Sensitivity to interpersonal timing at 3 and 6 months of age*

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Sensitivity to interpersonal timing was assessed in mother–infant interaction. In Study 1, 3-month-old infants interacted with their mothers over television and the mothers' audio-visual presentation was either live or temporally delayed by 1 second. Infants gazed longer when the mother was presented live compared to delayed by 1 second, indicating that they detected the temporal delay. In Study 2, mothers interacted with their 3-month-old infants over television and the infants' audio-visual presentation was either live or temporally delayed by 1 second. Mothers' behavior was not altered by a 1-second delay in their infants' behavior compared to a live presentation. In Study 3 and 4, the results were replicated with 6-month-old infants. Whereas infants detected the temporal delay in maternal responses, mothers likely adjusted to the delay in infant behavior. The discussion focuses on the role of interpersonal timing for detecting social contingency in dyadic and triadic communication.

Keywords: infant, timing, interpersonal, social behavior

Interpersonal timing is a crucial aspect of human communication. Temporal coordination of behavior, i.e., changes in the timing of one individual's behavior in relation to the timing of another's behavior, has been called the "bedrock of all social interaction" (Crown, Feldstein, Jasnow, Beebe, & Jaffe, 2002; see also, Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001). This temporal coordination of behavior confers a predictable structure to social interaction and likely

enables the interactants to perceive their behavior as mutually responsive. Thus the perception of temporal coordination might be used to infer a sense of togetherness (see Hobson, 2002), which is essential for humans, a species that engages in much joint and collaborative activity (Tomasello, 1999).

Prior research on adult conversation suggests that matching of speech rhythms is related to perceived quality of interaction and interpersonal attunement. Partners tend to match pause duration both within and between turns in adult conversation (Jaffe & Feldstein, 1970), and pauses during speech that exceed 1 second are perceived as disruptive (Clark, 1996). This "vocal congruence" is thought to reflect interpersonal attunement, as evidenced by relatively more positive ratings of relationships by adults whose speech rhythms are more tightly matched (Feldstein & Welkowitz, 1978).

Similarly, interpersonal timing might play a role in establishing the first experiences of mutual responsiveness in early caregiver–infant interaction, i.e., of primary intersubjectivity (Rochat & Striano, 1999; Trevarthen, 1979). In these early face-to-face interactions, parents often mirror the infants' behavior in affective quality and properties like intensity and rhythm (Stern, 1985; Gergely & Watson, 1999). Moreover, parental responses generally occur within 1–2 seconds after the infants' behavior (Egeren van, Barratt, & Roach, 2001; Keller, Lohaus, Völker, Cappenberg, & Chasiotis, 1999; Nicely, Tamis-LeMonda, & Bornstein, 1999; Papousek & Papousek, 1987). Therefore, in addition to form and content, the timing of parental behavior provides infants with cues for detecting socially contingent behavior.

According to Papousek and Papousek (1987), this promptness of parental responses reflects an evolutionarily shaped behavior adapted to infant learning. Interestingly, a series of studies by Watson and colleagues have shown that young infants would learn the contingent relatedness between their own action (e.g., leg kicking) and an outcome (e.g., movement of a mobile) only if the response-contingent stimulus occurred within 3 seconds after the infant's response (e.g., Millar & Watson, 1979; Watson, 1967). Thus, a parental response latency of 1–2 seconds falls within this 3-second time constraint on infant contingency detection in an instrumental learning situation. It is likely that there is a similar time constraint on infants' ability to detect the contingent relatedness between their own behavior and a parental response in social interaction. If so, then the prompt timing of parental behavior likely enables infants to detect socially contingent interactions. Detecting the contingency of their parents' behavior is necessary for infants to experience such behavior as a meaningful response to their own (Egeren van et al., 2001; Watson, 1979).

Prior research suggests that timing is an independent component of parenting behavior, as promptness of maternal behavior was not associated with warmth and affection (Keller et al., 1999; Lohaus, Keller, Ball, Elben, & Völker, 2003). Similarly, contingency and timing are likely independent dimensions of parental responsiveness. Whereas contingency conveys information about the probability of relatedness between events, timing conveys information about the distance between events with respect to a time line. For example, temporal contingency conveys information about the sequential relatedness between a maternal and an infant behavior and about the predictability of their relatedness, whereas timing of maternal responses pertains to the temporal interval between a maternal and an infant behavior.[1] Although maternal responses tend to be highly contingent as well as prompt, higher degrees of contingency do not imply greater promptness or vice-versa.[2] The goal of the current study is therefore to examine whether infants are sensitive to changes in the timing of maternal responsiveness, independent of social contingency.

