Early Interactive Emotional Development

Daniel S. Messinger, Mohammad H. Mahoor, Steven Cadavid, Sy-Miin Chow, Jeffrey F. Cohn

Abstract **- Early infant emotional development concerns the interactive emergence of emotional states that motivate approach and withdrawal. These are indexed by different patterns of infant facial expressions, vocalization, and gazing that emerge within parent-infant interactions in the first 10 months of life. Specifically, the interface of a limited number of interactive parameters creates complex real-time patterns which change over developmental time. These phenomena are described below using techniques from our laboratory such as statistical simulations, continuous ratings, and computer vision modeling.**

Index Terms **- Social development, models of emotion, autism.**

1. Introduction

Infants and the developers of epigenetic systems both confront the problem of motivation or value [1]. Early infant emotional development concerns the interactive emergence of emotional states that may motivate epigenetic systems such as robots. We begin with an overview of infant emotional expression and then proceed to the question of emotional development in interaction. Throughout, we highlight findings below using techniques from our laboratory based on techniques such as statistical simulations, continuous ratings, and computer vision modeling.

Our theoretical orientation stems from dynamic systems. We are interested in modeling the development of interactive capacities as they arise, in epigenetic fashion, during ongoing interchanges with others [2]. We conceive of emotions as felt, motivational states that are simultaneously inherently communicative [3]. From that basis, we use automated measurement and quantitative modeling to describe emotional interactions as they occur in real time.

2. Infant expressivity

Human infants are altricial in that they cannot locomote or care for themselves. However, their sensory and expressive systems are functional at birth. It is helpful to consider some general features of infant expressivity in social contexts that have emerged from our investigations of development in the first six months of life. These features involve the centrality of infant facial expressions, and two parallels between negative and positive expressions.

2.1. The centrality of facial expressions

Using statistical simulations of behavior, we analyzed the temporal coordination of infant gazing (at and away from the parent's face) with infant facial expressions and vocalizations. The temporal patterning that emerged was substantively and conceptually striking. Substantively, infant facial expressions were central to the coordination of communication (see Fig. 1). Gaze at parent's face set the stage for a facial expression that might itself be the context for a vocalization. In these data, there was no direct association of infant gazing and vocalizations (but see [4]). Conceptually, then, multi-modal communicative acts were not pre-formed, but emerged through links between individual communicative modalities. It may be, for example, that facial expressions have a lower threshold than vocal output (as suggested by a reviewer) such that conditions sufficient to produce vocal expressions would also be sufficient for the production of facial expressions. This suggests that communicative signals dynamically assemble in real-time.

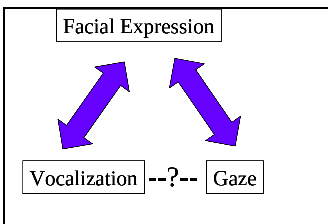

Fig. 1. Infant facial expressions are the link between vocalizations and gazing at the parent's face [5].

Supported by the Marino Autism Research Institute (MARI), Autism Speaks, NSF (0418400), NICHD (HD047417 & 052062) & NIMH (051435).
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3. Positive and negative expressions

Facial expressions and vocalizations are two central expressive modalities for infants. The prototypical positive infant facial expression is the smile in which the zygomatic major pulls the lip corners laterally upward. The prototypical negative expression is a cry-face, a frown or grimace in which the lip corners are pulled laterally, the mouth is typically open to some degree, and the brow is furrowed. (For modelers, it is noteworthy that while cry-faces are common, it is unclear whether discrete expressions of negative emotions such as fear and sadness can be reliably elicited from young infants.) We first consider some unexpected parallels between infant positive and negative emotional expressions, and then go on to consider the full range of affective engagement during interactions.

3.1. Facial expressions and vocalizations

The first parallel between positive and negative expressivity concerns the pairing of facial expressions and vocalizations. Although there is more variability than one might expect (Oller, 2000), neutral and positive vocalizations tend to occur with smiles; fusses and cries tend to occur with negative facial expressions. We have shown that the coordination of facial expressions and vocalizations is relatively fixed [5, 7]. Statistical simulations of actions in time indicate that infants tended to embed vocalizations in the course of both frowns and smiles as if to punctuate or call attention to these facial expressions (see Fig. 2). The embedding pattern was stronger for frowns than for smiles but did not change with age, suggesting this is a basic feature of the expressive system.

