

# The Temporal Coordination of Early Infant Communication

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The ability to coordinate expressive behaviors is crucial to the development of social and emotional communication. Coordination involves systematic sequencing of behaviors from two different modalities that have some temporal overlap. A bootstrapping procedure was used to determine whether preverbal 3- and 6-month-old infants sequence vocalizations, gazes at their mothers' faces, and facial expressions into pairs of coordinated patterns nonrandomly. Smiles and frowns were highly coordinated with vocalizations. Smiles were also coordinated with gazes at mothers' faces, which became stronger with age. Vocalizations were not coordinated with gazes at mothers' faces. These findings illustrate the manner in which infants temporally coordinate communicative actions and provide new evidence that facial expressions (particularly smiles) are central to early infant communications.

Infants use vocalizations, facial expressions, and gaze direction to interact with others. One characteristic of human infants' rapid expansion of interactive abilities in the first 6 months of life may be a developing ability to combine actions from different behavioral modalities into specific patterns that involve some temporal overlap. For example, a vocalization might begin and end within a smile, or a gaze at the mother's face might contain a smile that continues after the baby has gazed elsewhere. Such coordinated patterns may have specific communicative meanings that change with age, but relevant research is scarce. In this article, we examine whether young infants coordinate actions between different behavioral modalities into specific patterns nonrandomly in order to shed light on their interactive and expressive competence before the onset of speech.

Few studies have examined how infants' communicative behaviors in one modality are associated with behaviors in another modality. Previous studies have focused on the association of

infant gaze with other expressive behaviors. In the first 6 months of life, young infants spend more time smiling (Kaye & Fogel, 1980; Messinger, Fogel, & Dickson, 2001; Weinberg & Tronick, 1994) and smile more frequently (van Beek, Hopkins, & Hoeksma, 1994) while gazing at their mothers than when gazing away. It is not clear, however, whether infants do (Kaye & Fogel, 1980) or do not (van Beek et al., 1994) vocalize more frequently while gazing at their mothers' faces.

Weinberg and Tronick (1994) investigated the relationship between facial expressions and other communicative behaviors, including vocalizations and gazes at the mother's face in a group of 6-month-old infants. They found specific affectively concordant associations between facial expressions and vocalizations and between facial expressions and gaze direction. These associations existed for the group as a whole, though the strength of the associations for individual infants was not examined. Although this study provided important evidence concerning the coordination of infant expressive behaviors, only associations that involved facial expressions were examined. No study has simultaneously considered all possible links between infant facial expressions, gazes at the mother's face, and vocalizations. This makes it difficult to know whether any one of these expressive modalities serves as a potential organizer of the other two.

The affective configurations displayed by participants in Weinberg and Tronick's (1994) study were examined in the context of Tronick's face-to-face still-face paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978). The still face is thought to be an age-appropriate stressor in which, after a period of face-to-face interaction, the caregiver ceases interaction and responsivity (the still face) and then reengages with the infant. Cohn and Elmore (1988) found that maternal transition to a still face heightened the probability of infants transitioning from play-like behaviors to looking away from their mothers. This interruption of typical parent–infant face-to-face interaction may disrupt infant commu-

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native behaviors and provides an ideal framework in which to study changes in temporal coordination.

Methodological challenges have limited researchers' knowledge of the manner in which infants sequence expressive actions from different modalities. Investigations of infants in the first 6 months of life have examined the total amount of time two actions co-occurred (Weinberg & Tronick, 1994) and the frequency with which one action began during another (Kaye & Fogel, 1980; van Beek et al., 1994). The difficulty is that the co-occurrence of two behaviors or the more frequent onsets of one behavior during another do not indicate whether infants are inclined to create specific patterns of behaviors.

An initial step is describing and tabulating specific patterns of behavior in time. Investigators have described the temporal patterning of infant and mother vocalizations (Elias & Broerse, 1995; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001) and infant gazes and mother vocalizations (Crown, Feldstein, Jasnow, Beebe, & Jaffe, 2002). Infants and mothers create specific interactive patterns by interrupting each other's vocalizations (Jaffe et al., 2001). Time-series analyses indicate that the quantity of infant vocal interruptions can be predicted by the immediately preceding quantity of previous mother interruptions. In addition, the frequency of infant gazes during maternal vocalizations can be predicted by the immediately preceding frequency of maternal vocalizations during infant gazes (Crown et al., 2002). Time-series analyses allow one to predict when a particular pattern occurs during an interactive session. Time-series analyses do not indicate whether the pattern itself occurs at greater-than-chance levels. In order to account for chance occurrence, Elias and Broerse (1995) used a bootstrapping analysis to compare the observed frequency of interrupting vocalizations with the frequency expected by chance. They reported that, overall, infants and mothers tend to avoid vocalizing simultaneously, but they indicated that the role of the infant in creating or avoiding the vocal interruption patterns was unclear (Elias & Broerse, 1995).

A fundamental question is whether infants' coordination of their own expressive actions during interactions is due to chance. In a recent study, Yale, Messinger, Cobo-Lewis, Oller, and Eilers (1999) categorized how infant behaviors from different modalities with some degree of overlap are patterned in time. Using a bootstrapping procedure that employed randomization, the authors were able to determine whether infants sequenced facial expressions and vocalizations into specific coordinated patterns at greater-than-chance levels. In an initial investigation of 12 infants, they found that infants both began and ended vocalizations within facial expressions and began and ended facial expressions within vocalizations. Although the facial expressions and vocalizations may have reinforced each other's expressive message, such an interpretation is problematic without knowing whether each of these behaviors was coordinated with a clearly social behavior—gazing at their mothers' faces.

