; Van Egeren et al., 2001).

In general, infant positive expressions such as smiles tend to elicit parent positive expressions. Parent positive expressions typically precede but are not sufficient for eliciting infant positive expressions (Cohn & Tronick, 1987; Kaye & Fogel, 1980; Symons & Moran, 1994). Our analyses of dyadic smiling (Cohn & Tronick, 1987; Messinger, Fogel, & Dickson, 1999, 2001) reveal that parents respond both to the onset and to the offset of their infants' smiles. These patterns might be phrased as a set of dyadic "rules," although the rules are more obligatory for parents than for infants. Parents tend to smile before infants, although infants, particularly by 6 months of age and beyond, may initiate smiling. Parents must smile in response to an infant smile. Infants are free to smile or not in response to a parent smile. Once both partners are smiling, the infant may stop smiling; parents, however, must not stop smiling until the infant has stopped smiling.

## Time Series Analyses of Ordinal Behavior Scales

Another approach to the question of influence involves measuring infant and parent behavior with ordinal scales composed of affective engagement states (Beebe & Gerstman, 1984; Cohn & Tronick, 1988b; Weinberg, Tronick, Cohn, & Olson, 1999). These engagement states index aggregates of behaviors reflecting a continuum from negative to neutral to positive affective engagement (Cohn & Tronick, 1988b; Weinberg et al., 1999). Interaction is conceptualized with respect to associations between ordinal gradations in infant and parent engagement. These associations are typically examined with time series analyses.

In time series analyses, the influence of each partner on the other is examined with regression methods after having removed variance associated with autocorrelation (Cohn & Tronick, 1988b). Early work using time series analyses established that parent and infants display nonperiodic (variable) cyclicity (Cohn & Tronick, 1988b). That is, parents do not merely insert their behaviors in the midst of ongoing periodic (regular) infant behavioral cycles. Instead, infants and parents interact stochastically by influencing the likelihood of a change in the other partner's behavior (Cohn & Tronick, 1988a, 1988b).

Like contingency analyses, time series analyses typically indicate strong infant-to-parent interactive influence. They also reveal a developmental increase in parent-to-infant influence. Between 3 and 9 months, infants become increasingly responsive to their interactive partners. In some dyads, the joint presence of infant-to-parent and parent-to-infant influence yields bidirectional influence (Cohn & Tronick, 1987, 1988b; Feldman, Greenbaum, Mayes, & Erlich, 1997; Feldman et al., 1996; Weinberg et al., 1999; Yirmiya et al., 2006). Bidirectional influence occurs when each partner's behavior impacts that of the other.

## The Need for New Approaches

Discrete and ordinal measurement approaches both offer insights into infant–parent interaction, but both have limitations. A discrete behavior approach characterizes the temporal association of expressive behaviors exactly but does not provide a description of the rhythmicity of interaction. Ordinal scaling approaches capture the rhythmicity—the pseudoperidicity—of interactions, but each step of the scale lacks behavioral specificity. This lack of specificity means it is not entirely clear which behaviors of an infant or parent might be impacting the other partner.

In addition to this analytic impasse, both discrete and ordinal measurement approaches involve practical difficulties. Each typically relies on labor-intensive, manual coding of behavior (Cohn & Kanade, 2007). The laborious quality of manual coding represents a challenge for detailed measurement of human expressivity. Efficient measurement of human expressivity is essential for understanding real-time interaction and development. Conceptually and practically, then, alternative measurement approaches are necessary.

In this chapter, we describe two alternatives to the conceptual and practical problems with current measurement approaches. First, we employ automated measurement of behavior using computer vision and machine learning. Second, we ask nonexpert observers to make continuous ratings of affective valence using a joystick interface. On the face of it, these approaches appear to be quite different. Automated measurement is objective while the continuous ratings are subjective. Yet both approaches are oriented toward meaningful continuous measurement of ongoing interactions. Moreover, both promise efficiencies of measurement when compared with traditional manual measurement by human experts. Finally, each approach has the potential to uncover changes in infant–parent interactive dynamics over time. We begin by reviewing what is known about positive emotional expression as a medium for communication in infant–parent interaction.

## Positive Emotion Expression

Early infant–parent interaction has no topic external to the displays of the partners themselves and frequently involves the communication of positive emotion. Parents attempt to elicit smiles from infants during interaction, and episodes of joint smiling appear to represent high points of the dyadic transaction. The smile is the prototypic expression of positive emotion (joy) in infants and mothers. In smiling, the zygomatic major pulls the lip corners obliquely upward. There are, however, similarities and differences in *how* parents and infants smile.

Among both infants and adults, stronger smiles involving greater lip corner movement tend to occur during conditions likely to elicit positive emotion (Bolzani-Dinehart et al., 2005; Ekman & Friesen, 1982; Fogel, Hsu, Shapiro, Nelson-Goens, & Secrist, 2006; Schneider & Uzner, 1992). By the same token, infant and adult smiles with eye constriction—Duchenne smiles—tend to occur in situations likely to elicit positive affect (Fogel, Nelson-Goens, Hsu, & Shapiro, 2000; Fox & Davidson, 1988; Lavelli & Fogel, 2002; Messinger et al., 2001). We refer to these smiles—in which the orbicularis oculi (pars lateralis) raises the cheek under the eye and compresses the eyelid—as smiles with eye constriction. Stronger smiles and smiles with eye constriction are perceived to be more emotionally positive than smiles without these characteristics (Bolzani-Dinehart et al., 2005; Ekman, Davidson, & Friesen, 1990; Fogel, Hsu, et al., 2006; Fox & Davidson, 1988; Frank, Ekman, & Friesen, 1993; Messinger, 2002; Messinger et al., 2001).

