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Mother–Infant Face-to-Face Interaction: The Sequence of Dyadic States at 3, 6, and 9 Months

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Three untested hypotheses are central to the theory of Brazelton and colleagues about the sequential structure of mother–infant face-to-face interaction: (1) Interactions begin with the mother's positively eliciting her infant's attention; (2) maternal positive expression precedes the onset of infant's positive expression; and (3) when the infant becomes positive, the mother will remain positive until the infant again becomes disengaged. The present report tests these and related hypotheses with data from 54 mother–infant pairs—18 each at 3, 6, and 9 months of age. Mother–infant pairs were videotaped in a face-to-face paradigm for 2 min. Mother and infant behavior was coded with behavioral descriptors and a 0.25-s time-base. Log-linear modeling and related techniques were used to analyze the transitions among mother–infant dyadic states. We found support at 6 and 9 months but not at 3 months for Hypothesis 1, that periods of engagement originate with the mother's using positive affective expressions to try to elicit her disengaged infant. We found strong support at each age for Hypotheses 2 and 3, with one exception: At 9 months, there was a significant probability of the infant's becoming positive before the mother. The results suggest that with some revisions the hypotheses that were tested describe the structure of mother–infant face-to-face interaction from 3 to 9 months of age.

The dyadic-states model of mother–infant face-to-face interaction (Als, Tronick, & Brazelton, 1979; Brazelton, Tronick, Adamson, Als, & Wise, 1975; Tronick, Als, & Adamson, 1979) proposes that maternal positive affective expression (e.g., smile, exaggerated "play face," or animated vocal expression) frames the infant's positive affective expression (e.g., bright face, smile, or soft vocalization) as the infant cycles from attention to and away from the mother. In this model, the dyadic sequence between mothers and their 2- to 3-month-old infants proceeds as follows: The mother is passively watching her infant while the infant's attention is directed away from her; the mother then elicits her infant's attention by showing positive affect (bright, animated facial expression, which may be accompanied by bursts of animated vocalizations); the infant responds with neutral affective expressions; the infant then becomes positive in affective expression, and a dyadic state of positive engagement is achieved. This shared positive dyadic state is terminated when the infant becomes neutral in expression and turns his or her attention away from the mother while she remains positive.

The dyadic-states model rests on three untested hypotheses about the structure of mother–infant interaction: (1) The "initiation phase" begins with the mother's positively eliciting her infant's attention; (2) maternal positive expression precedes the onset of the infant's positive expression; and (3) when the infant becomes positive, the mother will remain positive until her infant again becomes neutral in expression and turns away from her. In addition, the model implicitly posits at least two additional hypotheses: (a) the mother and infant do not change simultaneously; and (b) the interaction conforms to a first-order Markov process in which state transitions are determined (only) by the preceding dyadic state. Psychologically, this second hypothesis implies that memory for dyadic states more distant than the most immediate is relatively unimportant in determining the dyadic structure.

Brazelton and colleagues did not test the three explicit hypotheses, but other investigators have presented data relevant to one or more. Evidence regarding Hypothesis 1 comes from Kaye and Fogel (1980; Fogel, 1982). They found that mothers did not use positive affective expressions in their attempts to elicit their infants' attention. Rather, mothers used touching and bouncing while remaining neutral in expression and substituted smiles or other positive expressions only once they had their infant's attention. Although it is not clear from Kaye and Fogel's report that vestibular stimulation was effective in eliciting the infant's attention, it is quite clear that positive expressions were not. Infants were 50% to 75% more likely to begin attending to the mother's face when it was at rest (with neutral expression) than when it was positive. Mothers were also less likely to become positive during periods when their infants were looking away. These findings are consistent with Kaye and Fogel's hypothesis (Fogel, 1977; Kaye & Fogel, 1980) that the mother's attention and neutral expression frame the infant's attention, but they are at variance with Brazelton's hypothesis that interaction (or the initiation phase) begins with the mother's using positive affective expressions to elicit her infant's at-

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tention. Of course, insofar as these data suggest that mothers effectively use bouncing and touching to elicit the infant's attention and then become positive in affective expression, they could be seen as modifying Brazelton's hypothesis. Viewed in this way, they are in contradistinction to the hypothesis that there is no elicitation of any kind prior to the onset of mutual visual regard (Stern, 1977).

Studies of both normal (Beebe & Gerstman, 1980; Fafouti-Milenkovic & Uzgiris, 1979; Kaye & Fogel, 1980) and experimentally manipulated (Cohn & Tronick, 1983; Tronick, Als, Adamson, Wise, & Brazelton, 1978) interactions support Hypothesis 2, that the change from a neutral expression to a positive expression follows the mother's becoming positive. The elicitation effects of adult positive expression have also been demonstrated in an operant paradigm (Bloom, 1975; Bloom & Esposito, 1975). Similar confirmatory findings come from studies of mother–infant vocal interaction. Infants are more likely to begin vocalizing once the mother has begun to vocalize than when the mother is silent (Anderson, Vietze, & Dokecki, 1977; Penman, Friedman, & Meares, 1986; Stern, Jaffe, Beebe, & Bennett, 1975). Indeed, Kozak-Mayer and Tronick (1985) demonstrated that specific maternal turn-taking signals are most effective at producing infant vocalizations.