The present study examined whether infants coordinate behaviors in three modality pairs: (a) vocalizations and facial expressions of positive and negative emotion, (b) facial expressions of positive and negative emotion and gaze direction, and (c) gaze direction and vocalizations. We chose to examine facial expressions of positive emotion (smiles) and negative emotion (frowns) because of their clear hedonic tone and canonical form and because we thought these expressions might be differentially coordinated

with infant gazes and vocalizations. We were especially interested in the specific patterns into which infants organized each pair of behaviors and whether specific patterns occurred nonrandomly, that is, more or less frequently than expected by chance. For each pair of behaviors, we categorized all occurrences of two target behaviors that had some temporal overlap into one of four possible logical patterns (see Figure 1). These patterns are a logical categorization of how two overlapping behaviors can occur.<sup>1</sup> In addition, we examined stability and change in each behavioral pair between 3 and 6 months in different interactive contexts.

## Method

### Participants

Participants included a subset of infants involved in a longitudinal investigation of early infant communication. All participants were recruited by mail solicitation on the basis of Florida Health Department birth records. A letter describing the longitudinal study was sent to parents soon after the infants' births. Recruited participants were all healthy, full-term infants with unremarkable pre- and postnatal medical histories. Infants were included in the present study if they completed the specified protocol at the 3- and 6-month visits to the laboratory. The present study involved 40 infants (21 girls and 19 boys). Mean ages of the 40 participants at the 3- and 6-month visits were 13.7 weeks ( $SD = 1.1$  weeks) and 26.5 weeks ( $SD = 0.8$  weeks), respectively. The ethnicity of the sample was 62.5% Hispanic, 30% White-Anglo, 2% Black-non-Hispanic, and 5% other.

### Apparatus

All visits were recorded in a sound-attenuated chamber (11 ft  $\times$  11 ft  $\times$  6.5 ft [3.4 m  $\times$  3.4 m  $\times$  2 m]) with high-fidelity audio recording from a microphone placed above participants' heads. Three pictures of Disney characters were placed on the walls, one to the left and one to the right of the infant, both in the infant's line of view, and the third on the wall behind the infant, out of the infant's line of view. During both the 3- and 6-month visits, the caregiver sat in a chair facing the infant. The infant was placed in an infant seat mounted on a table during the 3-month visit and in a highchair during the 6-month visit. The views from two cameras, one offering a full-frontal view of infants' faces and one offering a three-quarter frontal view of caregivers' faces, were combined in split screen format and recorded on a JVC Super VHS video recorder.

### Procedure

During each visit, an experimenter sat in a chair, behind the caregiver and out of the infant's view. As each new episode of the session was initiated, the experimenter provided instructions to the parent. Each session began with a 3-min face-to-face play segment. The experimenter instructed the mother, "Play with your infant as you normally would do at home. Talk to him/her and try and get your baby to talk back to you." The second episode was a 1-min still-face episode in which the mother was instructed to sit back and look at a picture placed on a wall behind the infant and

<sup>1</sup> Similar patterns have been used in descriptions of maternal and infant vocalization patterns (Crown et al., 2002; Jaffe et al., 2001) and in non-random patterns of infant vocalizations and facial expressions (Yale et al., 1999). Patterns between actions that do not involve overlaps have been used to investigate turn changes between two partners (Crown et al., 2002; Jaffe et al., 2001). We did not consider nonoverlapping behaviors, because we were focusing not on turn changes but on infants' coordination of their own behaviors.

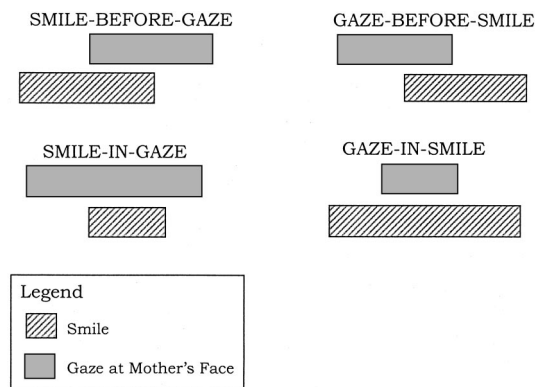


Figure 1. The four coordinated patterns depicting temporal overlap between behaviors in two communicative modalities. The positive/negative facial expression–gaze modality pair is used as an example.

maintain a still face without responding to her infant (Yale et al., 1999). The traditional still-face paradigm (Tronick et al., 1978) was modified to create a situation in which infants could make communicative bids toward an unresponsive partner while minimizing fussiness. It is noteworthy, however, that infants respond in an identical fashion to the standard and modified still face (Delgado, Messinger, & Yale, 2002). This modified still face was followed by another 3-min face-to-face play episode in which the mother was instructed to play with the infant as she had in the beginning of the session.

**Coding.** The infants' facial expressions, vocalizations, and gaze direction were coded independently of one another with the Action Analysis Coding and Training (AACT) system (Action Analysis Coding and Training, 1996). The AACT system (Oller, Yale, & Delgado, 1997) provides computer-assisted observational coding, with the target behaviors entered into a computer that directly controls the S-VHS videotape machine with single frame accuracy and automatic time-code capture. Coders identified the onsets and offsets of exclusive behaviors within a modality (duration = offset time minus onset time).

Infant facial expressions were coded by an individual trained to reliability in the anatomically based Facial Action Coding System (FACS; Ekman & Friesen, 1978) by a FACS-certified individual trained in applying the system to infants (Baby FACS; Oster & Rosenstein, 1996). Smiles and frowns were coded because they comprise a majority of infant positive and negative emotional expressions (Camras, Oster, Campos, Miyake, & Bradshaw, 1992; Weinberg & Tronick, 1994). Smiles involved contraction of the zygomatic major action unit (AU12). Frowns involved lowered brows (corrugator supercilii and/or procerus—AU3/AU4) with either (a) a prototypical open, squared anger mouth formed by lip stretching (risorius—AU20) and jaw dropping (e.g., relaxation of the masseter and the medial pterygoid, AU26c–e) or (b) a sad expression in which the lips touched and the chin boss was raised (mentalis, AU17). Expressions were coded without audio signal and with the infant's mother's face obscured.

