

The Cross-Modal Coordination of Interpersonal Timing: Six-Week-Olds Infants' Gaze with Adults' Vocal Behavior

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The purpose of this study was to examine the hypothesis that 6-week-old infants are capable of coordinated interpersonal timing within social interactions. Coordinated interpersonal timing refers to changes in the timing of one individual's behavior as a function of the timing of another individual's behavior. Each of 45, first-born 6-week-old infants interacted with his or her mother and a stranger for a total of 14 minutes. The interactions were videotaped and coded for the gaze behavior of the infants and the vocal behavior of the mothers and strangers. Time-series regression analyses were used to assess the extent to which the timing of each of the infants' gazes was coordinated with the timing of the adults' vocal behavior. The results revealed that (a) coordinated timing occurs between infants and their mothers and between infants and strangers as early as when infants are 6 weeks old, and (b) strangers coordinated the timing of their pauses with the infants to a greater extent than did mothers. The findings are discussed in terms of the role of temporal sensitivity in social interaction.

KEY WORDS: infant social behavior; coordinated interpersonal timing; vocal; visual; mother-infant interactions.

It don't mean a thing if it ain't got that swing.

Duke Ellington (1932)

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INTRODUCTION

The impetus motivating this investigation may be found in the above quotation of the esteemed Mr. Ellington. While rhythm may not be the only determinant of social interaction, it is a necessary component of all ordered interactions among individuals. Few, if any, social interactions are possible without an ordered temporal structure. For many years, our work has focused on a particular type of rhythmic interaction, namely, the temporal structure of dyadic vocal interaction (Feldstein & Welkowitz, 1987; Jaffe & Feldstein, 1970; Jasnow & Feldstein, 1986). In that context, we have demonstrated the ubiquity of the temporal coordination of dialogue among adults, children, and preverbal infants as young as 4 months of age (Feldstein, 1998; Feldstein, Jaffe, Beebe, Crown, Jasnow, Fox, & Gordon, 1993; Jasnow, Crown, Feldstein, Taylor, Beebe, & Jaffe, 1988). The coordination of sounds and silences have been shown to be associated with important variables that describe various aspects of dyadic relationships. For example, Crown (1991) found that coordinated interpersonal timing is related to how individuals feel about each other. In another study, we present evidence (Jaffe, Beebe, Feldstein, Crown, & Jasnow, in press) that the temporal patterning of vocal behaviors between 4-month-old infants and adults is predictive of such important developmental and social outcomes at 1 year as temperament, quality of attachment, and cognition as indexed by the Mental Development Index of the Bayley Scales.

All of our work to date has been concerned solely with the patterns of sounds and silences of vocal behavior. In the present study, we have altered the focus of our investigation to the coordination of infant gaze and adult vocal behavior. We did so for two reasons. The first is that infants younger than 12 weeks do not ordinarily utilize vocal behavior for social communication to any great degree, rendering the examination of infant sound-silence patterns unproductive in younger ages groups. Although this initial point is, in some sense, a practical matter, it relates to a second point that underlies the logical reason for studying the temporal coordination of infant gaze with adult vocal behavior. We believe, as we have stated elsewhere (Jasnow *et al.*, 1988) that temporal coordination of behavior is the bedrock of all social interaction and is, furthermore, a capability that is part of the biological heritage of human beings (and, indeed, of all social organisms). If this is so, then it follows that we should be able to detect sensitivity to the temporal aspects of behavior even in the earliest such encounters between the infant and the social world. From birth on, human beings are sensitive to the timing of socially relevant behaviors. We view this temporal sensitivity as separate and dis-

tinct from its behavioral expression through any particular behavioral channel. Thus, we hypothesize that the infant is capable of extracting temporal information from the social behavior of the adult, processing that information, and then utilizing that “purified” temporal information in the ordering of its own responses to adult social behavior. What this amounts to is simply that we expect the infant to demonstrate a discrete facility for the timing of socially salient behaviors that is independent of any particular modality. In older infants in whom vocal behavior has become prepotent, we have demonstrated the presence of such coordinated temporal patterning (Jaffe *et al.*, in press). In the very youngest infants, where this particular behavioral pathway is not yet available, we predict that evidence for temporal coordination of social behavior will be seen in the prepotent behavioral system available for social enactments at that time, that is, we predict that temporal coordination involves the infant visual system. We argue that evidence of the capacity to coordinate the temporal patterning of the infant gaze to adult vocal behavior in a manner analogous to the coordinated vocal behavior of older infants and adults is itself compelling evidence of a discrete capacity for temporal organization of behavior that subserves the organization of social relationships in human beings and is present virtually at birth.