All of the studies supporting Hypothesis 2, however, have involved infants younger than 6 months of age. Data and some theory suggest that Hypothesis 2 is not valid for infants older than about 4 months. At 6 and at 13 weeks, in the Kaye and Fogel (1980) study, the mother's positive expression increased the probability of the infant's positive expression. At 26 weeks, however, the probability of the infant's positive expression was unaltered by the mother's becoming positive, and infants were as likely to lead as to follow their mothers in becoming positive. Kaye and Fogel (1980) argued that the infant's and the mother's behaviors became more independent as the infant became more able to initiate during the interaction. Maccoby and Martin (1983), in their review, and also Schaffer (1984), theorized that during the second half-year of life there is a trend toward a more symmetrical relationship in which both mothers and infants initiate positive dyadic states. The implication for the dyadic-states model is that it may need to be modified to reflect an (hypothesized) increase in the probability of joint positive engagement being initiated by the infant.

Evidence for Hypothesis 3, that the mother's positive expression provides a frame for the infant's periods of positive expression, is inconclusive. Stern (1974), in his pioneering paper on gaze, found that infants are the breakers of mutual gaze, but he did not integrate that observation with observations of affective expression. Kaye and Fogel (1980) emphasized the temporal relation between the onset times of mother and infant behaviors. Although they implied that the mother's expression provides a frame for the infant's positive expression, the thrust of their data presentation emphasizes turn-taking rather than simultaneity or matching of affective expression. Fafouti-Milenkovic and Uzgiris (1979), in a study of mother–infant pairs at 3 to 6 months of age, reported dyadic-state transitions consistent with the framing hypothesis, but methodological problems in their encoding of maternal positive expression undermine that finding. They observed few or no periods in which mothers were not affectively positive according to their criteria, so there was little opportunity for a disconfirming observation.

Furthermore, the pattern most commonly reported is one of turn-taking (Beebe, Stern, & Jaffe, 1979; Davis, 1978; Kozak-Mayer & Tronick, 1985; Schaffer, Collis, & Parsons, 1977; Snow, 1977). Anderson et al. (1977) found some evidence of simultaneous vocalization initiated by the mother and terminated by the infant, but this framing relationship was relatively infrequent. Stern et al. (1975) and Beebe et al. (1979), on the other hand, argued that simultaneous vocalization (i.e., coaction) initiated by the mother is found only during periods of high activation. If activation level is a critical factor underlying the structure of interactions, it would explain the contradictory findings of the vocalization literature and lend support to Hypothesis 3, that the mother's positive expression frames the infant's expression.

The present report tests these three explicit hypotheses with data from infant–mother pairs at 3, 6, and 9 months. Three months was chosen because it is the age at which the dyadic-states model was initially applied, and it is within the period of the emergence of the social smile (Spitz, 1965). Moreover, according to most theorists (Sander, 1962; Sroufe, 1979; Stern, 1977), social play is the developmental task of the infant at this time. Six and 9 months were chosen because it is during the second half-year that the infant's behavior is said to become more intentional (Schaffer, 1984; Sroufe, 1979) and more focused on objects (Field, 1977; Kaye & Fogel, 1980; Pawlby, 1977). Indeed, some investigators (Field, 1977; Kaye & Fogel, 1980; Trevarthen, 1984) have suggested that after 3 months there is a decrease in the infant's attention to the mother in favor of attention to objects. Kaye and Fogel (1980) hypothesized that the mother responds to this change by seeking to accommodate objects in play episodes. Others (Cohn, Krafchuk, & Ricks, 1984; Tronick, Krafchuk, Ricks, Cohn, & Winn, 1985) have suggested that the increase in the infant's attention to objects is achieved at the expense of infant avert (i.e., time not looking at the mother or an object).

Interactions at these ages were described using a modification of the monadic phases system (Tronick, Krafchuk, Ricks, Cohn, & Winn, 1980). This coding system groups clusters of affective expressions, postures, vocalizations, and gestures and gaze into predetermined behavioral phases for infant and mother. By combining the infant and mother phases, a set of dyadic states can be generated that are appropriate for evaluating how the interaction is initiated, whether or not the mother's positive expression precedes the infant's positive expression, and whether maternal positive expression fully frames the infant's positive states. Thus far there has been no set of descriptive data on the structure of face-to-face play using one system of observation that would permit a description of what occurs in the interaction and how that changes from 3 to 9 months. Many of the inconsistencies in the literature may arise because different coding systems have been applied at different ages.

