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Infant Vocal Development in a Dynamic Mother–Infant Communication System

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This study is an investigation of the development of infant vocalization in a changing and dynamic mother–infant communication system. Thirteen infants and their mothers were observed weekly from 4 to 24 weeks of age in a face-to-face interaction situation. Three patterns of mother–infant communication dynamics were classified: symmetrical (mutual engagement by mother and infant), asymmetrical (mother active while infant inactive), and unilateral (mother active while infant disengaged). Two types of infant nondistress vocalizations were categorized: syllabic (speechlike) and vocalic (nonspeechlike) vocalizations. It was hypothesized that the quantity and quality of infant nondistress vocalizations are associated with the patterns of mother–infant communication and that these associations change developmentally. The results demonstrated that the rates of syllabic and vocalic vocalizations were positively associated with symmetrical communication but negatively associated with unilateral communication. Syllabic vocalizations were more likely to occur in symmetrical mother–infant communication. Developmentally, whereas a curvilinear growth pattern (inverted U shape) of the rate of syllabic vocalizations was found in symmetrical communication, a linear increase was found in unilateral communication. A relational approach to infant vocal development in a changing and dynamic communicative context is discussed.

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Rapid changes occur in various domains of development during infancy. Infant vocal production and mother–infant communication undergo major transitions during the first year, particularly during the first 6 months of an infant's life. Prelinguistic infants' nondistress (i.e., noncry) vocalizations are thought of as the precursors to later language development and interpersonal communicative skills. Whereas the early vocal production system is the origin of the structural aspect (i.e., the form) of language, speech pragmatics (i.e., the function) emerge from dyadic communication processes. It has been suggested that the parent–infant communication system is an essential component in infant vocal development because infant vocalizations have systematic sequential associations with maternal behavior and vocalization (Papousek, 1992). The main goal of this study is to better understand the relations between infant vocal production and the moment-to-moment dynamics of and developmental changes in mother–infant communication. To facilitate the clarity of discussion, the following literature reviews on infant vocalization are summarized into two distinct realms: language development and interpersonal communication.

VOCALIZATION AS A PRECURSOR TO LANGUAGE

In the literature on language development, later speech development is viewed as a continuation of early vocal production. During the first few months after birth, both quantitative and qualitative changes are detected in infant vocalizations. Various stagelike models of prespeech vocal development have been constructed (Koopmans-van Beinum & van der Stelt, 1986; Oller, 1980; Roug, Landberg, & Lundberg, 1989; Stark, 1980, 1981). Nondistress speechlike vocalizations are first observed during the first 2 months of life. When the frequency of crying falls off sharply after the 2nd month, speechlike vocalizations become more frequent in infants' vocal repertoires (Oller, 1980; Stark, 1978; Stark, Rose, & McLagen, 1975).

In this tradition, the view on infant vocal production has undergone several changes, from being viewed as a passive response to gravity, to a reflexive response to social simulation, to a product of exploratory discovery of vocal capacity, to a result of active learning (see Oller, 1981). In these views, infant vocalization develops from a Piagetian perspective, because infants creatively explore the sound-making abilities of their anatomical system with little need for adult motivation or shaping. Despite the fact that Stark's (Stark, 1993; Stark, Bernstein, & Demorest, 1993) recent work suggests that vocal production, social interaction, and communication may be interrelated processes, social influence on vocal development has been largely overlooked, particularly before the onset of babbling (Locke & Snow, 1997). After reviewing literature on early vocal production, Vihman (1996) concluded that "the role of social context in facilitating advances in vocal production is intriguing but unresolved" (p. 118). Therefore, more

research effort is needed to investigate the effects of social-communicative context on the development of vocal production in early infancy.

VOCALIZATION AS A COMPONENT OF EARLY PARENT–INFANT COMMUNICATION

In studies of interpersonal communication, such as gaze and facial expressions, vocalizations are considered to be one of the primary means by which infants communicate with others. This leads to research on mother–infant vocal exchange, focusing on the timing of the occurrence of infant vocalization in relation to that of the mother (Ginsburg & Kilbourne, 1988; Jasnow & Feldstein, 1986; Stern, Jaffe, Beebe, & Bennett, 1975). Within a dyadic communication system, adult responsiveness (looking, smiling, touching, and verbalizing) is thought to be the main factor in eliciting infants' vocal responses. In a series of experimental studies, Bloom and colleagues (Bloom, 1974, 1975, 1977, 1988; Bloom, Russell, & Wassenberg, 1987) reported that the eye contact, contingency, and responsiveness of the adult partner have effects on young infants' vocal pattern and quality. The concept of responsiveness in these studies rests on a stimulus–response model of communication.

The model of adult responsiveness as the main contributor to infant vocal development has a potential drawback: It views the development of infant vocalization as the result of a social learning and conditioning process. This contrasts with the view coming from the language development approach that early nondistress vocalizations are used creatively by infants to explore their vocal range and abilities (see Oller, 1981). If adults play a role in this process, we need a model that accounts for the inherent creativity of infant vocal exploration in the context of the mother–infant communication system. Such a model would need to go beyond mere elicitation or responsiveness and recognize the adult as a potential partner in the cocreation of vocalizations.

