

Early Emotional Communication: Novel Approaches to Interaction

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Early Interaction

This chapter is concerned with 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.

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 two years (Feldman, Greenbaum, Yirmiya & Mayes 1996; Feldman & Greenbaum 1997; Feldman, Greenbaum & Yirmiya 1999). More generally, interaction patterns characterized by maternal

responsivity and positive affect predict later toddler internalization of social norms (Feldman et al., 1999; Kochanska, Forman & Coy 1999; Kochanska & Murray 2000; Kochanska 2002).

As suggested by the longitudinal predictions, the fundamental question in infant-parent interaction concerns communicative influence. Do infant behaviours influence the parent? Do parent behaviours 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. There are two general approaches to measuring influence during interactions.

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), gazes and vocalizations (Crown, Feldstein, Jasnow, Beebe & Jaffe 2002). Contingency analyses are then 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 (Kaye & Fogel 1980; Fogel 1988; 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 are necessary but not sufficient for eliciting infant positive expressions (Kaye & Fogel 1980; Cohn & Tronick 1987; Symons & Moran 1994). Our analyses of dyadic smiling (Cohn & Tronick 1987; Messinger, Fogel & Dickson 1999; Messinger, Fogel & Dickson 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 six 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 1987; 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 1987; Weinberg et al., 1999). Ordinal scaling approaches are amenable to 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 auto-correlation (Cohn & Tronick 1987).

Early work using time-series analyses established that parent and infants' display nonperiodic (variable) cyclicity (Cohn & Tronick, 1988). 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 1988; Cohn & Tronick 1988).

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 bi-directional influence (Cohn & Tronick 1988). (Cohn & Tronick 1987; Feldman et al., 1996;

Feldman, Greenbaum, Mayes & Erlich 1997; Weinberg et al., 1999; Yirmiya et al., 2006). Bi-directional influence occurs when each partner's behavior impacts that of the other.

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 continuous rhythmicity of interactions, but each step of the scale lacks behavioral specificity. This 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 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.

Novel Approaches

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 non-expert 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 continuous ratings are inherently subjective. Yet both approaches are oriented toward meaningful continuous measurement of ongoing interactions. Moreover, both promise efficiencies of measurement when compared to traditional manual measurement by human experts. 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 highpoints 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 (Ekman & Friesen 1982; Schneider & Uzner 1992; Bolzani-Dinehart et al., 2005; Fogel, Hsu, Shapiro, Nelson-Goens & Secrist 2006). By the same token, infant and adult smiles with eye constriction—Duchenne smiles—tend to occur in situations likely to elicit positive affect (Fox & Davidson 1988; Fogel, Nelson-Goens, Hsu & Shapiro 2000; Messinger et al., 2001; Lavelli & Fogel 2002). We refer to these smiles—in which orbicularis oculi (pars lateralis) raises the cheek under the eye and compresses the eye lid—as smiles with eye constriction. Stronger smiles and smiles with eye constriction are perceived to be more emotionally positive than smiles without these characteristics (Fox & Davidson 1988; Ekman, Davidson & Friesen 1990; Frank, Ekman & Friesen 1993; Messinger et al., 2001; Messinger 2002; Bolzani-Dinehart et al., 2005; Fogel et al., 2006).

Among infants, smiling involving mouth opening also tends to involve eye constriction, and smiles with these characteristics tend to be stronger smiles (Messinger et al., 2001; Fogel et al., 2006). 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 (Keltner, Kring & Bonanno 1999; Fogel et al., 2000; Keltner & Ekman 2000; Harker & Keltner 2001; Carvajal & Iglesias 2002; Messinger 2002; Bolzani-Dinehart et al., 2005; Fogel et al., 2006; Oster 2006; Messinger, Cassel, Acosta, Ambadar & Cohn 2008; Messinger, Mahoor, Chow, Cadavid & Cohn 2008).

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's self-regulatory abilities during face-to-face interactions. These challenges are manifested in non-smiling actions which may communicate 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 potentially subtle features of interaction (Cohn & Kanade 2007). (Oster 2006; Messinger, Mahoor, Chow & Cohn 2008). (Weinberg & Tronick 1998; Tronick et al., 2005) . 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 which human beings notice but are not able to reliably and efficiently document. The ultimate goal 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 (Lien, Kanade, Cohn & Li 2000; Tian, Kanade & Cohn 2001; Tian, Kanade & Cohn 2002; Bartlett et al., 2005; Bartlett et al., 2006) 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. We then measured the strength of specified Action Units using the FACS (A-E, minimal – maximal) intensity metric (Mahoor et al., 2008; Messinger 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.

Applying Automated Measurement to Early Interaction

Here we report on the exploration of dyadic expressivity in two six-month-old infants engaged in face-to-face interaction with their mothers (Messinger et al., 2008). Mothers were asked to play with their infants as they normally would at home for three minutes. We designated the mother-infant dyads A (male infant) and B (female infant).

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.

Our computer vision approach was based on Active Appearance and Shape Models (AAMs). AAMs detect and track measure the face in a videorecord using a fitting algorithm (see Figure 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 which 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.

Insert Figure 1 about here

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 2). The mesh moves and deforms in response to changes in parameters corresponding to a face

undergoing both whole head rigid motion and non-rigid 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.

Insert Figure 2 about here

The appearance component of the SVM contains the 256 grey scale 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 twelve variables per frame. This reduced data metric was used to train Support Vector Machines (SVM).

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). Using 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.

Insert Figure 3 about here

Automated Measurement: Convergent and Construct Validity

We first established the convergent validity of automated measurement of the intensity of infant and mother expressive actions (see Figure 4). 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 Figure 3. 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 inter-rater reliability assessed between two manual raters. The results suggest the concurrent validity of automated measurements of expressive actions.

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 partner 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).

Insert Figure 4 about here

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 5). 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.

Insert Figure 5 about here

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 (Messinger et al., 1999; Messinger et al., 2001; Fogel et al., 2006).

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 & .3) and with smile strength (around .2 & .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.

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 et al., 2008), for similar results with a different set of infants). This is of import 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 non-emotional 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?’

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 pre-eminent communicative signal between infants and mothers.

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 five point intensity scale) than the mean intensity level of infant smiling. Moreover, periods in which infants were smiling and mothers were not were often periods in which mothers 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 6).

Insert Figure 6 about here

Overall, Dyad A's interactions appeared to be more fast-paced than Dyad B's. Infant A also displayed a large set of non-smiling actions not displayed by Infant B. At times, these actions appeared to attenuate positive affect expression (e.g., lip tightening and dimpling); at times, they appeared subtly negative (e.g., upper lip raising and lip stretching at the trace level); and, at 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 over-arousal and potential fussiness. When the infant displayed these nonsmiling actions, his smiling activity intensity level was reduced and so

too was that of his mother. Strikingly, these non-smiling 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, 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. When tickling, mother’s 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.