Among infants, smiling involving mouth opening also tends to involve eye constriction, and smiles with these characteristics tend to be stronger smiles (Fogel, Hsu et al., 2006; Messinger et al., 2001). In infants, combined open-mouth, cheek-raise smiling tends to occur during unambiguously positive periods of interaction (Dickson, Walker, & Fogel, 1997; Fogel et al., 2000; Messinger et al., 2001). More generally, degree of lip corner movement, mouth opening, and eye constriction all appear to index the positive emotional intensity of infant smiles (Bolzani-Dinehart et al., 2005; Carvajal & Iglesias, 2002; Fogel, Hsu et al., 2006; Fogel et al., 2000; Harker & Keltner, 2001; Keltner & Ekman, 2000; Keltner, Kring, & Bonanno, 1999; Messinger, 2002; Messinger, Cassel, Acosta, Ambadar, & Cohn, 2008; Messinger, Mahoor, Chow, Cadavid, & Cohn, 2008; Oster, 2006).

Smile intensity and eye constriction also appear to index the positive emotional intensity of smiles in adults. The role of mouth opening in adult smiles is less clear, although adult open-mouth, cheek-raise smiles tend to occur in response to humorous stimuli (Ruch, 1995). In fact, surprisingly little is known about the facial expressions of parents engaged in interacting with their infants (Chong, Werker, Russell, & Carroll, 2003).

A paucity of descriptive information also impedes our understanding of infant emotional dynamics during face-to-face interactions. Infant facial expressions are typically described generally, for example, as negative cry faces, neutral, and different types of positive smiles, but rarely in fine-grained fashion. Nevertheless, infants engage in a variety of nonsmiling actions that may communicate subtle negative affect or an attenuation of positive affect (e.g., dimpling of the lips and lip tightening). Automated measurement is a promising approach to measuring such expressions (Cohn & Kanade, 2007; Messinger, Mahoor, Chow, Cadavid et al., 2008; Oster, 2006; Tronick et al., 2005; Weinberg & Tronick, 1998). Ultimately, our application of automated measurement to early interaction was aimed at a better understanding of early emotional communication. As long-time investigators of infant–parent interaction, two things have become clear to us. On the one hand, detailed measurement is necessary to understand how communication is occurring. On the other hand, manual coding of that communication is not tenable for large-scale studies.

## Automated Measurement of Early Interaction

Automated measurement has the potential to objectively document real-time behavior (Bartlett et al., 2006; Cohn & Kanade, 2007). Ultimately, automated measurement may provide a means for objectively measuring aspects of behavior that human beings notice but are not able to reliably and efficiently document. Our goal, then, is to supplement and complement, rather than replace, human observation.

Historically, computer vision systems have been limited to the recognition of deliberate (i.e., posed) facial expressions recorded under controlled conditions that did not involve significant head motion (Essa & Pentland, 1994; Padgett, Cottrell, & Adolphs, 1996; Yacoob & Davis, 1997). More recent systems (Bartlett et al., 2005, 2006; Lien, Kanade, Cohn, & Li, 2000; Tian, Kanade, & Cohn, 2001, 2002) have achieved some success in the more difficult task of recognizing facial Action Units of the Facial Action Coding System (FACS) (Ekman & Friesen, 1978; Ekman, Friesen, & Hager, 2002). FACS—and its application to infants (BabyFACS) (Oster, 2006)—is the gold-standard manual system for objectively recording anatomically based appearance changes in the form of facial Action Units.

We recently developed a system capable of FACS action unit recognition in naturalistic interaction (Lucey, Ashraf, & Cohn, 2007). We then measured the strength of specified Action Units using the FACS (A–E, minimal–maximal) intensity metric (Mahoor et al., 2008). In other words, the system produces precise measurements of behavior on a meaningful continuous metric. This approach allows for a synthesis of the discrete and ordinal measurement approaches discussed previously. We use these measurements of intensity to examine the flow of interaction between infant and parent. While it is technically possible to conduct continuous manual coding of the intensity of FACS Action Units, we know of no examples of this somewhat impractical approach. Ultimately, we are using automated measurement to turn up a virtual microscope that may reveal how early interaction itself dynamically changes in time.

## Applying Automated Measurement to Early Interaction

Here we report on the exploration of dyadic expressivity in two 6-month-old infants engaged in face-to-face interaction with their mothers (Messinger, Mahoor, Chow, & Cohn, 2008). Mothers were asked to play with their infants as they normally would at home for 3 minutes. We designated the mother–infant dyads A (male infant) and B (female infant). We describe our measurement system in some depth because its focus on the intensity of emotional expressions is relatively novel.

Our automated measurement approach had two steps. First we tracked and measured information in the face using computer vision. Next we measured facial action intensity, primarily using a machine learning approach. This combined approach enabled us to document the coherence of expressions of positive emotion, changing levels of synchrony and tickling, and a class of infant facial actions that appeared to attenuate smiling. We supplemented these automated measurements with manual coding of mother tickling the infant, an activity that was central to dyadic emotional communication.

## Facial Tracking

Our computer vision approach was based on active appearance and shape models (AAMs). AAMs detect, track, and measure the face in a video record using a fitting algorithm (see Figure 10.1). In the current application, AAMs were trained using 3% of the frames in the video record. In these training frames, the software provided an approximate fit of the mesh to the videotaped image of the face, and a research assistant adjusted the vertices to ensure fit. Using the training frames as data, the model overlays the mesh on the facial image using a fitting algorithm that is guided by a Principal Components Analysis. Here, the AAM independently models the entire video sequence (including training frames) based on variation in the principal components.