From early on, infants perceive a variety of temporal information in stimulation, such as duration, rhythm, and rate, both within and across sensory modalities (see Lewkowicz, 2000, for a review), and discriminate differences of 25 msec. in speech and non-speech durations by 2 months of age (Jusczyk, Pisoni, Reed, Fernald, & Myers, 1983; see also Friederici, Friedrich, & Weber, 2002). This ability to perceive temporal information likely buttresses infants' early ability to temporally coordinate their behavior within fractions of a second with that of an adult social partner (Beebe, Alson, Jaffe, Feldstein, & Crown, 1988; Crown et al., 2002; Jaffe et al., 2001). By the time infants are 4 months of age, mother–infant vocal interaction shows a turn taking structure with switching pause congruence similar to that of adult conversation. Moreover, a high degree of intrapersonal pause matching within dyads is positively related to infant affective engagement (Beebe et al., 1988). These findings point to the possible role of timing in early social interaction and its relation to infant affect. However, the question remains whether young infants are sensitive to timing cues provided in early caregiver–infant interaction.

A series of studies have employed the closed-circuit double video paradigm developed by Murray and Trevarthen (1985) to assess infants' early sensitivity to social contingency (e.g., Bigelow & DeCoste, 2003; Bigelow, MacLean, & MacDonald, 1996; Hains & Muir, 1996; Nadel, Carchon, Kervella, Marcelli, & Réserbat-Plantey, 1999; Rochat, Neisser, & Marian, 1998). In this experimental procedure, infants interacted face-to-face with their mothers over a video system. In an initial live interaction the partners' audio-visual information was transmitted in real time. In a subsequent replay interaction, infants were pre-

sented with an audio-visual recording of their mother during the previous live interaction. Thus, in the replay period, contingency of maternal behavior upon infant behavior was unlikely and possible only by chance. Infants between 6–12 weeks of age responded with more positive behavior, such as gazing and smiling, and less self-comforting behavior in the live compared to the replay period (Murray & Trevarthen, 1985). Many research teams have attempted to replicate these results with different age groups and slight methodological variations. Despite controversial results for 2-month-olds (Bigelow & DeCoste, 2003; Nadel et al., 1999; Rochat et al., 1998) and for 5- to 6-month-olds (Bigelow & DeCoste, 2003; Bigelow et al., 1996; Hains & Muir, 1996; Rochat et al., 1998), findings suggest that by 4 months, if not earlier, infants are sensitive to the interruption of contingency in social interaction.

In the replay paradigm, however, the timing of maternal responses cannot be manipulated independently of other aspects of maternal behavior. In the present study, we thus developed a new paradigm with which it was possible to manipulate only the timing of responses while maintaining all other aspects of social contingency. Mothers and infants interacted over a double video system in real time (Live condition) and a temporal delay of 1 second was imposed within the on-going interaction per infant or mother (Delay condition). Thus, in this study only the timing of responses was manipulated and not their temporal contingency, i.e., responses were temporally delayed by 1 second without altering the probabilities with which one partner's behavior preceded and followed the other partner's behavior (Watson, 1997). However, timing and temporal contingency are related in that a temporal delay in responses exceeding 3 seconds likely interferes with infants' contingency detection (Millar & Watson, 1979; Watson, 1967). Hence in the present study, we assumed that contingency of maternal responses was maintained by employing a temporal delay of only 1 second.

Based on research on early temporal coordination in caregiver–infant interaction (e.g., Beebe et al., 1988; Crown et al., 2002), and given infants' early abilities in temporal perception (e.g., Lewkowicz, 2000), we expected that by 3 months of age infants would detect a change in timing of maternal responses. Mothers tend to respond to infants within a 1-second range (see Keller et al., 1999; Papousek & Papousek, 1987). Also, when talking to 3-month-olds, adults' vocal phrases are less than 1 second in duration, and their vocal pauses are close to 1 second (Stern, Beebe, Jaffe, & Bennet, 1977). Based on this promptness of response latency, the duration of adult vocal phrases and pauses, and the successful use of a 1-second time interval in analyses of contingency in mother–infant interaction (e.g., Bigelow, 1998; Symons & Moran, 1994), we expected

that a 1-second delay would be within the range detectable by infants. Given discrepancies in prior research reviewed above regarding the age of onset of sensitivity to social contingency, infants were tested at 3 and 6 months of age.

