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Relations Between Cyclicity and Regulation in Mother–Infant Interaction at 3 and 9 Months and Cognition at 2 Years

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This report addresses the relation between early interactive rhythms as determined by microanalysis and later toddler cognition. Thirty-six mother–infant dyads were videotaped in free play at 3 and 9 months. Mother and infant attentive states were recorded on an attentive–affective scale in .25s intervals and analyzed using time–series techniques. Synchrony between time–series of mother and infant was examined with cross correlations. At 2 years children were tested with the Stanford–Binet Intelligence Scale. A stochastic–cyclic organization of the infant's attention at 3 months (a pattern reflecting some degree of oscillation between attentive states) predicted general and verbal IQ. At 9 months, organized but not cyclic infant play predicted general IQ. Two measures of maternal regulation at 3 months, mother synchrony with the infant assessed by microanalysis and maternal regulation assessed globally, predicted visual IQ. The temporal organization of infant social attention was individually stable from 3 to 9 months and had concurrent and long-term correlations with mother–infant synchrony. Results are discussed in terms of information processing, the relations of biological, social, and cognitive regulatory mechanisms, and the associations between self- and mutual regulation during the first year and cognitive competence.

Theories of cognitive development emphasize that infants' earliest learning occurs within the context of mother–infant interaction (Flavell, 1992; Messer, 1994; Rogoff, 1990; Rutter, 1985; Vygotsky, 1978), yet studies that examined the relations of early interactions and later IQ have reported mixed results (Fin-

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dji, 1993; O'Connor, Sigman & Kasari, 1993; Tamis-LeMonda & Bornstein, 1989; Wachs & Gruen, 1982). Infants' performance on visual habituation and novelty preference tasks, however, have repeatedly revealed a moderate continuity with childhood IQ (Bornstein & Sigman, 1986; McCall & Carriger, 1993; Slater, 1995). Although quicker habituation to novelty predicts later cognitive abilities, the underlying mechanisms responsible for the continuity between visual processing and intelligence remain controversial. Most researchers suggest that habituation tasks tap early information processing abilities, which provide the basis for cognitive development (Colombo, Mitchell, Coldren, & Freeseman 1991; Fagan, 1984; Rose, Feldman, & Wallace, 1992). Recently, McCall (1994) stressed the central role of inhibition of attention in visual habituation to the construct of intelligence. Disengagement from stimuli and limitation of sensory input serve as a basis for perceptual development and neurological organization in infancy (Johnson, Posner, & Rothbart, 1991; Turkewitz & Kenny, 1982) and thus may provide a link to later cognitive competence.

One important context for the study of attention regulation is that of social play, a situation wherein infants are exposed to high doses of cognitive and social inputs. Mother–infant face-to-face interaction, emerging around the 3rd month of life, is the first expression of social play (Stern, 1974, 1985). Face-to-face interactions are composed of cyclic oscillations, often occurring in milliseconds, between states of attention and nonattention in each partner's play. This repetitive pattern enables a highly organized dialogue between mother and child (Beebe & Gerstman, 1980; Cohn & Tronick, 1987, 1988; Kaye & Fogel, 1980; Tronick, Als, & Brazelton, 1980). Messer (1994) suggested that the repetitive nature of early interactions may be conceptualized as a continuous habituation task; mothers maintain infants' attention at an optimal level for information intake and when attention declines, mothers introduce novel stimuli. The relation between regulation of social attention in the first year of life and later cognitive development, however, has not been examined in depth.

This study examines the underlying temporal organization of mother and infant attentive states at play at 3 and 9 months as potential predictors of intelligence at 2 years. Two types of temporal organization were examined by means of microanalysis: stochastic process and stochastic cyclicity. Second-by-second synchrony between mother's and infant's states was examined in order to determine relations between bidirectional processes and infant regulation of attention. In addition to the microanalyses, global assessment of infant attention and maternal regulation were carried out. We studied mother–infant interaction through both microanalyses and global measures in order to determine the relative contribution of each to the prediction of later cognition.