An alternative model is that communication is a dynamic process characterized by continuously coordinated and mutually regulated actions by both partners (Fogel, 1993; Gianino & Tronick, 1988; Trevarthen, 1979). In this view, when the communication is characterized by "dancelike" mutual involvement, a symmetrical partnership is shared between mothers and their infants. This pattern of communication has the quality of mutual creativity and a cocreation of novelty (Fogel, 1993; Fogel & Lyra, 1997). Asymmetrical patterns of communication occur when mothers actively engage their quietly observing infants, whereas unilateral patterns occur when mothers try to engage inattentive infants (Fogel & Lyra, 1997; Tronick & Cohn, 1989). Symmetrical, asymmetrical, and unilateral patterns of communication are all characterized by maternal responsiveness. Only one pattern, symmetrical, is characterized by mutual dyadic creativity. If infants vocalize because they are creatively exploring their vocal range and if parents play a role in

this process, we are more likely to observe nondistress vocalizations during periods of symmetrical communication.

DEVELOPMENTAL CHANGES IN MOTHER–INFANT COMMUNICATION

The emergence of social smiling and the decline in crying during the 2nd month of an infant's life mark the onset of mutual engagement in dyadic communication. The level of face-to-face communication reaches its peak around the 4th month. Beginning around 4 to 6 months of age, another developmental transition emerges, which is characterized by a shift from a dyadic pattern of mother–infant communication to a triadic pattern of mother–infant–object communication (Adamson, 1995). At this age, infants start to use facial actions and vocalizations to express their object-related experience (Adamson & Bakeman, 1985). Based on our suggestion that infant vocalization is a cocreation between infant and parent during face-to-face communication, developmental changes of nondistress vocalizations are expected to correspond with the transitions in mother–infant symmetrical communication, especially during face-to-face play.

QUANTITY VERSUS QUALITY OF INFANT NONDISTRESS VOCALIZATIONS

The occurrence of infant nondistress vocalization increases drastically when the adult partner (a stranger or mother) provides social response (talk, touch, and smile) to an infant's vocalization, regardless of whether the response is contingent or random (Bloom, 1988; Masataka, 1993). Nevertheless, when the quality of infant nondistress vocalization is considered, the occurrence rates of infant nondistress vocalizations that vary in speechlike quality are different. Speechlike quality is one of the main characteristics distinguishing types of early nondistress vocalizations. When the vowel-like elements and the transition between vowel- and consonantlike elements in infant nondistress vocalization resemble mature speech, the vocalization is perceived as more speechlike (Oller, 1986; Oller, Eilers, Steffens, Lynch, & Urbano, 1994).

Anecdotal reports suggest that infants are more likely to exhibit a variety of vocalizations with unique speech qualities, such as squeals, growls, yells, and screams, when they are left alone (Oller, 1981). Nonetheless, when mothers are available, infants produce more speechlike vocalizations (Stark, 1981). Contingent verbal response by adults increases the ratio of speechlike (syllabic) to nonspeechlike (vocalic) vocalizations emitted by 3- and 4-month-old infants (Bloom, 1988; Masataka, 1993). Legerstee (1991) also found that infants produce

significantly more nonspeechlike vocalizations when interacting with an unresponsive adult partner than when interacting with a responsive one. It seems that the responsiveness of the partner contributes to the changes in the speech quality of infant nondistress vocalization. Following our theoretical model, however, we would suggest that speechlikeness is not related to mere responsiveness but rather to periods of symmetrical cocreativity between mother and infant. It is expected that infants would be more likely to utter nondistress vocalizations with speechlike quality during symmetrical communication than in asymmetrical and unilateral patterns of communication.

This study is designed to explore the associations between the quantity and the quality of infant nondistress vocalizations and moment-to-moment changes in the pattern of mother–infant communication dynamics across the first 6 months of an infant's life, using a within-dyad approach to encompass the first two developmental transitions. The first aim of this study is to examine the concurrent associations between the characteristics of infant nondistress vocalization and the pattern of mother–infant communication dynamics. Based on previous research evidence, we predict that both the quantity (i.e., rate per minute) and the quality (i.e., speechlikeness) of infant vocalizations are more likely to be associated with symmetrical communication than with other patterns of communication. With regard to the quantity, we expect that the rate of infant nondistress vocalizations is positively associated with the amount of symmetrical mother–infant communication but negatively associated with the amount of asymmetrical and unilateral communication. With regard to the quality, we hypothesize that speechlike vocalizations will be more likely to be made than nonspeechlike vocalizations during symmetrical communication.

The second aim of this study is to investigate the developmental relations between infant nondistress vocalizations and the patterns of mother–infant communication. We expect that the rates of infant speechlike vocalizations increase with age during symmetrical communication but decrease with age during asymmetrical and unilateral communication. Significant individual differences in the growth trajectories are also expected. The change rates of speechlike vocalizations are expected to be more drastic for some infants than others.

METHOD

Participants

This study is based on 13 singleton infants (born between August 1988 and August 1989) who were born full term, had no major birth complications, came from intact families, and passed a hearing test at 6 months. Seventeen families were originally recruited to participate in a 2-year longitudinal study on the development of

mother–infant communication. Fifteen mother–infant dyads remained in the study during the first 6 months of their infants' lives. Two of these mothers had twins. Of the 13 mother–infant (singletons only) dyads included in this report, 12 were White and one was African American. Six of the infants were firstborns and 8 were boys. Nine of the mothers had a bachelor's degree, 2 had some college education, and 2 had their high school diploma. Seven of the mothers were employed full time, 2 were employed part time, and 4 were homemakers. All research participants were recruited from a university community in the Midwest by letters following up birth announcements in the local newspaper.