In addition to assessing infants' sensitivity to a temporal delay in maternal interaction, we also assessed mothers' sensitivity to a 1-second delay in infants' behavior at 3 and 6 months of age. Prior research has shown that in face-to-face interaction infants are less responsive than mothers (e.g., Egeren van et al., 2001; Symons & Moran, 1994), and that different from parental behavior, infant behavior is not characterized by short latency (Keller et al., 1999). We therefore used the working hypothesis that mothers are used to their infants' responses being less predictable than their own, and expected that mothers would not respond differently when their 3-month-old infants' behavior was live versus delayed. However, prior research has further shown that infants' social repertoire increases between 3 and 6 months of age, and that synchrony and matching within the dyad increases with infant age (e.g., Cohn & Tronick, 1987; Kaye & Fogel, 1980; Messer & Vietze, 1984; Rochat, Querido, & Striano, 1999; Tronick & Cohn, 1989). Given these findings, mothers might expect a greater responsiveness of 6-month-olds compared to 3-month-olds. We therefore expected that mothers would respond differently when their 6-month-old infants' behavior was live versus delayed.

In Study 1, 3-month-old infants interacted with their mothers over television and the mothers' audio-visual presentation was either live or temporally delayed by 1 second. In Study 2, mothers interacted with their 3-month-old infants over television and the infants' audio-visual presentation was either live or temporally delayed by 1 second. Similarly, in Study 3, 6-month-old infants interacted with their mothers over television and the mothers' audio-visual presentation was either live or temporally delayed by 1 second and, in Study 4, mothers interacted with their 6-month-old infants over television and the infants' audio-visual presentation was either live or temporally delayed by 1 second.

Method

Participants

Participants came from a small city in the east of Germany (see Table 1). Parents were contacted by telephone from a list of families who had expressed interest in volunteering for research on infant development. Infants came from

Table 1. Participants in Studies 1–4.

Study	Delayed	Age	Age in days			N (females)
			M	SD	range	
1	mother	3 months	97.97	12.02	76–128	34 (16)
2	infant	3 months	102.48	6.83	93–119	33 (20)
3	mother	6 months	182.24	15.15	135–200	29 (10)
4	infant	6 months	173.85	16.96	141–196	26 (11)

Note. Among all studies, an additional 24 infants were tested but excluded because they never looked at the stimulus ($n=6$), were fussy for more than 30 seconds ($n=7$), because of experimental error ($n=10$), or because the adult who accompanied the child was not the primary caregiver ($n=1$).

middle class background based on parental reports. They were given a small gift for participating.

Set-up and apparatus

As shown in Figure 1, a double closed-circuit color monitor system was built similar to that used by Murray and Trevarthen (1985) and Rochat et al. (1998). The apparatus was set up in two different rooms. The caregiver's image was transmitted to the infants' monitor and vice versa. A steel frame supported a TV monitor facing down. The image was reflected onto a one-way mirror, positioned diagonally in the steel frame and reflecting the partner's video image at eye level. Digital video cameras positioned at eye-level behind the mir-
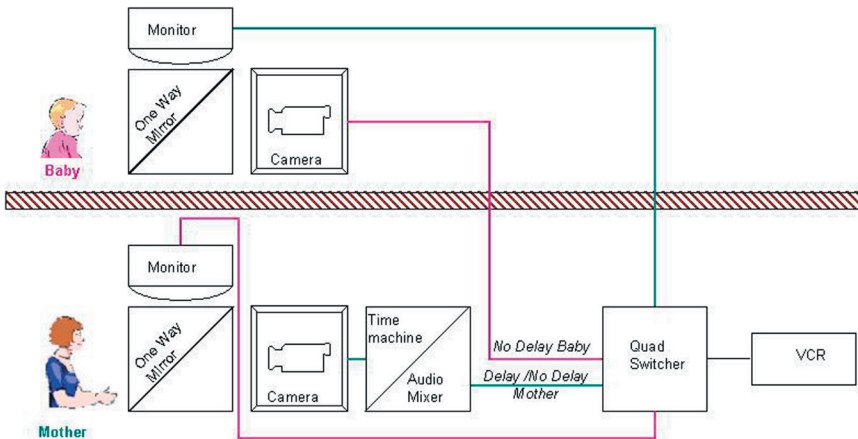

Figure 1. Experimental set-up.
Note. Figure 1 shows the set-up of Studies 1 and 3, where infants interacted with the live or delayed image of their mother. In the set-up of Studies 2 and 4, the positions of mother and infant are reversed.

rors filmed the interaction. The cameras connected to a Quad splitter that connected to an audio-video delay system (Prime-image Pipeline S/N 5207). As shown in Figure 2, the image and sound were recorded on a digital VCR on which one experimenter monitored the interaction. Caregiver and infant wore headphones that were connected to the audio input of the TV monitor so that the audio delay would be consistent with the image in the delay condition. The camera filming the infant had a microphone that recorded the infant's sound. To assure that infants could hear their mothers, even when they whispered, maternal sound was recorded by an external microphone that was attached to the bottom rim of the one-way mirror (i.e., at a 10–20 cm from the mother's face) and connected to the camera filming the mother. The recording of the digital VCR was used for later coding.