AAMs are anatomic models of an individual's head and face. AAMs consist of a shape component and an appearance component (Cootes, Edwards, & Taylor, 2001). The shape component is a triangulated mesh model of the face containing 66 vertices, each of which has an X and Y coordinate (Baker, Matthews, & Schneider, 2004; Cohn & Kanade, 2007) (see Figure 10.2). The mesh moves and deforms in response to changes in parameters

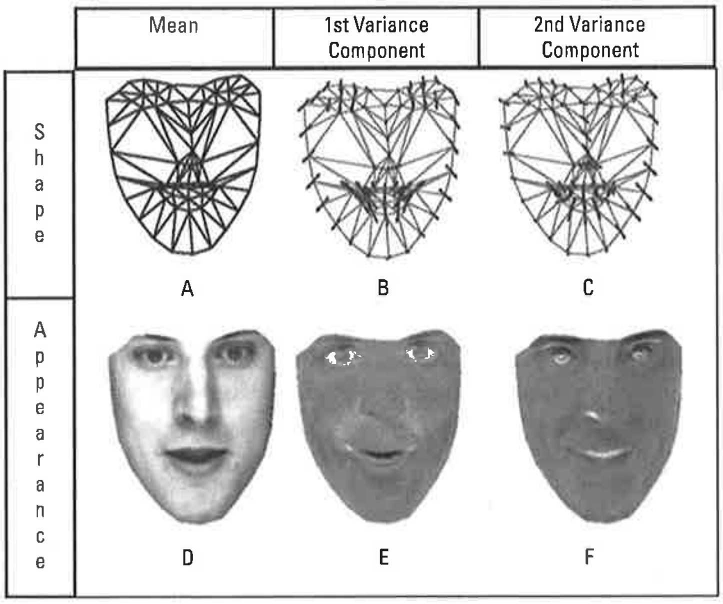


FIGURE 10.1 Active appearance and shape model. The shape model consists of a network of geometric points located on facial landmarks. The appearance model contains the grayscale values of the pixels within the shape model. For both shape and appearance, a mean model is displayed along with the first two variance components. These are principal components that parsimoniously describe changes in each of the models. They are derived from training images and used to track and measure the video sequence in its entirety.

FIGURE 10.2 Display of the shape model of an AAM applied to video frames of an infant interaction. A 2D+3D AAM is shown, which yields 3D shape and rigid motion and 3D nonrigid motion of expression.

corresponding to a face undergoing both whole-head rigid motion and nonrigid motion (facial movement). In the current application, we measured mouth opening directly from the shape component of the AAM as the mean vertical distance between the upper and lower lips.

The appearance component of the AAM contains the 256 grayscale values (lightness/darkness) for each pixel contained in the modeled face. The appearance data generated by the AAM are highly complex, containing 256 possible grayscale values for each of the approximately 10,000 pixels in the AAM for each frame of video. We used manifold learning (Belkin & Niyogi, 2003)—a nonlinear technique—to reduce the dimensionality of the appearance and shape data to 12 variables per frame. This reduced data metric was used to train support vector machines (SVMs).

### Support Vector Machine Classification

SVMs are machine learning algorithms frequently used in computer vision applications (Chang & Lin, 2001). Littlewort, Bartlett, & Movellan (2001), for example, used SVMs to distinguish the presence of eye constriction (AU6) in adult smiles (Littlewort, Bartlett, & Movellan, 2001). Employing the reduced shape and appearance dataset, we trained separate instances of SVMs to measure three classes of expressive action. We specifically measured smiling intensity (AU12, from absent to maximal) and eye constriction (AU6, from absent to maximal). We also measured the presence of a class of infant actions that appeared to be subtle signs of upset or, at least, reductions in positive affect expression (e.g., lip tightening, AU23). Each instance of training was carried out using a separate sample of the frames that were selected to encompass the entire range of actions being classified.

In the next section, we examine the convergent and construct validity of the automated measurements of facial actions. We then use the measurements to examine the structure of infant and mother smiling with the goal of identifying summary measures of emotional intensity with which to describe interaction. Our treatment of interaction involves a microanalytic description of how infants and mothers interact, and how this interaction changes in time.

### Automated Measurement: Convergent and Construct Validity

*Convergent Validity.* We first established the convergent validity of automated measurement of the intensity of

FIGURE 10.3 This composite rendering illustrates the measurement of infant and mother facial expressions during an interaction. Automated tracking of the lips, eyes, brows, and portions of the facial outline are outlined in white on the infant's and mother's face.

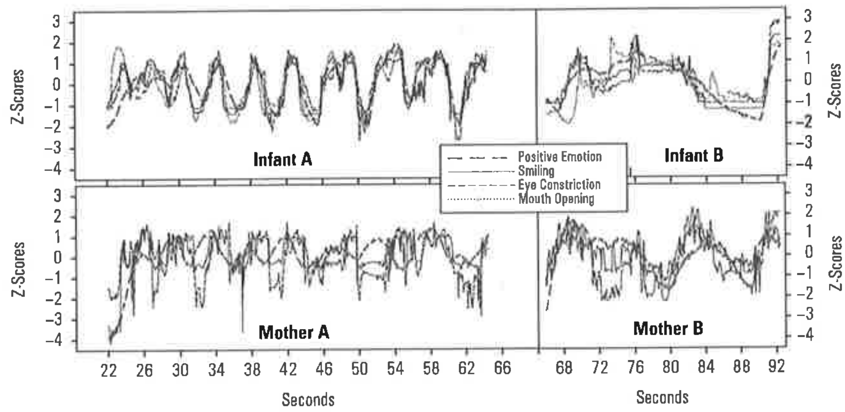


FIGURE 10.4 Smile parameters and rated positive emotion over time. Infant graphs show the association of automated measurements of smile strength, eye constriction, mouth opening, and rated positive emotion. Mother graphs show the association of automated measurements of smile strength, eye constriction, and rated positive emotion. Positive emotion is offset by three fifths of a second to account for rating lag.

infant and mother expressive actions (see Figure 10.3). Correlations between automated measurements and manual coding were high. Mean correlations for infant and mother smiling and eye constriction were above .9; the mean for mouth opening was around .8. The high associations between automated and manual measurements of smiling and eye constriction are illustrated in. Automated measurements of the presence and absence of individual infant actions that might be associated with smile attenuation (e.g., lip tightening) showed adequate agreement with manual measurements (89%, K = .54) (Bakeman & Gottman, 1986). In all cases, reliability between automated and manual measurements was comparable or better than interrater reliability assessed between two manual raters. The results suggest the concurrent validity of automated measurements of expressive actions.