Within each dyad, the association of infant and mother smiling activity showed substantial variability between segments of interaction (see Figure 6). 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 et al., 2000; Fogel et al., 2006). 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

To explore the possibility that there were moment-to-moment changes in the association of infant and mother smiling activity, we examined successive three 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 values of zero-order correlations correspond to the different colors displayed on the midline of the rectangular plots in Figure 6. 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.

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 6. 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.

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 (Tronick & Cohn 1989; Schore 1994) 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; Newtonson, 1993). A subjective parallel would be to 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 changing interactive influence using non-expert ratings of affective valence. This final study examined self-regulation and interactive influence in the context of the face-to-face/still-face among infants who have an older sibling with an Autism Spectrum Disorder (ASD-Sibs).

Continuous Ratings of Early Interaction

We examined 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 (Tronick, Als, Adamson, Wise & Brazelton 1978; Cohn, Campbell & Ross 1991; Matias & Cohn 1993; Bendersky & Lewis 1998; Delgado, Messinger & Yale. 2002; Adamson & Frick 2003; Yale, Messinger & Cobo-Lewis 2003). The procedure involves a three minute naturalistic face-to-face (FF) interaction, a two minute still-face (SF) in which the parent is asked not to initiate or respond to the infant, and ends with a three minute "reunion" in which the parent attempts to re-engage with the infant. (The previous study utilizing automated measurement described only face-to-face interaction.)

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.

The primary risk factor in this study was being an ASD-Sib, i.e., being the younger sibling of a child with an Autism Spectrum Disorder (ASDs). ASDs involve qualitative impairments in nonverbal social interaction, verbal communication, and the presence of repetitive/stereotyped behaviors (Lord, Rutter & Le Couteur 1994; American_Psychiatric_Association 2000). ASD-Sibs are at risk not only for developing an ASD

but for a spectrum of related difficulties including expressions of ASD-related symptomatology that are below threshold for a clinical diagnosis (Bolton, Pickles, Murphy & Rutter 1998; Murphy et al., 2000; Boelte & Poustka 2003; Wassink, Brzustowicz, Bartlett & Szatmari 2004; Constantino et al., 2006). 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.

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 (Yirmiya, Kasari, Sigman & Mundy 1989; Kasari, Sigman, Mundy & Yirmiya 1990; Adrien, Perrot, Sauvage, Leddet & et al. 1992; Joseph & Tager-Flusberg 1997; Bryson et al., 2004; Zwaigenbaum et al., 2005; McIntosh, Reichmann-Decker, Winkielman & Wilbarger 2006; Mariëlle Stel, Claudia van den Heuvel & Smeets 2008). Likewise, there is subtle evidence for behavioral flatness—increased neutrality and decreased smiling—in ASD-Sibs during the FFSF (Yirmiya et al., 2006; Cassel et al., 2007). 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) (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.

To engage these issues, we collected a sample of 38 infants were six months of age and their parents. Twenty infants were ASD-Sibs and eighteen 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 were rated by separate undergraduates using a joystick interface (see Figure 7). Ratings captured a scale from

positive emotion (joy, happiness, pleasure) to negative emotion (distress, sadness, anger).

Ratings were made individually. Ratings from approximately 18 undergraduates were averaged to create a mean emotional valence time-series for each second of interaction.

Insert Figure 7 about here

Continuous non-expert 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. 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 (see Rating Figure 5) and high associations when summed over the episodes of the FFSF.

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. An intriguing interaction effect suggested that infant siblings of children with ASDs showed lower levels of affective valence in the still-face than did infant siblings of typically comparison children.

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. Results stemming from this analysis - one of the first group

time-series models to rigorously demonstrate these fundamental features of early interaction – are displayed in Figure 8.

Insert Figure 8 about here

Group differences in level of self-regulation were also evident. Infant siblings of children with ASDs (ASD-sibs) exhibited higher levels of self-regulation than comparison infants. This reflected group differences in the variance of the auto-regression parameters. The effect was only evident during the still-face and reunion, i.e., during and after the perturbation introduced by asking the parent to be non-responsive. In other words, ASD-sibs were, on average, less emotionally perturbed by the FFSF procedure than other infants.

Based on our investigations using automated measurement approaches, we asked whether interactive influence parameters might change in time. We used stochastic regression models to ask whether there was 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 X). 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, that 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. With few exceptions, the few widely disseminated behavioral coding systems available are sufficiently complex as to limit the extent of their adoption by potentially interested investigators. Here we explored analyses of early emotional interaction using two novel approaches designed to overcome the dichotomy between discrete behavior and ordinal engagement scales.

We employed facial image analysis using computer vision supplemented with measurement of facial action intensity using machine learning. We validated these measurements and expanded our analyses using non-expert's continuous ratings of emotional valence. Despite their differences, each approach is oriented toward understanding continuous interactive processes as they occur in time.

It is worth noting that these approaches are themselves continuously evolving. We are currently training Active Appearance and Shape Models with frames from multiple subjects (infants or 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 by Movellan, etc., in this Volume).

The use of non-expert 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. It nevertheless detected both infant-to-parent and parent-to-infant influence during

interaction, suggesting its sensitivity to time-dependent signals. Moreover, preliminary data suggest that the infant-to-parent influence parameter—in accord with our understanding of the role of parent responsivity—predicts subsequent infant attachment security. Finally, these non-expert ratings are showing extremely high levels of association with expert ratings of family conflict, suggesting the broad applicability of this procedure to multiple, emotionally relevant constructs.

Substantively, we used the two approaches to investigate the time-linked changes in interactive influence. Automated measurements followed by windowed cross-correlations 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).

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 below.

Variability in influence over time is mirrored by variability between 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. Among depressed mothers, for example, mothers who were more self-critical showed lowered levels of

responsivity to infant gaze direction and emotional expression; but they greater responsivity of their own touch to infant touch.

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 appears most predictive of optimal development (Kochanska et al., 1999; Kochanska & Murray 2000; Kochanska 2002). By contrast, the level of influence (mid-range versus high) evident in vocal turn-taking that is associated with infant security of attachment may vary dependent 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.

Finally, variability of influence parameters in time may play a role in development. Infants become more responsive to their parents between two and six months, setting the stage for the possibility of reciprocal (bidirectional) influence (Kaye & Fogel 1980; Cohn & Tronick 1987). Infants also become more likely to initiate smiles and positive greetings as they reach six 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; Venezia, Messinger, Thorp & Mundy 2004; Parlade et al., 2008).