Figure 2. Synchronized image of 3-month-old infant and caregiver in the Live condition.

Note. Figure 2 depicts the recorded, synchronized image of infant and caregiver that corresponds to the Live condition in Studies 1 and 3, where infants interacted with the live or delayed image of their mother. Panel 1 corresponds to the image of the partner that is seen always live (the infant in Study 1). Panel 2 corresponds to the image of the partner that is seen either live or delayed (the caregiver in Study 1). Panel 3 corresponds to the live image of the partner that is seen either live or delayed (the caregiver in Study 1). The image on Panel 3 is not displayed on any partner's monitor. The images on Panels 2 and 3 match during Live and don't match during Delay.

Procedure

Caregiver and infant sat in separate rooms and interacted over the TV monitors. Infants sat in a commercial infant seat. Caregivers were instructed to interact with their infant as they normally would for 4 minutes. The interaction was separated into two 2-minute seamless segments. For 2 minutes the dyad interacted in real time (Live condition), and for 2 minutes the image and voice of one partner was delayed by 1 second (Delay condition). The order of conditions was counterbalanced across infants. An experimenter, hidden from the infant by a white curtain, monitored the time from the timeline imposed on the video recording, which was displayed on the screen of the mini-digital VCR, and implemented the seamless delay or switch back to non-delay, by pressing a button on the delay-device. Another experimenter stayed in the adult's room and overlooked the quality of the mother's video image. Mothers were told that the study assessed infants' ability to recognize their mothers when interacting with them over television. Only following testing caregivers were debriefed about the purpose and design of the study.

Coding

Trained coders coded the video recordings of the interaction sessions. Main coders and coders for reliability of all studies were naïve to the hypotheses of the study. The videotapes were coded in real time using a computerized coding system (Interact 6.8, Thiel, 2002) designed to register the occurrence of the different behaviors via an event recorder. Coders viewed each behavior separately, and activated the event recorder with different keys on the computer keyboard corresponding to the occurrence of the following infant and maternal behaviors:

Infant behaviors:
a.   Gazing: any look to the mother's image on the monitor.
b.   Smiling: raised cheeks and corner of lips turned up with mouth open or closed.
c.   Positive vocalizing: vocalizing with an overall positive or neutral quality.
d.   Negative vocalizing: fussing, crying and vocalizing with a protest-like quality.

Maternal behaviors:
e.   Gazing: any look to the infant's image on the monitor.

f.   Smiling: raised cheeks and corner of lips turned with mouth open or closed.

g.   Vocalizing: any utterances that mothers produced.

For inter-observer reliability, a second observer coded a random 20% of all infant and maternal measures. Cohen's Kappas were calculated with a 1-second accuracy interval and using a computerized program (Interact 6.8, Thiel, 2002). Across studies, Kappas ranged from 0.83 to 0.95 for infant gazing, from 0.73 to 0.90 for infant smiling, from 0.71 to 0.82 for infant positive vocalizing, from 0.74 to 1.0 for infant negative vocalizing, from .95 to 1.0 for maternal gazing, from .76 to .83 for maternal smiling, and from 0.66 to 0.78 for maternal vocalizing.[3]

Analyses

The analyses were done using the percentage of time a behavior (smiling, gazing, or vocalizing) was shown during each experimental condition. We used General Linear Mixed Models (GLMMs) to assess whether infant behaviour (Studies 1 and 3) varied in dependency of maternal timing (Live vs. Delay), while controlling for possible confounding effects of maternal behaviour. By including maternal behaviors as continuous covariates in the model we can assess the effect of maternal timing while statistically factoring out the effects of maternal behaviour, e.g., in Studies 1 and 3, a GLMM allows us to assess if there is a significant difference in infant behavior between the two maternal timing conditions while keeping the amount of time of maternal behavior constant. Similarly, in Studies 2 and 4, we assessed whether mother's behavior varied in relation to the timing of infant responses while controlling for possible confounding effects of infant behaviour.

A GLMM is an extension of the General Linear Model, which accounts for repeated observations on the same subject (Pinheiro & Bates, 2000). It allows analysis of the effect of categorical (timing condition, order) and continuous variables (e.g., maternal behavior) on a dependent continuous variable (e.g., infant behavior). Restricted maximum likelihood method was used to estimate the models and Satterthwaites F-test was employed for fixed parameter effects.[4] Covariates were only included as main effects, and non-significant factors were removed from the final model. GLMMs were run for every infant and maternal measure, and preliminary analyses yielded no main effects of order or gender.[5] All means are presented in Tables 2 (3-month-olds) and 3 (6-month-olds). A null hypothesis was rejected at an α-level of 0.05.