Stochastic processes differ from periodic sequences, which are characteristic of activity in physiological systems, in the degree of their regularity (Cohn & Tronick, 1988). Stochastic process represent a nonrandom temporal structure in which events can be predicted only from the immediately preceding events, but in which sequences do not appear in predetermined regularity (in this study events are attentive states which often change within split seconds and are described later, following Tronick et al., 1980, as monadic phases). Microanalytic studies of mother–infant interaction have demonstrated the stochastic organization of face-to-face play. For example, mother positive expression often precedes the infant's becoming positive, infant high arousal is often preceded by states of quiet alert, and mother vocalization often frames the infant babbling (Cohn & Tronick, 1987; Feldstein et al., 1994; Fogel, 1977; Kaye & Fogel, 1980).

Stochastic cyclicity is a specific case of stochastic process reflecting some degree of oscillation between attentive states, in addition to predictable relations between subsequent events (Cohn & Tronick, 1988; Gottman & Ringald, 1981). Stochastic cyclicity bears a close resemblance to the "on" and "off" physiological cyclicity observed in the respiratory or brain systems, but its cyclicity is probabilistic (Gottman, 1981). An example of stochastic cyclicity in early social interactions is the "burst–pause" pattern typical of face-to-face play. This pattern describes oscillations between short periods of intense activity by one individual, in terms of arousal, vocalization, and focused attention, followed by a period of rest, which gives the partner an opportunity to react (Brazelton, Koslowski, & Main, 1974; Tronick, Als & Brazelton, 1977).

Synchrony is defined as a match between mother's and infant's activities that promotes positivity and mutuality in play (Isabella & Belsky, 1991). By synchronizing with the child's attentive states, mothers structure playful interactions, regulate infant attention, facilitate the development of verbal dialogue, and promote the infant's capacity for self-regulation (Beebe, Alson, Jaffe, Feldstein, & Crown, 1988; Gable & Isabella, 1992; Isabella, 1993; Jasnow & Feldstein, 1986). Synchrony may also be viewed as a process by which two series of events follow each other within a time lag (Rosenfeld, 1981) and can occur in mother–infant play in one of three ways. Mothers may respond to shifts in the infant's states by an appropriate increase or decrease of stimulus input. Alternately, infants may adjust to changes in maternal state or level of stimulation. Finally, mutual synchrony exists when both partners simultaneously adjust their attention and stimulation in response to the partner's signals (Beebe, 1982; Cohn & Tronick, 1988).

Systems theory models, which propose a relation among regulatory mechanisms in biological, social, and cognitive systems, provide a basis for the hypothesis that social stochastic cyclicity may be related to biological and cognitive functioning (Emde, 1994; Fogel & Thelen, 1987; Hinde, 1992; Sameroff, 1984). Cyclicity, within the infant and between mother and child, serves as a regulator of rapidly developing systems. For instance, the consolidation of sleep–wake cyclicity during the first weeks of life provides a context for the development of predictable mother–infant relationships (Linkowski et al., 1993; Menna-Barreto, Benefit-Silver, Marques, de Andrade, & Louzada, 1993; Sander, 1984). Biological periodicities, the cyclic on and off activity in the respiratory or brain systems, help regulate immature physiological systems (Sollberger, 1965; Winfree, 1980), but also serve as a basis for interactive rhythms (Stratton, 1982). Rhythmic patterns of neonate activity, such as crying, nursing, or sucking, are the earliest means of infant communication (Burke, 1977; Crook, 1979; Pipp & Harmon, 1987; Wolff, 1967), and precede interactive rhythms observed in face-to-face play (Tronick et al., 1977). Similarly, the degree of maternal sensitivity during face-to-face interactions affects the infant's adrenocortical regulation. Spangler, Schieche, Ilg, Maier, and Ackermann (1994) found an increase in cortisol level in infants following interaction with insensitive mothers at 3 and 6 months, suggesting that the infant had experienced the interaction as a stressful, unregulated event.

Biological and social rhythms are possible concomitants of efficient cognitive functioning. The renin–angiotensin system, which regulates the cyclic production of reproductive hormones, also plays a role in functions, such as memory, recall, sensory acuity, and exploratory behavior (Wright & Harding, 1992). Sleep–wake cyclicity reflects neurological maturation in neonates, tends to be a stable characteristic within individuals, and predicts later cognitive abilities (Thoman et al., 1981; Thoman & Whitney, 1989; Whitney & Thoman, 1993). Premature infants, whose heart rate cyclicity is often less regular (Eiselt et al., 1993), rarely present an underlying pattern of stochastic cyclicity in play (Lester, Hoffman, & Brazelton, 1985) and tend to perform poorly on novelty recognition tasks (Rose et al., 1992). Mother–infant ongoing relationships provide a context for the integration of biological and social rhythms, which, in turn, mediate the development of cognitive skills (Beebe, 1982; Hoffer, 1984; Sigman, Cohen, & Forsythe, 1981).