*Assessing Construct Validity via Ratings.* We were interested in ascertaining the degree to which automated measurements of smiling-related facial actions were associated with positive emotion expression. To do this, we employed the Continuous Measurement System (CMS)[1] as a check on construct validity for one segment of interaction for partners in each dyad. Employing a joystick interface, undergraduates were asked to rate "positive emotion, joy, and happiness" using *none* and *maximum* as anchors as the video segment was shown. To offset for the lag between videotaped behavior and joystick movement, ratings were corrected for 3/5 of a second. We calculated the mean of the ratings for each second of interaction because of the well-documented reliability of aggregated measures of the estimates of independent observers (Ariely, 2000).

*Construct Validity Results.* Infant smile strength, eye constriction, and mouth opening were all highly associated with infant positive emotion with a mean correlation of almost .8 (see Figure 10.4). This suggests that infant positive emotion is expressed by a set of facial actions including and related to smiling. Mother smile strength exhibited moderate correlations (almost .6) with mother positive emotion, while mother eye constriction and mouth opening exhibited lower correlations (approximately .3 and .35, respectively). These more variable associations may reflect the multiple roles parents occupy when interacting with their infants (see Cohn et al., 2004). They are responsible not only for engaging positively with their infants but also for simultaneously entertaining their infants and maintaining their emotional states. Parents' multiple roles may reduce the degree to which eye constriction and mouth opening are associated with perceived maternal positive emotion.

## The Structure of Infant and Mother Smiling

*Infant Smiling.* Measurements of intensity levels allowed us to explore the structure of infant and mother smiling. The intensities of infant smile strength and eye constriction were highly correlated (around .85), and the correlations of these actions with degree of mouth opening were moderate to high (around .6). This suggests that early infant positive emotion is a unitary construct expressed through the intensity of smiling and a set of linked facial actions (Messinger & Fogel, 2007). This interpretation is supported by research indicating that infants preferentially produced smiles with these characteristics in periods of interaction likely to elicit positive emotion (Fogel, Hsu et al., 2006; Messinger et al., 1999, 2001).

*Mother Smiling.* Infants and mothers showed similarities and differences in their expression of positive emotion. As with infants, the intensity of mother smile strength and eye constriction were highly associated (correlations around .8). However, the correlations of mother mouth opening with eye constriction (around .2 and .3) and with smile strength (around .2 and .5) were lower and more variable than among infants. Mothers appeared to use mouth opening in part to convey positive affective intensity, but also as an element in visual displays used to entertain infants. A common pattern, for example, involved a mother leaning back from an infant, opening her mouth wide, and then bringing her face toward the infant while closing her mouth and vocalizing.

*Smiling As a Continuous Process.* For both infants and mothers, then, smile strength and eye constriction (the Duchenne marker) were linked indices of the intensity of positive emotional communication. For both infants and mothers, it was not clear that there were different "types" of smiling during interactions (see Messinger, Cassel et al., 2008, for similar results with a different set of infants). This is relevant because dichotomies between different forms of smiling are prevalent in the literature. Duchenne smiles, for example, are thought to be expressions of joy while smiles without the Duchenne marker (eye constriction) are thought to be nonemotional social signals. For mothers and infants, however, the appropriate question was not "Is a Duchenne smile being displayed?" but "How much Duchenne smiling is being displayed?" In fact, given the association of smiling strength with other characteristics of smiling, the most appropriate questions appeared to be simply, "How much smiling is present?"

*A Composite Index of Smiling.* The association of smile strength and eye constriction within infants and within mothers led us to take the mean of these variables to create a single index of smiling activity for each partner over the course of the interactions. This smiling activity index can be understood as a measure of the intensity of each partner's Duchenne smiling. The associations of individual facial actions between infants and mothers support the construction of this index. In each dyad, degree of mouth opening exhibited weak and sometimes negative associations with the smile strength and eye constriction of the other partner. However, associations of the intensity of smile strength and eye constriction were moderately positive between partners. This suggests level of Duchenne smiling activity was a preeminent communicative signal between infants and mothers.

*Mean Smiling Levels.* Overall, mothers smiled for more time, and smiled more intensely, than their infants. The two mothers smiled for over three quarters of the interaction while infants smiled for approximately two thirds of the interaction. The mean intensity level of mother smiling was about three quarters of a point (on the 5-point intensity scale) than the mean intensity level of infant smiling. Moreover, when infants were smiling and mothers were not smiling, mothers often appeared to be actively trying to elicit infant smiles by, for example, pursing their lips and vocalizing.

## General Interaction Patterns

The face-to-face interactions were characterized by variability in the associations between tickling, infant smiling activity, and mother smiling activity. The interactions were divided into segments, between which there was occlusion (i.e., obstruction) of the face. These were typically caused by mothers engaging in actions designed to hide her face from the infant (e.g., peek-a-boo). These occlusions divided the interactions into segments between which interactive variability could be assessed (see Figure 10.5).

*Nonsmiling Actions.* Overall, Dyad A's interactions appeared to be more fast paced than Dyad B's. Infant A also displayed a large set of nonsmiling actions not displayed by Infant B. At times, these actions appeared to attenuate positive affect expression (e.g., lip tightening and dimpling); at other times, they appeared subtly negative (e.g., upper lip raising and lip stretching at the trace level); and, at other times, they appeared to be clear instances of dysregulation (e.g., a brief instance of spitting up). Mother tickling almost never occurred with these infant actions, perhaps because the actions were interpreted by the mother as indices of overarousal and potential fussiness. When the infant displayed these