In conclusion, 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 the affective facial-feedback characteristic of the smile with the arousal frequently coincident with gazing at another with 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 in the infant him or herself are part of a single fabric. In this sense, these are transactional processes involving the dynamic emergence of co-constructed state of dyadic positivity.

References

- Adamson, L. B. and J. E. Frick (2003). "The still-face: A history of a shared experimental paradigm." Infancy 4(4): 451-474.
- Adrien, J. L., A. Perrot, et al. (1992). "Early symptoms in autism from family home movies: Evaluation and comparison between 1st and 2nd year of life using I.B.S.E. Scale." Acta Paedopsychiatrica: International Journal of Child & Adolescent Psychiatry 55(2): 71-75.
- American Psychiatric Association (2000). Diagnostic and Statistical Manual of Mental Disorders DSM-IV-TR Fourth Edition (Text Revision). Washington, DC, American Psychiatric Association.
- Ariely, D., Au, W.T., Bender, R.H., Budescu, D.V., Dietz, C., Gu, H., Wallsten, T.S., Zauberman, G. (2000). "The effects of averaging subjective probability estimates between and within judges." Journal of Experimental Psychology: Applied 6: 30-147.
- Bakeman, R. and J. Gottman (1986). Observing Interaction: An Introduction to Sequential Analysis. New York, NY, Cambridge University Press.
- Baker, S., I. Matthews, et al. (2004). "Automatic Construction of Active Appearance Models as an Image Coding Problem." IEEE Transactions on Pattern Analysis and Machine Intelligence 26(10): 1380 - 1384.
- Bartlett, M., G. Littlewort, et al. (2006). "Automatic Recognition of Facial Actions in Spontaneous Expressions." Journal of Multimedia 1(6): 22-35.
- Bartlett, M. S., G. Littlewort, et al. (2005). Recognizing Facial Expression: Machine Learning and Application to Spontaneous Behavior. Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, IEEE Computer Society. 2: 568-573.

- Beebe, B. and L. Gerstman (1984). "A method of defining "packages" of maternal stimulation and their functional significance for the infant with mother and stranger." International Journal of Behavioral Development 7(4): 423-440.
- Beebe, B., J. Jaffe, et al. (2007). "Six-week postpartum maternal self-criticism and dependency and 4-month mother-infant self- and interactive contingencies." Developmental Psychology 43(6): 1360-1376.
- Belkin, M. and P. Niyogi (2003). "Laplacian Eigenmaps for dimensionality reduction and data representation." Neural Computation Archive 15(6): 1373 - 1396.
- Bendersky, M. and M. Lewis (1998). "Arousal modulation in cocaine-exposed infants." Developmental Psychology 34(3): 555-564.
- Boelte, S. and F. Poustka (2003). "The recognition of facial affect in autistic and schizophrenic subjects and their first-degree relatives." Psychological Medicine 33(5): 907-915.
- Boker, S. M., J. L. Rotondo, et al. (2002). "Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series." Psychological Methods 7(3): 338-355.
- Bolton, P., A. Pickles, et al. (1998). "Autism, affective and other psychiatric disorders: Patterns of familial aggregation." Psychological Medicine 28(Mar): 385-395.
- Bolzani-Dinehart, L., D. S. Messinger, et al. (2005). "Adult perceptions of positive and negative infant emotional expressions." Infancy 8(3): 279-303.
- Bryson, S. E., R. Landry, et al. (2004). "Autistic Spectrum Disorders: Causal mechanisms and recent findings on attention and emotion." International Journal of Special Education 19(1): 14-22.

- Carvajal, F. and J. Iglesias (2002). "The Duchenne smile with open mouth in infants with Down syndrome." Infant Behavior & Development 24(3): 341-346.
- Cassel, T., D. S. Messinger, et al. (2007). "Early social and emotional communication in the infant siblings of children with Autism Spectrum Disorders: An examination of the broad phenotype." Journal of Autism and Developmental Disorders 37: 122-132.
- Chang, C. C. and C. J. Lin (2001). LIBSVM: a library for support vector machines.
- Chong, S. C. F., J. F. Werker, et al. (2003). "Three facial expressions mothers direct to their infants." Infant and Child Development 12: 211-232.
- Cohn, J., S. B. Campbell, et al. (1991). "Infant response in the still-face paradigm at 6 months predicts avoidant and secure attachment at 12 months." Development and Psychopathology 3(4): 367-376.
- Cohn, J. and T. Kanade (2007). Automated facial image analysis for measurement of emotion expression. The handbook of emotion elicitation and assessment. J. A. Coan and J. B. Allen. New York, Oxford: 222-238.
- Cohn, J. and E. Tronick (1987). "Mother-infant face-to-face interaction: The sequence of dyadic states at 3, 6, and 9 months." Developmental Psychology 23(1): 68-77.
- Cohn, J. F., L. Reed, et al. (2004). "Multimodal coordination of facial action, head rotation, and eye motion." Proceedings of the Sixth IEEE International Conference on Automatic Face and Gesture Recognition: 129-135.
- Cohn, J. F. and E. Z. Tronick (1988). "Discrete versus scaling approaches to the description of mother-infant face-to-face interaction: Convergent validity and divergent applications." Developmental Psychology 24(3): 396-397.

- Cohn, J. F. and E. Z. Tronick (1988). "Mother-infant face-to-face interaction: Influence is bidirectional and unrelated to periodic cycles in either partner's behavior." Developmental Psychology 24(3): 386-392.
- Constantino, Davis, et al. (2003). "Validation of a Brief Quantitative Measure of Autistic Traits: Comparison of the Social Responsiveness Scale with the Autism Diagnostic Interview-Revised." Journal-of-Autism-and-Developmental-Disorders Vol 33(4): 427-433.
- Constantino, J., C. Lajonchere, et al. (2006). "Autistic social impairment in the siblings of children with pervasive developmental disorders." Am Journal of Psychiatry 163(2): 294-6.
- Cootes, T. F., G. J. Edwards, et al. (2001). "Active appearance models." Pattern Analysis and Machine Intelligence 23: 681-685.
- Crown, C. L., S. Feldstein, et al. (2002). "The cross-modal coordination of interpersonal timing: Six-week-olds infants' gaze with adults' vocal behavior." Journal of Psycholinguistic Research 31: 1-23.
- Delgado, E. F., D. S. Messinger, et al. (2002). "Infant responses to direction of parental gaze: A comparison of two still-face conditions." Infant Behavior and Development 137: 1-8.
- Dickson, K. L., H. Walker, et al. (1997). "The relationship between smile-type and play-type during parent-infant play." Developmental Psychology 33(6): 925-933.
- Ekman, P., R. J. Davidson, et al. (1990). "The Duchenne smile: Emotional expression and brain physiology II." Journal of Personality and Social Psychology 58: 342-353.
- Ekman, P. and W. Friesen (1978). The Facial Action Coding System, Palo Alto: Consulting Psychologists Press.

