Developmental Science 8:6 (2005), pp 509–518

REPORT

Sensitivity to social contingencies between 1 and 3 months of age

Tricia Striano,[1,3,4] Anne Henning[1] and Daniel Stahl[2]

1. *Max Planck Institute for Evolutionary Anthropology, Cultural Ontogeny, Leipzig, Germany*
2. *Max Planck Institute for Evolutionary Anthropology, Developmental and Comparative Psychology, Leipzig, Germany*
3. *Max Planck Institute for Human Cognitive and Brain Sciences, Neurocognition and Development, Leipzig, Germany*
4. *Center for Advanced Studies, Neurocognition and Development, University of Leipzig, Germany*

Abstract

Infants' sensitivity to social contingencies was assessed. In Study 1, 1-month-old infants and their mothers interacted face-to-face in three types of imperfect contingent interactions: Normal, Non-Contingent and Imitation. One-month-old infants did not discriminate these conditions. In Study 2, 3-month-old infants were tested as in Study 1. At 3 months of age, infants gazed reliably longer in the Imitation condition and smiled reliably more in the Normal than in the Non-Contingent and Imitation interactions. These findings suggest a developmental transition in the sensitivity to social contingencies between 1 and 3 months of age. The relationship between the developing sensitivity to social contingencies and social cognition is discussed.

> At the age of two to three months, infants begin to give the impression of being quite different persons. When engaged in social interaction, they appear to be more wholly integrated. It is as if their actions, plans, affects, perceptions, and cognitions can now all be brought into play and focused, for a while, on an interpersonal situation. (Stern, 1985/2000)

Much research on the behavioral development of human infants points to a dramatic transition occurring sometime around the second month. Infants by the second month focus their attention on the internal features of faces (Haith, Bergman & Moore, 1997; Maurer & Salapatek, 1976), spend more time in an awake and alert state (Wolff, 1987) and reciprocate in the context of face-to-face interactions (Fogel, 1993; Trevarthen, 1979). In addition, infants show changes in their sensitivity to contingencies. In general, sensitivity to contingency is a well-documented fact in human infancy. Infant learning and self-efficacy is moderated by the degree of control that they have over their surroundings (Watson, 1972; Watson & Ramey, 1972). By 2 months of age, infants manifest positive affect when they can control an event (Lewis, Sullivan & Brooks-Gunn, 1985) and start to pay special attention to the quality of effects that they cause in the environment (see also Rochat & Striano, 1999).

Reciprocal social interactions that include aspects of imitation and affective attunement are thought to play a key role in the development of human social understanding, which includes an understanding of intentional relations (Barresi & Moore, 1996; Iacoboni, 2005; Stern, 1985/2000). Given the role of social interaction in communicative development, researchers have looked to the ontogeny of social sensitivities – what exactly is it that infants are sensitive to and when do such sensitivities begin?

A variety of paradigms have been developed and employed over the last decades to address this question. The still-face paradigm has been widely used to assess infants' social expectations (Tronick, Als, Adamson, Wise & Brazelton, 1978). In the traditional paradigm, infants engage for several minutes in a normal face-to-face interaction with an adult social partner. This dyadic interaction is halted when the adult suddenly holds a neutral still face. By 2 months of age, infants react to the still face with reduced smiling and gazing, together with increased self-comforting (Muir & Hains, 1993; Toda & Fogel, 1993; Tronick *et al.*, 1978). In the mid-1980s, Murray and Trevarthen (1985) developed a new paradigm to overcome the abrupt loss of social contact in the still-face procedure. Infants and mothers interacted via a closed-circuit television, and infants were presented with either a video of their mother interacting with them live, or were presented with a replay of her interacting. Thus,

Address for correspondence: Tricia Striano, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, Leipzig, Germany; e-mail: striano@cbs.mpg.de

in the replay period, the mothers' behavior was not synchronous with or contingent upon the infants' behavior. Infants between 6 and 12 weeks of age responded with more positive behavior such as gazing and smiling in the live compared to the replay period. These results suggested sensitivity to social contingency, and are significant since such sensitivity is considered to be a precursor to later social competencies (see Nadel, Carchon, Kervella, Marcelli & Réserbat-Plantey, 1999; Rochat & Striano, 1999). Many research teams have attempted to replicate these findings with different age groups and with slight procedural modifications.

Hains and Muir (1996) found that at 5 months of age, human infants did not discriminate between seeing a live or replay interaction of their mother, but that they did for a stranger (see also Bigelow, MacLean & MacDonald, 1996). While Nadel *et al*. (1999) replicated Murray and Trevarthen's (1985) results with 9-week-olds, Rochat, Neisser and Marian (1998) reported a failure to replicate with 2-month-olds. Similarly, Bigelow and DeCoste (2003) found contingency and carry-over effects for 4- and 6-month-olds' gazing and smiling responses, but not for 2-month-olds. However, analyses of effect sizes indicated that 2-month-olds might be beginning to discriminate between live and replay interactions in their visual response. Clearly, there is much controversy around this topic, given the inconsistencies in results at early ages tested, but it is generally agreed that at some point within the first 6 months of age, infants manifest these sensitivities. As articulated by Bigelow (2001), the question is 'not whether infants show this sensitivity to contingency, but when they begin to do so' (p. 336).