The stochastic–cyclic structure of early social interactions may facilitate cognitive development. Augmented, rhythmic patterns are specifically suited to the infant's rudimentary information processing abilities (Lester et al., 1985), assist the construction of mental hypotheses and their repeated testing, and may promote the development of antecedent–consequent thinking (Stern & Gibbon, 1978). Regular shifts between attention and inhibition (McCall, 1994) and mechanisms of sensory limitation (Turkewitz & Kenny, 1982) contribute to efficient information processing and may predict later cognitive skills.

Mother–infant synchrony activates a set of complex cognitive processes as well. By taking part in synchronous play, infants indicate their abilities to generalize, encode, and classify repeated events in the partner's play, assess the rules that govern their representation, and integrate perception and motor reaction. These cognitive skills are acquired during the first months of life (Flavell, 1985; Sternberg, 1987) and synchrony may be related to the emerging properties of infant cognition. Fogel (1988) suggested that the concept of stochastic cyclicity affords unique theoretical and methodological perspectives on the development of self-regulation and bidirectional contingencies, and recommends its examination in relation to specific developmental outcomes.

The amount of infant attention in play versus the mechanisms by which infant's attention is regulated represent a well-known contrast between levels and processes. (e.g., Horowitz, 1992; Sander, 1987; Stern, 1994). The general level of infant attention and maternal regulation as assessed globally, in addition to attention regulation examined in milliseconds, may be related to cognitive development as well. Measures of infant attention are related to intelligence in childhood (Sigman, Cohen, Beckwith, & Parmelee, 1986). Mother's encouragement of infant attention is related to later verbal abilities (Tamis-LeMonda & Bornstein, 1989) and to infant exploratory behavior (Belsky, Goode, & Most, 1980) and mother's direction of infant attention predicts intelligence scores at 4 years, particularly verbal skills (Bornstein, 1985).

This study aims to examine three questions that have not been previously addressed: (a) the longitudinal development of microanalytically derived processes occurring during the first year of life, (b) the relations between microanalyses of early mother–infant interaction and the simultaneous global assessment of the interaction, and (c) the relation of these first-year measures to later cognitive competence. We hypothesized that a stochastic–cyclic organization of the infant's attention during face-to-face play at 3 months will be related to IQ at 2 years, particularly to verbal abilities. Bidirectional regulation and self-regulation are conceptualized as related processes, and thus mutual synchrony is hypothesized to correlate with stochastic cyclicity and stochastic processes. Maternal regulation at 3 months old, expressed in microanalysis by the mother's synchrony with the infant's attentive states and in the global assessment as the level of maternal adaptation to the infant's signals, is hypothesized to facilitate cognitive growth and will be related to 2-year IQ.

METHOD

Participants

Thirty-six mother–infant pairs with equal number of boys and girls, first-born and second-born infants participated in the study. Participants meeting the study criteria were selected from a list of healthy newborns in Well Baby clinics in Jerusalem. Mothers were recruited by phone and were asked to participate in a longitudinal study on infant development.

Infants were healthy, born at full-term gestation, weighed at least 2,700 g, and received an Apgar score of 8 or above. Infants were between 12 and 15 weeks old (M = 13.2 weeks, SD = 1.75 weeks) at the first visit, between 36 and 39 weeks old (M = 37.6 weeks, SD = 1.2 weeks) at the second visit, and within 1 month of their second birthday at the last visit (M = 24.3 months SD = 1.8 weeks). The ages of 3 and 9 months old represent two stages in the development of social play and possibly require different modes of self- and mutual regulation. At 3 months old, face-to-face play is established as the first expression of social interchange and at 9 months old major leaps in cognitive and affective development that occurred between 6 and 8 months old are expressed in play (Emde, 1994; Stern, 1985).

Mothers were between 25 and 36 years old (M = 28.7, SD = 1.5 years), had completed on average 14.2 years of education (SD = 1.1 years), were currently married to the child's father, and all fathers were employed. All families were considered middle class by Israeli standards (Harlap, Davis, Grower, & Prywes, 1977). According to the Well Baby Clinic records, none of the mothers suffered serious illness, maternal psychopathology, serious pregnancy problems, or perinatal complications.