The specific hypothesis of the study reported here is that 6-week-old infants coordinate their gaze behavior with the vocal behaviors of adults. Interest in the phenomenon of coordinated interpersonal timing has increased considerably over the past several years (e.g., Cohn & Tronick, 1988; Crown, Feldstein, Jasnow, Jaffe, & Beebe, 1985; Crown, Feldstein, Jasnow, Beebe, & Jaffe, 1992; Gottman, 1979; Gottman & Ringland, 1981; Jasnow & Feldstein, 1986; Lester, Hoffman, & Brazelton, 1985; Martin, 1981; Thomas & Malone, 1979; Crown & Cummins, 1998). The literature concerned with coordinated timing in dyadic interaction structures has been extensively reviewed in several reports (Beebe, Jaffe, & Lachmann, 1992; Crown, 1991; Feldstein, 1998; Feldstein & Welkowitz, 1987). Although it has been defined and named in multiple ways, coordinated interpersonal timing is used here to refer to “an alteration in the temporal patterning of one speaker’s behavior as a function of that of the other speaker’s behavior” (Jasnow *et al.*, 1988). In this instance, behavior refers to visual attention on the part of the infant and vocal behavior on the part of the adult. Although most of the research concerned with coordinated interpersonal timing has focused on vocal behavior, the coordination of infants’ visual attention and inattention with adult vocal sounds and silences was examined in this study, since few types of vocalizations other than reflexive sounds, such as coughing, burping, sneezing, and other vowel-like sounds that accompany biological functions or involuntary actions, have emerged by the end of 6 weeks of life (e.g., Bates, O’Connell & Shore, 1987).

Interpersonal coordination is reflected, in this study, in the relation between two streams of behavior, i.e., infant gaze behavior and adult vocal behavior. Support from a variety of studies for the role of temporal organization as a reflection of the integrity of the nervous system from as early as the neonatal period provides a rationale for expecting an early capacity for coordinated interpersonal timing (e.g., Zeskind & Marshall, 1991). Although coordination is examined over a span of time, its description is analogous to that of the relation implied by a simple correlation coefficient: as the behavior of one individual changes, the behavior of the other individual changes in the same or opposite direction.

Infant Gaze Behavior

Although gaze behavior in infancy has been extensively studied and is known to play an important role in social development, most investigations have examined infants at 8 weeks old or older. However, the infant's visual system is functional at birth (Haith, 1978) and, by about the fifth week postpartum, the infant is able to attend to the interior configuration of a visual stimulus. By 7 weeks of age, newborns fixate for 87.5% of the time on the mother's face (Haith, Bergman, & Moore, 1977). It is at this time that mothers report an increased affective potency in face-to-face interactions with their infants (Emde & Robinson, 1980; Haith, 1978; Stern, 1974). Some research suggests that infants who have a severe deficit in the capacity for sustained visual regard for their caretakers are at increased risk for the development of psychopathology (Fraiberg, 1974). A thorough review of research on sustained attention has been provided by Ruff (1990).

Infants' gaze toward adults is an important social cue, but coordinated interpersonal timing also requires that the infants be capable of hearing and responding to adults vocalizations. It is equally clear that most infants are born well equipped for auditory perception. The brainstem and auditory cortex are functional at birth; cochlear function and myelination of auditory tracts occur before birth (Eisenberg, 1976).

Several studies have examined the role of infant visual regard within the context of social communication with infants younger than 12 weeks old (e.g., Noble, Self, and Shafaie, 1983; Self, Shafaie, and Noble, 1984). Wolff (1963) noted that true eye-to-eye contact begins at 6 weeks of age and has a dramatic impact on mothers as they experience an increased interpersonal responsiveness on the part of the infant. Stern (1977) observed the importance of the visual system as one of the only neonatal on-off perceptual systems under voluntary control, for the development of parent-infant attachments. Haith *et al.* (1977) explored the development of facial scanning in eye con-

tact in infants from 3 to 11 weeks of age. A developmental trend was found such that, when given the opportunity, the 3- to 5-week-olds fixated on an adult face 22.1% of the time. The 7-week-old infants fixated 87.5% of the time, while the 9- to 11-week-old group fixated on the adult face 89.9% of the time. Haith *et al.* (1977) found that adult vocalizations served to shift the area of fixation to the adult eye-face region. They concluded that visual stimuli are not the only factors that control an infant's visual scanning. Arco, Self, and Gutrecht (1979) found that the duration of maternal visual regard for the infant was positively correlated with the duration of neonatal visual regard for the mother. Noble, Schafaie, and Self (1982) looked at the effects of individual differences in neonatal gaze aversion on the first day of birth upon maternal responsiveness on days 2 and 3. They found that mothers of male infants who generally tended to look directly at their mothers (low gaze-averters) engaged in more tactile responses with their infants than mothers of infants who tended to look away from their mothers (high gaze-averters). Mothers in the low gaze-averting group also used longer vocalizations by comparison with mothers in the high gaze-averting group. Noble *et al.* concluded that visual attentiveness is a powerful cue to the mother, signaling that her newborn is ready for social interaction.

Cross-modal Behavior

Research on CIT has involved infants, children, or adults who have the capacity for greater vocal productivity than is possible as early as 6 weeks. In order to examine CIT at 6 weeks it is necessary to measure some other communication mode. However, for another communication mode to be relevant to CIT requires that the 6-week-old be able to receive vocal communication and respond via another communication channel, i.e., cross-modal integration. The capacity to pick out invariant relationships from stimuli across modalities is one means by which the infant constructs a stable representation of its world. Infants are capable of integrating information across diverse sensory pathways, and the provision of integrated, tactile, olfactory, vestibular, visual, gustatory, and thermal stimulation has been seen to be an essential feature of normal development (Turkewitz & McGuire, 1978). Numerous investigations have convincingly demonstrated the very early capacity for cross-modal integration (e.g., Bahrick, 1983; Bower, Broughton, & Moore, 1970; Fowler & Deckle, 1991; Lewkowicz & Turkewitz, 1980; Meltzoff & Borton, 1979; Meltzoff, Kuhl, & Moore, 1991; Meltzoff & Moore, 1977, 1983; Spelke, 1979; Rose, 1990).