Research Design and Procedure

Infants and their mothers were videotaped weekly in a laboratory playroom beginning when the infants were between 4 and 9 weeks of age (M = 5.3 weeks) during the first year and then biweekly during the 2nd year in four conditions (including lap, floor, high chair, and table conditions). Mothers were instructed to play with their infants as they normally would at home. During the first 6 months of visits, the mothers and their infants played in two different conditions: on the mother's lap and on the floor. Only the face-to-face interaction data from the lap conditions during the first 6 months were analyzed for this study.

Each mother in the study was seated on a straightback chair with the baby in her lap, and no toys were provided in this condition. Most of the sessions lasted approximately 5 min, with the exception of when the infant became too fussy to continue (9 out of a total of 213 sessions). The average session duration was 287 sec (range = 80–300). The average number of sessions collected from each dyad was 16 (range = 9–20). Three remote-controlled cameras were used to film the play sessions. One camera was focused on the mother's upper body and the side of the infant and the other two cameras were focused on the infant's face and body. The outputs from these two cameras, which had the best views of the mother and the infant, were passed through a special-effects generator to produce a split-screen image with an electronic digital timer superimposed on the screen. A microphone (Shute 575SB), hung from the ceiling about 12 in. from the mother's head, transmitted the audio signals to an amplifier (Shure M267) for recording.

Several research papers have been published using this longitudinal data set. Our previous reports focused on infant facial expressions during the first 6 months (Messinger, Fogel, & Dickson, 1999) as well as infant and maternal laughter throughout the first 2 or 3 years of the infants' lives (Nwokah, Hsu, Davies, & Fogel, 1999; Nwokah, Hsu, Dobrowolska, & Fogel, 1994). This report and one previous article on infants' nondistress vocalizations (Hsu, Fogel, & Cooper, 2000) have different focuses. The previous report focused on the changing relations between the melodic complexity and the speech quality of infant nondistress

vocalization during the first 6 months. The interplay between infant vocal production and the dynamics of mother–infant communication was not the concern. This article focuses on the link between the quantity and the quality of infant nondistress vocalization and the changing mother–infant communication system, with an emphasis on developmental changes.

Behavioral Coding

Pattern of mother–infant communication. A relational coding system developed by Fogel and colleagues (Fogel & Lyra, 1997; Fogel, Walker, & Dodd, 1996) was employed to assess the dynamics of mother–infant communication. Coding was done second by second, continuously, from the video. When a change in the pattern was observed, the coder stopped the tape and noted the time. In this coding system, five different patterns of communication dynamics can be identified in the dyadic interaction between a mother and her infant, namely symmetrical, asymmetrical, unilateral, disruptive, and unengaged (see Table 1 for definitions and examples). In our data, three types of communication dynamics accounted for most of the occurrences: symmetrical, asymmetrical, and unilateral. In principle, the active agent (who initiates communication and engages the partner) in an asymmetrical or unilateral communication could be the infant or the mother. In our data, however, the active agent in all the observed instances of asymmetrical and unilateral communication was the mother. Disruptive behaviors only occurred one time (2 sec long) with one dyad during the observations. The total duration coded for unengaged communication between mothers and infants was 158 sec (10 occurrences; less than 0.3% of total observation) across all participants and all sessions. Because of their rarity, occurrences of disruptive and unengaged communication were excluded from the data analysis. The reliabilities of the coding were calculated based on 16% of randomly selected sessions. Using a 2-sec time window within which coders' identification of the change of the pattern of mother–infant communication was considered as agreement, the average kappa was .65 and the percentage of agreement was 85%.[1] The reliability was within acceptable range for behavioral research; however, the relatively low kappa reflects the difficulty in precisely identifying the on- and offset times of the communication patterns due to the fast pace and high complexity of mother–infant face-to-face communication in early infancy.

Infant vocalization. The primary coder was a professionally trained vocalist (who had voice training designed for opera singers and concert artists) and an experienced mother majoring in psychology. The on- and offset times of a nondistress or nonvegetative vocalization were coded from the video. The coder watched and lis-

[1]In a separate study with a group of 12-month-olds, the reliability kappa was .79 (Fogel et al., 1996) for the coding of parent–infant communication pattern.

TABLE 1
Definitions and Examples of Different Mother–Infant Communication Patterns

Communication Pattern	*Definitions and Examples*
Symmetrical	This is characterized by the mutual coordination and elaboration of novelty by both the partners in an ongoing interaction. Novel actions are created by the continuous coordinated exchange between the two. An example of this pattern of communication is a mother and infant actively engaged in a peek-a-boo game. The mother covers the infant's face and changes the timing of the uncovering during each round of the game. The infant smiles, laughs, and shows excited bodily movements. The actions of mother and infant are continuously coordinated with each other during the game.
Asymmetrical	The two participants are interested in the same activity; however, while one partner is actively elaborating an activity, the other is merely attending without active participation. An example is a mother wiggling her fingers and then beginning to walk her fingers on the infant's tummy. The infant observes the mother's actions but shows no other behavioral indications of participation in the game.
Unilateral	Unilateral communication occurs when one of the two partners is actively trying to engage the second in an activity while the second is engaging in other activities. There is no mutual coordination between the two participants. An example is a baby intensely sucking on her own thumb, disregarding the mother's attempt to get a smile from her by tickling and kissing her feet.
Disruptive	The first partner attempts to become involved in the activity of the second, who is not responsive. This typically occurs when the first partner acts in a way that is inconsistent with the flow of the second parent's activity and the second shows active avoidance or resistance. An example is an infant sucking on his thumb vigorously, and his mother suddenly grabbing his hand and pulling it away from his mouth. The infant then fusses to protest the mother's abrupt movement.
Unengaged	There is an absence of any communicative engagement between mother and infant; the two are not engaged in any mutual activity. For example, while mother is looking at the camera in the room, infant is looking at and chewing on his shirt.