Vocalizations were coded at the utterance level, without any visual information, by a coder trained in identifying and classifying different types of early infant vocalizations (Oller, 1980). Vegetative and reflexive vocalizations (i.e., burps, hiccups, coughs, and sneezes) were not included in analyses. Onsets and offsets were carefully identified for each vocalization by repeatedly listening to each utterance (see Jaffe et al., 2001, for automated coding).

Gaze codes included gazing at the mother's face (looking at the mother's face or eyes) or other (looking anywhere except at the mother's face or eyes). Infant gaze direction was coded with the sound off and the mother's face covered (a portion of the mother's shoulder and head were visible in the infant side of the split-screen display).

**Behavior reliability.** Interobserver agreement for facial expression, vocalization, and gaze direction codes was assessed for 15% of the sessions. Cohen's kappas were calculated for each individual session (Cohen, 1960). The average kappa for facial expressions was .82, with an average agreement of 93%. For vocalizations, the average kappa was .61, with an average agreement of 92%. For gaze direction, the average kappa was .79, with an average agreement of 95%.

**Bootstrapping procedure.** Coordination was examined separately in the three pairs of modalities (vocalization and smile/frown patterns, smile/frown and gaze patterns, and gaze and vocalization patterns). For each pair of modalities, four patterns described any instance of temporal overlap between behaviors in the two modalities (see Figure 1).

Using the smiles from the smile/frown and gaze pair as an example, the four sequence patterns are as follows: (a) smile-before-gaze—a smile that begins before and ends within a gaze at the mother's face; (b) smile-in-gaze—a smile that begins and ends within a gaze at the mother's face; (c) gaze-before-smile—a gaze at the mother's face that begins before and ends within a smile; and (d) gaze-in-smile—a gaze at the mother's face that begins and ends within a smile. Smiles and frowns formed identical patterns not only with gazing at the mother's face but with infant vocalizations, as did vocalizations and gazes at the mother's face.

After the observed frequencies of different types of coordinated patterns were calculated, the frequencies expected by chance were determined using a bootstrapping–Markov model procedure that is a form of a randomization procedure (Davison & Hinkley, 1997; Efron & Tibshirani, 1993; Elias & Broerse, 1995; Mooney & Duval, 1993; Yale et al., 1999). The procedure simulated the temporal progression of infant actions independently within the facial, gaze, and vocal modalities. For each infant, at each age, for each protocol episode, and for each behavioral modality, the actual frequencies, durations, and sequential transition probabilities of the behaviors in that modality were used as raw data. Individual observed behaviors of a given duration were sampled—with replacement—using the sequential transition probabilities within that modality to simulate the behavior stream of facial expressions, gazes, or vocalizations for each infant in each episode separately.

Each of the three modality pairs was analyzed separately. For each modality pair, 1,999 simulated sessions were created for each infant, at each age, and for each protocol episode by the bootstrapping procedure. Behaviors for each modality in a pair were simulated independently of the behaviors in the other modality. This bootstrapping procedure yielded multiple simulated sessions for each infant, at each age, and for each protocol episode in which only random levels of coordination existed between modalities. The patterns between each pair of modalities from these simulated sessions were then tabulated, which yielded the frequency of each type of coordinated pattern expected by chance. We analyzed  $z$  scores (observed minus expected frequencies, divided by the standard deviation of sampling distribution of the 1,999 expected frequencies) to evaluate whether coordination between modalities exceeded chance levels.

**Pattern reliability.** The primary theoretical and analytical focus of this research was the patterning of behaviors from different expressive modalities. To specifically ascertain the reliability of these patterns, a coder viewed 10% of the sessions in real time. A behavior for which reliability had previously been established (see above) was used as a key. Smiles or frowns were used as the key for modality pairs involving facial expressions of positive and negative emotion; vocalizations were used for the gaze and vocalizations pair. The key behavior was categorized as falling into one of the four patterns described above or as occurring alone. Cohen's kappas were calculated for each session (Cohen, 1960). The average kappa for vocalization and smile/frown patterns was .85, with an average agreement of 92%. For smile/frown and gaze patterns, the average kappa was .94, with an average agreement of 96%. For gaze and vocalization patterns, the average kappa was .90, with an average agreement of 96%.

**Data analysis.** The bootstrapping procedure yielded  $z$  scores that quantified the frequency of patterns observed in the data relative to the fre-

quency of patterns expected by chance for each infant individually. A *z* score was computed for each pattern as the number of patterns observed in the data minus the mean number of patterns that occurred during the simulations (i.e., patterns expected by chance), divided by the standard deviation of the sampling distribution expected by chance (Yale et al., 1999).

Results

Table 1 describes the observed frequencies and durations of behaviors in each communicative modality—vocalizations, facial expressions (smiles and frowns), and gazes at the mother’s face—separately. Smiles occurred more frequently than frowns, and the duration of smiles showed some increase between 3 and 6 months. As expected, smiles tended to decrease and frowns tended to increase during the still face. Gazes at the mother’s face tended to occur for longer periods of time than other behaviors, but these gazes decreased in duration between 3 and 6 months.

To describe characteristics of coordination between modalities, we tabulated the frequency of patterns observed in the actual data and the expected frequencies from the simulated data (see Table 2). Systematic coordination between modalities involves differences between the expected and observed pattern frequencies. These are reported as *z* scores, the dependent measure in all of the following analyses. Separate 2 (age) × 3 (episode) × 4 (pattern) × 2 (expression type) repeated measures analyses of variance (ANOVAs) with Greenhouse–Geisser corrections for factors of more than two levels (Greenhouse & Geisser, 1959) were performed on the vocalization and smile/frown pair and the smile/frown and gaze pair to determine whether specific coordinated patterns occurred more than others and whether coordination differed by type of facial expression. The analysis of the gaze and vocalization pair was identical except that the type of facial expression factor was omitted.