Thirty-two infants were assessed at 2 years. Two families moved abroad, one could not be located, and one cited returning to work as the reason for not participating. No significant differences on demographic variables were found between those who returned and those who did not. The final sample included 15 girls and 17 boys, as well as 16 second-born children. At 2 years, three first-born children had younger siblings and two mothers were expecting a baby. Second-born children had siblings who were 1.5 to 5 years older (M = 2.8 years, SD = 0.6 years). Older and younger siblings of participants were healthy with no history of pre- or postnatal complications.

Procedure

Mothers and infants were invited to a university laboratory at their convenience. In the laboratory, there were two adjoining rooms separated by a one-way mirror. After a short interview, mother and infant entered a studio, the infant was placed in an infant seat mounted on a table, and the mother sat next to him or her on the adjustable stool. Mothers were instructed to play freely with the infant as they normally would at home. Five minutes of play interactions were videotaped by two movable cameras that were fixed on two walls, one focused on the infant's face and the other on the mother's. Cameras were controlled by a technician in the adjoining room and were transmitted through a split-screen generator and character generator. The finished picture showed a split frame: The right half contained the mother's face, the left half contained the infant's. The minutes, seconds, and milliseconds from beginning of filming were indicated on the upper right.

The 24-month visit was scheduled after the children's 2nd birthday and prior to reaching 25 months old. Children were tested by two trained graduate students in psychology who were unaware of their 3- and 9-month interactional patterns with the fourth edition of the Stanford–Binet Intelligence Scale (Delaney & Hopkins, 1987). Three scores were calculated from the Stanford–Binet subtests; visual reasoning, verbal reasoning, and general IQ. Four children who did not pass the baseline requirements for the Stanford–Binet Intelligence Scale were tested with the Measurement of Intelligence of Infants and Young Children–Revised (Cattell, 1960).

Coding

Videotapes of the 3 and 9 months were coded employing the Monadic Phase Manual (Tronick, Krafchuk, Ricks, Cohn, & Winn, 1980). Monadic phases are response categories specifically created for the analysis of split-second changes in mother or infant states during face-to-face interactions (Tronick et al., 1980). Monadic phases represent a continuum of attentive–affective states ranging from negative to positive engagement in the interaction and are coded separately for mother and infant. The infant phases include protest, avert, object attend, social attend, object play, social play, and talk. The mother phases include avert, social attend, social elicit, object attend, play, object play, and talk.

Coding was performed for 3 min of interaction: the 2nd, 3rd, and 4th min. Two teams of two coders observed the tapes at normal speed, determined the approximate time of phase change, and returned to examine the exact time of change while the tape was running in slow motion. Phase changes were rounded to the nearest .25 s, and every .25 s was entered as separate variable, whether or not a phase change occurred, resulting in time series of 720 variables for 3 min of interaction. Coding of mother and infant were not performed successively to ensure independent assessment of their phases. Both teams coded an additional five-dyad pilot sample and achieved an interrater reliability correlations of .85 (range = .82–.88) for the different phases at 3 months, and .87 (range = .84–.89) at 9 months. Five additional dyads at each age were randomly selected and analyzed by the two teams, and reliability stayed within the same range.

Play sessions were also coded using global measures. Four measures addressed the infant level of involvement in play and one examined the degree of maternal regulation and adaptation. These measures were developed by Feldman (1993) and are based on the Rating Scale of Interactional Style (Clark & Seifer, 1983). The following measures were of particular interest in our study: (a) infant gaze (infant looks at mother or object of joint attention), (b) infant arousal (infant is attentive and displays positive emotions; both the duration and the degree of arousal are considered), (c) infant initiation (play consists of infant-originated activities and infant frequently initiates play), (d) infant vocalization (infant utters speech sounds during interaction), and (e) maternal regulation (mother adjusts the amount of stimulation in accordance with the infant's messages e.g., mother lowers her voice when the infant seems tired). Global coding was done by an independent team of two coders, who viewed the entire session and then rated each measure from 1 (*low*) to 5 (*high*). Interrater reliability correlations were computed for five dyads at each age. The mean coefficient was .85.

Data Reduction

In line with previous studies that employed the monadic phases (Cohn & Tronick, 1988; Lester et al., 1985), scores were averaged within each 1-s period, resulting in time series of 180 observations. Time series of mother and infant at both 3 and at 9 months were analyzed independently.