Table 2. Study 1 and 2: Means and standard deviations for infant and maternal behavior in percent of time in conditions Live and Delay at 3 months

	Behavior	Study 1				Study 2			
		Live		Delay (mother)		Live		Delay (infant)	
		M	(SD)	M	(SD)	M	(SD)	M	(SD)
Infant	Gazing	57.91*	(29.63)	41.85	(32.47)	59.42	(32.00)	56.90	(31.88)
	Smiling	4.87	(9.29)	2.65	(8.21)	5.90	(10.34)	4.01	(6.04)
	Pos. Vocalizing	0.88	(2.57)	0.78	(2.26)	2.22	(4.35)	2.57	(7.69)
	Neg. Vocalizing	1.69	(3.78)	3.04	(8.47)	1.48	(4.42)	2.52	(7.29)
Mother	Gazing	99.35	(1.15)	99.12	(1.39)	96.12	(13.64)	94.95	(15.59)
	Smiling	26.26	(11.91)	21.60	(11.02)	18.86	(12.77)	20.00	(17.08)
	Vocalizing	52.58	(17.29)	48.78	(15.18)	45.73	(13.66)	42.58	(14.35)

Note. $*p < .05$, p values refer to significance of condition when statistically controlling for the other partner's behavior.

Table 3. Study 3 and 4: Means and standard deviations for infant and maternal behavior in percent of time in conditions Live and Delay at 6 months

	Behavior	Study 3				Study 4			
		Live		Delay (mother)		Live		Delay (infant)	
		M	(SD)	M	(SD)	M	(SD)	M	(SD)
Infant	Gazing	69.36*	(22.46)	61.96	(20.68)	77.37	(15.06)	75.65	(17.97)
	Smiling	5.67	(12.59)	4.58	(9.65)	5.80	(7.82)	5.37	(8.59)
	Pos. Vocalizing	1.53	(4.76)	0.53	(1.34)	3.84	(5.69)	3.23	(7.65)
	Neg. Vocalizing	2.64	(9.77)	2.52	(5.25)	3.20	(9.76)	7.47	(22.50)
Mother	Gazing	99.80	(0.37)	99.35	(1.72)	99.62	(0.63)	99.21	(1.27)
	Smiling	34.98	(19.11)	33.98	(22.23)	28.25	(19.54)	25.56	(16.87)
	Vocalizing	50.44	(15.66)	50.63	(15.15)	60.85	(11.92)	59.83	(16.55)

Note. $*p < .05$, p values refer to significance of condition when statistically controlling for the other partner's behavior.

Results

Effects of Live and Delay conditions on maternal and infant behavior

Study 1. Three-month-old infants interacted with their mothers over television and the mothers' audio-visual presentation was either live or temporally delayed by 1 second. Results yielded a significant effect of condition for infant gazing, $F(1, 34.3) = 5.08$, $p < .05$. Infants gazed reliably more at their mother's video image when she was interacting live compared to when her responses were delayed by 1 second, when statistically controlling for the influence of

maternal behavior on infant behavior. There were no significant effects of condition for any other infant or maternal measure, $ps > .16$.

Study 2. Mothers interacted with their 3-month-old infants over television and the infants' audio-visual presentation was either live or temporally delayed by 1 second. Results yielded no significant effects of condition for any infant or maternal measure, $ps > .10$. Infant and maternal behavior did not differ as a function of Live and Delay conditions.

Study 3. Six-month-old infants interacted with their mothers over television and the mothers' audio-visual presentation was either live or temporally delayed by 1 second. Results yielded a significant effect of condition on infant gazing, $F(1, 27.0) = 4.38$, $p < .05$, when statistically controlling for the influence of maternal behavior. Infants gazed reliably more at their mother's video image when she was interacting live compared to when she was interacting delayed by 1 second. There were no significant effects of condition for any other infant or maternal measure, $ps > .13$.

Study 4. Mothers interacted with their 6-month-old infants over television and the infants' audio-visual presentation was either live or temporally delayed by 1 second. Results yielded no significant effects of condition for any infant or maternal measure, $ps > .08$. Infant and maternal behavior did not differ as a function of Live and Delay conditions.

Relations between maternal and infant behavior

In all studies, there were several significant relations between maternal and infant behavior, independent of condition, i.e., when statistically controlling for the effect of Live and Delay conditions on maternal and infant behavior. All significant relations are presented in Table 4. In addition to the F statistics, the regression coefficients (β) of significant covariates are presented. At both ages, independent of condition, and when both maternal (Studies 1 and 3) or infant behavior (Studies 2 and 4) was temporally delayed, there was a general tendency for an increase in maternal behavior to be related to an increase in infant attention and positive affect. For example, the more infants gazed (in percent of time) at their mother's video image, the more mothers vocalized to their infants (Studies 1–4). Similarly, the more infants smiled, the more mothers smiled to their infants (Studies 1, 2, and 4). Importantly, although the same relations were not found in each study, relations between maternal and infant behavior were consistent within and between studies in terms of

Table 4. Relations between covariates and dependent variables for every GLMM across Studies 1–4.