In brief, infants coordinated smiles and frowns with both vocalizations and gazes at the mother’s face in specific patterns but did not coordinate vocalizations with gazes at the mother’s face (see Figure 2). The coordination of smiles/frowns and gaze patterns varied by age and expression type, but the coordination of smiles/frowns and vocalization patterns did not. Patterns involving smiles and gazes at the mother’s face became more coordinated with age and showed different patterns at 3 and 6 months. All types of coordination approached chance levels of occurrence during the still face.

Patterns of Smiles/Frowns and Vocalizations

A significant main effect of pattern indicated that infants coordinated vocalizations with smiles/frowns in specific patterns,  $F(2.68, 104.56) = 15.75, p < .01, \eta^2 = .29$ . Simple contrasts revealed that the vocalization-in-smile/frown pattern had higher levels of coordination than the other three patterns (see Figure 2). The main effects for age, episode, and expression type were not significant. Overall, the coordination of vocalizations with smiles/frowns did not change from 3 to 6 months or between interactive episodes. In addition, vocalizations were not differentially coordinated with smiles or frowns. Significant Episode × Pattern,  $F(5.10, 198.86) = 2.31, p = .04, \eta^2 = .06$ , and Episode × Pattern × Expression Type,  $F(4.70, 183.39) = 3.73, p < .01, \eta^2 = .09$ , interactions indicated that there was little tendency for vocal-

Table 1  
Mean Frequencies and Durations (and Standard Deviations) of Individual Observed Infant Communicative Behaviors by Age and Protocol Episode

Behavior and measure	3 months	6 months
Face-to-face play episode		
Smiles		
Frequency	4.57 (2.34)	3.86 (1.75)
Duration	0.93 (0.46)	1.48 (0.82)
Frowns		
Frequency	1.07 (1.47)	0.15 (0.51)
Duration	0.57 (0.75)	0.15 (0.47)
Vocalizations		
Frequency	8.85 (6.55)	4.291 (5.09)
Duration	0.63 (0.26)	0.52 (0.25)
Gazes at mother		
Frequency	3.03 (1.67)	5.59 (1.71)
Duration	7.76 (10.43)	1.34 (0.83)
Modified still-face episode		
Smiles		
Frequency	2.00 (1.30)	2.33 (2.47)
Duration	1.12 (1.19)	1.93 (1.85)
Frowns		
Frequency	1.30 (1.70)	0.93 (1.54)
Duration	1.50 (2.26)	1.74 (4.68)
Vocalizations		
Frequency	7.25 (6.85)	8.18 (8.35)
Duration	0.52 (0.38)	0.60 (0.38)
Gazes at mother		
Frequency	4.43 (2.19)	5.73 (2.87)
Duration	12.08 (13.03)	2.91 (2.22)
Reunion face-to-face play episode		
Smiles		
Frequency	3.71 (2.44)	2.92 (1.88)
Duration	0.76 (0.37)	1.51 (0.88)
Frowns		
Frequency	1.43 (1.65)	0.74 (0.95)
Duration	0.75 (1.13)	0.78 (1.48)
Vocalizations		
Frequency	10.90 (7.50)	8.12 (8.50)
Duration	0.73 (0.29)	0.66 (0.28)
Gazes at mother		
Frequency	3.01 (1.60)	4.73 (1.66)
Duration	7.78 (10.68)	1.54 (1.35)

Note. Frequencies are per minute, and durations are in seconds. *N* = 40.

izations to begin and end within smiles during the still-face episode, whereas the tendency of vocalizations to begin and end within frowns increased during and after the still-face episode (see Figures 3A and 3B).

Patterns of Gazing and Smiles/Frowns

Infants also coordinated these two facial expressions with gazes at the mother’s face in specific patterns,  $F(2.62, 102.29) = 28.09, p < .01, \eta^2 = .42$ . The coordination of these two facial expressions and gaze patterns became stronger with age,  $F(1, 39) = 17.12, p < .01, \eta^2 = .31$ , and varied between smiles and frowns,  $F(1, 39) = 4.36, p = .04, \eta^2 = .10$  (see Figure 2).

Table 2  
*Mean Frequencies (and Standard Deviations) of Patterns by Age and by Protocol Episode*