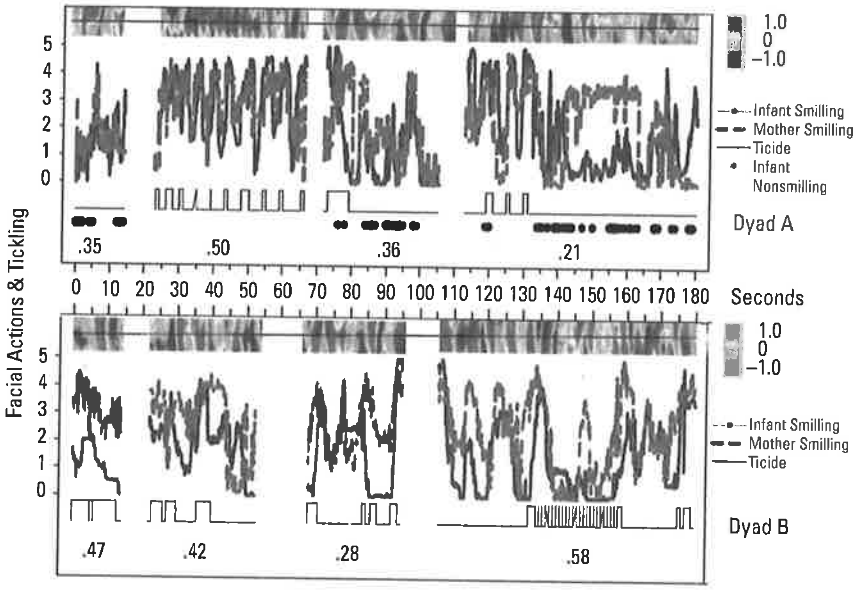


FIGURE 10.5 Tickling and smiling activity are plotted over seconds. Smiling activity is the mean of smile strength and eye constriction intensity. Correlations between infant and mother smiling activity for each segment of interaction are displayed below that segment. Above each segment of interaction is a plot of the corresponding windowed cross-correlations between infant and mother smiling activity. The horizontal midline of these plots indicates the zero-order correlation between infant and mother smiling activity. The correlations are calculated for successive 3-second segments of interaction. The plots also indicate the associations of one partner's current smiling activity with the successive activity of the other partner. Area above the midline indicates the correlation of current infant activity with successive lags of mother smiling activity. Area beneath the midline indicates the correlation of mother smiling activity with successive lags of infant smiling activity. Three lags of such activity are shown. For example, the area at the very bottom of a plot shows the correlation of a window of 3 seconds of current mother activity with a window of 3 seconds of infant activity that is to occur after three fifths of a second. A color version of this figure can be found on Oxford Scholarship Online.

nonsmiling actions, his smiling activity intensity level was reduced, and so, too, was that of his mother. Strikingly, these nonsmiling actions were associated with reductions in infant–mother synchrony, the magnitude of the correlation between infant and mother smiling activity. The potentially nonlinear role of infant negative affect expressions in transforming an interaction—e.g., by changing the parent's goal from eliciting smiles to reducing fussing—is a promising goal of future research.

*Tickling.* Tickling, which occurred in the interactions of both dyads, is of interest because it may elicit positive affect in the infant but is not necessarily expressive of maternal positive affect. Tickling has received surprisingly little attention in investigations of early interaction (but see Fogel, Hsu et al., 2006). When tickling, mothers engaged in more intense smiling activity. This may serve to emphasize tickling's playful intent despite its faux aggressive—"I'm gonna get ya"—quality (Harris, 1999). Although tickling often appeared to elicit increased infant smiling activity, this was not always the case, (i.e., in the last two segments of Dyad B's interaction). Tickling and other forms of touch represent a tactile mode of communication, which, like fussing, can introduce nonlinear changes in infant–mother communication.

*Variability Between Segments of Interaction.* Within each dyad, the association of infant and mother smiling activity showed substantial variability between segments of interaction (see Figure 10.5). The interactive meaning behind this variability can be illustrated by examining specific segments of Dyad A's interaction. Dyad A's second segment of interaction involved closely matched, regular rhythms of oscillating infant and mother smiling activity in which peaks of joint smiling coincided with mother tickling the infant. During these periods of tickling and intense smiling, the infant would look away from the mother, only to look toward the mother again, as if to elicit another round of tickling (Fogel, Hsu et al., 2006; Fogel et al., 2000). The third segment contained apparent mismatches in levels of infant and mother smiling activity, followed by a brief spit-up on the part of the infant, and expressions of concern on the part of the mother; these were followed by a brief synchronization of levels of infant and mother smiling activity, an interactive repair. The final segment began with rhythmic simultaneous peaks and valleys of smiling activity, punctuated by tickling, which then proceeded, in the face of infant fussing actions, to a long period of relatively constant levels of mother smiling and low levels of infant smiling. In sum, there appeared to be meaningful moment-to-moment changes in levels of dyadic synchronization.

## Local Interaction Patterns

*Local Cross-Correlations.* To explore the possibility that there were moment-to-moment changes in the association of infant and mother smiling activity, we examined successive 3-second windows of the interaction (Boker, Rotondo, Xu, & King, 2002). Within these windows, we calculated the zero-order correlations between infant and mother smiling activity. We also calculated predictive cross-correlations within these windows, which indicate the degree to which the infant's current smiling activity predicted the mother's subsequent smiling activity, and vice versa. This was done with software based on Boker et al. (2002).[2]

*Changing Correlations.* Changing values of zero-order correlations correspond to the different colors displayed on the midline of the rectangular plots in Figure 10.5. For both dyads, local zero-order correlations alternated between highly positive (red), moderately positive (yellow), moderately negative (light blue), and highly negative (dark blue) values. The changing values index dramatic changes in the level of dyadic synchrony over time. Substantively, they point to the importance of local processes in negotiating affective communication early in life.

*Mirroring.* Each partner tended to mirror changes in the other partner's level of smiling activity. This mirroring can be seen in the lagged correlations that are displayed above and below the midline of the rectangular plots in Figure 10.5. Area above the midline indicates the correlation of infant smiling activity with successive lags of mother smiling activity. Area beneath the midline indicates the correlation of mother smiling activity with successive lags of infant smiling activity. Prominent throughout each dyad's interaction were symmetries between the top and the bottom halves of the cross-correlation plots. These are bands representing a relatively uniform value for a local period of infant–mother correlation that extend from the top to the bottom of the plot. Red bands, for example, indicate that each partner was mirroring the other's changes in smiling activity. Similar patterns have been described by Boker et al. (2002) in analyses of head movement during conversation. Increases and decreases in smiling activity were an essentially dyadic phenomenon. Substantively, it was not always possible to discern which partner began an episode of smiling.