Meltzoff and Moore (1989), for example, conducted a study that involved 40 newborns who were less than 72 hours old. Using a carefully

controlled experimental procedure, the investigators exposed each infant to a both a tongue-protrusion display and a head-movement display in a randomly determined, repeated measures design. Each display was followed by a brief "passive face" display by the experimenter. Findings indicated that infants matched the appropriate display more than would be expected by chance. Furthermore, the matching often occurred during the passive face display (e.g., the infant protruded his or her tongue after the experimenter had finished protruding his tongue and displaying a passive face). The investigators proposed that early imitation is mediated by a process of *active intermodal mapping* (AIM), rather than a series of innate release mechanisms (IRMs) with attendant fixed-action patterns and that imitation is but one manifestation of an underlying representational system that unites the perception and production of human acts within the same framework (p. 961). Deficiencies in cross-modal transfer have been found in a variety of clinical populations: mental retardates, brain-damaged children, learning-disabled children, autistic individuals, and premature infants (Friedes, 1974; Jones & Robinson, 1973; Rose, Gottfried, & Bridger, 1978).

In addition to infants' capacity for cross-modal integration, several factors are involved in the coupling of infant gaze with adult vocalization. At 6 weeks of age, the capacity to control the direction and duration of gaze is the best way the infant can control environmental inputs (Stern, 1977). With the exception of crying, the vocal repertoire of the infant is quite circumscribed at this time. It has been noted that, within the context of face-to-face play, the low variability of maternal gaze and infant vocalization suggests that each uses the opposite for regulating the interaction, i.e., that mothers' vocalizations and infants' gazes modulate their interactions (Zelner, Beebe, Jaffe, & Feldstein, 1984). A number of investigators have also pointed out that vocal behavior is, in fact, a component of kinesic behavior and, as such, may be equivalent to gaze behavior, which is itself a kinesic behavior. Thus, for example, Beebe, Alson, Jaffe, Feldstein & Crown (1988) pointed out that it may be useful to think of speech as a special case of kinesic interaction. Jaffe & Anderson (1979) observed that speech is a patterned sequence of articulatory gestures, and that this fact is often discounted because these gestures are ordinarily destined for acoustic rather than visual perception. The temporal patterning of adult-infant kinesic events has been found to closely resemble aspects of the temporal coordination of adult dialogue (Stern, Beebe, Jaffe, & Bennett, 1977). Moreover, mother-infant gaze interaction has been found to conform to the same stochastic model that best describes adult dialogue (Jaffe, Stern, & Peery, 1973). This model, a first-order Markov model, also predicts the occurrence of sound-silence and gaze-at versus gaze-away in adult dialogue (Hedge, Everitt, & Frith, 1978; Natale,

1976). Moreover, DeCasper & Spence (1991) presented a series of studies that they state indicate that, before 3 days of age, infants can discriminate among acoustic stimuli, i.e., that they are active listeners whose “encounters with the acoustic environment can be mediated by a functioning cognitive system” (p. 63). Bates, O’Connell, & Shore (1987) argue that 15 years of research provides convincing evidence that infants in the first few weeks of life can hear most of the phonological contrasts that are used by human languages. All of these considerations suggested that it would be reasonable to directly explore the temporal organization of 6-week olds’ gaze and adult vocalization in terms of the same descriptors that characterize vocal interactions. Thus, the study presented here tested the hypothesis that adults coordinate the timing of their vocal behaviors with the gaze behaviors of their 6-week-old infants, and the infants coordinate the timing of their visual behaviors with the vocal behaviors of the adults. In addition, the study explored two important questions.

1. What is the magnitude of coordinated interpersonal timing for each dyad?
2. Is there a difference between the magnitudes of the mothers’ and strangers’ coefficients of coordination and/or between the coefficients of the infants with their mothers and those of the infant with the strangers?

METHOD

Participants

The participants were 45 first-born infants, each 6 weeks old, and each of whom interacted with his or her mother and with a stranger. All of the participants were Caucasian and of the 45 infants, 20 were female. The mothers were recruited for the study within 24 hours of the infants’ birth from Babies Hospital of the Columbia-Presbyterian Medical Center (New York City). Ethical guidelines of the American Psychological Association were followed.

Recruitment

The participants were recruited on the basis of stringent criteria for the determination of a normal pregnancy, birth, and infant. After reviewing the medical charts, a clinical psychologist visited each mother in her hospital room to briefly describe the study and recruit her participation. The following list of inclusion and exclusion criteria were used to determine the acceptability for participation of a mother-infant dyad. The inclusion crite-

ria were the following: (a) mothers had to be at least 18 years old and married, (b) their primary language had to be English, (c) they could exhibit no positive prenatal urine screen, and (d) they had no pre-eclampsia or significant medical complications. Infants could participate if (a) they had 1-minute Apgar scores of less than 8 if the 5-minute Apgar score was 8 or more, (b) they were delivered by cesarean section if there was no evidence of fetal distress, (c) they weighed more than 3200 g, and (d) they were discharged from hospital with their mothers (the complete list of inclusion criteria can be found in Jaffe *et al.*, in press).