	Study	DV	Infant gazing	Infant smiling	Infant pos. voc.	Infant neg. voc.
Maternal gazing	1	I	ns	ns	ns	$F(1,57.2)=7.17, p=.010, \beta=-1.75$
		M	$F(1,63.8)=5.35, p=.024, \beta=.01$	ns	ns	$F(1,55.5)=8.36, p=.005, \beta=-.06$
	2	I	ns	ns	ns	$F(1,35.9)=6.86, p=.013, \beta=-.15$
		M	ns	$F(1,33.7)=16.69, p<.001, \beta=.03$	ns	ns
	3	I	ns	ns	ns	ns
		M	ns	ns	ns	ns
	4	I	ns	ns	ns	ns
		M	ns	ns	ns	ns
Maternal smiling	1	I	$F(1,59.5)=15.16, p<.001, \beta=1.1$	$F(1,48.4)=15.77, p<.001, \beta=.24$	ns	ns
		M	$F(1,59.5)=11.66, p=-.001, \beta=.14$	$F(1,57.2)=11.58, p=.001, \beta=.59$	ns	ns
	2	I	$F(1,58.1)=8.13, p=.006, \beta=.65$	ns	ns	ns
		M	$F(1,62.0)=5.96, p=.017, \beta=.15$	$F(1,46.0)=6.83, p=.012, \beta=.44$	ns	ns
	3	I	ns	ns	ns	ns
		M	$F(1,44.8)=4.80, p=.034, \beta=.22$	ns	ns	ns
	4	I	ns	$F(1,47.5)=16.13, p<.001, \beta=.23$	ns	$F(1,36.6)=5.24, p=.028, \beta=-.31$
		M	ns	$F(1,45.3)=20.16, p<.001, \beta=1.15$	ns	$F(1,30.1)=10.52, p=.003, \beta=-.28$
Maternal vocalizing	1	I	$F(1,60.6)=4.69, p=.034, \beta=.53$	ns	ns	ns
		M	$F(1,54.0)=6.15, p=.016, \beta=.12$	ns	ns	ns
	2	I	ns	$F(1,50.0)=10.81, p=.002, \beta=.23$	ns	ns
		M	$F(1,60.6)=5.45, p=.023, \beta=.12$	$F(1,45.6)=12.27, p=.001, \beta=.49$	ns	$F(1,53.1)=5.80, p=.019, \beta=.21$
	3	I	$F(1,49.3)=5.03, p=.029, \beta=.43$	ns	ns	ns
		M	$F(1,52.1)=4.63, p=.036, \beta=.18$	ns	ns	ns
	4	I	ns	ns	ns	ns
		M	$F(1,30.9)=9.0, p=.005, \beta=.23$	ns	ns	ns

valence. Maternal behaviors correlated positively with infant behaviors index-ing attention and positive affect (i.e., gazing, smiling and positive vocalizing), and except for one relation, maternal behaviors correlated negatively with in-fant negative vocalizing indexing negative affect. Overall, maternal and infant behaviors were consistently related, within and between studies, and indepen-dent of conditions Live and Delay.

Discussion

Social contingency in mother–infant interaction has been extensively studied (e.g., Gergely & Watson, 1999; Symons & Moran, 1994; see also Rochat, 1999). Although an important aspect of early social interaction, sensitivity to inter-personal timing has never been assessed independent of social contingency. The goal of the current series of studies was therefore to assess infant and care-giver sensitivity to only the timing in interaction, at the ages of 3 and 6 months. Infants interacted with their mothers over television, and the amount of time that they gazed, smiled and vocalized at each other during a real-time interac-tion (Live) was compared to their behaviors in an interaction where the audio-visual presentation of the mother (Studies 1 and 3) or the infant (Studies 2 and 4) was temporally delayed by 1 second (Delay).

We predicted that at both ages infants would detect a temporal delay in maternal responses, indexed by a decrease in visual attention and positive af-fect in the Delay compared to the Live condition. Results were in accordance with predictions for infant gazing. Three- and 6-month-olds gazed more re-liably at their mother's image when she interacted in real time compared to when she was delayed by 1 second, independent of maternal behavior (Studies 1 and 3). This decrease in infant attention in the Delay compared to the Live condition suggests that at both ages infants were sensitive to the 1-second delay implemented in the face-to-face interaction. These results are consistent with research on temporal coordination in early dyadic interactions (e.g., Crown et al., 2002), and support and extend prior findings of Murray and Trevarthen (1985) and Nadel et al. (1999)[6] that by 3 months of age infants are not only sensitive to overall interpersonal contingency but also to the timing of social interaction.