*Time-Varying Changes in Interaction.* In this study, we utilized adopted automated measurement of moment-to-moment communication to understand the process of interaction. This represents an increase in the magnification level of a virtual microscope. Analyses of automated measurements of facial expressivity suggested that the disruption and repair of emotional engagement (Schore, 1994; Tronick & Cohn, 1989) was a common feature of infant–mother interactions. These are time-varying changes in the association of the partner's behaviors, a violation of the assumption of (soft) stationarity between the parent and infant time series (Boker, Xu, Rotondo, & King, 2002; Newtson, 1993). A subjective parallel would be finding oneself becoming more or less responsive to a conversational partner during the course an interaction, or noticing changing levels of responsivity in one's partner. We pursued this possibility with a more formal investigation of interactive influence using nonexpert ratings of affective valence.

## Continuous Ratings of Early Interaction

The second study examined changes in interactive influence and self-regulation utilizing continuous ratings of early interaction. The ratings are made by nonexperts moving a joystick in correspondence with the affective valence they perceive in the infant or mother. This approach unites continuous ratings of affect (Gottman & Levenson, 1985; Levenson & Gottman, 1983; Ruef & Levenson, in press), with mean measures of multiple nonexpert evaluations (Waldinger, Schulz, Hauser, Allen, & Crowell, 2004). The resulting continuous nonexpert ratings have strong face validity. Measurements are based on a brief, layperson's description so that results reflect a precise but easily interpretable understanding of a construct.

We used the continuous ratings to examine self-regulation and interactive influence in the context of the face-to-face/still-face procedure (FFSF). The FFSF was used to examine naturalistic interaction and its perturbation (Adamson & Frick, 2003; Bendersky & Lewis, 1998; Cohn, Campbell, & Ross, 1991; Delgado, Messinger, & Yale., 2002; Matias & Cohn, 1993; Tronick, Als, Adamson, Wise, & Brazelton, 1978; Yale, Messinger, & Cobo-Lewis, 2003). The procedure involves a 3-minute naturalistic face-to-face (FF) interaction, and a 2-minute still-face (SF) in which the parent is asked not to initiate or respond to the infant, and ends with a 3-minute "reunion" in which the parent attempts to reengage with the infant.

*Interactive Influence in the FFSF.* Generally, there is a weak tendency for the level of matching engagement states between infant and parent to decline following the still-face (Tronick et al., 2005), suggesting an overall decrease in interactive coordination following this stressor. We have found, however, that infants' coordination of their communicative behaviors approaches chance levels during the still-face but returns to baseline levels in the reunion (Yale et al., 2003). This suggests that the parent's interactive behavior scaffolds the infant's ability to create meaningful patterns of expressive behavior but that infant coordination of communicative behaviors recovers robustly after perturbation. In this study, we examined the possibility that levels of interactive influence or self-regulation change over time. We thought these changes might be more evident in the reunion that followed the still-face perturbation and more evident among infants who were not at risk.

*Autism Risk.* The primary risk factor in this study was being an ASD-Sib, that is, being the younger sibling of a child with an autism spectrum disorder (ASD). ASDs involve qualitative impairments in nonverbal social interaction, verbal communication, and the presence of repetitive/stereotyped behaviors (American Psychiatric Association, 2000; Lord, Rutter, & Le Couteur, 1994). ASD-Sibs are at risk not only for developing an ASD but also for a spectrum of related difficulties including expressions of ASD-related symptomatology that are below threshold for a clinical diagnosis (Boelte & Poustka, 2003; Bolton, Pickles, Murphy, & Rutter, 1998; Constantino et al., 2006; Murphy et al., 2000; Wassink, Brzustowicz, Bartlett, & Szatmari, 2004). Autistic symptomatology is highly heritable (Szatmari et al., 2000), and we were interested in potential deficits in reciprocal social interaction (Constantino et al., 2003) in ASD-Sibs as a group.

*ASD-Sib Affect.* As a group, infant siblings of children with ASD and their parents show behavioral deficits that may be related to the broad spectrum of autism symptomatology. Individuals with ASDs show a propensity toward expressive neutrality (flatness) and negativity (Adrien, Perrot, Sauvage, Leddet & et al., 1992; Bryson et al., 2004; Joseph & Tager-Flusberg, 1997; Kasari, Sigman, Mundy, & Yirmiya, 1990; Mariëlle Stel, Claudia van den Heuvel, & Smeets, 2008; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006; Yirmiya, Kasari, Sigman, & Mundy, 1989; Zwaigenbaum et al., 2005). Likewise, there is subtle evidence for behavioral flatness—increased neutrality and decreased smiling—in ASD-Sibs during the FFSF (Cassel et al., 2007; Yirmiya et al., 2006). There is also evidence for subtle deficits in self-regulation and interactive influence in dyads composed of a parent and an ASD-Sib, an infant sibling of a child with an ASD. Yirmiya et al. (2006) found that the parents of ASD-siblings showed lower levels of responsivity to their infants in the FFSF than comparison parents.

*Sample and Ratings.* To engage questions of autism risk, we collected a sample of 38 infants who were 6 months of age and their parents (Chow, Haltigan, & Messinger, 2010). Twenty infants were ASD-Sibs and 18 were younger siblings of a child with no known psychopathology (COMP-Sibs). Separate video clips of infants and of parents were created for each episode of the FFSF. The emotional valence of infants and parents was rated by undergraduates using a joystick interface (see Figure 10.6). Ratings captured a scale from positive emotion (joy, happiness, pleasure) to neutral to negative emotion (distress, sadness, anger). Ratings were made individually and a given rater rated either infants or parents. Ratings from approximately 18 undergraduates were averaged to create a mean emotional valence time series for each second of interaction.