The exclusion criteria were (a) any mother with positive results on a prenatal urine drug screen and any infant with a positive result on a urine toxicology screen, (b) multiple births, and (c) mothers who exhibited gross psychopathology during the initial contact.

The mother was contacted again by telephone within 6 weeks of the initial contact. In that contact, the mothers were again provided with an explanation of the study and an appointment was made for the mother to bring the infant to the laboratory when the latter was six weeks old. The arrangement of the laboratory appointment took into account the infants' natural eating and sleeping schedules as assessed by the Wolff criteria (1966).

Strangers

The protocol of the study called for the infants to interact with one adult besides their mother. These individuals were called "strangers" in the study because they were, in fact, not known by either the mother or infant. The strangers were female graduate students, recruited from Columbia and Yeshiva Universities and from the City University of New York, and were screened for suitability before their acceptance. They were provided with appropriate training sessions by one of the investigators (BB) and paid a fee for their participation. The training sessions elaborated upon the proper methods of handling newborn infants and involved their observation of a series of criterion interactions between mothers and infants.

The inclusion of strangers in the study was for the purpose of examining whether young infants engage in temporal coordination only with the familiar figure of their mothers or whether that facility extends to other adult figures. There is evidence (Feldstein, Jaffe, Beebe, Crown, Jasnow, Fox, & Gordon, 1993; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Jasnow *et al.*, 1988) that 4-month-old infants are able to engage in such coordination with mothers and strangers, and one of the purposes of the present inquiry was to determine how early in an infant's life coordinated timing occurs. It is conceivable that when the infant is so young, the facility is elicited only by a mother-infant interaction and only later is extended to interactions with other adults.

Procedure

Each mother was asked to complete a statement of informed consent upon her arrival at the laboratory. Each infant was videotaped while interacting face-to-face with both his or her mother and with a stranger. The order in which the taping was carried out, mother-infant first or stranger-infant first, was randomized. Each videotape represents approximately 14 minutes of interaction (approximately half with the mother and half with the stranger) during which the infant was in a quiet, alert state. If a baby became fussy to the point of crying, and if the crying persisted for longer than 30 seconds, the interaction was interrupted. The period of crying was deleted from the tape either at the time of recording or at the time that the tape was coded. The taping was resumed only after the infant again entered a quiet, alert state (Wolff, 1966).

The recordings were made in a specially constructed room that was sound-proofed and partially sound-deadened. The infant sat in an infant seat that was on a table directly in front of the mother's chair such that the infant's face was at the mother's eye level (this procedure was also followed when the infant interacted with the stranger). The vocal behavior of the adults was recorded by means of a air microphone that is sealed in a small, circular chamber about 1 $\frac{1}{4}$ inches in diameter and a half inch thick. One side of the chamber is a sensitive diaphragm which, when placed directly against the skin, allows the unit to function as a contact microphone. Two wall-mounted, motor-driven cameras were focused continuously upon the faces of the infant and adult. These cameras fed into a special effects generator that created a split-screen image of a full-frontal view of the faces of the infant and adult. To clarify the direction of the infants' gaze, a small portion of the adults' shoulder was recorded in the infants' screen. It was this videotape that was used for the coding of infant gaze behavior and the adult vocal behavior.

All recording equipment was located in an isolated area outside of the room in which the adult and infants interacted. Also located outside of this room was a room that was equipped with a changing table, comfortable chairs, toys, diapers, juice, and coffee for the comfort of the infants and adults. This area was especially important for the rest periods that the infants needed to be able to engage in approximately 14 video-recorded minutes of "quiet, alert" interaction (7 minutes with the mother and 7 minutes with a stranger).

Behavioral Coding

The coding of the visual and vocal behavior was accomplished by means of the direct input of two sequences of audio signals (to be described) into a specialized computer system known as the Automatic Vocal Transaction Analyzer (AVTA; Jaffe & Feldstein, 1970). AVTA is a

hardware and software system that performs a number of operations. The hardware component is an analog-to-digital converter that “listens” to two channels of incoming audio signals to determine whether the signal in each channel is on or off. In the case of actual conversation, the audio signals represent the vocal behavior of the two partners. In the present study, one of the sequences of signals represents the gaze behavior of the infant (transmitted via a microswitch), while the other represents the vocal behavior of the adult. Both sequences of signals are sampled by the A-to-D converter every 250 ms and are stored digitally in the computer in the form of a sequence of decimal numbers that index the four possible outcome states of the signals, i.e., one signal is on and the other is off or vice versa, both are on, or both are off. The AVTA software transforms the decimal numbers into the set of dialogic measures defined in Table I and summarizes them as average durations, proportions, frequencies, standard deviations, and percentages for a fixed-time interval determined by the investigator. The interval can be for the duration of the interaction or, as in the present study, every 10 seconds, for the purpose of time-series regression analysis.