tened to the sound until a nondistress vocalization was made by the infant. The coder then stopped the tape and recorded the onset time. The procedure was repeated to obtain the offset time of a vocalization and to recheck the recorded times. A vocalization was defined as a discrete sound occurring within one respiration cycle. Two separate vocalizations were recorded if the sound was segmented by a perceivable silence. Following previous studies (e.g., Oller et al., 1994; Stark, 1978), vegetative sounds (e.g., wheezes, sneezes, coughs, hiccups, and clicking sounds), effort sounds (e.g., grunts), negative vocalizations (e.g., whimpers, fusses, and cries), and laughs were excluded.

After the on- and offset times of the nondistress vocalization were identified, the sound quality was evaluated and categorized as either syllabic or vocalic, based on Bloom's (Bloom, 1988; Bloom et al., 1987) definitions. *Syllabic vocalizations* are sounds that tend to be uttered in the anterior area of the mouth, contain greater oral resonance, and are perceived as more relaxed and speechlike. *Vocalic vocalizations* are sounds that are more likely to be produced in the posterior area of the mouth, contain greater nasal resonance, lack oral projection, and are perceived as more forced and less speechlike. Sixteen percent of the sessions (34 sessions) were coded by an independent coder for the reliability testing. Using a 2-sec time window within which coders' identification of the onset of infant vocalization was considered as agreement, the percentage of agreement between the two independent coders was 85% and kappa was .80.

Data Aggregation and Analysis

Because of variations in session length, the occurrence of infant nondistress vocalizations and the amount of mother–infant communication were calculated, respectively, as rate per min and percentage of session. For the same reason, the rates per min of total, syllabic, and vocalic vocalizations occurring in each of the three patterns of mother–infant communication were computed separately. For data analyses concerning the associations between the rate per min of infant vocalization and different patterns of communication, aggregated data collapsing across weekly sessions were derived for each infant. For data analyses concerning the likelihood of different patterns of mother–infant communication for types of infant vocalization, the aggregated frequency data were also derived separately for each infant.

To test correlational associations and developmental effects, the rate of infant vocalization was calculated for each weekly session separately for each infant. Multilevel analysis (ML3 software; Prosser, Rasbash, & Goldstein, 1991) was chosen to reveal developmental relations between the rate of infant nondistress vocalizations and the pattern of mother–infant communication. This choice was made on the basis of its ability to (a) handle missing data, (b) deal with the unique hierarchical structure of the data (e.g., multiple observations are embedded in each individual mother–infant dyad), (c) use individual infants as the unit of analysis, and (d) detect the significance of variance due to individual differences.

A growth-curve modeling approach assessing developmental changes was applied to the data (Bryk & Raudenbush, 1987; Hoeksma & Koomen, 1992; van den Boom & Hoeksma, 1994). Two steps are involved in this analysis. First, the average growth curve of all individual dyads as a group is modeled by an *n*th degree polynomial function of infant age (i.e., age, age^2, age^3, etc.) to describe the rate of vocalization occurring in different patterns of mother–infant communication across time. A higher order age parameter is added to the model when it exceeds

twice its standard error. This process is repeated until no more significant higher order age parameters can be added to the model. The most parsimonious model that best describes the data is selected as the final model. The shape of the developmental trajectory is determined by the parameters derived from the modeling. Individual infants' developmental curves are expressed as deviations from the average developmental curve. Second, statistical significance of individual differences is tested by a likelihood ratio statistic (a chi-square test) comparing two nested models with and without the variances contributed by individuals. Using rate per min of infant vocalization as the response variable, three separate sets of analyses were performed: the rate per min of syllabic vocalization in symmetrical mother–infant communication, in asymmetrical mother–infant communication, and in unilateral mother–infant communication.

RESULTS

Descriptive Statistics

A total of 1,692 nondistress infant vocalizations were sampled across all 13 infants over the course of the first 6 months. Of these vocalizations, 61% were classified as syllabic vocalizations and 39% as vocalic. On average, the infants uttered 0.98 (*SD* = 0.61, range = 0.05–2.44) speechlike syllabic sounds and 0.63 (*SD* = 0.36, range = 0.14–1.43) nonspeechlike vocalic sounds per min during each play session with their mothers. Overall, across all dyads over time, the mothers and their infants spent their time in symmetrical patterns of communication about 19% (*SD* = 14.85, range = 3.5%–45.9%) of the time, asymmetrical 12% (*SD* = 5.5, range = 2.0%–22.2%) of the time, and unilateral 69% (*SD* = 13.2, range = 45.6%–90.9%) of the time.

Associations Between Infant Vocalization and Mother–Infant Communication: Concurrent Analysis

The first hypothesis of this study was that there are significant concurrent associations between the quantity (i.e., rate per min) and quality (i.e., speechlikeness) of infant nondistress vocalizations and the patterns of mother–infant communication.