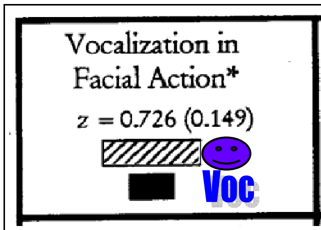

Fig. 2. Vocalizations tend to be temporally embedded in smiles and cry-faces at greater than expected levels given the temporal parameters of the constituent actions [5, 7].

3.2. Positive and negative expressions

Infant positive and negative facial expressions have parallel features which suggest possible economies in modeling. First, we examine qualitative and continuous affect interpretations of infant smiles, and then note parallels with infant negative expressions.

3.2.1. Qualitatively different smiles

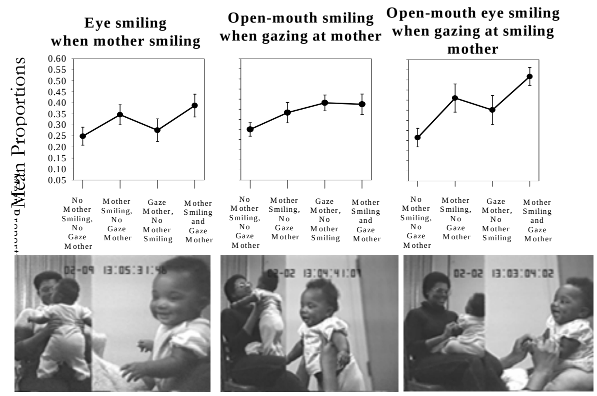

Fig. 3. Different smiles have different functions. Smiling with eye constriction (left) occurs in association with parent smiling; smiling with mouth opening (middle) occurs when the infant gazes at the parent; open mouth smiling with eye constriction occurs when the infant is gazing at the smiling parent [6].

Infants smile in different ways and these smiles may have different social functions (see Fig. 3). The Duchenne smile – in which the eyes are constricted by the action of orbicularis oculi, pars lateralis – may be involved in reciprocating the smiles of others. Open mouth smiles tend to be particularly associated with social situations producing arousal and excitement. Despite these different associations, there is also evidence that infant positive emotion is a single continuous dimension.

3.2.2. Smiles and continuous affect. Open mouth and eye constriction smiles tend to co-occur and each is associated with a pre-eminently continuous dimension: the actual strength of the smile indexed by degree of lip movement. Computer vision techniques, in fact, suggest that infant smile strength, eye constriction, and mouth opening may all covary continuously in time. Each parameter is associated with adult perceptions of positive infant emotion, suggesting the utility of modeling infant positive emotion as a single dimension (see Fig. 4).

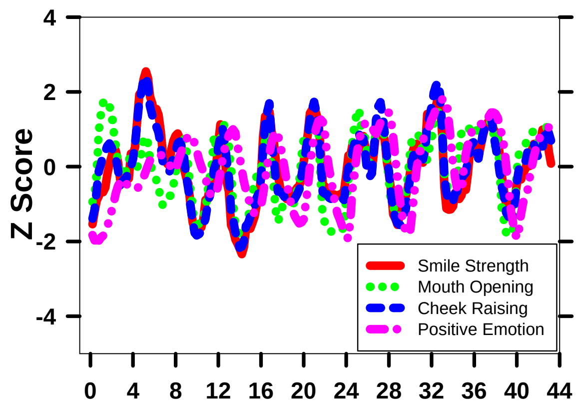

Fig. 4. Computer vision measurements of infant smile strength, eye constriction (cheek raising), and mouth opening covary in time; each is associated with continuous ratings of positive emotion.