The fact that the AVTA system was designed to detect an audio signal required that the gaze behavior of the infant be transformed into an audio signal. This transformation was accomplished by an observer who watched a videotape of an interaction and depressed a microswitch each time the infant looked directly at the adult’s eye-face region and released the switch when the infant’s gaze shifted away from the eye-face region. The microswitch was attached to a tone generator, which converted the gaze-at and gaze-away pattern of the infant into an audio signal that was then input directly into one channel of the AVTA system. Simultaneously, the (adult’s) vocal signal was input directly from the videotape into the other channel of the AVTA system. Thus, the record was accurate, in real time, for both infant and adult.⁶ As mentioned earlier, the vocal and visual behaviors of each dyad were summarized by the AVTA system in terms of 10-second intervals. The reliability of the gaze coding will be described.

⁶ The observer had been trained to quickly press the microswitch as soon as the infant began to gaze at the mother’s facial region and to just as quickly release the switch when the infant’s gaze changed direction. Although her response time could not be as rapid as that of the AVTA system, it was very likely to be consistent throughout her coding of the videotapes. If the infant’s direct gaze or gaze avert had actually begun milliseconds before she pressed or released the microswitch, it was likely to have happened throughout the tape. It is as if we were adding a constant to each behavioral observation. But once it was put into the AVTA system, it was treated as if it were another voice and sampled every 250 msec and averaged into 10-second time units. Thus, the potential small but consistent “error” in the coder’s response time was not likely to affect the estimate of temporal coordination yielded by the time-series regression (TSR) analysis.

Table I. Definitions of the Adult Vocal States and Infant Gaze Measures Used in the Study

Adult (Vocal)	Infant (Gaze)
A <i>vocalization</i> is a segment of sound uninterrupted by any discernible silence.	A <i>direct gaze</i> is that period of time during which the infant's eyes are oriented toward the adult's eye-face region.
A <i>pause</i> is a period of adult silence coupled with the infant's gaze avert and bounded by the adult's vocalizations.	A <i>gaze avert</i> is an interval of time during which the infant's eyes are oriented away from the adult's eye-face region and the adult is silent. The interval is bounded by the infant's gaze.
A <i>switching pause</i> is an interval of adult silence and infant gaze avert initiated by the adult and terminated by the beginning of an infant gaze.	A <i>switching gaze avert</i> is an interval of gaze aversion initiated by the infant and terminated by an adult vocalization. Thus, it culminates in a change of the turn.
A <i>interruptive simultaneous speech</i> is a vocalization that begins while the infant is gazing at the adult and has the turn and that ends after the infant gazes away. The outcome is thus a change in who has the turn.	A <i>interruptive simultaneous gaze</i> is a gaze that begins during a vocalization of the adult and ends after the vocalization has ceased. Thus, the outcome is a change in who has the turn.
A <i>noninterruptive simultaneous speech</i> is a vocalization that begins and ends while the infant is gazing at the adult and has the turn. Thus, the infant retains the turn.	A <i>noninterruptive simultaneous gaze</i> is a gaze that begins and ends during a vocalization of the adult. Thus, the adult retains the turn.

Five vocal states (Feldstein & Welkowitz, 1987; Jaffe & Feldstein, 1970) generated by the AVTA system are *vocalizations*, *pauses*, *switching pauses*, and *interruptive* and *noninterruptive simultaneous speech*. For purposes of this study, the gaze measures that paralleled the vocal states are shown in Table I.

Coordinated timing is computed in terms of the average durations of each of the measures. For example, the successive average durations (for a fixed time unit) of an infant's direct gaze are compared to the successive average durations (again for a fixed time unit) of his or her mother's vocalizations. The average durations of direct infant gaze for a given time interval are coordinated with the average durations of maternal vocalizations during the previous interval. Fehr and Exline (1987) presented an extensive review of research that has examined both visual and vocal behavior to examine a variety of social phenomena.

Reliability

The high level of reliability of the AVTA system has been demonstrated in previous studies (e.g., Feldstein & Welkowitz, 1987; Jaffe & Feldstein,

1970). The data for the assessment of the intrarater reliability of coding were collected by having the individual who coded infant gaze and the individual who operated the AVTA system (by setting the threshold levels needed by the system to categorize sound and silence) practice processing interactions for several weeks. Each interaction was coded twice so that reliability could be monitored throughout the study. The data from each interaction were summarized in terms of average durations for each 10 seconds of the total interaction (thirty-eight 10-second units for each) for each of the adult-infant behaviors. The data for each behavior from the first and second processing were compared by means of a product-moment correlation analysis. The average coefficient for each of the visual measures was: direct gaze, .74; gaze avert, .83; turn, .74; switching gaze avert, .14; noninterruptive simultaneous gaze, .56; and interruptive simultaneous gaze, .62. Because of their unreliability, switching gaze averts were subjected to no further analyses. Furthermore, because in the comparison of infant and adult measures, the infants' switching gaze averts would be compared with the adults' switching pauses, the latter were also subjected to no further statistical analyses.