The infant's global measures—gaze, arousal, initiation, and vocalization—were highly correlated and were averaged into a composite variable entitled infant play involvement (alpha coefficient of internal consistency = .81).

Data Analysis

Time-series of mother and infant at 3 and at 9 months were analyzed in the time domain with Autoregressive Integrated Moving Average (ARIMA) available on

SPSS. ARIMA models detect the internal structure in series of events sampled at equal intervals and enable predictability based on a best fitted model estimated from these observations. Model building involves three stages: identification, estimation, and diagnostic checking. Identification was based on the charting of autocorrelations (ACF) and partial autocorrelations (PACF) functions for each time series (time series of different internal structure have distinct ACF and PACF plots). Estimation was computed as the best fitted model and the significance of its parameters was examined. Diagnostic checking of the series of residuals from the estimated model was assessed with the Box–Ljung Q statistic for lack of autocorrelation. In addition, spectral density functions were computed for all time series using SPSS Spectra with a Tukey–Hanning window (for details see Cohn & Tronick, 1988, Appendix A–D; Gottman, 1981). Each time series of mother and infant at 3 and 9 months was coded for the existence of stochastic process. Series with stochastic process were further coded for the existence or nonexistence of stochastic cyclicity.

Stochastic process was determined when the time series was stationary and was fit by first- or second-order autoregressive parameters (AR(1) or AR(2)). From the general group of series with stochastic process, a subgroup of time series had one nonperiodic cycle on the spectral density function. Stochastic cyclicity was detected when the autoregressive model was of the second order (AR2), and the two estimated autoregressive parameters were in regions of stationarity that fit the following: $a_1^2 + 4a_2 < 0$, when a_1 and a_2 are the two autoregressive parameters. The presence of stochastic cyclicity was further validated in the frequency domain. Stochastic cyclicity was detected when the spectral density function showed a major peak over a broad band of frequencies.

Synchrony was examined by means of cross-correlation regressive functions (CCF), for each dyad at 3 and at 9 months. The CCF assessed whether a lead–follow relation exists between mother's and infant's time series, and if a relation was found, which is the leading or following time series. Three types of synchrony were identified by means of CCF: mother's time series synchronized with the infant's (Type 1), infant's time series synchronized with the mother's (Type 2), or both series synchronized with one another (Type 3). Each dyad at 3 and 9 months was coded for the existence of each type of synchrony. The existence of mutual synchrony (Type 3) implies the existence of the first two types of synchrony as well.

RESULTS

In Table 1, the percentages of mothers and infants whose time series was described by a stochastic process, stochastic cyclicity, and synchrony at 3 and 9 months are presented. Differences in percentages between 3 and 9 months for stochastic process, stochastic cyclicity, and synchrony were examined using a $2 \times 2 \times 2$ MANOVA (2 = gender, 2 = birth order, 2 = age) with repeated

TABLE 1
Temporal Organization of Mother and Infant Attentive States and Synchrony at 3 and 9 Months

	3 Months	9 Months	$F(1, 34)$
	Temporal Organization		
Infant			
Stochastic process	.61	.63	*ns*
Stochastic cyclicity	.44	.43	*ns*
Mother			
Stochastic process	.80	.83	*ns*
Stochastic cyclicity	.61	.63	*ns*
	Synchrony		
Mother synchrony with infant	.41	.68	6.51*
Infant synchrony with mother	.38	.54	5.41*
Mutual synchrony	.11	.40	7.39*

*$p < .01$.

measures on age. Significant differences were found beween 3 and 9 months overall the seven measures on age, Wilks F (7,26) = 2.61, p < .01, and for birth order Wilks F (7,26) = 2.46, p < .01. No overall interaction effects were found. Table 1 presents the mean percentages of the univariate ANOVA for differences in each measure.

As shown in Table 1, time series of most mothers and infants were described by a stochastic process, and approximately half showed stochastic cyclicity. No significant differences were found between the percentages of mothers and infants whose time series showed a stochastic process or stochastic cyclicity at 3, as compared to 9 months. Synchrony between mothers and infants was significantly higher at 9, as compared to 3 months (observed for all three types of synchrony). The univariate ANOVAs revealed that significantly more second-born infants and second-time mothers had time series described by a stochastic process, and more mutual synchrony (Type 3) was observed between second-time infants and their mothers. F values for birth order (df = 1,34) were 5.00 for infant stochastic process, 4.93 for mother stochastic process, and 5.41 for mutual synchrony, all significant at p < .01.