3.2.3. A positive - negative parallel

A second parallel between negative and positive expressions concerns the structure of the facial expressions (see Fig. 5). Stronger eye constriction, mouth opening and lip movement make cry-faces appear more negative, just as they make smiles appear more positive [8, 9]. Not all positive expressions and negative expressions exhibit this parallel structure, of course. Nevertheless, the earliest infant expressions may utilize relatively simple base configurations to express positive and negative emotion. Increasing the intensity of these expressions may involve adjusting the same parameters in the negative and positive expressions.

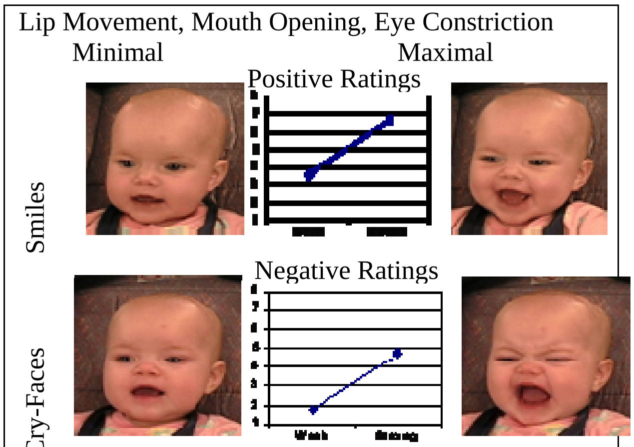

Fig. 5. The presence of greater lip movement, mouth opening, and eye constriction is associated with greater ratings of positive emotion for smiles and greater ratings of negative emotion for cry-faces.

3.3. Smiles and arousal

Although smiles signal enjoyment, infants also use smiles to manage arousal. Infant heart rate is more rapid during smiling than during neutral expressions [10] and infants are likely to mouth their hands while smiling, as if dispelling tension. It may be that infant smiles are a way to maintain face-to-face eye contact even when it is arousing. At times infants smile and negative indices of cry-face expressions can occur in close temporal proximity or even at the same time. In these cases, the arousal regulation capacity of infant smiles may be overwhelmed, leading to a negative expression.

4. Face-to-face interaction and the development of positive emotion

We focus here on early interaction as a window into the development of infant positive emotion and approach motivation between one and six months. In these interactions, infants can be conceptualized as having two major modalities of action: gaze (at or away from the parent's face) and smiling. In this section we focus on the presence or absence of smiling. In the next section, we focus on continuous measures of facial action and emotion.

The patterning of gazing and smiling changes over developmental time - and these changes seem to convey different psychological meanings. We review this development sequentially using overlapping age categories to accommodate individual differences in development.

4.1. Gazing and smiling (1-2 months)

In the first two months, smiles tend to occur after auditory (e.g. high pitched tones) and visual (e.g., static human faces) stimuli. These smiles are preceded by brow furrowing, a potential index of the cognitive effort involved in recognizing the stimulus, which relaxes and disappears as the infant smiles. The same pattern holds for social smiles –occurring while gazing at the parent's face – which develop between 1and 2 months of age. In the second month of interaction, infants gaze at the parent's face, furrow their brows in concentrated attention to her face, and then relax their brows and smile at the parent [11, 12]. These may be early mastery smiles - which are thought to index positive emotion following a successful cognitive or physical effort – which have clear implications for motivating epigenetic systems.

4.2. Gazing and smiling (2-3 months)

By two to three months of age, infants spend relatively long periods of time gazing at the parent’s face. Infant gaze typically elicits a parent smile, which may then be followed by an infant smile. Three-month-olds tend to begin and end their smiles within the course of a gaze at the parent’s face [5]. Infant smiles, in turn, are likely to elicit parent smiles and parents typically do not cease smiling until the infant has stopped smiling. In sum, early expressions of positive emotion are dependent on ongoing visual contact with the typically smiling parent. Through repeated experience of this type, infants are likely to develop the expectation that their gazes will be greeted with parent smiles.

4.3. Gazing and smiling (3-6 months)

In the period between three and six months, infant-parent interaction becomes more fast-paced, more contingent, and more affectively intense. The duration of infants' gazes at the parent's face, for example, become briefer. At the same time, however, infants become more discriminating. Infant spend less time gazing at the parent when he or she is not smiling, but time spent gazing at the parent when the parent is smiling remains stable. Time gazing away from the parent’s face replaces time gazing at the parent when he or she is being less expressive.