- Ekman, P., W. Friesen, et al. (2002). The Facial Action Coding System on CD ROM, Network Information Research Center.
- Ekman, P. and W. V. Friesen (1982). "Felt, false, and miserable smiles." Journal of Nonverbal Behavior 6(4): 238-252.
- Elias, G. and J. Broerse (1995). "Temporal patterning of vocal behaviour in mother-infant engagements: Infant-initiated "encounters" as units of analysis." Australian Journal of Psychology 47(1): 47-53.
- Essa, I. A. and A. Pentland (1994). A vision system for observing and extracting facial action parameters. IEEE CVPR.
- Feldman, R. (2006). "From biological rhythms to social rhythms: Physiological precursors of mother-infant synchrony." Developmental Psychology 42(1): 175-188.
- Feldman, R. and C. W. Greenbaum (1997). "Affect regulation and synchrony in mother-infant play as precursors to the development of symbolic competence." Infant Mental Health Journal 18(1): 4-23.
- Feldman, R., C. W. Greenbaum, et al. (1997). "Change in mother-infant interactive behavior: Relations to change in the mother, the infant, and the social context." Infant Behavior and Development 20(2): 151-163.
- Feldman, R., C. W. Greenbaum, et al. (1999). "Mother-infant affect synchrony as an antecedent of the emergence of self-control." Developmental Psychology 35(1): 223-231.
- Feldman, R., C. W. Greenbaum, et al. (1996). "Relations between cyclicality and regulation in mother-infant interaction at 3 and 9 months and cognition at 2 years." Journal of Applied Developmental Psychology 17(3): 347-365.

- Fogel, A. (1988). "Cyclicality and stability in mother-infant face-to-face interaction: A comment on Cohn and Tronick." Developmental Psychology 24(3): 393-395.
- Fogel, A., A. Garvey, et al. (2006). Change processes in relationships: A relational-historical research approach, Cambridge University Press: New York.
- Fogel, A., H.-C. Hsu, et al. (2006). "Effects of normal and perturbed social play on the duration and amplitude of different types of infant smiles." Developmental Psychology 42: 459-473.
- Fogel, A., G. C. Nelson-Goens, et al. (2000). "Do different infant smiles reflect different positive emotions?" Social Development 9(4): 497-520.
- Fox and R. J. Davidson (1988). "Patterns of brain electrical activity during facial signs of emotion in 10 month old infants." Developmental Psychology 24(2): 230-236.
- Frank, M. G., P. Ekman, et al. (1993). "Behavioral markers and the recognizability of the smile of enjoyment." Journal of Personality and Social Psychology 64(1): 83-93.
- Harker, L. and D. Keltner (2001). "Expressions of positive emotion in women's college yearbook pictures and their relationship to personality and life outcomes across adulthood." Journal of Personality and Social Psychology 80(1): 112-124.
- Harris, C. R. (1999). "The mystery of ticklish laughter." American Scientist July-August 1999 v87 i4 p344(8) Page 1.
- Jaffe, J., B. Beebe, et al. (2001). "Rhythms of dialogue in infancy: Coordinated timing in development." Monographs of the Society for Research in Child Development 66(2): vi-131.
- Jones, S. S. and H.-W. Hong (2001). "Onset of voluntary communication: Smiling looks to mother." Infancy 2(3): 353-370.

- Joseph, R. and H. Tager-Flusberg (1997). "An investigation of attention and affect in children with autism and Down syndrome." Journal of Autism and Developmental Disorders 27(4): 385-396.
- Kasari, C., M. Sigman, et al. (1990). "Affective sharing in the context of joint attention interactions of normal, autistic, and mentally retarded children." Journal of Autism and Developmental Disorders 20(1): 87-100.
- Kaye, K. and A. Fogel (1980). "The temporal structure of face-to-face communication between mothers and infants." Developmental Psychology 16(5): 454-464.
- Keltner, D. and P. Ekman (2000). Facial expression of emotion. Handbook of emotions. M. Lewis and J. M. Haviland-Jones. New York, Guilford Press: 236-249.
- Keltner, D., A. M. Kring, et al. (1999). "Fleeting signs of the course of life: Facial expression and personal adjustment." Current Directions in Psychological Science 8(1): 18-22.
- Kochanska, G. (2002). "Mutually responsive orientation between mothers and their young children: A context for the early development of conscience." Current Directions in Psychological Science 11(6): 191-195.
- Kochanska, G., D. R. Forman, et al. (1999). "Implications of the mother-child relationship in infancy socialization in the second year of life." Infant Behavior & Development 22(2): 249-265.
- Kochanska, G. and K. T. Murray (2000). "Mother-child mutually responsive orientation and conscience development: From toddler to early school age." Child Development 71(2): 417-431.
- Lavelli, M. and A. Fogel (2002). "Developmental changes in mother-infant face-to-face communication: Birth to 3 months." Developmental Psychology 38(2): 288-305.

- Lien, J. J., T. Kanade, et al. (2000). "Detection, tracking, and classification of subtle changes in facial expression." Journal of Robotics and Autonomous Systems 31: 131-146.
- Littlewort, G., M. S. Bartlett, et al. (2001). "Are your eyes smiling? Detecting genuine smiles with support vector machines and Gabor wavelets." Proceedings of the 8th Annual Joint Symposium on Neural Computation.
- Lord, M. Rutter, et al. (1994). "Autism Diagnostic Interview-Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders." Journal of Autism Development Disorders 24(Oct): 659-685.
- Mahoor, M. H., D. S. Messinger, et al. (2008). Studying Facial Expressions Using Manifold Learning and Support Vector Machines. IEEE 7th International Conference on Development and Learning, Monterey, CA.
- Malatesta, C. Z., C. Culver, et al. (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): 1-104.
- Mariëlle Stel, Claudia van den Heuvel, et al. (2008). "Facial Feedback Mechanisms in Autistic Spectrum Disorders." J Autism Dev Disord. .
- Matias, R. and J. F. Cohn (1993). "Are MAX-specified infant facial expressions during face-to-face interaction consistent with differential emotions theory?" Developmental Psychology 29(3): 524-531.
- McIntosh, D. N., A. Reichmann-Decker, et al. (2006). "When the social mirror breaks: Deficits in automatic, but not voluntary, mimicry of emotional facial expressions in autism." Developmental Science 9: 295-302.