Whereas in previous studies using a replay or still-face paradigm, infants generally both gazed and smiled less when social contingency was interrupted (e.g., Adamson & Frick, 2003; Murray & Trevarthen, 1985), in the current work using a delay paradigm, condition effects were apparent only for infant gazing

response but not for infant smiling and vocalizing (Studies 1 and 3). These differences between infant attention and affect may be accounted for by a differential influence of present and past interactions as found by Bigelow and Birch (1999). Infants in their study were simultaneously presented with two strangers interacting via video with the infant. One stranger interacted contingently (live) and the other noncontingently (replay), and infants gazed and smiled more to the contingent stranger. In a second interaction 6 days later, the same strangers now both interacted contingently (live), and infants smiled equally at both but attended more to the one that had previously been contingent. The authors suggested that infant attention and affect are regulated by two systems that may operate independently, with infant affect being more influenced by the current interaction, and infant attention being also influenced by expectations resulting from past experiences.

Similarly, in Studies 1 and 3 of the current work, the absence of a condition effect on infant affect may be explained by the contingent nature of the interaction, while the decrease in infant visual attention in the Delay compared to the Live condition may be explained by the infant's expectation of prompt maternal responses based on prior experience. The absence of a condition effect on infant smiling and vocalizing indicated that infants were not perturbed by this temporal delay and suggests that 1-second delay likely did not interfere with contingency detection (e.g., Watson, 1967), and hence with affective attunement (Stern, 1985) within the dyad. The relations found between maternal and infant behavior further support this assumption, as they point to a mutual attunement between partners, independent of changes in the timing of one partner's behavior. As to the results for infant visual attention, infants form expectations regarding the nature of dyadic interaction from early on (e.g., Rochat, 1999), and not only expect their social partner's behavior to be responsive upon their own (e.g., Adamson & Frick, 2003), but also discriminate and prefer familiar over unfamiliar degrees of social contingency (Bigelow, 1998). Similarly, and given that parents tend to respond to infant behavior within 1–2 seconds (e.g., Keller at al., 1999; Papousek & Papousek, 1987), infants might come to expect a familiar degree of promptness of parental responses. Hence, infants likely lost interest in the interaction when maternal timing differed from a familiar level of promptness, as indexed by a decrease in the time they gazed at their mother's TV image in the Delay compared to the Live condition (Studies 1 and 3).

Since infants are less responsive than mothers (e.g., Symons & Moran, 1994) but synchrony and matching within the dyad increases with age (Tronick & Cohn, 1989), we had predicted that mothers of 6-month-olds but not of

3-month-olds would behave differently across conditions. However, we found that at both ages, mothers did not behave differently when the infants' behavior was live versus delayed. One possible explanation for these results is that mothers did not notice the temporal delay in their infant's behavior, as mothers are likely accustomed to infants being less responsive and to respond less promptly compared to themselves (e.g., Egeren van et al., 2001; Keller et al., 1999; Symons & Moran, 1994).

Alternatively, and in line with prior research on maternal adjustment to infant attentional, affective and behavioral state (e.g., Brazelton et al., 1974; Collis & Schaffer, 1975; Stern, 1985), mothers might have noticed a difference in their infants' behavior in the Delay compared to the Live interaction (Studies 2 and 4) but were not disturbed by it and in that sense adjusted to it. Especially at 6 months, when mothers should expect a higher degree in synchrony and matching than at 3 months (Tronick & Cohn, 1989), they might have detected but adjusted to the delayed interaction of their 6-month-olds. However, the negative results only allow speculations regarding maternal awareness of a difference in infant behavior. Since the absence of condition effects on maternal behavior does not necessarily index maternal unawareness of a difference in infant behavior, in a similar study and using the same delay paradigm, we are currently assessing mothers' awareness of the experimental manipulation via interview.

The relations found between maternal and infant behavior, however, point to maternal adjustment to the temporal delay in infant behavior. Although direction of effects cannot be established from correlational data, it is interesting to note that infant behavior varied both as a function of condition (Studies 1 and 3) and in relation to maternal behavior (all studies), whereas maternal behavior only varied in relation to infant behavior (all studies). Also, relations between maternal and infant behavior were systematic within and between studies in terms of valence. For example, an increase in maternal smiling consistently related to an increase in infant gazing and smiling. These relations between maternal and infant behavior together with an absence of condition effect on maternal behavior suggest that mothers in the present study were engaging in affect-mirroring (e.g., Gergely & Watson, 1996) throughout the session and adjusted to temporal delays in the infant's behavior, e.g., the more the infant smiled the more mothers smiled, regardless of the timing of the infant's smile.