By comparison with the reliability estimates of other studies (for review, see Fehr and Exline, 1987), the coefficients of this study may appear to be unusually low. The estimates of the present study differ from those of other studies for three important reasons: (a) the infants in this study were only 6 weeks old, (b) the behaviors assessed in this study are more detailed than the typical gaze-on and gaze-avert estimates of other studies, and (c) the present estimates are based upon average durations within successive 10-second units, rather than upon the total amount of time spent gazing in the interaction, across many interactions. When the total amount of time was used to estimate reliability, the obtained coefficients were all above .95. Such an approach would be inappropriate in the present study because the data analyses were based on the 10-second units.

Data-analytic Procedures

Three data-analytic strategies were utilized to address the questions of the study. Time-series regression (TSR) analysis (Gottman, 1979) was used to assess the magnitude of coordinated interpersonal timing for each of the mother-infant and stranger-infant pairs. Meta-analyses were used to determine whether the magnitudes with which coordinated interpersonal timing occurred across the mother-infant and stranger-infant pairs were a function of chance. Repeated-measures ANOVA were computed to determine whether the overall magnitude of coordinated interpersonal timing of the mother-infant interactions differed from that of the stranger-infant interactions.

Time-series Regression

There are, in this study, two “streams” of behavior, or two time series, for each adult-infant interaction. The infant’s gaze behavior forms one series and the adult’s vocal behavior forms the other, and each one lasts as long as the duration of the interaction. The infant’s series represents the criterion (dependent) variable in the analysis of the infant’s coordination and the predictor (independent) variable in the analysis of the mother’s coordination, and the reverse is true for the analysis of the mother. TSR analysis is used to compare the two series to determine whether they are dependent upon each other, i.e., to determine the extent to which the behavior in one series at a particular instant in time is coordinated with the behavior in the other series at the previous instant.⁷ However, only pairwise comparisons are made in the present study (e.g., the average direct gazes of the infant with the average vocalizations of the adult, the average gaze averts of the infant with the average pauses of the adult). The time unit within which the gaze behavior of the infants and the vocal behaviors of the adults averaged was 10 seconds. Although in our previous studies we have used a 5-second unit because it was long enough to include the possible occurrences of several of the vocal states, gaze behaviors generally tend to be longer than vocal behaviors and a 10-second unit allows several of them to occur within the same unit. Thus, the approximately 7 minutes that each of the interactions lasted in this study yield two time series, each having approximately forty-two 10-second units.

Each of the two series of each adult-infant pair was subjected to an SPSSX ARIMA (Auto-Regressive Integrated Moving Average) modeling procedure in order to remove autocorrelational effects. In addition, visual and statistical checks were made to determine which of the models best fit the data. An AR2 model was selected, on the basis of the residuals, as the best fit with the data. The AR2 model uses two lags to remove autocorrelational effects from a time series. In this study, autocorrelational effects were removed from the adult’s and infant’s time series. The resulting data contained only the cross-correlational effects of the adults and infants, that is, only the interpersonal influence of the adults and infants in each of their interactions.

Each TSR analysis yields, among other statistics, a squared incremental semi-partial regression coefficient (the squared cross-correlation) that represents the proportion of variance of the infant’s current behavior

⁷ The relationship of the predictor (independent) variable to the criterion (dependent) variable is indexed by the cross-correlation coefficient (i.e., the semi-partial regression coefficient) generated by the time-series regression (TSR) analysis.

accounted for by the adult's previous behavior and another coefficient that is the proportion of variance of the adult's current behavior that is accounted for by the infant's previous behavior. In other words, coordination occurs, for example, when an infant's increased direct visual attention toward the mothers is predicted by the mother's vocalization durations. To put it still another way, the duration of the infant's direct visual attention depends on (i.e., coordinated with) the duration of the mother's previous behavior. The semi-partial R^2 s are used in this study as the coefficients of coordination. They represent the magnitudes of coordination achieved by the adults and infants in the study.

Meta-analysis

Inasmuch as each of the dyads were analyzed separately, each was considered a separate experiment. Thus, to evaluate the hypothesis that, in general, infant and adults in interaction coordinate the timing of their gaze and vocal behaviors, the probability levels associated with the coefficients of coordination of the infants and adults—over dyads—were subjected to meta-analyses. A meta-analysis was performed for each of the gaze and vocal measures. Two groups of meta-analyses used the probability levels of the infants' coefficients derived from their interactions with their mothers and the strangers, and two used the probability levels of the mothers' and strangers' coefficients derived from their interactions with the infants.

Each group of meta-analyses used the procedure described by Rosenthal (1984). The precise, one-tailed probability level associated with each coefficient was transformed to a standard normal deviate, or z . Rosenthal uses the algebraic sign of the z to denote the direction of the results from which it is obtained; two z s will be given the same sign if the two experiments that yield them show effects in the same direction and opposite signs if the effects are in the opposite direction. However, in each of the dyads in the present study, a member either does or does not coordinate the timing of his or her behavior with that of the other member. That is, whatever the direction of the coordination (as the average durations of one participant gets longer, those of the other get longer, or as the average durations of one participant gets longer, those of the other get shorter), it is still coordination. Thus, all the z s used in the meta-analyses have the same sign. Each group of z s was then summed and divided by the square root of its N to obtain an unweighted, overall standard normal deviate (z_0). The probability level associated with the z_0 provides the likelihood that the pattern of coordinated timing over dyads was a function of chance.