Quantity of infant vocalization. Using weekly summary measures, correlational analyses were performed for each infant separately to test the prediction that the rate per min of infant nondistress vocalizations is positively associated with the amount of symmetrical mother–infant communication but negatively associated with the amount of asymmetrical and unilateral communication. A sum-

mary of the results reporting the averages of 13 infants is shown in Table 2. Significant positive correlations were found between the rate of infant vocalization and the amount of symmetrical communication, whereas significant negative relations were found only between the rate of infant vocalization and the amount of unilateral communication. The direction of correlations was the same for speechlike syllabic, nonspeechlike vocalic, and total nondistress vocalizations. In other words, the longer the mothers and their infants were mutually involved in the communication, the more the infants uttered syllabic and vocalic vocalizations. On the other hand, the longer the infants disengaged from the communication, the less the infants exhibited syllabic and vocalic vocalizations.

Quality of infant vocalization. We also predicted that the quality of infant nondistress vocalizations changes with the dynamics of mother–infant communication. To test this prediction, the data collapsing over weekly sessions by each infant were used in the analysis. The rate of speechlike syllabic and nonspeechlike vocalic vocalizations occurring in the three patterns of mother–infant communica-

TABLE 2
Mean Correlations Between Rate (per Min) of Infant Vocalization and Amount of Mother–Infant Communication

	r				
Mother–Infant Communication Pattern	*M*	*SD*	*Range*	*t(12)*	*Number of Infants Showing Effects*
Total nondistress infant vocalization					
Symmetrical	.49	.23	–.06–.88	6.12****	12
Asymmetrical	.01	.26	–.31–.63	0.28	7
Unilateral	–.37	.28	–.81–.10	–4.29***	11
Syllabic vocalization					
Symmetrical	.56	.19	.34–.87	7.44***	13
Asymmetrical	.05	.25	–.39–.37	0.69	6
Unilateral	–.45	.24	–.88– –.03	–5.36**	13
Vocalic vocalization					
Symmetrical	.23	.31	–.40–.58	2.77**	9
Asymmetrical	.03	.30	–.31–.78	0.53	7
Unilateral	–.19	.35	–.78–.46	–1.98*	9

Note. $N = 13$. Correlations were computed across sessions for each dyad individually. The correlation coefficients were then transformed into *z* scores, which were subjected to one-sample *t* tests to determine the significance of association. Number of infants showing effects indicated the number of infants that showed the *z* scores in the expected directions.

*$p < .10$. **$p < .05$. ***$p < .01$. ****$p < .001$.

tion was compared by using a 2 (types of vocalization: syllabic vs. vocalic) × 3 (patterns of communication: symmetrical, asymmetrical, and unilateral) repeated-measures analysis of variance (ANOVA). The results for the repeated-measures ANOVA indicated a significant main effect for types of infant vocalization, $F(1, 12) = 8.38$, $p < .02$, a significant main effect for patterns of communication, $F(2, 24) = 18.46$, $p < .0001$, and a significant Types of Infant Vocalization × Patterns of Communication interaction, $F(2, 24) = 6.42$, $p < .01$ (see Table 3). Because the interaction was significant, follow-up tests using Tukey's post hoc comparisons (at a significance level of .05) were conducted. The results revealed that (a) infants produced significantly more speechlike syllabic and nonspeechlike vocalic vocalizations during symmetrical communication than either asymmetrical or unilateral communication, and (b) infants produced significantly more speechlike syllabic vocalizations than nonspeechlike vocalic vocalization only during symmetrical communication.

To further verify the finding that speechlike syllabic vocalizations were more likely to occur in symmetrical communication, the pattern of mother–infant communication in which the vocalization occurred was tabulated. A 2 (types of vocalization) × 3 (patterns of communication) contingency table was formulated individually for each infant using frequency data collapsing over weekly sessions. Conditional probabilities of vocalizations the infant would produce given different patterns of communication were then computed. A summary of the results is presented in Table 4. Following Bakeman's (Bakeman & Robinson, 1997) suggestion, Yule's Q was computed to measure the extent to which a conditional probability is significantly different from its expected simple probability.

Yule's Q is simply a transformation of the odds ratio and its values range from –1 (perfect negative association) to +1 (perfect positive association; Bakeman, McArthur, & Quera, 1996). To calculate Yule's Q, the 2 × 3 table was decomposed into two 2 (types of vocalization) × 2 (symmetrical and asymmetrical communication or symmetrical and unilateral communication) tables. A Yule's Q was com-

TABLE 3
Rate per Min of Infant Nondistress Vocalizations by Three Patterns of Mother–Infant Communication

	Patterns of Mother–Infant Communication					
	Symmetrical		*Asymmetrical*		*Unilateral*	
Types of Infant Vocalization	*M*	*SD*	*M*	*SD*	*M*	*SD*
Syllabic	1.96	1.00[a]	0.44	0.41[c]	0.82	0.52[bc]
Vocalic	1.28	0.83[b]	0.43	0.47[c]	0.63	0.35[c]

Note. $N = 13$. Different superscripts denote significant difference between the means. Pairwise post hoc comparisons were done by using the Tukey method, with $\alpha = .05$.