Pattern	3 months		6 months	
	Observed	Expected	Observed	Expected
Face-to-face play episode				
Vocalization and smile/frown patterns				
Voc in smile/frown	3.74 (3.86)	2.36 (2.79)	2.37 (3.41)	1.69 (2.45)
Smile/frown in voc	0.11 (0.29)	0.05 (0.09)	0.03 (0.10)	0.01 (0.02)
Voc before smile/frown	0.58 (0.78)	0.58 (0.60)	0.16 (0.29)	0.18 (0.26)
Smile/frown before voc	0.61 (0.79)	0.57 (0.59)	0.18 (0.27)	0.19 (0.28)
Smile/frown and gaze patterns				
Smile/frown in gaze	4.16 (2.21)	3.64 (1.99)	0.60 (0.83)	1.27 (1.08)
Gaze in smile/frown	0.13 (0.22)	0.24 (0.27)	1.26 (1.16)	1.06 (0.91)
Smile/frown before gaze	0.39 (0.50)	0.68 (0.45)	0.40 (0.46)	0.84 (0.53)
Gaze before smile/frown	0.68 (0.64)	0.70 (0.48)	1.62 (1.01)	0.92 (0.57)
Gaze and vocalization patterns				
Gaze in voc	0.01 (0.53)	0.01 (0.03)	0.01 (0.05)	0.02 (0.04)
Voc in gaze	7.14 (5.65)	6.83 (5.49)	1.48 (1.99)	1.33 (1.51)
Gaze before voc	0.23 (0.53)	0.29 (0.38)	0.23 (0.51)	0.21 (0.27)
Voc before gaze	0.18 (0.32)	0.29 (0.38)	0.18 (0.38)	0.20 (0.26)
Modified still-face episode				
Vocalization and smile/frown patterns				
Voc in smile/frown	1.85 (3.40)	1.16 (2.72)	2.75 (6.20)	1.80 (4.88)
Smile/frown in voc	0.13 (0.40)	0.03 (0.08)	0.10 (0.50)	0.05 (0.12)
Voc before smile/frown	0.35 (0.70)	0.31 (0.55)	0.30 (0.69)	0.31 (0.50)
Smile/frown before voc	0.33 (0.73)	0.30 (0.53)	0.30 (0.56)	0.32 (0.48)
Smile/frown and gaze patterns				
Smile/frown in gaze	1.53 (1.47)	1.06 (1.51)	0.53 (0.88)	0.45 (0.59)
Gaze in smile/frown	0.18 (0.50)	0.13 (0.21)	0.58 (0.87)	0.65 (0.61)
Smile/frown before gaze	0.25 (0.63)	0.39 (0.50)	0.58 (0.87)	0.65 (0.61)
Gaze before smile/frown	0.60 (0.90)	0.54 (0.52)	0.75 (1.01)	0.55 (0.65)
Gaze and vocalization patterns				
Gaze in voc	0.00 (0.00)	0.01 (0.02)	0.05 (0.22)	0.08 (0.15)
Voc in gaze	4.35 (5.94)	4.51 (5.85)	1.50 (2.68)	1.73 (2.10)
Gaze before voc	0.38 (0.71)	0.29 (0.39)	0.38 (0.74)	0.41 (0.43)
Voc before gaze	0.23 (0.48)	0.26 (0.36)	0.28 (0.51)	0.40 (0.42)
Reunion face-to-face episode				
Vocalization and smile/frown patterns				
Voc in smile/frown	3.86 (4.40)	2.58 (3.26)	4.88 (7.12)	3.27 (5.15)
Smile/frown in voc	0.13 (0.25)	0.08 (0.16)	0.02 (0.11)	0.02 (0.03)
Voc before smile/frown	0.93 (1.15)	0.74 (0.87)	0.41 (0.56)	0.38 (0.49)
Smile/frown before voc	0.58 (0.71)	0.73 (0.85)	0.37 (0.50)	0.39 (0.50)
Smile/frown and gaze patterns				
Smile/frown in gaze	3.86 (2.77)	3.49 (2.68)	0.77 (0.93)	0.75 (0.87)
Gaze in smile/frown	0.09 (0.21)	0.22 (0.37)	0.73 (0.84)	0.86 (0.79)
Smile/frown before gaze	0.30 (0.42)	0.52 (0.39)	0.46 (0.45)	0.69 (0.55)
Gaze before smile/frown	0.60 (0.53)	0.57 (0.39)	1.15 (0.86)	0.74 (0.57)
Gaze and vocalization patterns				
Gaze in voc	0.02 (0.07)	0.04 (0.09)	0.04 (0.14)	0.04 (0.06)
Voc in gaze	7.25 (5.67)	6.90 (5.63)	3.31 (4.84)	2.76 (3.66)
Gaze before voc	0.38 (0.56)	0.37 (0.41)	0.31 (0.49)	0.36 (0.42)
Voc before gaze	0.33 (0.56)	0.37 (0.41)	0.34 (0.40)	0.35 (0.41)

Note. Frequencies are per minute. *N* = 40. Voc = vocalization.

Smile-gaze patterns showed more coordination and more variability in their coordination than frown-gaze patterns,  $F(2.89, 112.84) = 40.02, p < .01, \eta^2 = .51$  (Pattern  $\times$  Expression Type). The gaze-in-smile and gaze-before-smile patterns occurred above chance levels, whereas the smile-before-gaze pattern occurred below chance levels. Infants' preference for the smile-in-gaze

pattern at 3 months shifted to a preference for the gaze-before-smile pattern at 6 months, whereas frown-gaze patterns tended to remain at, or slightly below, chance levels at both ages,  $F(2.73, 106.60) = 13.11, p < .01, \eta^2 = .25$  (Age  $\times$  Pattern  $\times$  Expression Type; see Figures 4A and 4B). For both 3- and 6-month-olds, all four smile-gaze patterns approached chance levels of occurrence

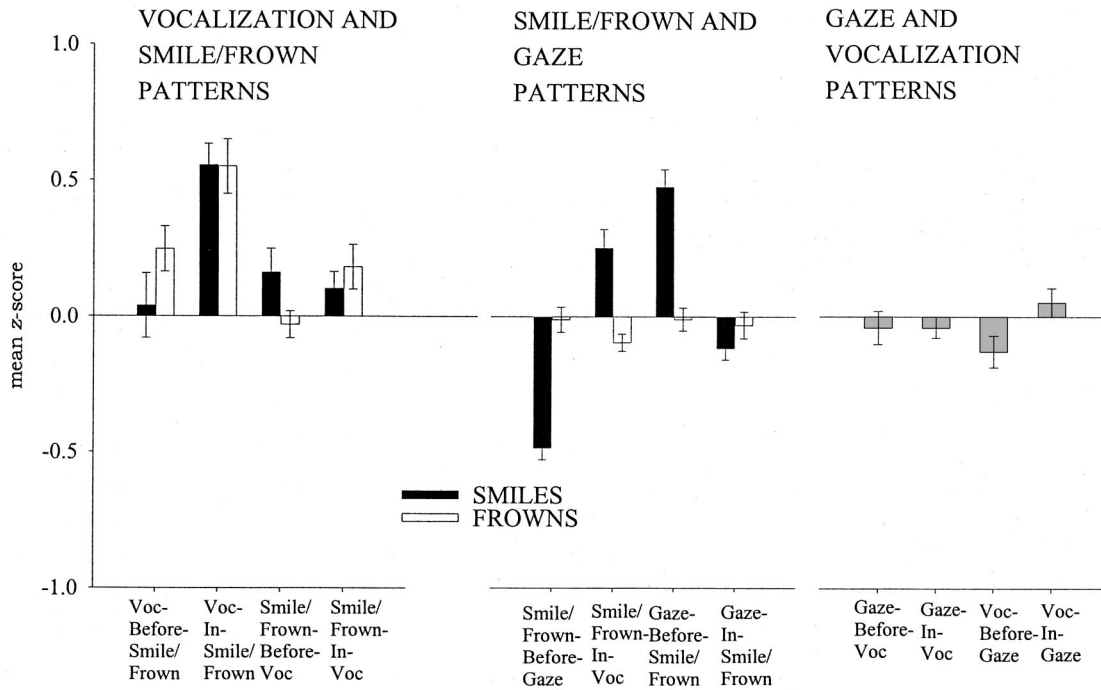


Figure 2. Mean z scores of coordinated patterns for the vocalization–positive/negative facial expression, positive/negative facial expression–gaze, and gaze–vocalization modality pairs. Vertical lines depict standard errors of the means. Voc = vocalization.