Each of the semi-partial coefficients yielded by the TSR analyses was transformed to a Fischer z (i.e., z') and the z' s for each vocal or gaze mea-

sure for each of the four groups (infant with mother, infant with stranger, mother with infant, and stranger with infant) were arithmetically averaged. Each average z' was again transformed to R to index the average magnitude of coordination for each group.

RESULTS

The general hypothesis of the study is that the gaze and vocal interactions of the infants and adults reflect coordinated interpersonal timing, i.e., the average coefficient of the infants and that of the adults, for each type of behavior, is greater than that expected by chance.

The hypothesis was evaluated by meta-analyses. A TSR analysis was computed for each participant in each of the interactions for each of the temporal parameters (i.e., all behaviors in Table I). The results of the meta-analyses (Table II) indicated that, over dyads, coordinated interpersonal timing occurred at a level that was greater than chance for all of the temporal behaviors, infants coordinated with both the mothers and strangers, and

Table II. Summary of the Meta-analyses of the Coefficients of Coordination^{a,b}

			Measures			
			V	P	NSS	ISS
Adults						
Mother	<i>N</i>		44	36	44	42
	<i>R</i>		.40	.13	.19	.16
Stranger	<i>N</i>		29	22	29	27
	<i>R</i>		.46	.14	.20	.14
			DG	GA	NSG	ISG
Infants						
Mother	<i>N</i>		45	37	44	42
	<i>R</i>		.37	.13	.19	.16
Stranger	<i>N</i>		29	18	29	28
	<i>R</i>		.38	.12	.17	.18

^a The p value for each combined effect size is $\leq .001$ and also represents the combined p values over the number (N) of interactions for each measure. The top half of the table is the analyses of the adults' interactions with the infants (i.e., adult is the criterion, infant is the predictor), and the bottom half, the analyses of the infants' interactions with the adults (i.e., infant is the criterion, adult is the predictor).

^b V, vocalizations; P, pauses; NSS, noninterruptive simultaneous speech; ISS, interruptive simultaneous speech; N , number of mothers or strangers in the analyses; R , correlation coefficients, each of which represents the effect size over number (N) of interactions for each measure; DG, direct gaze; GA, gaze away; NSG, noninterruptive simultaneous gaze; ISG, interruptive simultaneous gaze.

mothers and strangers coordinated with the infants. Thus, the results support the general hypothesis. They do not, however, tell us what the magnitudes of the coefficients are.

What is the magnitude of coordinated interpersonal timing for each dyad?

A TSR analysis was computed for each participant in each of the interactions for each of the temporal measures. To present all of the coefficients of coordinated timing would require an unwieldy table of 1800 entries. Instead, Table III presents the coefficient for each temporal behavior averaged over the participants in each type of interaction plus its standard deviation.

Is there a difference in the magnitude of infants' coordinated interpersonal timing with those of the mothers and with strangers?

A repeated-measures ANOVA was calculated for each of the vocal measures in the case of the adults and each of the gaze measures in the case of the infants. In the former analyses, the coefficients of the mothers were compared with those of the strangers; in the latter, the coefficients of the infants with their mothers were compared with those of the infants with the strangers. The results of the ANOVA tests are presented in Table IV. As

Table III. Means and Standard Deviations of the Coefficients of Coordination for Each of the Vocal and Gaze Measures^{a,b}

			Measures			
			V	P	NSS	ISS
Adults						
Mother	M		.446	.368	.409	.482
	SD		.126	.193	.228	.195
Stranger	M		.467	.495	.461	.487
	SD		.157	.202	.193	.198
			DG	GA	NSG	ISG
Infants						
Mother	M		.429	.359	.394	.428
	SD		.131	.201	.181	.191
Stranger	M		.492	.447	.428	.443
	SD		.198	.200	.202	.184

^a The top half of the table is the analyses of the adults' interactions with the infants, and the bottom half, the analyses of the infants' interactions with the adults.

^b V, vocalizations; P, pauses; NSS, noninterruptive simultaneous speech; ISS, interruptive simultaneous speech; DG, direct gaze; GA, gaze away; NSG, noninterruptive simultaneous gaze; ISG, interruptive simultaneous gaze.

Table IV. Analyses of the Magnitudes with which the Mothers and Strangers Coordinated Their Vocal Behaviors with the Infants and to which the Infants Coordinated Their Gaze Behaviors with the Mothers and Strangers

Behaviors	Source	<i>df</i>	MS	<i>F</i>	<i>p</i>
V ^a		1	.06	2.93	.096
Error		34	.02	—	—
P	Mothers with Infants	1	.25	5.66	.03
Error		21	.04	—	—
NSS	vs.	1	.06	1.70	.20
Error	Strangers with Infants	33	.04	—	—
ISS		1	.00	<1	.66
Error		34	.02	—	—
DG		1	.01	<1	.85
Error		34	.02	—	—
GA	Infants with Mothers	1	.02	.60	.45
Error		21	.03	—	—
NSG	vs.	1	.02	<1	.54
Error	Infants with Strangers	33	.05	—	—
ISG		1	.08	1.32	.26
Error		34	.06	—	—
V, DG		1	.02	<1	.41
Error		34	.02	—	—
P, GA		1	.01	<1	.64
Error		21	.04	—	—
NSS, NSG	MI, SI × IM, IS	1	.00	<1	.78
Error	(Adults × Infants)	33	.04	—	—
ISS, ISG		1	.00	<1	.87
Error		33	.03	—	—

^a See Table III, footnote *b* for names of the behaviors.

can be seen in the table, the magnitude of the coordinated interpersonal timing of pauses significantly differentiated the mothers and strangers when they were interacting with the infants. The cell means of the two types of interactions indicate that the strangers' average coefficient of pause coordination was greater than that of the mothers (see Table III). None of the other *F* ratios was statistically significant.