TABLE 4
Conditional Probabilities of Infant Nondistress Vocalizations Given Different Patterns of Mother–Infant Communication

	Given Patterns of Mother–Infant Communication								
	Symmetrical			*Asymmetrical*			*Unilateral*		
Types of Infant Nondistress Vocalization	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Syllabic	0.54	0.29	.11–.96	0.10	0.14	.01–.37	0.35	0.21	.04–.69
Vocalic	0.31	0.29	.04–.81	0.11	0.13	.02–.51	0.58	0.27	.14–.94

Note. $N = 13$.

puted for each table, in which the symmetrical communication served as the baseline for comparison. The average Yule's Q across 13 infants for the contingency table with symmetrical and asymmetrical communication was 0.52 (SD = 0.35), whereas the average for the contingency table with symmetrical and unilateral communication was 0.54 (SD = 0.34). One-sample t tests demonstrated that they were significantly smaller than 0 (ps < .001), suggesting that the odds of the infants exhibiting syllabic vocalizations increased significantly when they engaged in symmetrical communication rather than in asymmetrical and unilateral communication. Furthermore, infants' nonspeechlike vocalic vocalizations were more likely to occur in unilateral communication during which they were disengaged from their mothers. Twelve out of 13 infants revealed the same pattern of associations for both sets of analyses. In summary, our hypothesis that there are concurrent associations between the quantitative and qualitative characteristics of infant vocalization and the patterns of mother–infant communication dynamics was largely supported. When the infants engaged in symmetrical communication with their mothers, they not only were more likely to produce nondistress vocalizations but also were more likely to utter them with speechlike quality.

Associations Between Infant Vocalization and Mother–Infant Communication: Developmental Analyses

The second hypothesis of this study was that there are age effects on the relations between the rate of infant speechlike syllabic vocalizations and the patterns of mother–infant communication. We predicted that the developmental growth trajectories of syllabic vocalization occurring in the three different patterns of mother–infant communication would be different. Growth-curve modeling of the rate of syllabic vocalization occurring during symmetrical, asymmetrical, and uni-

lateral communication across time was performed separately. With respect to the rate of syllabic vocalizations occurring during symmetrical communication, a significant quadratic trend was found. As a group, the rate of infant speechlike syllabic vocalizations occurring in symmetrical communication increased first and then started to decline around 16 weeks of age (see Table 5 and Figure 1a). Individual differences in the predicted growth trajectories were also found to be significant, $\chi^2(2, N = 13) = 7.17$, $p < .05$, explaining 6.9% of the variance. A clear pattern of individual differences emerged around 8 to 9 weeks; for this analysis, see Figure 1b. After this age period, some infants reached the peak of the quadratic curve earlier and declined faster, whereas others reached the peak later and declined at a slower pace. With respect to the rate of syllabic vocalizations occurring in unilateral mother–infant communication, a significant linear increase was found (see Table 5 and Figure 1a). No significant individual difference was found, however, $\chi^2(2, N = 13) = 2.19$, $p > .10$. With respect to the rate of syllabic vocalization occurring during asymmetrical communication, no specific age effect was found.[2]

In summary, as a group, the rate of syllabic vocalization occurring in symmetrical communication showed a nonlinear growth pattern, and the rate of syllabic vocalizations occurring in the unilateral communication gradually increased across the first 6 months. Our hypothesis that the development of the infant speechlike syllabic vocalization differs as a function of the pattern of mother–infant communication was supported; however, the shapes and directions of the predicted pattern were not confirmed by the data. Individual differences in the development of syllabic vocalizations were found only in the symmetrical pattern of mother–infant communication.

DISCUSSION

A number of nonverbal behaviors are in infants' social communication repertoires. In comparison to facial expressions, vocalizations have received relatively little attention in infancy developmental research. The difficulty of studying early vocalization lies in its short duration as well as in its low and variable frequency of occurrence (Bloom, 1990). To better understand the development of early vocalizations, a unique study design is called for. In infancy studies, a population study design is typically employed, in which data are collected on large samples and target behav-

[2]The group means of the modeled value for the occurrence rate of syllabic vocalization during symmetrical and unilateral patterns of communication at all time points are shown in Figure 1a. The modeled values during symmetrical communication for all 13 infants at all time points are shown in Figure 1b, which displays the range of the predicted values for the occurrence rate of syllabic vocalization. The means, standard deviations, and ranges based on the raw data for the occurrence rate of syllabic vocalization during the three communication patterns are available from the first author.

TABLE 5
Parameters of Predicted Developmental Trajectories: Rate of Infant Vocalizations Occurring in Symmetrical and Unilateral Mother–Infant Communication

	Symmetrical		*Unilateral*	
Parameters	*M*	*SD*	*M*	*SD*
Intercept	0.684	0.626	0.283	0.235
Age	0.298	0.141	0.043	0.018**
Age^2	–0.013	0.006*	—	—
Total variance explained	12.3%		13.7%	

Note. $N = 13$. Values in parentheses are standard errors.
*$p < .05$. **$p < .01$.

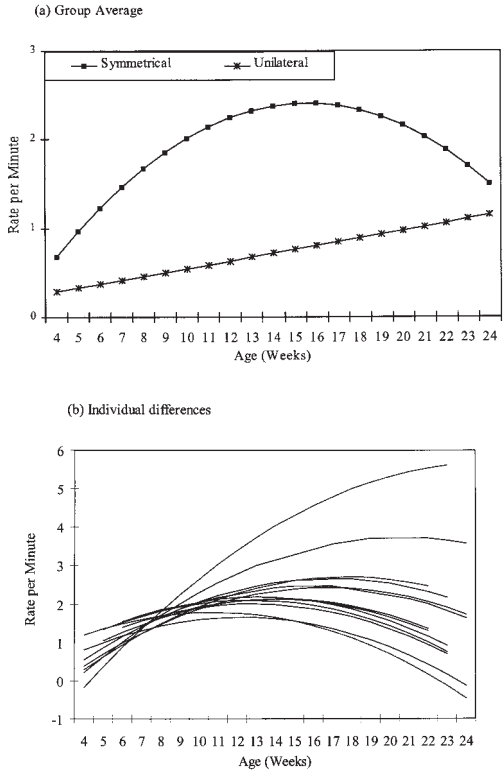

FIGURE 1 (a) Modeled development trajectories of the rate of infant syllabic vocalization during symmetrical and unilateral communication, based on group average. (b) Modeled individual developmental trajectories of the rate of infant syllabic vocalization during symmetrical communication.

iors are observed infrequently. With this type of study design, we learn very little about whether and when individual differences arise over time. A historical approach is thought to be a more useful approach, in which frequent observations with a smaller number of infants in a meaningful social context are necessary to keep track of an individual's behavior as it unfolds over time. Therefore, this study investigated infant vocal development in a dynamic and changing mother–infant communication system across the first 6 months by using an intensive repeated-measures design (i.e., weekly observation).