*Rating Validity.* Continuous nonexpert ratings have strong face validity. Measurements are based on a brief, layperson's description; results, then, reflect a precise but easily interpretable understanding of a construct.

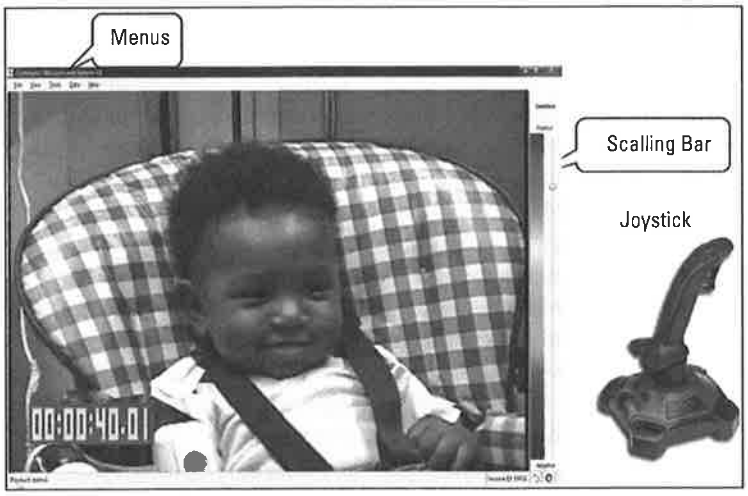


FIGURE 10.6 A representation of the Continuous Measurement System used for continuous rating.

Raters showed high levels of consistency with each other both at a second-to-second level and at the level of FFSF episode. Mean ratings showed reasonable associations with objective measurements of facial expression within time (Figure 10.4) and high associations when summed over the episodes of the FFSF.

*Affective Valence Levels.* Mean levels of infant affective valence were higher in face-to-face interactions than in the still-face or reunion episodes. Higher valence reflects ratings that are more positive and less negative. Parent affective valence also showed a dip in the still-face, essentially a manipulation check. The rating study revealed subtle differences in mean levels of affective valence related to risk. Infant siblings of children with ASDs showed lower levels of rated positive affect (ratings above neutral) in the still-face than did infant siblings of typical comparison children (Baker, Haltigan, Brewster, Jaccard, & Messinger, 2010).

*Interactive Influence.* Both infant-to-parent and parent-to-infant interactive influence were evident. However, infant affective valence had a greater impact on parent affective valence than vice versa. As expected, interactive influence in each direction was stronger during the interactive episodes—face-to-face and reunion—than during the still-face. These findings emerged in a set of bivariate time series models with random effects designed to explore between-dyad differences in self-regulation and interactive dynamics. This is one of the first group time series models to rigorously demonstrate this fundamental feature of early interaction (see Figure 10.7).

*Self-Regulation.* Group differences in level of self-regulation were also evident (Chow et al., 2010). Infant siblings of children with ASDs exhibited higher levels of self-regulation than comparison infants. This was indexed by lower values of the autoregression variance parameter among ASD-Sibs. In other words, there was less variability in temporally based self-regulatory dynamics among ASD-Sibs than COMP-Sibs. The effect was only evident during the still-face and reunion, that is, during and after the perturbation introduced by asking the parent to be nonresponsive.

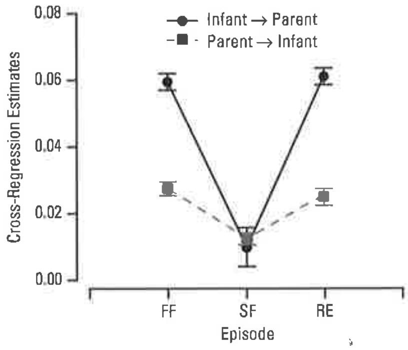


FIGURE 10.7 Cross-regression estimates of infant-to-parent and parent-to-infant interactive influence are shown for the face-to-face (FF), still-face (SF), and reunion (RE) episodes of the procedure. Infant-to-parent influence is higher than the reverse in episodes involving interaction.

On average, then, ASD-Sibs were less emotionally perturbed by the FFSF procedure than other infants.

*Summary.* Our microanalytic investigation using automated measurement led us to ask whether interactive influence parameters might change in time. Stochastic regression models revealed significant variance in the impact of the parent's affective valence on that of the infant over the course of an interactive episode. The strength of interactive influence varied with time during the face-to-face and reunion episodes, but not during the still-face. There also appeared to be greater interactive variance over time in the reunion than in the face-to-face interaction, suggesting subtle effects of the still-face perturbation (see Figure 10.7). These analyses confronted the problem of nonstationarity by modeling interactive influence. The time-dependent changes in interactive influence were allowed to vary randomly. In subsequent modeling we hope to ask substantive questions about time-varying influence. One might expect, for example, parent-to-infant influence in facial expressions of emotion to be attenuated during tickling but strengthened when the infant is gazing at the parent's face.

## Conclusion

Obtaining efficient, replicable measurement of ongoing behavior is a chronic difficulty for students of interaction. This chapter presents new approaches to studying early emotional transactions by combining the collection of continuous measures of emotional intensity with appropriate analysis tools. These approaches helped produce meaningful measures of continuously occurring interaction, helping to overcome the dichotomy between discrete behavior and ordinal engagement scales. The results raised questions about the temporal stability of early interaction and its links to later development. We first consider methodological and then substantive implications of our work.

## Methodology

We first employed an automated measurement approach that combined facial image analysis using computer vision and categorization of facial action intensity using machine learning. This microanalytic approach was supplemented with examination of local windows of correlation between infant and mother smiling to reveal changes in mother emotional interaction at a variety of timescales. We next separately collected nonexpert's continuous ratings of infant and mother emotional valence during interactions. These were modeled using stochastic regression techniques that allowed us to assess temporal changes in interactive influence and self-regulation. Despite their differences, each approach is oriented toward understanding continuous interactive processes as they occur in time.