DISCUSSION

The point that emerges most clearly from the data is that, by 6 weeks of age, human newborns display sensitivity to the temporal patterns encountered during the course of a social exchange. This capacity for coordinated interpersonal timing is more than imitative: the invariant temporal properties of their partners in one modality (vocal) is extracted and the informa-

tion is expressed in terms of a different modality (visual). Thus, the data tend to support the contention that human beings possess, from very early on, a temporal sensitivity that plays an important role in social exchanges (Jasnow *et al.*, 1988). Finally, the data indicate that the adults' vocal behaviors are also influenced by the temporal organization of infants' gaze behaviors and that both vocal and gaze coordination occurs with a probability that is well beyond chance.

An interesting finding is that the strangers coordinated the timing of their pauses with the infants to a greater extent than did the mothers. It might be conjectured that this difference derives from the possibility that the strangers, given their specific training about how to handle infants, were more comfortable in the laboratory than the mothers. It may also be that the finding reflects a genuine difference in mother-infant and stranger-infant interactions, in that a similar effect has been demonstrated in a number of studies (Beebe *et al.*, 1984; Mays, 1984). A perhaps more likely conjecture, given the results of a later study (Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001) is that the strangers felt more uncomfortable with the infants than did the mothers and that their greater coordination represented a greater effort to control the interaction. Indeed, there is evidence (Crown, 1991) suggesting that, among adults, coordinated interpersonal timing is more pronounced when the interacting individuals are strangers to one another than when they are friends. On the other hand, given the number of analyses, it may be that the finding is a function of chance. Clearly, it needs to be replicated.

Previous research has demonstrated that adult-like patterns of temporal coordination are observable in vocal exchanges between 9-month-old infants and their mothers (Jasnow & Feldstein, 1986). More recently (Jasnow, Crown, Feldstein, Taylor, Beebe, & Jaffe, 1988; Crown, Flaspohler, Feldstein, Jaffe, Beebe, & Jasnow, 1996; Feldstein *et al.*, 1993; Feldstein, Jaffe, Beebe, & Jasnow, 1996; Crown & Cummins, 1998), similar patterns have been observed in the vocal exchanges of 4-month-old infants with adults. These patterns of coordinated interpersonal timing appear to be similar, if not identical, to the temporal coordination observed to occur in the conversations of adults (Cappella, 1981; Crown, 1991; Crown & Feldstein, 1981). The results of the present investigation, therefore, demonstrate that coordinated interpersonal timing occurs as early as 6 weeks.

The results also highlight the fact that coordinated interpersonal timing is a capacity that is expressed cross-modally. Both adults and 6-week-old infants are apparently capable of extracting the temporal information expressed in one sensory modality (gaze or vocalization) and transferring it, so that it may be expressed via the other modality. This finding is conso-

nant with the research discussed earlier (Allen, Walker, Symonds, & Marcell, 1977; Bryant, Jones, Claxton, & Perkins, 1972; Friedes, 1974; Jones & Robinson, 1973; Rose, Gottfried, & Bridger, 1978; Turkewitz & McGuire, 1978) that demonstrates that infants are able to engage in quite complex cross-modal integrations. As the interesting discussions of Meltzoff and his colleagues (e.g., Meltzoff, 1990), and DeCasper and Spence (1991) suggest, future studies might be designed to tease apart the extent to which coordinated interpersonal timing serves some cognitive function.

The temporal coordination between the adult and the 6-week-old infant is a shared rhythmic behavior. Many researchers have commented on the important role played by such phenomena in *homo sapiens* as well as in a myriad of species along the phylogenetic scale (e.g., Jasnow *et al.*, 1988). Schaffer (1977) observed that “What seems to matter most about ‘successful’ mother-infant interaction is above all the temporal integration of the two partners’ responses, and when we talk about mothers’ sensitivity it is often this temporal characteristic that we have in mind” (p. 214). Bullowa (1979) wrote that, “for an infant to enter into the sharing of meaning, he has to be in communication, which may be another way of saying sharing rhythm” (p. 15). The anthropologist, Byers (1976), wrote that “We can . . . imagine a human or animal world that is communicationally related through the sharing of time forms in multiple levels of behavioral organization” (p. 160). The findings of the present study are consistent with the position expressed by these statements. We suggest that the capacity for coordinated interpersonal timing is a necessary (though not sufficient) condition for two human beings to enter into an effective dialogue with one another, be they 6 weeks or 60 years old.

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