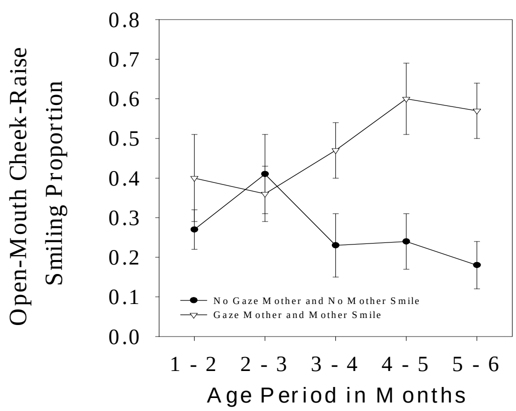

Fig. 6. Combined open-mouth smiling with eye constriction (cheek raise) increases only in interactive periods likely to elicit positive emotion [6].

Between two and six months, infants spend increasing amount of time smiling and the duration of individual epochs of smiling increases [13]. Most types of smiling (see 3.2) rise rather indiscriminately during multiple periods of face-to-face interaction [6]. However, more emotionally positive open-mouth smiling involving eye constriction shows a distinct developmental trajectory (see Fig. 6). Infants become increasingly likely to engage in open-mouth smiling with eye constriction when they are gazing at their smiling mothers. They become increasingly less likely to engage in this smiling when they are not gazing at mother and mother is not smiling. Infants’ increasing tendency to engage their smiling mothers with open-mouth smiling with eye constriction appears to reflect their growing capacity to dynamically engage in intensely joyful interactions (see Fig. 6).

Between two and six months of age, infants also become more likely to control their own positive emotion by gazing away from mother during the course of a smile. Such gaze shifts tend to occur during higher intensity smiles [14]. That is, infants simultaneously become more actively positive during interactions and become more active at regulating the conditions when they will become positive engaged. It is unclear, however, which way the causal arrow runs. The infant’s capacity to disengage – to gaze away – may be a precondition to the development of intense smiling during engaging episodes of interaction. Alternately, intense smiling may trigger gazing away [14].

5. Continuous dimensions of face-to-face interaction

Current approaches to emotion and interaction are limited. Continuous emotional signals are measured as present or absent. Here we review our current exploration of interactive dynamics using continuous measures of facial expression and emotion.

5.1. Rating approaches to emotion and interaction

We are attempting to directly measure a affective valence during interaction [15]. We asked non-experts to continuously rate negative-to-positive emotional valence using a joystick interface (see Fig. 7). We subjected separate ratings of infants and parents to time-series analyses to explore mutual infant-parent responsivity during interaction. The analyses indicated that infant→parent interactive influence was more prominent than parent→infant influence. That is, parents were more responsive to their infants than vice-versa. We also found that instructing the parent to cease interacting (the still-face condition) was not sufficient to eliminate subtle infant-parent interaction. What distinguished these conditions was that levels of infant-parent synchrony changed over time when parents were instructed to interact with their infants, but not in the still-face. Similar patterns of time-varying interactive synchrony were also evident in analyses of interaction based on computer vision measurements, the topic of the next section.

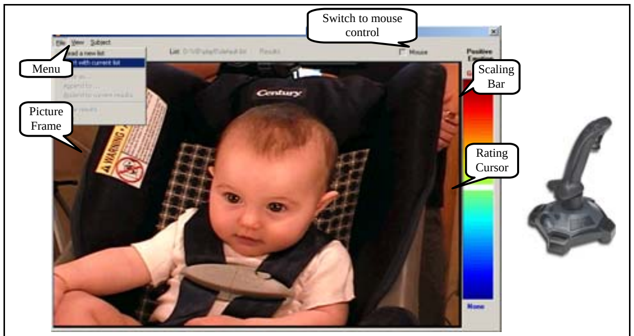

Fig. 7. Screenshot of Continuous Measurement System and joystick used to obtain expert or non-expert ratings of construct of interest (e.g., emotional valence) (http://psy.miami.edu/faculty/dmessinger/dv/).