In addition, by describing interaction at these different ages and evaluating the sequential dyadic structure, it is possible to evaluate the two additional hypotheses that are implicit in the dyadic-states model. The hypothesis that infant and mother do not change simultaneously can be evaluated by examining dyadic-state transitions. Condon and Sander (1974) and Tronick, Als, and Brazelton (1980) presented evidence for simultaneity at 3 months, but others have not demonstrated such changes (Fafouti-Milenkovic & Uzgiris, 1979; Stern, 1974). The hypothesis that the interaction conforms to a first-order Markov process can be tested by evaluating how well the observed transition frequencies are fit by a first-order process versus one of zero or of higher order. This hypothesis stands in contrast to a developmentally based hypothesis that the interaction is becoming increasingly influenced by earlier events in the interaction as the infant's memory increases with development.

More generally, by describing and evaluating the dyadic structure of the interaction, the degree to which it is constrained can be evaluated. Either of two changes that are hypothesized to occur with development—the increase in the infant's object interest and the decrease in the dependence of the infant's positive expression on that of the mother—would, we expected, lead to a decrease in the predictability of interaction.

Method

Subjects

The subjects were 54 white mother–infant pairs. The infants were 9 boys and 9 girls at each of 3, 6, and 9 months of age. All were from middle-class families. Appropriate-aged infants were identified from published birth reports and invited to participate in the study. Mothers who agreed were asked to bring their babies to our laboratory at a time when they were likely to be rested and alert.

An additional 27 mother–infant pairs participated in the study, but their data were excluded for one of the following a priori reasons: The infant had experienced substantial medical complications ($n = 8$); the mother introduced a toy into the play interacion ($n = 1$); we experienced technical problems ($n = 3$); or the baby fussed or cried for more than a minute during the taping session (4 babies at 3 months, 6 at 6 months, and 5 at 9 months, *ns*).

Setting and Equipment

The observation room was equipped with an infant seat mounted on a table, a facing, adjustable stool for the mother, two videocameras, and a microphone. One camera was focused on the mother and the other on the infant. The video output was transmitted into an adjoining recording-and-interview room where (a) the output from each camera was combined by a split-screen generator, (b) a digital time-code was added, and (c) the resulting signal was recorded together with the audio output on a Sanyo reel-to-reel videorecorder (see Als et al., 1979, or Tronick, Als, & Brazelton, 1980, for details).

Procedure

Mothers were greeted by an experimenter and escorted to the interview room. They were encouraged to make themselves and their infants comfortable. After informed, written consent was obtained, the experimenter asked the mothers a set of questions about their infants and families. The mother and her baby were then taken to the observation room, where the infant was placed in the infant seat and the experimental procedure was explained.

The procedure consisted of three parts: 2 min of normal interaction during which mothers were instructed to "play with your baby"; a following 2 min of either continued normal interaction or an interaction in which the mother was instructed to remain unresponsive ("still face"); and then a final 2 min of normal interaction. At the end of the procedure, the mothers were invited to view the videotape with the experimenter. They were also given a copy of the Carey Infant Temperament Questionnaire to complete at home and return by mail. Only data from the first period of normal interaction are included in this report.

Coding

Videotapes were coded using the Monadic Phases Manual (Tronick, Krafchuk, Ricks, Cohn, & Winn, 1980, 1985). This manual is a revised version of a system described by Tronick, Als, and Brazelton (1980; Als et al., 1979). Its principal departure from that system is that individual expressive modalities (e.g., voice, facial movement) are not scored separately. The principal monadic phases for mother and for infant are as follows: avert, social attend, object attend, social play, object play, and (for the infant only) positive away. These phases are exhaustive and mutually exclusive.

Avert refers to slightly negative (grimace, pout) to neutral or bright facial expression and gaze directed away from the partner and not toward an object. *Attend* refers to slightly negative to neutral or bright facial expression and gaze directed either at the partner (*social attend*) or an object (*object attend*). The mother in attend can be touching her baby or talking in a quiet nonanimated way (i.e., no burst–pause or rhythmic vocalizations). Or she can be attempting to elicit her infant with staccato-like vocalizations or movements as long as these are not accompanied by positive facial expressions (i.e., no smiles or exaggerated facial expressions).

Social play and object play refer to positive facial expression (smile, animated or play face) and gaze directed either at the partner (*social play*), an object (*object play*), or neither (*positive away*). Burst–pause and sing-sing vocalizations (by the mother) are also coded as play when accompanied by positive facial expression. Object phases refer to mother or infant looking at an object naturally present within the setting (e.g., the shoulder strap of the infant seat) or using a body part as an object (e.g., "butterfly" hands).

Mother and infant monadic phases were scored separately by teams of two coders. One member operated the videoplayer and manually put the machine on pause whenever a change in phase was observed. The videotape would then be reversed and replayed at full speed and at slow speed in order to determine whether and what type of change in phase had occurred and the time of its occurrence. Times, read from the digital time-display, were rounded to the nearest .25 s. We decided on this level of precision so that the data would be suitable for sequential analysis, in which the sampling interval must be briefer than the shortest-duration behavior.

For comparison purposes, videotapes of 12 mothers and 5 infants were recorded by a second team of coders. Agreement, defined as both teams of coders observing the same phase at the same time, ranged from 77% to 96% (52% to 63% agreement corrected for chance, as measured by Cohen's kappa) for the mother's phases. Agreement for the infant's phases ranged from 87% to 100% (67% to 80% by Cohen's kappa). The kappa coefficients were slightly lower than those of some other studies because we used a much stricter criterion (i.e., agreement to 0.25 s, rather than to the nearest 1 or 2 s, as is more common).