In sum, our findings suggest that while mothers adjust to a 1-second delay in infant behavior, infants expect prompt responses and detect disruptions of a familiar level of timing. This suggestion is consistent with prior research

indicating that while mothers provide and maintain contingency (Tronick & Cohn, 1989; also Gergely, personal communication, July, 2003), infants expect contingent interaction and are sensitive to disruptions of a familiar level of contingency (e.g., Adamson & Frick, 2003; Bigelow, 1998; Nadel et al., 1999; see also Gergely & Watson, 1996, 1999).

We propose that timing and contingency are distinct but interrelated dimensions of parenting behavior. Young infants' perception of timing cues is likely involved in experiencing a sense of togetherness and mutual responsiveness in early dyadic interaction (e.g., Hobson, 2002), as timing provides a cue for the relatedness of parents' responses upon the infants' behavior. Watson (e.g., 1967) has provided evidence for a 3-second time constraint on infant detection of temporal contingency in non-social contexts. There is likely a similar time constraint on infant perception of temporal contingency in social interaction, as infants' sensitivity to contingencies pertaining to interaction with both the physical and social world, is thought to be mediated by the same innate "contingency detection module" (Gergely and Watson, 1999). The present finding that only infant attention but not affect (e.g., smiling and vocalizing) was influenced by a 1-second delay in maternal responses suggests that this temporal delay did not interfere with infant contingency detection. To further address this question we are currently extending the temporal delay to 3 seconds to assess whether a 3-second delay would instead interfere with infant contingency detection.

Sensitivity to interpersonal timing may also play a role in triadic contexts in which two partners' interaction is about a third entity, as timing may provide cues about the referential aspects of communicative signals. Understanding referentiality requires understanding that signals are about something and perceived as relevant (see Baldwin, 1993). Relevance of communicative signals is determined not only by the quality of information, but also by the timing of such signals. In studies assessing infants' understanding of the intentions underlying others' actions (e.g., Carpenter, Akhtar, & Tomasello, 1998; Tomasello & Barton, 1994), adults utter expressions like "There!" or "Whoops!" to mark a performed action as a success or failure of achieving the intended goal. The timing of these cues is likely essential for infants to perceive the performed action as intentional or accidental, once they understand intentionality. Future research is needed to investigate the mechanisms that promote sensitivity to temporal aspects of social contingencies in affective dyadic contexts as well as in referential triadic contexts.

Developmental research on infant detection of interpersonal timing could also be relevant to robotic systems that learn in interaction with a responsive,

scaffolding instructor (e.g., Breazeal & Scassellati, 2002). For example, a robot motivated to engage in an imitation game should select as model that agent in the environment who promptly responds to his overture, and should disengage from inattentive agents. Also, in an imitation game with a turn-taking structure, the timing of the model's behavior could serve as a cue to when the model's action is a response (feedback) compared to when it is a new action. If the model's action occurs within a time interval x, then it is a response and the topic of interaction remains the same. If the model's action occurs after a time interval x, then a new topic will be introduced and the robot needs to reorient attention, e.g., to the model's face if direction of regard is used as a cue to the topic of interaction. To conclude, timing provides a cue to contingent relatedness in dyadic as well as in triadic social interaction, and might therefore be used to detect the responsive nature of others' behavior to one's own, i.e., to establish when to consider others' behavior as response to one's own.

Notes

1. Please note that we distinguish between contingency and timing as well as between different sources of contingency, i.e., time, space and sensory relations (Watson, 1984).

2. For example, it is possible that in two dyads both mothers respond to their infant's smiles with an average latency of 1 second, but in one dyad, an infant smile precedes and is followed by a maternal response in 9 out of 10 times, whereas in the other dyad, an infant smile precedes and is followed by a maternal response in only 6 out of 10 times.

3. All Kappas reported were calculated using a computerized program that takes 1/25 seconds (25 frames/second) in account. When calculating Kappa by hand and taking only full seconds in account, for maternal vocalizing in Study 1 Kappa is .955 (and .66 when calculated by computer). There was a strong correlation between percent of time per dyad between the two coders (Pearson's correlation: $r = .973$, $p < .001$), and mean difference between coders was less than 4%.

4. Because Satterthwaites F-tests do not have exact F-distributions, the denominator degrees of freedom are real numbers.

5. For GLMMs, preliminary analyses with gender and order as independent factors yielded some significant interactions. Given that these were unsystematic, gender was collapsed in the subsequent analyses. For detailed statistics involving gender, please contact the corresponding author.

6. Note that Murray and Trevarthen (1985) tested 6- to 12-week-olds and that Nadel et al. (1999) tested 9-week-olds. Infants tested here were 3 and 6 months old.

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