In this study, the quantitative and qualitative characteristics of infant nondistress vocalizations were found to be associated with the dynamics of face-to-face mother–infant communication. The rates of both speechlike (syllabic) and nonspeechlike (vocalic) vocalizations proliferated during symmetrical mother–infant communication but inhibited during unilateral communication. Furthermore, speechlike syllabic vocalizations were more likely to occur in symmetrical communication. Previous explanations for the observed relations between syllabic vocalizations and communication were based on concepts of contingent responsiveness (cf. Bloom, 1990). In this study, because the mothers were always readily available[3] for interaction, the level of their contingency, sensitivity, and responsiveness to their infants' vocalizations might not have differed across the three patterns of communication. Responsiveness, therefore, may not be sufficient for the enhanced production of speechlike vocalizations. It seems that maternal responsiveness needs to be coupled with opportunities for mutual creativity, as defined in our category of symmetrical communication.[4]

A number of theoretical interpretations are available to explain the associations of the quantity and quality of infant nondistress vocalizations with the dynamics of

[3]Based on our observation, the mothers in this study were almost always engaged with their infant in a variety of activities. When the mothers were disengaged and the infants were not attentive to their mother, an "unengaged" code was applied; this occurred very infrequently, as reported in the Method section. Of course, mothers are sensitive to and affected by social context. According to our observation, when the infants were passively observing or disengaged from their mother, the observable maternal responsive behavior was not the same as when the infants were actively engaged; for example, mothers smiled less. This difference, however, was not because the mothers were not available for interaction, but simply because their behaviors were not reciprocated by and/or coupled with their infant's behaviors.

[4]One may argue that it is not surprising to find the associations between the quantity of infant nondistress vocalizations and the patterns of mother–infant communication, given the definitions for those communication patterns; however, one has to keep in mind that the communication pattern is coded based on the coder's global perception of the creativity in the dyadic interaction given the ongoing verbal and nonverbal interactive actions by mother and infant, such as facial expression, gazing, physical contact, and postural position. Maternal and infant vocalizations are just one of the constituents of the dyadic communication system. Furthermore, the developmental data do suggest that the occurrence rate of infant speechlike vocalizations during symmetrical and unilateral reach about the same level by the end of the 6th month (see Figure 1a).

mother–infant communication. For example, D'Odorico and Franco (1991) proposed that infants choose specific types of vocalizations to utter during communication. A cognitive-constructive theory (e.g., Ferguson, 1986; Ferguson & Macken, 1983) suggests that infants exercise their articulatory skills and respiratory control through active play and repeated self-exploration. A "push-and-pull effects" hypothesis, proposed by Scherer (1985, 1988, 1992) to explain qualitative differences in animal calls, might also be used to explain why speechlike vocalizations are more likely to occur in symmetrical communication when both mother and infant are mutually involved. According to Scherer (1985, 1988, 1992), vocal production is subjected not only to an internal physiological push elicited by cognitive or emotional processes, but also to an external pull effect constrained by environmental factors. During symmetrical communication, for example, infants' heightened arousal generated from gazing and smiling during mutual exchanges with their mothers may "push" infants to vocalize, whereas the upright postural position and maternal, infant-directed speech may work to "pull" the vocalizations. During unilateral communication, although infants may be pushed by the elevated arousal from assimilating information related to object properties, the attractiveness of the object and the distance between infant and object may pull infants to vocalize. On the other hand, during asymmetrical communication, even though the pull effects may work similarly, infants' arousal levels may not be pushed up to a consistent and robust level as are those during symmetrical and unilateral communication for all infants; therefore, infants are less likely to utter vocalizations during asymmetrical communication. This may also explain the result regarding the variability in the relations between the quantity of nondistress vocalization and the amount of asymmetrical communication: Although about half of the infants showed positive relations, the other half showed negative ones. These concepts may help us understand what infants bring into communication with their mothers and what mothers might provide in the way of simple responsiveness. These push-and-pull effects, however, are not likely to be sufficient to promote vocal development in the absence of opportunities to be creative with an adult partner for the purpose of sharing positive emotion (Gianino & Tronick, 1988; Stern, 1974; Trevarthen & Marwick, 1986).