Data Reduction

Mother's phases were reduced to two states, mother-neutral (M-neutral) and mother-positive (M-positive), because we were interested in the relation between the mother's alternation between neutral and positive affective expression and changes in the infant's monadic phase. M-neutral consisted of social attend and object attend. M-positive consisted of social play and object play. Mother-negative was not considered because it was extremely rare, which is consistent with the findings of Malatesta and Haviland (1982) that mothers rarely display negative affective expressions during face-to-face interactions. Our data reduction ignores

Table 1
Means and Standard Deviations for Percentages of Time in Dyadic States

Dyadic state	Infant age (months) 3	6	9	F
Dyadic-state MANOVA				2.97***
M-neutral/I-avert				
M	26.82[a]	14.03[b]	12.01[b]	5.99***
SD	19.70	12.09	7.85	
M-neutral/I-object				
M	16.20	24.72	12.35	2.79*
SD	19.31	16.44	10.87	
M-neutral/I-attend				
M	9.24	7.93	6.21	*ns*
SD	7.30	9.23	6.13	
M-neutral/I-positive				
M	2.43	2.70	3.45	*ns*
SD	5.89	7.21	4.51	
M-positive/I-avert				
M	9.59	7.38	14.23	2.33*
SD	9.82	9.24	9.77	
M-positive/I-object				
M	4.33[a,b]	16.25[b]	12.28[b]	5.95***
SD	4.85	15.33	8.44	
M-positive/I-attend				
M	16.01	15.14	14.21	*ns*
SD	13.23	10.51	8.97	
M-positive/I-positive				
M	14.96[a,b]	12.01[a]	24.65[b]	4.84**
SD	13.31	9.63	14.78	

Note. For the multivariate analysis of variance (MANOVA), $df = 16, 88$ and for the univariate ANOVAS, $df = 2, 51$. Row means with similar superscripts form homogeneous subsets using the Tukey honestly significant difference procedure, $p < .05$. M = mother; I = infant.
* $p < .10$. ** $p < .05$. *** $p < .005$.

the mother's visual orientation (i.e., toward infant, toward object, or neither) for two reasons. Mother-avert accounted for less than 1% of mothers' behavior at all infant ages and hence would have no measurable influence on the composition of this state. Further, Mother-object, with few exceptions, represented occurrences of mutual attention to objects, in which the mother was following the infant's line of visual regard. Changes in the mother's visual regard, therefore, did not reflect differences in level of affective engagement, as was the case with the infant. Two infants' phases, positive away and object play, occurred infrequently and were therefore combined with play to form the cluster Infant-positive (I-positive).

To test the hypotheses of the dyadic-states model, mother and infant codes were combined to form eight dyadic states. These were as follows (mother/infant): M-neutral/I-avert, M-neutral/I-object, M-neutral/I-attend, M-neutral/I-positive, M-positive/I-avert, M-positive/I-object, M-positive/I-attend, and M-positive/I-positive. The use of these dyadic states allowed us to test the dyadic-states hypotheses stated earlier.

Data Analysis

Validity check on dyadic states. To be meaningful and valid, the use of dyadic states must be based on a mutual dependence between what the mother and her infant are doing at any point in time. We used chi-square tests of independence to evaluate the null hypothesis that the durations of dyadic states are a function only of the marginal distributions of mother and infant states (i.e., mother and infant states are unrelated).

Percentage of time in dyadic states. The percentage of time spent in each dyadic state was analyzed by multivariate analysis of variance (MANOVA) with age and sex of infant as the between-groups factors. Because percentages typically have a skewed distribution, they were transformed (arcsine transformation) prior to analysis.

Transitions among dyadic states. Dyadic-state transitions were analyzed using log-linear modeling (Bishop, Feinberg, & Holland, 1975; Upton, 1978) rather than the more common lag-sequential analysis (Sackett, 1979). There are two advantages to the log-linear approach. The dyadic-states model implicitly hypothesizes that interactions conform to a first-order Markov process. Log-linear modeling provides a means of testing this hypothesis prior to examining individual first-order transitions. This approach also reduces the probability of Type I error, which is typically higher with lag analysis (Sackett, 1979), and it provides an acceptable means of testing whether transitions differ as a function of age or sex. As Allison and Liker (1982) noted, simple comparison of *z* scores based on independent lag analyses is not sufficient to infer group differences.

In the presentation of results below, the reader should note that in log-linear modeling the use of significance testing is different from that usual in factorial designs. In log-linear modeling, we are using models in order to derive estimated frequencies (or estimated probabilities; the two are conceptually equivalent). As in analysis of variance (ANOVA), these models are linear and may consist of main effects and interactions. In order to test a model, we compare how closely cell frequencies estimated from the model compare with the observed frequencies. If the omission of an interaction term results in a significant value of chi-square, then that is evidence that the variables in that interaction term are associated (i.e., not independent of each other). A suitable model is one that both allows a close fit of the observed frequencies and contains the fewest necessary parameters.