- Messinger, D. (2002). "Positive and negative: Infant facial expressions and emotions." Current Directions in Psychological Science 11(1): 1-6.
- Messinger, D., T. Cassel, et al. (2008). "Infant Smiling Dynamics and Perceived Positive Emotion." Journal of Nonverbal Behavior 32: 133-155.
- Messinger, D. and A. Fogel (2007). The interactive development of social smiling. Advances in Child Development and Behavior, 35. R. Kail. Oxford, Elsevier: 328-366.
- Messinger, D., A. Fogel, et al. (1999). "What's in a smile?" Developmental Psychology 35(3): 701-708.
- Messinger, D., A. Fogel, et al. (2001). "All smiles are positive, but some smiles are more positive than others." Developmental Psychology 37(5): 642-653.
- Messinger, D., M. Mahoor, et al. (2008). Early Interactive Emotional Development. IEEE 7th International Conference on Development and Learning, Monterey, CA.
- Messinger, D., M. Mahoor, et al. (2008). "Automated Measurement of Facial Expression in Infant-Mother Interaction: A Pilot Study." Infancy in press.
- Murphy, M., P. F. Bolton, et al. (2000). "Personality traits of the relatives of autistic probands." Psychological Medicine. Nov Vol 30(6) 1411-1424.
- Oster, H. (2006). "Baby FACS: Facial Action Coding System for Infants and Young Children." Unpublished monograph and coding manual. New York University.
- Padgett, C., G. W. Cottrell, et al. (1996). Categorical perception in facial emotion classification. Cognitive Science Conference.
- Parlade, M. V., D. S. Messinger, et al. (2008). "Anticipatory Smiling: Linking Early Affective Communication and Social Outcome." Infant Behavior & Development: in press.

- Ruch, W. (1995). "Will the real relationship between facial expression and affective experience please stand up: The case of exhilaration." Cognition and Emotion 9: 33-58.
- Schneider, K. and L. Uzner (1992). "Preschoolers' attention and emotion in an achievement and an effect game: A longitudinal study." Cognition and Emotion 6(1): 37-63.
- Schore, A. N. (1994). Affect Regulation & the Origin of Self: The Neurobiology of Emotional Development. Hillsdale, NJ, Erlbaum.
- Symons, D. and G. Moran (1994). "Responsiveness and dependency are different aspects of social contingencies: An example from mother and infant smiles." Infant Behavior and Development 17(2): 209-214.
- Szatmari, P., J. E. MacLean, et al. (2000). "The familial aggregation of the lesser variant in biological and nonbiological relatives of PDD probands: A family history study." Journal of Child Psychology and Psychiatry 41(5): 579-586.
- Tian, Y., T. Kanade, et al. (2001). "Recognizing Action Units for Facial Expression Analysis." IEEE Transactions on Pattern Analysis and Machine Intelligence 23(2): 97-116.
- Tian, Y. L., T. Kanade, et al. (2002). Evaluation of Gabor-wavelet-based facial action unit recognition in image sequences of increasing complexity. Proceedings of the Fifth IEEE International Conference on Automatic Face and Gesture Recognition, Washington, DC.
- Tronick, E. Z., H. Als, et al. (1978). "The infant's response to entrapment between contradictory messages in face-to-face interaction." American Academy of Child Psychiatry 17: 1-13.
- Tronick, E. Z. and J. F. Cohn (1989). "Infant-mother face-to-face interaction: Age and gender differences in coordination and the occurrence of miscoordination." Child Development 60(1): 85-92.

- Tronick, E. Z., D. Messinger, et al. (2005). "Cocaine Exposure Compromises Infant and Caregiver Social Emotional Behavior and Dyadic Interactive Features in the Face-to-Face Still-Face Paradigm." Developmental Psychology 41(5): 711-722.
- Van Egeren, L. A., M. S. Barratt, et al. (2001). "Mother-infant responsiveness: Timing, mutual regulation, and interactional context." Developmental Psychology 37(5): 684-697.
- Venezia, M., D. S. Messinger, et al. (2004). "The Development of Anticipatory Smiling." Infancy 6(3): 397-406.
- Wassink, T. H., L. M. Brzustowicz, et al. (2004). "The Search for Autism Disease Genes." Mental Retardation and Developmental Disabilities Research Reviews 10(4): 272-283.
- Weinberg, K. M. and E. Z. Tronick (1998). *Infant and Caregiver Engagement Phases system*. Boston, MA, Harvard Medical School.
- Weinberg, M. K., E. Z. Tronick, et al. (1999). "Gender differences in emotional expressivity and self-regulation during early infancy." Developmental Psychology 35(1): 175-188.
- Yacoob, Y. and L. Davis (1997). "Recognizing human facial expression from long image sequence using optical flow." IEEE Transactions on Pattern Recognition and Machine Intelligence 18: 636-642.
- Yale, M. E., D. S. Messinger, et al. (2003). "The temporal coordination of early infant communication." Developmental Psychology 39(5): 815-824.
- Yirmiya, N., I. Gamliel, et al. (2006). "The development of siblings of children with autism 4 and 14 months: social engagement, communication, and cognition." Journal of Child Psychology and Psychiatry 47(5): 511-523.
- Yirmiya, N., C. Kasari, et al. (1989). "Facial expressions of affect in autistic, mentally retarded and normal children." Journal of Child Psychology and Psychiatry 30(Sep): 725-735.

Zwaigenbaum, L., S. Bryson, et al. (2005). "Behavioral manifestations of autism in the first year of life." International Journal of Developmental Neuroscience 23: 143-152.

Figure Captions

Figure 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 which 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 2. Displays 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 non-rigid motion of expression.

Figure 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 4. Displays automated and manual FACS intensity coding for two key characteristics of positive emotional expression: Smiling produced by zygomatic major and the Duchenne marker, eye constriction produced by orbicularis oculi, pars lateralis. Concatenated frames from an infant and mother are displayed.

Figure 5. 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.

Figure 6. 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. As illustrated by the color bar to the right of the cross-correlation plots, high positive correlations are deep red, null correlations a pale green, and high negative correlations are deep blue. The horizontal midline of these plots indicates the zero-order correlation between infant and mother smiling activity. The correlations are calculated for successive three 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 three seconds of current mother activity with a window of three seconds of infant activity that is to occur after three fifths of a second.

Figure 7. A representation of the Continuous Measurement System used for continuous rating.

Figure 8. 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.

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>.

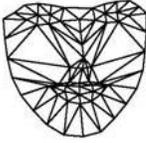
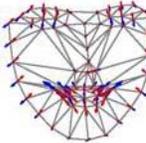
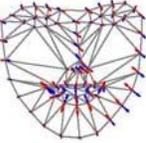
	Mean	1 st Variance Component	2nd Variance Component
Shape			
Appearance			
	A	B	C
	D	E	F

Figure 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 which 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.