Changes in the global measures of play, infant play involvement and maternal regulation were examined with ANOVA. Infant play involvement increased significantly with age, $F(1, 34) = 10.71, p < .01$. The degree of maternal regulation did not change significantly with age. Individual stability in temporal patterns of mother and infant was examined with Pearson correlations.

The data presented in Table 2 reveals that an underlying stochastic process is a stable characteristic in the play of mother and infant between 3 and 9 months, whereas stochastic cyclicity is stable for infants, but not for mothers. Correlations between stochastic cyclicity of mother and infant were not significant at each age, but long-term correlations were found between infant stochastic cyclicity at 3 months and mother stochastic process at 9 months (r = .37, p < .05). Infant stochastic process and mother stochastic process at 3 months were correlated (r = .38, p < .05). Mother synchrony with infant (Type 1) at 3 months correlated with infant stochastic process at 9 months (r = .36, p < .05) and mutual synchrony (Type 3) at 3 months correlated with infant stochastic cyclicity at 3 months (r = .35, p < .05).

Stability in the global measures of play was similarly examined with Pearson correlations. The correlation between infant play involvement at 3 and 9 months was .08, and between maternal regulation at 3 and 9 months was .24, both not significant. Correlational analysis between microanalytic and global assessment revealed that infant stochastic cyclicity and infant play involvement at 3 months were not significantly correlated (r = −.03). Similarly, stochastic process and infant play involvement at 9 months (r = −.27), mother synchrony with infant (Type 1) and maternal regulation at 3 months (r = .13), and at 9 months (r = −.01), were not significantly correlated.

Correlations between microanalytic and global assessment at 3 and 9 months and the three measures of intelligence—general IQ, verbal IQ, and visual IQ—are reported in Table 3.

As shown in Table 3, the 3-month microanalytic measures of infant stochastic process and infant stochastic cyclicity and the global measure of infant play involvement were related to general and verbal IQ. The 3-month global measure

TABLE 2
Stability of Mother and Infant Temporal Organization From 3 to 9 Months

	Infant	
3 Months:	**Stochastic Cyclicity**	**Stochastic Process**
9 Months		
Stochastic cyclicity	.32*	.57***
Stochastic process	.38*	.46**
	Mother	
3 Months:	**Stochastic Cyclicity**	**Stochastic Process**
9 Months:		
Stochastic cyclicity	.11	.35*
Stochastic process	.18	.53***

*p < .05. **p < .01. ***p < .001.

TABLE 3
Relations Between IQ Scores at 2 Years With Microanalytic and Global Measures of Play at 3 and 9 Months

	General IQ	Verbal IQ	Visual IQ
Infant Temporal Organization			
Stochastic process			
3 months	.36*	.30	.18
9 months	.44**	.40*	.24
Stochastic cyclicity			
3 months	.54**	.53**	.40*
9 months	.27	.12	.32*
Mother Temporal Organization			
Stochastic process			
3 months	.14	.24	.12
9 months	.36*	.37*	.27
Stochastic cyclicity			
3 months	−.03	.13	.00
9 months	.30	.30	.39*
Synchrony			
Infant synchrony with mother			
3 months	−.25	−.18	−.29
9 months	−.11	.04	.03
Mother synchrony with infant			
3 months	.27	.23	.50**
9 months	.03	.09	.03
Mutual synchrony			
3 months	.18	.08	−.15
9 months	−.03	.03	.39*
Global Analysis of Play			
Infant play involvement			
3 months	.25	.53**	.23
9 months	.19	.15	.16
Maternal regulation			
3 months	.27	.28	.53**
9 months	.00	.03	.13

*$p < .05$. **$p < .01$.

of maternal regulation and the microanalytic measure of mother synchrony with infant (Type 1) correlated with visual IQ. The 9-month microanalytic measures of infant stochastic process and mother stochastic process correlated with general and verbal IQ. None of the 9-month global measures was related to IQ.