All log-linear models were fit after deleting those transitions from each state to itself. These were omitted because there were no hypotheses concerning the amount of time spent in dyadic states. The data were, in Sackett's (1979) terminology, *event-sequential.*

In order to evaluate whether interactions become less constrained or predictable with development, we assessed the degree of sequential constraint at each level of age with Goodman and Kruskal's proportional reduction in error (PRE) measure, tau (Bishop et al., 1975). As used here, the tau coefficients assess the relative difference in the proportions of incorrect predictions made when predicting transitions on the basis of only the marginal distribution of dyadic states versus those made when predictions are based on conditional probabilities. Tau has an important advantage relative to other measures of association that might have been used (e.g., coefficient lambda): Tau coefficients can also be interpreted as indexes of the proportion of variance accounted for. They are, therefore, a nonparametric analogue of statistics such as the squared correlation coefficient. Developmental differences in tau coefficients were tested with z statistics, a procedure adapted from Castellan (1979).

Results

Validity Check on Dyadic States

For each of the 54 mother–infant pairs, the joint distributions of mothers' and infants' states were highly related and not independent (for all but two dyads, chi-square tests, with $df = 3$, were significant at $p < .001$).

Percentage of Time in Dyadic States

Table 1 presents the percentages of time spent in each of the eight dyadic states by age. Because there were no main effects or interactions related to infant sex, data were collapsed across this variable.

Dyadic-State Transitions

The first- and second-order transition probabilities for male and female infants at each level of age did not significantly differ. The transition frequencies were, therefore, collapsed across sex for all analyses. The following results are presented in terms of the implicit and explicit hypotheses of the dyadic-states model. The presentation proceeds from the testing of the two implicit hypotheses (i.e., mother and infant do not change simultaneously; and interactions conform to a first-order process) to the selection of an appropriate log-linear model to tests of the three explicit hypotheses.

Hypothesis a: Mother and infant do not simultaneously change states. Simultaneous transitions (e.g., M-neutral/I-avert to M-positive/I-positive) were rare events (cf. Condon & Sander, 1974; Tronick, Als, & Brazelton, 1980) with a modal probability of zero. To evaluate whether they occurred less than would be expected by chance, we calculated their expected probabilities under the null hypothesis that dyadic states at Event 1 and Event 2 are independent, which can be written as

$$u_{ijk} = u + u_{0(i)} + u_{1(j)} + u_{2(k)} + u_{01(ij)} + u_{02(ik)}, \quad 1$$

where i = infant's age, j = Event 1, and k = Event 2. Expected probabilities are a function of main effects for age, dyadic state at Event 1, and dyadic state at Event 2 and interactions between dyadic state at Event 1 and age and between dyadic state at Event 2 and age.

The standardized residuals for all simultaneous transitions were highly significant, thus indicating that simultaneous transitions occur significantly less than would be expected by chance. Because this finding was equally strong at each age, simultaneous transitions were considered structurally zero in all further analyses. An additional, methodological reason is that test statistics would be severely biased were we to allow for the many nonzero estimates their retention would introduce.

Hypothesis b: Transitions among dyadic states conform to a first-order Markov process. To test the hypothesis that the process was first-order rather than second-order, we compiled a four-way table: age by Event 1 by Event 2 by Event 3. This table was too large for a single log-linear analysis; hence it was necessary to partition it into three three-way tables (i.e., one for each age) and analyze them separately. For each table, the first-order model was represented by

Model 1

$$u_{(jkl)} = u + u_{1(j)} + u_{2(k)} + u_{3(l)} + u_{12(jk)} + u_{23(kl)}, \quad 2$$

where j = Event 1, k = Event 2, and l = Event 3. The second-order model was represented by

Model 2

$$u_{(jkl)} = u + u_{1(j)} + u_{2(k)} + u_{3(l)} + u_{12(jk)} + u_{23(kl)} + u_{13(jl)}. \quad 3$$

Both models include terms to represent interactions between Event 1 and Event 2 and between Event 2 and Event 3 (which are significant if the process is at least of first-order; see further on). Model 2 includes an additional term to represent the Event 1 × Event 3 interaction. Inclusion of this term makes Model 2 a second-order model.

Model 1, the first-order model, resulted in an acceptable value of chi-square at each age: $\chi^2(47) = 54.54$ at 3 months, 49.75 at 6 months, and 51.68 at 9 months; $p > .20$ at each age. The second-order model was redundant and therefore rejected.

To test the alternative hypothesis that the process is zero-order rather than first-order, we compiled a three-way table, age by Event 1 by Event 2, and fit the transition frequencies with the most complete zero-order model:

Model 3

$$u_{(i,j,k)} = u + u_{0(i)} + u_{1(j)} + u_{2(k)} + u_{01(ij)} + u_{02(ik)}, \quad 4$$

where i = age, j = Event 1, and k = Event 2. This model omits the defining feature of a first-order model, the interaction between Event 1 and Event 2. The test of Model 3 produced a highly unsatisfactory chi-square, $\chi^2(79) = 492.44$, $p < .0001$, and contraindicated the hypothesis that the transitions could be fit by a zero-order model.