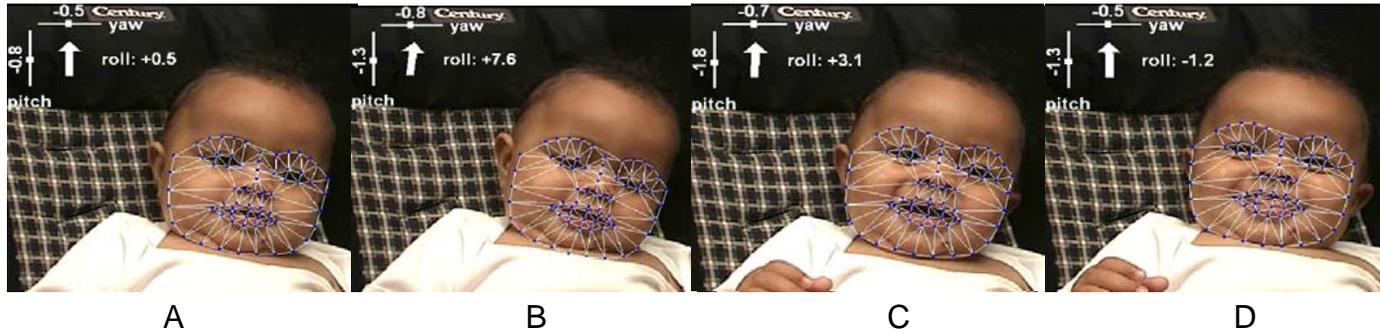
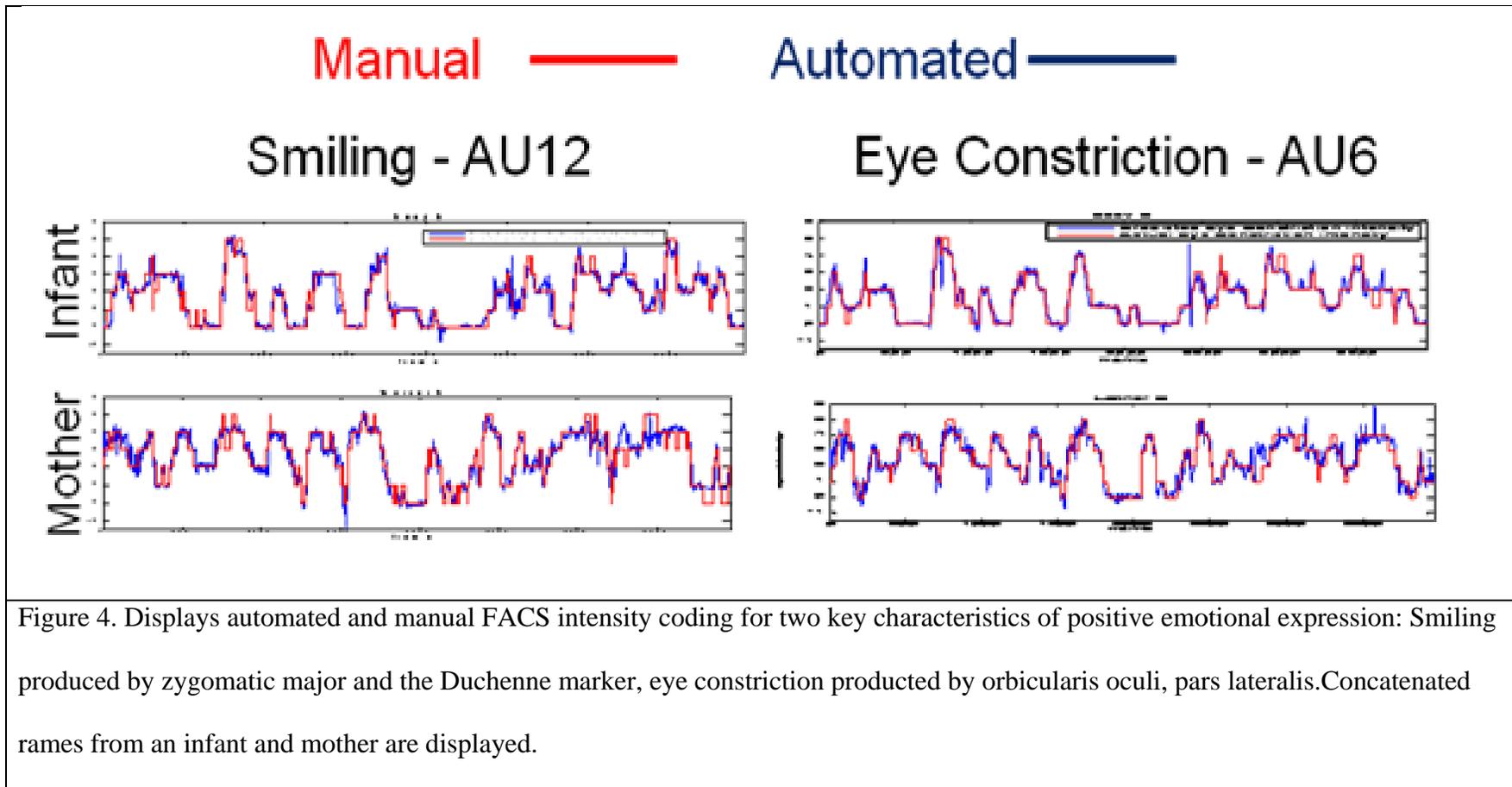


Figure 2. Displays the shape model of an AAM applied to video frames of an infant interaction. A 2D+3D AAM is shown, which yields 3D shape and rigid motion and 3D non-rigid motion of expression.



Figure 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.