Prediction of IQ at 2 years from microanalytic and global measures of play at 3 and 9 months was examined with two hierarchical stepwise regression models. Dependent variables were general, verbal, and visual IQ, and predictors were the

TABLE 4
Prediction of Intelligence at 2 Years From Microanalytic and Global Measures of Play

Dependent	Predictor	Multiple *R*	R^2 Change	*F* Change
	Prediction of IQ From Play at 3 Months			
General IQ	Infant stochastic cyclicity	.54	.29	11.48***
Verbal IQ	Infant stochastic cyclicity	.53	.28	9.08***
	Infant play involvement	.74	.27	13.66***
Visual IQ	Maternal adaption	.53	.28	9.16**
	Mother synchrony with infant	.66	.16	8.78**
	Prediction of IQ From Play at 9 Months			
General IQ	Infant stochastic process	.44	.19	6.71*
Verbal IQ	Mother stochastic process	.37	.13	3.64*
Visual IQ	Mother stochastic process	.27	.07	1.95

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

microanalytic measures of mother and infant temporal patterns and synchrony and the global measures of infant play involvement and maternal regulation. Beta weights were positive. Analyses of the 3- and 9-month play variables were conducted separately.

Results presented in Table 4 reveal that the 2-year general and verbal IQ were predicted from infant stochastic cyclicity at 3 months. Verbal IQ was also independently predicted from the global measure of infant play involvement. Visual IQ was predicted by the global measure of maternal regulation and by the microanalytic measure of mother synchrony with infant at 3 months. At 2 years, general IQ was predicted from the 9-month infant stochastic process and verbal IQ was predicted from the 9-month mother stochastic process.

DISCUSSION

The temporal organization of mother and infant attentive states during face-to-face play, synchrony between mother and infant, and global assessment of infant attention and maternal regulation at 3 and 9 months were examined as predictors of IQ at 2 years. Stochastic cyclicity, a temporal structure reflecting some degree of oscillation between on and off states of attention, predicted intelligence scores, particularly verbal abilities. Mutual synchrony between mother and child correlated with organized infant play at both ages; with stochastic cyclicity at 3 months and stochastic process at 9 months. These patterns, in turn, predicted later intelligence. Global and microanalytic indices of maternal regulation at 3 months predicted visual IQ. In global analysis, maternal regulation was expressed by a general maternal tendency to adapt to the infant's signals and on a microanalytic level, as the mother's second-by-second synchrony with the infant's attentive states.

Face-to-face play was generally characterized by a predictable structure, a finding in line with previous reports (Cohn & Tronick, 1987; Kaye & Fogel, 1980). Time series of most mothers and infants were organized in a nonrandom stochastic process and the existence of stochastic process at both 3 and 9 months was related to 2-year IQ. Stochastic organization of early play may facilitate cognitive development for two complementary reasons: It permits some degree of regularity and predictability, yet enables flexibility and change. Sigman et al. (1981) suggested that the sense of stability in early interactions provides an important mediating link to later cognitive competence. To make sense of their environment, children need to integrate effectively between the rules of inner cognitive schemata and the variability of incoming stimuli (e.g., accommodation and assimilation, Piaget, 1963).

Stochastic cyclicity provides a link not only to complex cognitive processes, but also resembles physiological patterns of neural activity; a short period of intense activity followed by a longer period of rest. The existence of this pattern at 3 months, but not at 9 months, was predictive of verbal abilities. Fogel (1988) proposed that stochastic cyclicity represents an important step in the development of system regulation. It illustrates the system's ability to adhere simultaneously to two different temporal principles—physiological and psychological—which represent temporal determinism versus temporal variability. At 9 months, a less stringent temporal structure of stochastic process correlated with IQ. This finding may point to the developmental course of regulatory mechanisms during the first year. Toward the end of the first year, less repetitive mechanisms are possibly the more adaptive ones. The relation found in this study between the organization of attention during social interaction and cognitive abilities suggests that the ability to integrate order within variability effectively may be important for mental development.

Information-processing sequences are generated by stimulus input, followed by a period of processing in which stimuli are encoded. It is possible that infants who are able to shift regularly between attention and inhibition during social interactions are more efficient processors of information. Short habituation duration and stochastic cyclicity may both indicate the degree of attention regulation which, according to McCall (1994), is the underlying mechanism responsible for the continuity between habituation and intelligence. The validation of this hypothesis, however, awaits further research in which habituation performance of infants will be compared to their stochastic cyclicity in play.