Model-testing. To determine the most parsimonious first-order model, we began with a step-down procedure from the saturated model:

Model 4

$$u_{(ijk)} = u + u_{0(i)} + u_{1(j)} + u_{2(k)} + u_{01(ij)} + u_{02(ik)} + u_{12(jk)} + u_{012(ijk)}, \quad 5$$

where i = age, j = Event 1, k = Event 2. Saturated models are overparameterized (i.e., they include as many parameters as

Table 2
Developmental Change in the Probability of M-Neutral and M-Positive Preceding I-Attend

Dyadic-state transition	Infant age (months) 3	6	9
M-neutral/I-avert to M-neutral/I-attend	.56	.32	.38
M-positive/I-avert to M-positive/I-attend	.48	.32	.37
M-neutral/I-object to M-neutral/I-attend	.22	.33	.29
M-positive/I-object to M-positive/I-attend	(.31)	.31	.39

Note. Cell entries are transition (i.e., conditional) probabilities. Probabilities based on low frequencies appear within parentheses. M = mother, I = infant.

there are estimated cell frequencies) and thus provide a perfect fit. The next smallest model is

Model 5

$$u_{(ijk)} = u + u_{0(i)} + u_{1(j)} + u_{2(k)} + u_{01(ij)} + u_{02(ik)} + u_{12(jk)}.$$

The chi-square statistic for this model is significant, $\chi^2(34) = 58.58$, $p < .01$, but examination of the standardized residuals found none larger than ±1.7, which is within expected variation for a unit-normal population. All other first-order models produced excessively large values of chi-square and large numbers of significant standardized residuals. We therefore accepted Model 5. Estimated transition frequencies (or probabilities) according to Model 5 are the product of main effects for age, Event 1, and Event 2 and of two-way interactions between age and Event 1, age and Event 2, and Event 1 and Event 2.

Age effects on dyadic-state transitions. To investigate the influence of the infant's age on the first-order transitions, we underfit the transition frequencies by deleting an interaction term from Model 5, which resulted in

Model 6

$$u(ijk) = u + u0(i) + u1(j) + u2(k) + u01(ij) + u12(jk).$$

The Event 2 × Age interaction was omitted. As expected, this model resulted in a poor fit of the transition frequencies, $\chi^2(48) = 147.6$, $p < .0001$. By inspecting the standardized residuals for this model the influence of age on transition probabilities can be assessed. Inspection of these residuals suggests which transitions contribute to the significant test statistic (see further on).

Hypothesis 1: The initiation phase begins with the mother's positively eliciting her infant's attention. The probability that the infant would change from a state of disengagement (i.e., I-avert or I-object) to a state of neutral engagement (I-attend) was relatively unaffected by whether or not the mother became positive (Table 2). The one exception occurred at 3 months, when there was an increased probability of the infant's changing from I-avert to I-attend during M-neutral. However, when the transition probabilities are considered in the context of developmental changes in the base rates for dyadic states, there is evidence of an increase in the frequency with which I-attend follows the mother's becoming positive.

As can be seen from Table 1, from 3 to 6 months, the proportion of M-neutral/I-avert decreases sharply and the proportion of M-positive/I-object increases fourfold. These changes in the base rates of M-neutral/I-avert and M-positive/I-object generate many more opportunities for M-positive to precede I-attend (e.g., *n* of transitions from M-positive/I-object to M-positive/I-attend increases from 13 at 3 months to 33 at 6 months and 45 at 9 months). Thus, with development, the likelihood increases that the initiation phase will begin with the mother's positively eliciting her infant.

Hypothesis 2: Maternal positive expression precedes the onset of infant's positive expression. This hypothesis was strongly supported at 3 and 6 months (Table 3). At these ages, the mother almost always became positive before the infant. At 9 months, although M-positive remained a more effective elicitor of I-positive, there was a significant increase in the probability of the infant's becoming positive before the mother.

Hypothesis 3: When the infant does become positive, the mother will remain positive until the infant disengages. This hypothesis was strongly supported at each age. Infants were two and one half to five times more likely than mothers to end the joint positive state. The probability of the infant's leading out of joint positive ranged from .69 at 3 months to .81 at 9 months. The corresponding probabilities for the mother ranged from .27 at 3 months to .16 at 9 months.

Change with development in the predictability of dyadic interaction. From 3 to 9 months there was a steady decrease in the strength of association, or sequential constraint, among dyadic states. Tau decreased from .23 to 3 months to .19 at 6 months ($z = 2.67$, $p < .01$) and to .17 at 9 months. (Standard errors = .012, .009, .007, respectively.) Progressively less variability in dyadic state at Event 2 was attributable to initial state at Event 1.