during the still-face episode,  $F(4.65, 181.27) = 5.99, p < .01, \eta^2 = .13$  (Episode  $\times$  Pattern  $\times$  Expression Type; see Figures 4C and 4D).

Patterns of Vocalizations and Gazing

Infants did not coordinate gazes with vocalizations into specific patterns at statistically reliable levels,  $F(2.61, 101.58) = 1.96, p = .13, \eta^2 = .05$  (see Figure 2). The main effects for age and episode

and the interactions were not significant. There was a slight fluctuation in the four patterns across episodes (Episode  $\times$  Pattern),  $F(4.62, 179.97) = 2.33, p = .05, \eta^2 = .06$ , but all gaze–vocalization coordination levels remained near chance levels.

Discussion

This study provides strong evidence that infants systematically coordinate facial expressions of positive and negative emotion

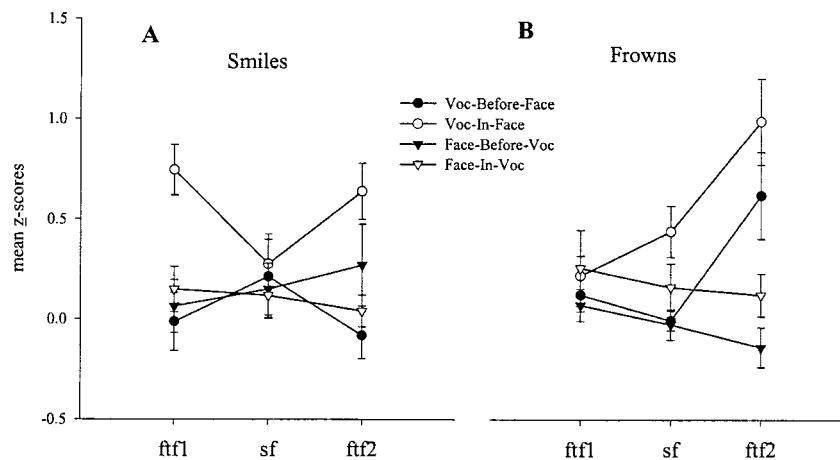


Figure 3. Mean z scores of the coordinated vocalization–smile (A) and vocalization–frown (B) patterns across the three interactive episodes. Vertical lines depict standard errors of the means. Voc = vocalization; ftf1 = first face-to-face play episode; sf = modified still-face episode; ftf2 = reunion face-to-face play episode.

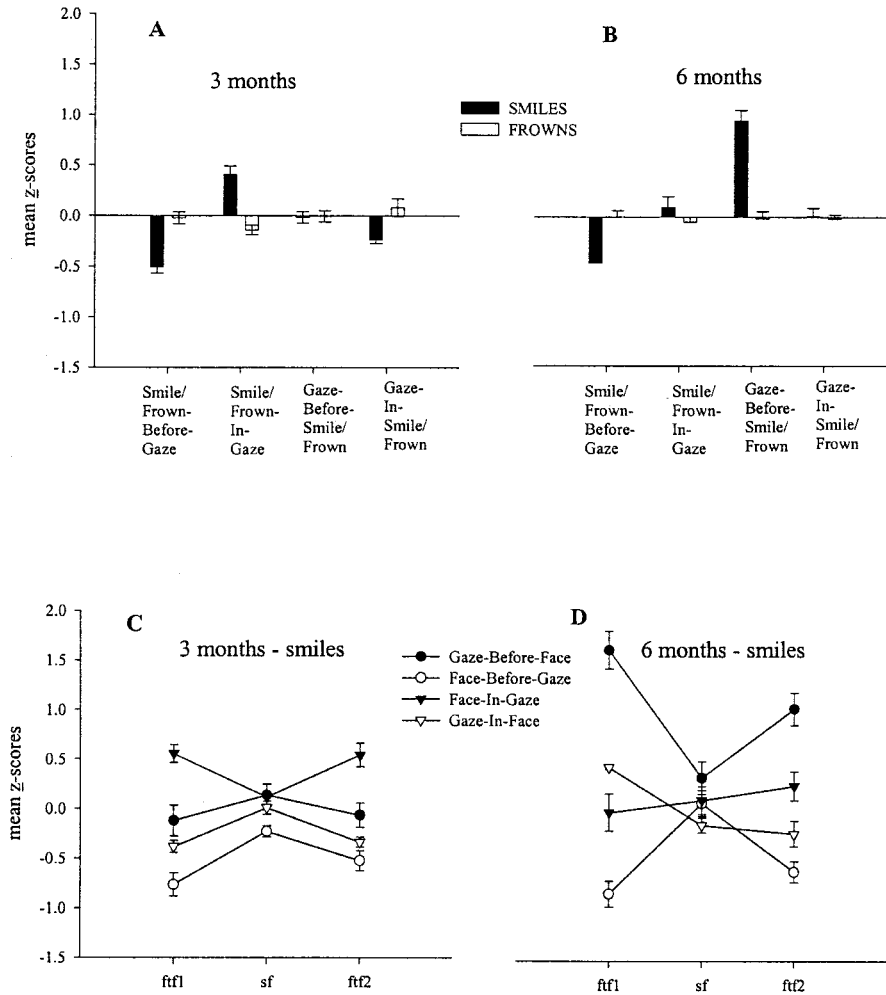


Figure 4. Mean z scores of the coordinated positive/negative facial expression-gaze patterns at 3 months (A) and 6 months (B) and the smile-gaze patterns at 3 months (C) and 6 months (D) across the three interactive episodes. Vertical lines depict standard errors of the means. ftf1 = first face-to-face play episode; sf = modified still-face episode; ftf2 = reunion face-to-face play episode.

with vocalizations and with gazes at their mothers' faces in the first 6 months of life. Infants did not coordinate vocalizations and gazing at their mothers' faces at greater-than-chance levels. This suggests that facial expressions of positive and negative emotion are central to young infants' coordinated expressive signaling during social interactions. By linking the vocal and gaze modalities together in time, facial expressions of positive and negative emotion may serve as a framework for infants' emerging communicative abilities.