*Automated Measurement Limitations.* It is worth noting limitations of our automated measurement approach, and future directions in its application. Our particular automated measurement approach emulated the intensity measurements of FACS Action Units, yielding precise assessment of emotional expression in time. This may be a limitation, however, in that the FACS intensity metric is ordinal (1–5) and designed to be readily identifiable by human beings. It is possible that other automated measurement approaches will bypass FACS to produce bottom-up measurements of facial activity that can be used to reliably index emotional communication. While it is technically possible to conduct continuous manual coding of the intensity of FACS Action Units, we know of no examples of this somewhat impractical approach. Nevertheless, despite the potential efficiency of automated measurement, we are unaware of empirical comparisons of the efficiency of automated and manual coding.

*Automated Measurement: Future Directions and Recent Advances.* We are currently training active appearance and shape models with frames from multiple subjects (infants and parents). This minimizes the training needed for any given subject. We have also achieved high levels of reliability employing a leave-one-out approach with support vector machines. This means the SVMs are trained and tested on different subjects. Finally, we have expanded the range of actions we measure to include indices of negative emotion and infant gaze direction. This approach is part of a broader movement toward automating the measurement of human communication (see Chapters 6 and 7 by Whitehill et al. and Busso et al., respectively, in this volume).

*Limitations and Potential of Continuous Rating.* The use of nonexpert continuous ratings is also evolving to realize its potential for providing efficient measurement of emotional and other types of communication. The method provides less temporal precision than automated measurement because it is dependent on rater reaction time. Ratings nevertheless revealed both infant-to-parent and parent-to-infant influence during interaction, suggesting their sensitivity to time-dependent signals. Other sets of nonexpert ratings are exhibiting high levels of association with expert ratings of maternal sensitivity and family conflict, suggesting the broad applicability of this procedure to multiple, emotionally relevant constructs.

### Substantive Findings—Time-Varying Changes

Substantively, we used the automated measurement and continuous ratings to investigate time-linked changes in interactive influence. Automated measurements followed by windowed cross-correlation analyses revealed changes in interactive synchrony. We demonstrated the existence of these changes in interactive synchrony statistically using continuous ratings of emotional valence. The ubiquity of these time-varying changes is not surprising given that variable responsivity and change are hallmarks of human interaction (Fogel, Garvey, Hsu, & West-Stroming, 2006).

*Prediction.* In longitudinal research, summary measures of infant–parent interactive influence are used to predict outcome. While it is not clear that relevant influence and related parameters are stable over the course of an interaction, it appears that influence parameters represent a strong dyadic signal with an important place in development. It will be crucially important to determine whether real-time variance in interaction can contribute to our understanding of individual differences in development. We speak to these issues in the sections that follow.

*Variability in Communicative Modality.* Variability in influence over time is mirrored by variability in interactive influence in different modalities of communication. Beebe and her colleagues (Beebe et al., 2007) have related these different patterns of influence to personality characteristics. Depressed mothers, for example, who were more self-critical, showed lowered levels of responsivity to infant gaze direction and emotional expression, yet they exhibited greater responsivity of their own touch to infant touch. Thus, there may be psychologically important variability in responsivity between different modalities of communication.

*Variable Patterning and Development.* Different patterns of contingency in different communicative modalities occurring in different contexts may also be associated with different outcomes. In the realm of positive emotional communication, higher levels of parental responsivity appear most predictive of optimal development (Kochanska, 2002; Kochanska et al., 1999; Kochanska & Murray, 2000). By contrast, the level of influence (midrange versus high) in vocal turn taking, which is associated with infant security of attachment, may vary depending upon the context (home or laboratory) in which the original interaction was observed (Jaffe et al., 2001). These patterns point to the possibility that variability in influence patterns is more widespread—and developmentally significant—than is typically acknowledged.

*Variability in Influence as Development.* Finally, variability of influence parameters in time may play a role in development. Infants become more responsive to their parents between 2 and 6 months, setting the stage for the possibility of reciprocal (bidirectional) influence (Cohn & Tronick, 1987; Kaye & Fogel, 1980). Infants also become more likely to initiate smiles and positive greetings as they reach 6 months and beyond. This type of greeting or bidding is developmentally crucial. It represents an action that may be taken with the goal of eliciting a reaction. At the same time, such initiations are, somewhat by definition, not contingent on what has occurred previously. They represent, then, a breaking of synchrony, variability in time-varying influence parameters (Boker et al., 2002). This capacity to alter influence patterns may also be a precursor to the infant's use—later in the first year of life—of gaze, gesture, and smiling to intentionally refer to objects and events (Jones & Hong, 2001; Parlade et al., 2008; Venezia, Messinger, Thorp, & Mundy, 2004).

*Conclusion.* Finally, the dyadic or transactional nature of early interaction may be its most important feature. In the interactions explored with automated measurements, for example, both infants had their smiles reciprocated and intensified by their caregivers. These smiles are likely to unite (a) the affective facial-feedback characteristic of the smile with (b) the arousal frequently coincident with gazing at another with (c) the perception of the other's smile (Messinger & Fogel, 2007). These temporally linked experiences and actions are likely part of a process in which the perception of joy in the parent and the infants' perceptions of their own affect become the warp and woof of a single fabric. In this sense, these are transactional processes involving the dynamic emergence of coconstructed states of dyadic positivity.

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## Notes

1. Here we use the Continuous Measurement System (CMS) as a construct validity check. Later in the chapter, we employ it as a measurement instrument in its own right. The CMS can also be used to conduct continuous behavioral coding (e.g., FACS/BabyFACS) via mouse and keyboard. The CMS is available for download at http://measurement.psy.miami.edu/cms.phtml.

2. Software to calculate and view running cross-correlations is available for download at http://measurement.psy.miami.edu/wcc.phtml.

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