Discussion

The dyadic-states model was initially proposed to characterize the structure of face-to-face interaction at 2 to 4 months of age. Our findings indicate that with some revisions the hypotheses of this model provide a valid characterization of the sequence of face-to-face interaction from 3 through 9 months of age.

Hypothesis a of the dyadic-states model, that mother and infant do not change states simultaneously, was strongly supported. Other investigators have proposed that they do change simultaneously. Examples include Condon and Sander's study

Table 3
Developmental Change in the Probability of I-Positive Preceding M-Positive

Dyadic-state transition	Infant age (months) 3	6	9
M-neutral/I-attend to M-neutral/I-positive	.03	.03	.11
M-positive/I-attend to M-positive/I-positive	.33	.33	.22
M-neutral/I-object to M-neutral/I-positive	.02	.05	.11
M-positive/I-object to M-positive/I-positive	(.17)	.05	.19
M-neutral/I-avert to M-neutral/I-positive	.00	.03	.06
M-positive/I-avert to M-positive/I-positive	.06	.07	.10

Note. Cell entries are transition (i.e., conditional) probabilities. Probabilities based on low frequencies appear within parentheses. M = mother, I = infant.

of mothers' vocalizations and infants' movement; Stern's (1971) study of mothers' and infants' approach and withdrawal behavior; and Tronick's (Tronick, Als, & Brazelton, 1980) study of affective/attentional behavior. Contrary to what one might expect on the basis of these studies, we found no evidence of simultaneity even with a sampling interval several orders larger than that used by Condon and Sander (1974) and Stern (1971). The use of a larger sampling interval would have inflated the likelihood of identifying simultaneous changes. Mother and infant appear to regulate their behavior in response to that of the other, but not in the precisely synchronized manner proposed by Condon and Sander. Although our difference with Condon and Sander may be due to differences in the types of behavior studied, our findings are consistent with other recent data (Dowd & Tronick, 1986) and theory (Rosenfeld, 1981) challenging the hypothesis of precise synchrony of the type studied by Condon and Sander. These findings also question Tronick's hypothesis (Tronick, Als, & Brazelton, 1980) that mothers and infants adjust their behavior within the same 1-s interval, although it is possible that we might have found support for their hypothesis had we used a larger sampling interval.

Hypothesis b of the dyadic-states model, that the sequence of dyadic states conforms to a first-order Markov process, was also strongly supported. Our results indicate that changes in dyadic state do not occur in a random fashion, nor do they occur in patterns requiring a higher order model. A first-order model implies that a change in state is influenced only by the current state; a second-order model implies that a change in state is influenced by both the current and the previous state. Since infants' ability to recall previous events is known to emerge over the first year (Brody, 1981; Fox, Kagan, & Weiskopf, 1979), one might have expected that with development the sequencing of dyadic states would change to a second-order process in which a past event maintains salience. We did not find this to be the case. Instead, we found that transitions remained dependent on the dyad's current state. Others have found evidence consistent with the hypothesis that a first-order model is superior to one of zero-order (e.g., Malatesta, 1985; Stern, 1974), but with few exceptions (Jaffe, Stern, & Peery, 1973), neither have first-order models been tested against ones of higher order nor have alternative first-order models been considered. Jaffe and Feldstein (1970) analyzed adult interactions and found that first-order models are sufficient. Therefore, it appears that formal aspects of the dyadic-states model are quite general.

With development, there is an increase in the number of states that occur more than 5% of the time, and the sequencing of states becomes less tightly coupled. The proportion of variance in dyadic state at Event 2 attributable to dyadic state at Event 1 declines at each age after 3 months. The first-order model becomes increasingly more differentiated and flexible. We speculate that this trend toward increased differentiation and a looser coupling of dyadic states extends beyond the age range studied here. Mother and infant continue to use interactive rules to guide their behavior, but these rules permit an increasing range of choice.

There may be important individual differences in how predictable or constrained the dyadic structure is between a mother and infant (or possibly other types of dyads) that have developmental implications. Although it has not been looked at in infants or younger children, we know from the clinical literature (Gottman, 1979) that the interaction of distressed marital dyads is characterized by greater patterning and structure than is that of nondistressed dyads. Patterson's findings (e.g., Patterson & Moore, 1979) suggest that interactions in families with aggressive children may also be characterized by increased constraint. There may be optimal levels of constraint as a function of developmental level, type of relationship, and so on.

We found mixed support for Hypothesis 1, that periods of engagement originate with the mother's positively eliciting her disengaged infant. The probability of the infant's changing from I-avert or I-object to I-attend was relatively unaffected by the mother's affective expression, except at 3 months when the probability of transitions from M-neutral/I-avert to M-neutral/I-attend was greater. Developmental changes in the base rates for dyadic states, however, brought about an increase in the frequency of M-positive's preceding I-attend. We cannot say, however, whether mothers used vestibular stimulation prior to becoming positive, as found by Kaye and Fogel (1980).