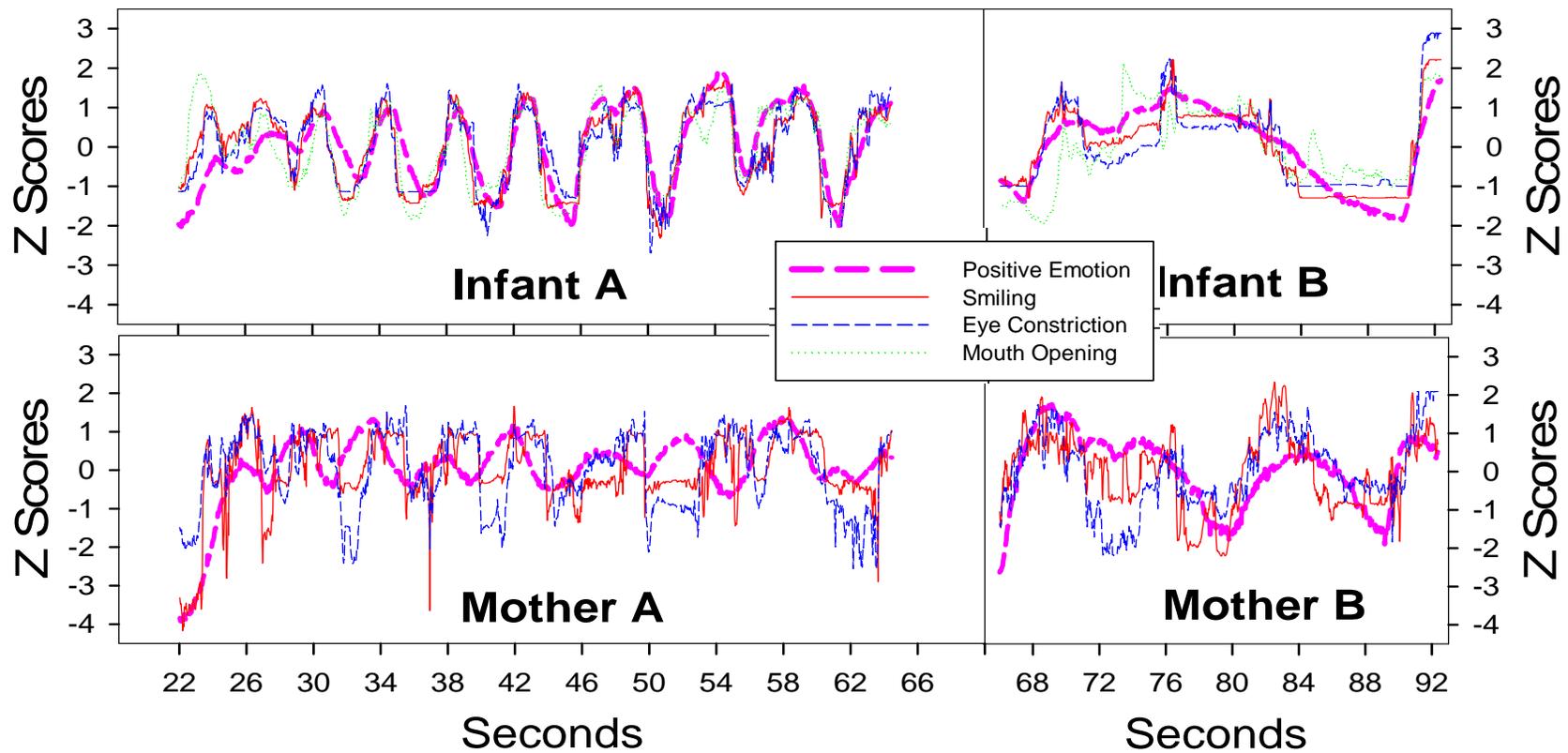


Figure 5. *Smile parameters and rated positive emotion over time.* Infant graphs show the association of automated measurements of smile strength, eye constriction, mouth opening, and rated positive emotion. Mother graphs show the association of automated measurements of smile strength, eye constriction, and rated positive emotion. Positive emotion is offset by three fifths of a second to account for rating lag.

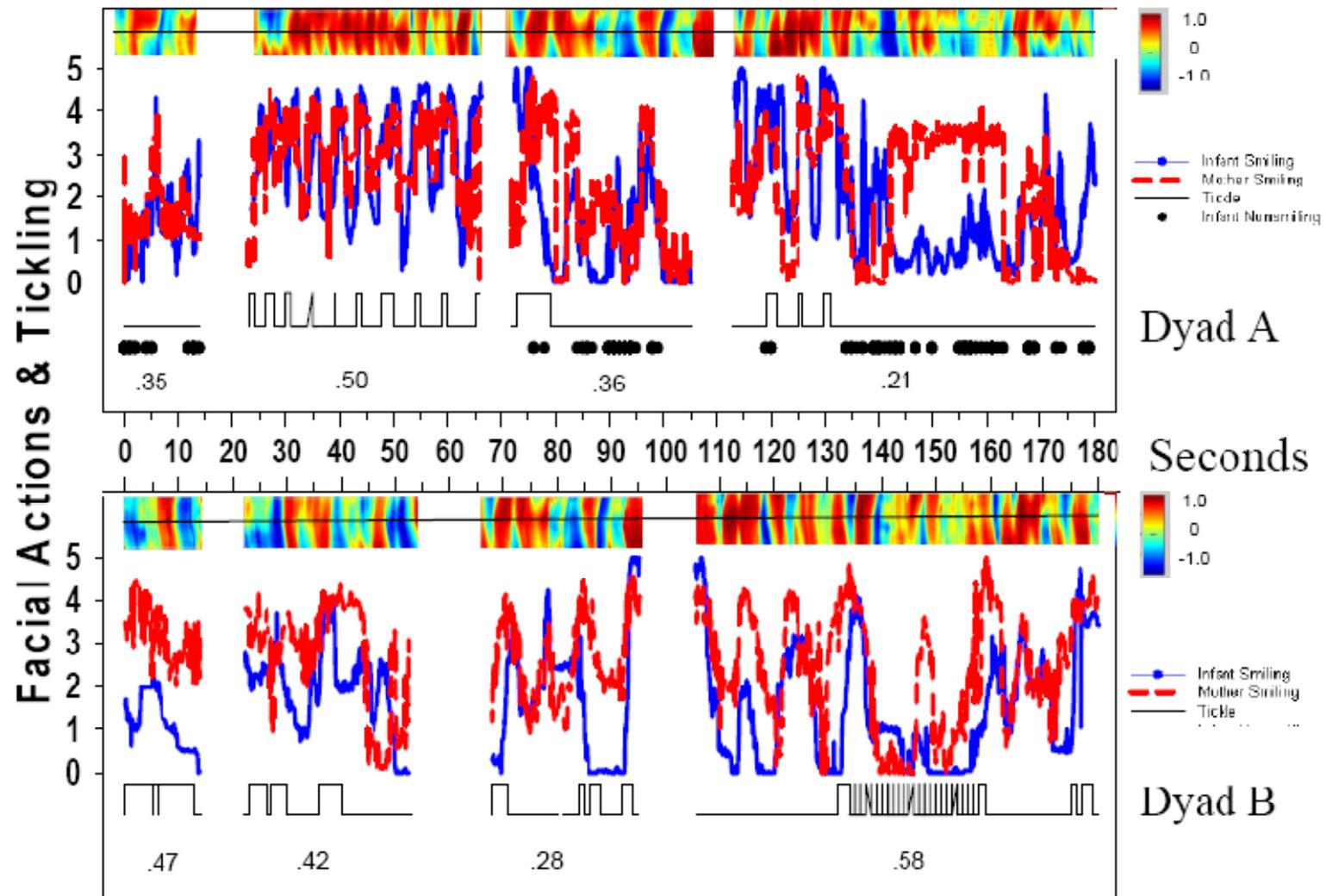


Figure 6. Tickling and smiling activity are plotted over seconds. Smiling activity is the mean of smile strength and eye constriction intensity. Correlations between infant and mother smiling activity for each segment of interaction are displayed below that segment. Above each segment of interaction is a plot of the corresponding windowed cross-correlations between infant and mother smiling activity. As illustrated by the color bar to the right of the cross-correlation plots, high positive correlations are deep red, null correlations a pale green, and high negative correlations are deep blue. The horizontal midline of these plots indicates the zero-order correlation between infant and mother smiling activity. The correlations are calculated for successive three 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 three seconds of current mother activity with a window of three seconds of infant activity that is to occur after three fifths of a second.