It has been suggested that one of the vehicles through which infants learn speech and language is vocal imitation. Infants as young as 4 months of age can match the vowel sound they just heard from a model in a well-controlled laboratory setting (Kuhl & Meltzoff, 1996). Even though it is difficult to disentangle who is imitating whom during social interaction, results from naturalistic studies also suggest that infants imitate not only the phonetic but also the prosodic structure in their mothers' speech (Kugiumutzakis, 1993; Masataka, 1992; Papousek & Papousek, 1989). Therefore, it is plausible that vocal imitation is one of the mechanisms that contribute to the quantitative and qualitative differences in infant vocalizations among different patterns of communication. It needs to be pointed out,

however, that face-to-face interaction in the first half-year, although nonverbal, is no less spontaneous and creative (Kaye & Fogel, 1980; Stern, 1974). The mutual delight discharged from approximating, matching, and echoing each other's vocalization is likely to impel the cocreativity and innovation in the mother–infant communication system, which, in turn, may amplify both the quantity and the quality of infant nondistress vocalization. Kugiumutzakis (1993) described the mirroring and echoing in vocal exchanges between infants and their mothers as an integral part of intersubjective communication.

Developmentally, results from this study reveal that the rate of speechlike vocalization occurring in symmetrical communication showed an inverted U shape (increasing first, then decreasing) with the emergence of individual differences around the 2nd month and the peak of growth at about 4 months of age. When speechlike vocalizations decreased during symmetrical communication after the 4th month, they began to increase during unilateral communication. A linear increase in speechlike vocalization during unilateral communication was found in this study. The observed developmental changes, from speechlike vocalizations occurring primarily during symmetrical communication before 4 months to their increased occurrence during unilateral communication after 4 months, may reflect a transition in the mother–infant communication system from a dyadic form of face-to-face interaction to a triadic form of mother–infant–object interaction (Adamson, 1995). During this time period, infants' undivided attention to their mothers' faces declines dramatically, whereas their attention to objects in the environment in the company of their mother increases (Kaye & Fogel, 1980; Papousek & Papousek, 1989). Most parents notice this shift and provide verbal support to infant vocal expression about their object-related experience (Hunter, McCarthy, MacTurk, & Vietze, 1987). Furthermore, because age only explained less than 14% of the total variance for the growth of speechlike syllabic vocalization in symmetrical and unilateral communication, other factors that contribute to the developmental change need to be explored in future studies. Research is needed to investigate the effects of developmental changes within the child, such as anatomical and articulatory structures, and cognitive factors, such as attention and memory representation (see Kuhl & Meltzoff, 1996). Maternal communicative actions (e.g., infant-directed speech) may also exert important influences on the developmental growth of speechlike vocalizations. Most important, research would be fruitful in identifying the dyadic factors (e.g., mutual gazing or smiling) that promote or inhibit the individual differences in early vocal development.

Taken together, results from this study provide additional support for previous claims that sound production and vocal communication are two interrelated systems (Stark, 1993; Stark et al., 1993), that prelinguistic infant vocalizations are specific to their communicative context (D'Odorico & Franco, 1991), and that reorganizations in the early vocal system are associated with social interaction (Stark, 1989). The significant individual differences in the development of syl-

labic vocalization in symmetrical mother–infant communication during the first 6 months further indicate the importance of the relational perspective on infant vocal development. We suggest that infant vocal development may not be completely explained by what arises from "within the child," but also by what emerges in the mother–child relationship. In other words, the development of prelinguistic nondistress vocalization is highly connected to the cocreated relational processes between an infant and his or her caregiver during social communication. The developmental history of the communication within individual dyads may be critical to the quantity and quality of vocal production.

In summary, this study demonstrated that the quantitative and qualitative characteristics of infant nonvocalizations are closely tied to the moment-to-moment dynamics of mother–infant communication and that the growth of vocal production is in concert with developmental changes in mother–infant communication. Nevertheless, the generalizability of the results from this study may be limited due to the fact that this study is based on data from 13 mother–infant dyads observed in 5-min sessions, which is a relatively small sample size with a minimum sampling of mother–infant behaviors. Replication with a larger sample size and longer observational time would permit examinations of the mechanisms for these associations in greater detail. For example, assessments of the level of infant's arousal (e.g., indexed by heart rate or respiration) in response to the dynamics of dyadic interaction and the associations of arousal with the occurrences and characteristics of infant nondistress vocalization would discern the infant's contribution to dyadic creativity. Experimental manipulations of the social-contextual factors that enhance or limit mutual creativity would better clarify the roles of these factors in vocal development. Given the evidence that there are significant sex differences in infants' nondistress vocalization during mother–infant communicative interactions (Weinberg, Tronick, Cohn, & Olson, 1999), integration of vocalization and communication with infants' mothers might be different for boys and for girls. Infants' sex could also be included as a variable in the future study.[5] Further empirical research based on a relational approach as opposed to an individual or "within the child" approach is

[5]In addition to types of vocalization and patterns of communication, infant sex was added to the repeated-measures ANOVA as an additional independent variable to explore its effect on the rate per min of infant nondistress vocalization, using data collapsing over weekly sessions. The result showed that there was neither significant main effect for infant sex, $F(1, 11) = 0.26$, $p = .62$, nor any significant two-way interaction effect associated with infant sex, F values = 0.67–0.72, $p > .10$. The three-way interaction approached significance level, $F(2, 22) = 2.98$, $p < .08$. Furthermore, in addition to age, infant sex was added to the growth-curve models to test its effect on the developmental growth of infant syllabic vocalizations occurring in the three patterns of mother–infant communication. The result revealed that the developmental growth of syllabic vocalization in different patterns of communication did not vary as a function of infant sex, z values = –1.81–0.18, $p > .10$. These nonsignificant findings concerning infant sex may be due to the small sample size of this study and there is therefore insufficient statistical power to reject the null hypothesis.

needed to investigate the developmental processes of infant vocal and nonverbal actions in a dynamic and changing interactive context.

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