We found strong support at 3 and 6 months but not at 9 months for Hypothesis 2, that maternal positive expression precedes the onset of infants' positive expression. At 3 and 6 months, M-positive/I-positive was almost always reached by the mother's becoming positive first. At 9 months, however, there was a significant increase in the probability of the infant's becoming positive before the mother. This finding was not unexpected. What was surprising, in fact, was that we did not find such evidence at younger ages. Kaye and Fogel (1980) found unelicited infant's positive expressions as early as 13 weeks, although Schaffer (1984) and others proposed that this increase, which has been interpreted as a trend toward the infant's becoming more autonomous or intentional within the interaction, does not occur before the second half-year.

One reason that our data do not support Kaye and Fogel's (1980) finding of infants' initiating at 3 and 6 months may be that at these ages infants do not have much of this capacity. In the normal interaction, the mother may do most of the initiating: Only when she decreases her rate or average duration of positive expression, as may occur in a protracted observational period, does one find an increase in the infant's interest or eliciting behavior (Field, 1977). Kaye and Fogel (1980) used a longer, 5-min observational period, and it is probable that the mother's rate and duration of positive behavior waned over the course of this period. The infant may then have looked at and elicited the mother at those times that her positive expression was less frequent. In this regard, Fogel (1982) found that shorter bouts of maternal positive expression coupled with longer bouts of neutral expression are more likely to elicit the infant's interest. These studies suggest that it is only when the mother's rate of positive expression is decreased that one sees evidence of the younger infant's (i.e., under 9 months) becoming positive before the mother (i.e., the infant's eliciting).

Consistent with the view that the younger infant's eliciting is brought about by a reduction in the mother's rate of positive expression, one finds that many infants elicit with positive, and also negative, affective expressions when they are stressed by their mother's pervasive lack of positive affective expression. When mothers are instructed either to maintain a still face (Tronick et al., 1978) or to simulate depression (Cohn & Tronick, 1983), the infant is likely to respond with brief positive displays and also with negative affect. Clinically depressed mothers may routinely interact with extreme disengagement. The infants of these mothers, during face-to-face interactions, show no positive but much negative affective expression (Cohn, Matias, & Tronick, in press; Field, 1984). Therefore, it seems possible that it is only when the mother's rate of positive expression is decreased that the younger infant shows the capacity to elicit, or initiate, interaction.

Hypothesis 3 was strongly supported: When the infant does become positive, the mother will remain positive until the infant again becomes neutral or disengaged. Stated differently, coaction (Stern et al., 1975) is frequent in states of high activation. The joint positive state was almost always terminated by the infant, not by the mother. This finding extends to the affective domain Stern's (1974) original finding that the infant terminates states of mutual gazing, and it is consistent with Fogel's (1977) view of the mother's attention framing the infant's periods of positive expression.

Given these data, the following revision of the dyadic-states model appears necessary. At 3 months, the initiation phase begins when the infant is looking at the mother. Once the infant is attending to the mother, she may become positive and the infant may then follow. The mother's positive expression provides a frame for the infant's periods of positive expression, and the joint positive state is terminated by the infant. At 6 months, the structure is becoming more differentiated. The portion of the infant's time spent looking away from the mother is more often spent attending to objects, and the mother is more likely to become M-positive when the infant is in I-object. These changes increase the frequency with which M-positive precedes infant transitions to I-attend. At 9 months the structure has changed in two ways. M-positive also precedes infant changes from I-object to I-positive, and the probability of the infant's becoming positive in expression before the mother is significantly greater. Even though the dyadic-states model was originally applied to interactions at 3 months, unrevised it appears most accurate at 6 months.

The dyadic-states model does not include any provision for turn-taking, which has typically been found to characterize mother–infant vocal exchanges (Kozak-Mayer & Tronick, 1985; Schaffer et al., 1977; Snow, 1977). The absence of a turn-taking component suggests a possible limitation to the dyadic-states model and also suggests an alternative to arguments concerning whether turn-taking *or* coaction typifies the interaction. It seems from our perspective that different structures may characterize the different aspects, or content domains, of mother–infant interaction. Coaction seems to characterize highly aroused affective exchange, at least in our culture (cf. Dixon, Tronick, Keefer, & Brazelton, 1986), whereas turn-taking may characterize the prelinguistic aspects. Some structure not yet determined may characterize exchanges with inanimate objects. It may be that the structures of these various domains are hierarchically related. For instance, the turn-taking that is generally characteristic of vocal exchanges may be framed within periods of similar affective expression.

Our results are consistent with the additional hypothesis that each partner changes in response to the other's changes in state, but it must be stressed that this hypothesis, which is assumed by the dyadic-states model, was not explicitly tested. Although it is common to find researchers inferring mutual influence from data such as our own (e.g., Malatesta, 1985; Tronick, Als, & Brazelton, 1980), analysis of conditional probabilities, using either Sackett's lag-sequential technique or log-linear modeling such as used here, is typically inadequate to control for the confounding effects of serial correlation (Allison & Liker, 1982; Gottman & Ringland, 1981; Maccoby & Martin, 1983; Thomas & Malone, 1979). Because testing the hypothesis that mother and infant are each responsive to the other's changes in state requires an altogether separate data-analytic approach, the testing of this hypothesis is the subject of a separate report.

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