*Specific Coordinated Patterns*

Infants coordinated facial expressions of positive and negative emotion (i.e., smiles and frowns) into specific patterns with remarkable consistency. Eta-squared values ranged from .29 to .52, indicating the proportion of variance in the sample reliably associated with these patterns. These very large effect sizes (Cohen's  $d > 1$ ) indicate strong regularities in the patterning of early infant communicative expressions.

The vocalization and smile/frown pattern that occurred most frequently with respect to chance involved a vocalization beginning and ending within a smile or frown. The strength of this coordinated pattern did not change with age or differ between smiles and frowns. This is consistent with previous findings (Yale et al., 1999) and highlights the importance of facial expressions of positive and negative emotion as a frame for communicating affective states (Weinberg & Tronick, 1994). It may be that vocalizations draw attention to the communicative signal that is introduced and concluded by the smile or frown, thereby clarifying and strengthening its affective message.

Expressive behaviors, such as facial expressions and vocalizations, appear to be more communicative when they are produced while looking at a partner's face (Fogel & Thelen, 1987). Specifically, gazing at the parent appears to provide a social stage on which infants produce affective displays. Infants' gazes at their parents were more coordinated with smiles and frowns at 6 months than at 3 months, were more coordinated with smiles than with

frowns, and became especially coordinated with smiles with age. The patterns in which infants coordinated smiles with gaze also changed with age.

At 3 months, infants tended to begin and end their smiles within gazes at their parents' faces. At 6 months, infants tended to gaze at their mothers' faces, smile, gaze away, and only then end the smile. These developments shed light both on early emotional regulation and on the early development of intentional communication. At 3 months, infants' expression of positive emotion was dependent on visual contact with the parent. At 6 months, infants displayed a more mature pattern of redirecting attention to other matters after a positive emotional experience (Carver, in press). This pattern may indicate an emotion regulation strategy characterized by gazing away from their parents' faces.

From a communicative perspective, 6-month-olds establish social contact by first gazing at their mothers' faces and then delivering the smile's emotional message. Six-month-old infants look away before the smile is terminated, which suggests that they are more strategic in redirecting their attention after sharing positive emotional expressions with their mothers. Between 9 and 15 months of age, infants coordinate smiles, eye contact, and gestures to communicate about objects during bouts of joint attention (Messinger & Fogel, 1998; Yale, Henderson, & Yoder, 2001). This ability to coordinate smiles with gazes at a parent in the service of sharing experiences about an object may have its origins in the increasing precision with which infants communicate their positive affect at 6 months of age.

It is important to note, however, that infants of 3 and 6 months do not appear to share emotional states by producing a positive or negative facial expression and then looking at their mothers' faces. This pattern (face before gaze) had a negative  $z$  score, indicating that it occurred less frequently than expected by chance. By contrast, 10-month-olds frequently smile, look at their mothers, stop smiling, and then look away (Jones, Collins, & Hong, 1991). This pattern is more pronounced among infants who have a greater understanding of means–end relations (Jones & Hong, 2001), which suggests that the pattern involves the affective sharing of a preexisting emotion. Six-month-olds, then, are developing the capacity to communicate positive emotion by smiling at a parent and then looking away but are not yet sharing preexisting positive emotions in a more intentional fashion.

Some patterns were observed infrequently, indicating that infants rarely combined behaviors in this way (see Table 2). Sampling behavior for longer periods of time would, of course, produce more stable estimates of these means, and we are currently using longer observational periods in our work. On a practical level, however, infrequently occurring patterns often involved a behavior that typically had a longer duration occurring in the midst of a behavior that typically had a shorter duration—making it unlikely that we dramatically underestimated their frequency. Of more importance, the frequency of the behaviors that comprised these patterns was not low (see Table 1), allowing us to determine whether observed patterns occurred nonrandomly given the base rates of these behaviors. Specifically, the  $z$  scores analyzed in our results express the likelihood of specific patterns with respect to chance, not their absolute frequency.

In this light, it is important to note that a nonsignificant  $z$  score indicates that a particular behavioral pattern occurs at levels that do not differ reliably from chance. These occurrences may be

psychologically meaningful to infants when they occur, but it is not parsimonious to ask why these patterns occur. The bootstrapping results indicate that in the absence of additional information, the chance arrangement of constituent behaviors may be an adequate explanation of their occurrence.

### *Effects of the Still-Face Episode*

Disruptions in typical parent–infant interaction moderately influenced the coordination of smiles and frowns with both vocalizations and gazes at the mother's face. Eta-squared values of .06 and .09, indicating variance accounted for, correspond to medium effect sizes (Cohen's  $d \approx .5$ ). In general, patterns moved toward chance levels of coordination when the mother ceased interacting, indicating the importance of parental interaction to the infant's coordination of expressive signals. The exception was frown–vocalization patterns ending with a frown that became more likely with respect to chance during and after the still face. This frown-specific pattern may index increased negative emotion that characterizes infant responses to and recovery from the still face (Weinberg & Tronick, 1996). A previous, independent study found that infants responded to the modified still face used here (parent gazes above the infant's shoulder rather than directly at the infant) in a manner (i.e., negative facial expressions, fussing, and crying increased) similar to that in which infants responded to the standard still face (Delgado et al., 2002). These results suggest that the still face is an age-appropriate stressor that reduces infants' coordination of all expressive behaviors, with the exception of frown–vocalization patterns.