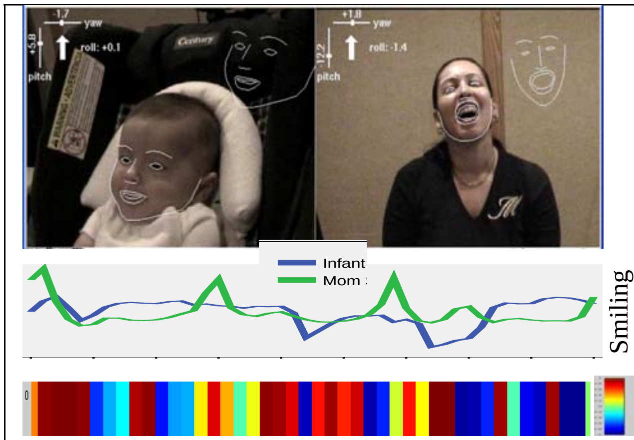

Fig. 8. Four-month-old and mother engaged in face-to-face interaction. An AAM is applied to measure rigid motion and smile-related features (note white outlines). Normalized infant (blue) and mother (green) smile strength is displayed in time beneath the video of the two partners. A windowed correlation [16] of a brief nine second interaction segment shows peaks of high correlation (purplish) interspersed with periods of zero correlation (yellowish) and periods of negative correlation (bluish) between infant and mother smile strength.

5.2. Computer vision approaches to emotion and interaction

We use Active Appearance Models (AAMs, i.e., CMU/Pitt Automated Facial Analysis) to measure infant and mother facial movement during relatively long segments of naturalistic infant-mother play (see Fig. 8) [17, 18]. Typically, a nonlinear data reduction technique - a Laplacian Eigenmap [19] - is then used to represent the appearance and shape data from the AAM as a system of twelve variables per frame. These are used as input to a Support Vector Machine (SVM) [20], a classifier, which is trained on random samples of <15% of manually coded data consisting of the presence and A-E intensity of selected FACS Action Units. The SVMs achieved agreement > 85% and correlations > .85 with manual coding of, respectively, the presence and intensity of smile strength and related parameters such as eye constriction.

Automated continuous measurements of these parameters indicated that infants and mothers exhibit similar but distinct configurations of facial movement. For both infants and mothers, smile strength is linked to degree of eye constriction (the Duchenne marker). This suggests that the dichotomy between felt (Duchenne) and unfelt smiles is misleading. There appears to be an underlying continuum of smile activity intensity. For infants, smile strength and eye constriction are also linked to mouth opening. Mother mouth opening showed weaker links to smile strength and eye constriction. Mothers instead used mouth opening to speak and to elicit infant smiles (e.g. by making “raspberries” by vibrating the lips).

We also constructed composite variables of infant and mother smile activity based on each partner’s linked actions to describe infant-mother interaction in these interactive segments. In some segments, infant and mother smiling activity was tightly synchronized, rising and falling in patterns that often involved mother tickling the infant. A more prevalent pattern of interaction occurred when periods of affective synchrony (single or linked periods of synchronous increases and decreases in smiling activity) were separated by periods in which there was no synchrony or negative synchrony. These may occur, for example when mothers elicit infant smiles but are not themselves smiling, or when a mother increases her smiling activity as an infant sobers or becomes upset (see Fig. 8).

The changing association between infant and mother smiling activity suggests that measurements of synchrony over the course of an entire interaction may mask changes in communicative microstructure. Time changing measures may be necessary to highlight patterns of dissynchrony and synchrony that index processes of disruption and interactive repair in early human interaction. We are currently working to compare such processes in dyads that do and do not contain an infant at risk for autism. The ultimate goal of this work is to model the dyadic patterning of expressive actions over interactive and development time.

Acknowledgment

The authors thank A. Fogel, M. Parlade, M. Yale Kaiser, & J.D. Haltigan for their contributions to this work.

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