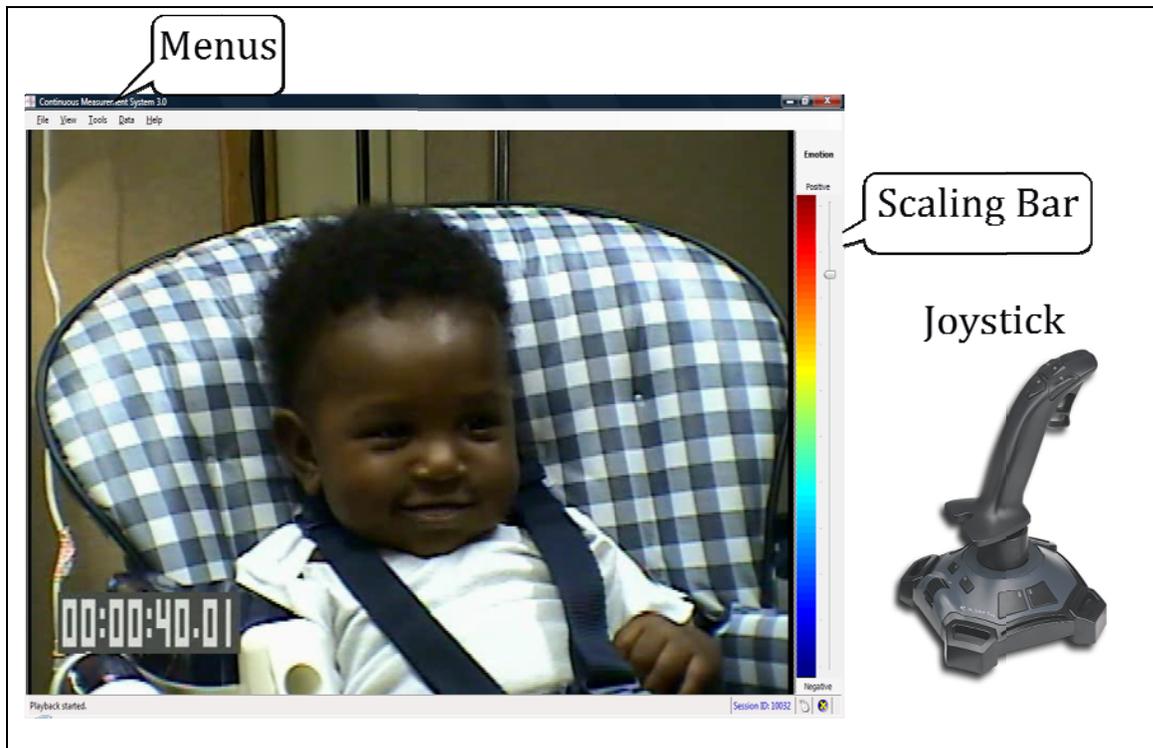


Figure 7. A representation of the Continuous Measurement System used for continuous rating.

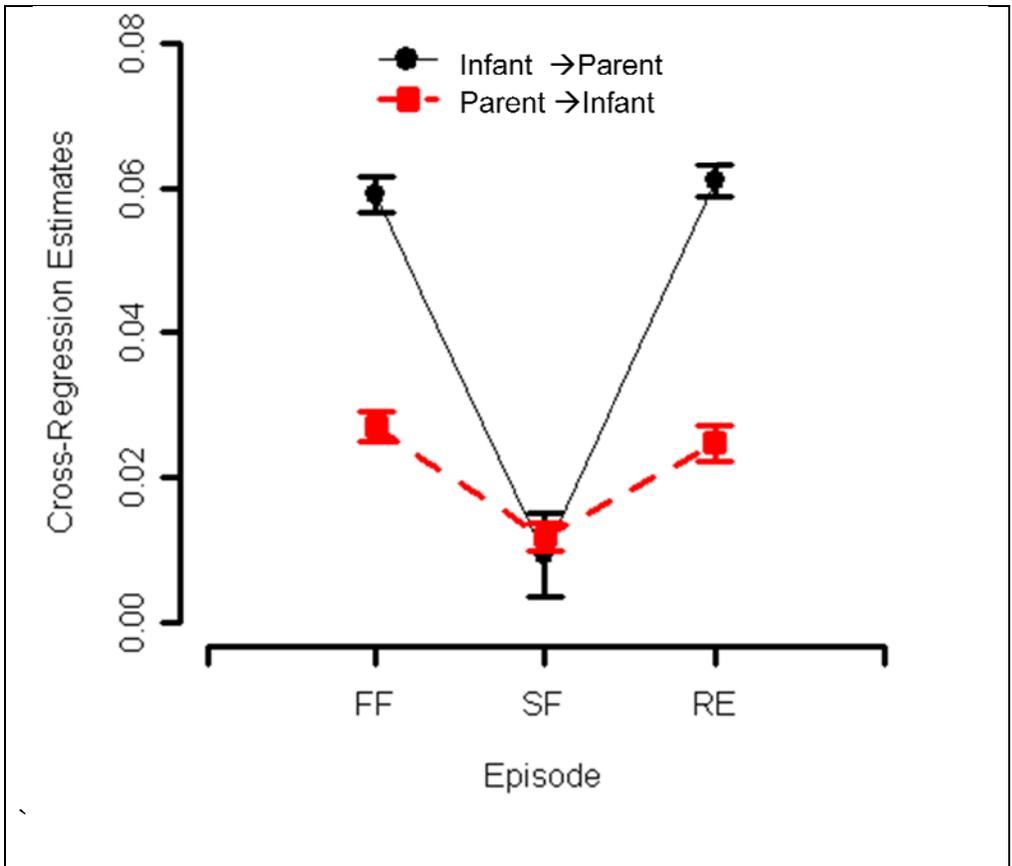


Figure 8. Cross-regression estimates of infant-to-parent and parent-to-infant interactive influence are shown for the Face-to-Face (FF), Still-Face (SF), and Reunion (RE) episodes of the procedure. Infant-to-parent influence is higher than the reverse in episodes involving interaction.