### *Methodological Implications of the Bootstrapping Procedure*

Bootstrapping, in which observed frequencies are compared with randomized frequencies, offers a solution to both concrete and abstract methodological issues in quantifying measures of coordination (see Elias & Broerse, 1995). With regard to concrete issues, investigators are not limited to studying the duration of the total co-occurrence of two behaviors, the frequency of the onsets of one behavior in another, or even the frequency of specific patterns of behaviors. Bootstrapping and other randomization procedures allow investigators to compare the frequency of behavior patterns of specific theoretical or practical interest with the frequency expected by chance.

Bootstrapping procedures also overcome more abstract methodological difficulties with the common practice of using chi-square and similar statistics to assess the significance of observed versus expected occurrences. These statistical procedures assume independence of units, typically seconds in co-occurrence analyses. However, this assumption is violated if the time units are not independent because behaviors within successive time intervals are correlated (see Bakeman & Dorval, 1989, for another perspective). The bootstrapping procedure used in the present study circumvents this issue and makes no assumptions regarding the independence of time intervals. Expected levels of coordination were calculated for each infant by using that infant's observed behaviors as raw data and sampling with replacement. Significance levels are not based on an assumed statistical distribution but on random levels of coordination expected for each infant.



### Future Directions

One strength of the bootstrapping procedure is its general utility in examining a variety of behaviorally defined outcome measures. Similar randomization or bootstrapping techniques have been used, for example, to demonstrate the reliability of parents' perceptions of their infants' communicative acts (Elias, Meadows, & Bain, in press; Meadows, Elias, & Bain, 2000). In the current study, we used the bootstrapping procedure to examine four logically derived patterns that describe how two behaviors can overlap in time. Examining more complex patterns that do not involve behavioral overlaps, one might ask whether infant emotional expressions tend to precede conventional gestures (see Messinger & Fogel, 1998) or whether emotional expressions follow but do not co-occur with early speech acts (see Bloom & Tinker, 2001).

As in a previous study (Yale et al., 1999), infant coordination of expressive behaviors was robust during playful face-to-face interactions with parents and approached chance levels during the still face. If infant coordination is dependent on ongoing interactions, then bootstrapping techniques may shed light on how infants and their partners coordinate their actions in time. One could ask whether  $z$  scores indexing infant coordination of specific behaviors are associated with  $z$  scores indexing parental coordination of the same behaviors. One could also ask directly whether and how infants and caregivers coordinate their interaction. We are currently investigating, for example, whether infants and mothers create interactive patterns of smiling (see Symons & Moran, 1994).

Investigators using time-series analyses have already explored a different sort of interactive coordination. Jaffe et al. (2001) showed that the quantity of certain infant interactive behavior patterns can be predicted by the preceding quantity of identical mother interactive behavior patterns. The frequency, for example, with which infants vocalize during a pause in maternal vocalizations can be predicted by the prior frequency with which mothers vocalized during infant pauses—and vice-versa. Moreover, mid-range levels of predictability for both mother and infant are associated with secure rather than disorganized infant attachment at 1 year (Jaffe et al., 2001).

Bootstrapping and other randomization procedures offer a model for a more rigorous understanding of the development of early infant communication and other complex temporal processes involving discrete behaviors. An integration of time-series and bootstrapping techniques would allow one to ask whether infant behavior patterns that occur nonrandomly are better predicted by preceding caregiver patterns that also occur nonrandomly. In other words, those infant behavioral patterns that occur at greater-than-chance levels throughout an interaction may show a special propensity to occur after similar acts by the parent. In summary, the study of infant, caregiver, and infant-caregiver coordination promises a fuller understanding of infant development during interaction. Bootstrapping techniques should join a suite of tools with which to understand how infants interact and to more accurately predict infant outcomes.

In conclusion, the bootstrapping technique illustrated how infants created specific patterns of expressive behaviors in the first half year of life. Infants embedded vocalizations within facial expressions in a relatively invariant communicative pattern. Infants' coordination of gazes at the parent and facial expressions

changed and grew stronger with age. A developing pattern of looking away from the parent before ending a smile suggested early emotion regulation and, perhaps, the basis of later referencing abilities. More generally, links between facial expression and other expressive behaviors suggested a central role of emotion in infant communication. These results highlight the growing promise of bootstrapping procedures for understanding changes in infant and interactive coordination of expressive signals.

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### New Editors Appointed, 2005–2010

The Publications and Communications Board of the American Psychological Association announces the appointment of two new editors for 6-year terms beginning in 2005:

- *Journal of Consulting and Clinical Psychology*: **Annette M. La Greca**, PhD, ABPP, Professor of Psychology and Pediatrics, Department of Psychology, P.O. Box 249229, University of Miami, Coral Gables, FL 33124-0751.
- *Developmental Psychology*: **Cynthia García Coll**, PhD, Brown University, 21 Manning Walk, Providence, RI 02912.

**Electronic manuscript submission.** As of January 1, 2004, manuscripts should be submitted electronically via the journal's Manuscript Submission Portal. Authors who are unable to do so should correspond with the editor's office about alternatives. Portals are available at the following addresses:

- For *Journal of Consulting and Clinical Psychology*, submit via [www.apa.org/journals/ccp.html](http://www.apa.org/journals/ccp.html).
- For *Developmental Psychology*, submit via [www.apa.org/journals/dev.html](http://www.apa.org/journals/dev.html).

Manuscript submission patterns make the precise date of completion of the 2004 volumes uncertain. Current editors, Mark B. Sobell, PhD, and James L. Dannemiller, PhD, respectively, will receive and consider manuscripts through December 31, 2003. Should 2004 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2005 volumes.