Infant stochastic cyclicity was particularly related to verbal, in contrast to visual abilities. Similarly, habituation and novelty recognition tasks often correlate with later verbal skills (Slater, 1995). The cyclic rotation between communicative focus and rest underlies early covocalization (Feldstein et al., 1994) and enables continuity in the interaction. Mothers prime their infants to shift between periods of talking and listening, thus facilitating language acquisition (Beebe et al., 1988). The development of language draws on the abilities to organize repetitive stimuli (i.e., syllables, words, syntax) into a coherent sequence and to master interactive rhythms. Because habituation tasks may be related to regulation of attentive states, they may be associated more with verbal abilities than with perceptual–motor intelligence. DiLalla et al. (1990) attributed the lack of continuity between infant scores on measures developed by Bayley, Gessell, and Griffith and later IQ to the emphasis these scales place on perceptual–motor abilities, which are not necessarily continuous with cognitive measures of a verbal child.

Maternal regulation of infant states, both in term of second-by-second synchrony and global adaptation, are possibly related to cognitive development as mediators of the infant organization of attention. During face-to-face play, the level of arousal is particularly high, shifts of states are rapid, and the integration between social and cognitive inputs is essential for self organization, learning, and mastery. Maternal regulation of infants states at play correlated with a more organized infant play, and the association was both concurrent and long term. Although stochastic cyclicity may be an individual characteristic of infants, maternal regulation may structure the infant's attention to a more efficient information processing within the context of early interactions.

Cyclicity and synchrony at 3, as opposed to 9 months, predicted later intelligence and the predicting measures at 3 months, as compared to 9 months, accounted for a higher percentage of the variability in IQ. These findings are, once more, similar to the findings of habituation and novelty recognition tasks which predict IQ only between 4 and 8 months (McCall & Carriger, 1993). Similarly, theories of self-development (Sander, 1975; Sroufe, 1990) and studies of emotion regulation (Cassidy, 1994; Porges, Doussard-Roosevelt, & Maiti, 1994) stress the centrality of the infant's regulatory capacities during the first 6 months of life and the maternal function as an "external regulator" at that stage. According to Slater (1995), this period presents a "window of opportunity" for the observation of attention and information processing abilities. Between 2 and 4 months, infants develop the ability to shift regularly between engaging and disengaging from stimuli (Johnson et al., 1991). Infants who show a stochastic cyclicity at 3 months are possibly the quick-to-mature visual processors. At 9 months, mechanisms that limit sensory input are not required for neurological development, therefore quick habituation is achieved by all infants (Slater, 1995; Turkewitz & Kenny, 1982), and the existence of cyclic patterns do not predict intelligence. Furthermore, at 9 months, although the underlying temporal structure of infant play remains cyclic, infants do not cycle between states of attention and aversion, but rather between states of attention and social involvement (Feldman, 1993). It is possible that only the regulation of attention and inattention, presented at 3 months, predicts cognitive abilities.

Finally, comparisons between two levels of observation on similar phenomena—microanalytic and global—may enrich our understanding of developmental processes. In this study, two play measures, infant play involvement observed globally and stochastic cyclicity observed on a second-by-second level, each had an independent contribution to the prediction of Verbal IQ. The process by which infants organize attention as well as the level of social attention are both important components of cognitive competence. The examination of process (as indicated in microanalytic measures) and levels (global assessment) may be a fruitful way of examining early interactions (Horowitz, 1992). A possible contribution of this study is the suggestion that the integration of these measures, and not exclusive reliance on either one, may provide the key to a better understanding of early parent–child interactions.

The application of time-series analysis to the study of infant development may open new research vistas. Time-series analysis emphasizes the examination of interrelated processes and does not capitalize on the independence between observations, a necessary condition for the application of standard statistical tests. Cyclicity and synchrony may afford new theoretical and methodological perspectives on normal and pathological interactive processes and on the study of self-regulation and bidirectional mutuality. For the study of some infants at risk, especially those who suffer later problems of attention and state control (i.e., preterm infants, infants exposed to cocaine prenatally, infants with endocrinological deficiencies), standard psychometric assessment devices are often not specific enough. Although microanalytic coding demands much labor, conceptualization gained from split-second observations may lead to the development of computerized microanalytic assessment (reported for infant vocalizations by Feldstein et al., 1994) or coding systems that use larger time segments with similar focus. Examination of cyclicity and synchrony as regulatory mechanisms within the context of parent–child interaction may provide tools for future research concerning early diagnosis and assessment of intervention gains in infancy.

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