Watson and colleagues' research on infant perception of contingency points to a transition in contingency preferences around 3 months of age (Bahrick & Watson, 1985; Gergely & Watson, 1996, 1999; see also Gergely, Koos & Watson, 2000). Whereas young infants' attention is captured by perfectly contingent response–stimulus relations, e.g. by a contingent live display of their own leg motion, by 3 months of age infants begin to discriminate between perfect and imperfect contingencies and show a preference for imperfect contingent relations, e.g. a display of a non-contingent self or a peer (Bahrick & Watson, 1985). Social contingencies are generally imperfect since the magnitude of response–stimulus contingencies in social interaction is usually below 1. Given that mothers engage in affective attunement and mirroring with their infants (e.g. Stern, 1985/2000; Gergely & Watson, 1999), maternal responsiveness in early interaction is characterized by high but imperfect degrees of response-contingent stimulation. Gergely and Watson (1996) argue for the existence of an innate contingency detection module whose initial bias toward perfect contingencies is re-set in infants around 3 months of age towards high but imperfect degrees of contingency.

The current study was designed to dig a bit further into the question addressing when human infants are sensitive to imperfect social contingencies. This is the first large-scale developmental study of infants' sensitivity to social contingency within the first 3 months of age. Following Gergely and Watson's hypothesis that infants start to seek out imperfect contingencies by 3 months of age but not before this age (e.g. 1999), and also based on a range of research suggesting a transition in social skills at around 2 months of age (see e.g. Nadel *et al*., 1999; Rochat & Striano, 1999; Stern, 1985/2000), we used the working hypothesis that 3-month-old infants, but not 1-month-olds, would distinguish between differing degrees of imperfect social contingencies with their gazing and smiling responses.

One- and 3-month-old infants interacted face-to-face with their mother, and type of maternal social contingency was manipulated (Normal interaction, Non-Contingent interaction, and Imitative interaction). We chose to assess 1- and 3-month-olds, rather than 2-month-olds, given the inter-individual differences in social responsiveness that have been reported at around 2 months of age (e.g. Bigelow, 2001), and that may have accounted for much discrepancy in previous research.

Study 1

Method

Participants

Sixty-eight infants and their mothers participated in the study (M = 45.2 days, range: 36–58 days). Twenty-nine males and 39 females were included in the final sample. An additional 11 infants were tested but excluded because they were fussy or did not engage in at least one of the experimental conditions. All participants were full-term (at least 36 weeks of gestation), healthy infants with a birth weight of 2,500 g or higher, and a 1 and 5 minute APGAR score of 7 or higher. Infants were recruited from a small city hospital where a research assistant visited mothers at the time of the birth of the infants and later contacted them by telephone. Infants were Caucasian and living in a small city in the east of Germany. Infants received a T-shirt and mothers a videotape of the session and a travel allowance for their participation.

Set-up and procedure

Testing took place in a carpeted room within an area surrounded by white curtains to eliminate any possible

Figure 1 *Set-up for Studies 1 and 2.*

distractions. All sessions were filmed using four digital video cameras. As shown in Figure 1, two cameras captured a close-up view of the infant, another one a close-up view of the mother, and a fourth one captured a view of the mother and the infant. The output of all four cameras was fed into a digital quad, which allowed for simultaneous viewing of the different filmed angles for coding purposes.

Mothers and infants interacted in two visits. Infants sat in an infant seat (with a 30° backrest tilt) placed on a 44 cm high table. Mothers sat on a stool (44 cm high) facing their infants, approximately 50 cm apart from them. This seating arrangement afforded for eye contact between the dyad. Because of postural constraints of the infant at the first visit, some mothers held their infants in an en-face position, generally holding the infant's head from behind with one hand, and the infant's trunk and buttocks[1] with the other hand. Mothers were instructed to interact for 3 minutes with their infants as they normally do. The session was recorded and an audio recording of 60 seconds during which the infant was not excessively distressed was made for the subsequent visit.

In the second visit ($M = 6.9$ days later), all infants sat in an infant seat and the seating arrangement was the same as in visit 1. Mothers were asked to wear a headset attached to an audio recorder and instructed to interact with the infant in each of the following ways without touching the infant during assessment. Each interaction lasted 60 seconds and order was originally counterbalanced across infants. However, some infants dropped out of the study and the final number of subjects differed between the order groups. All infants participated in all conditions within the study. The number of infants per order group is presented in Table 1. Only the recorded 3-minute interactions of the second visit were used for all analyses.

Table 1 *Sample sizes within each order of condition for Studies 1 and 2*

Order	N-NC-I	N-I-NC	I-NC-N	I-N-NC	NC-N-I	NC-I-N
Study 1	9	13	10	11	12	13
Study 2	13	11	11	11	10	10

Note: N = Normal condition, I = Imitation condition, and NC = Non-Contingent condition.

Conditions

Normal interaction: Mothers were instructed to interact with their infant as they normally do.

Non-Contingent interaction: Mothers were instructed to press play on the audio recorder and to repeat what

[1] In visit 2, all infants were placed in the infant seat. There was no significant main effect or interaction for infant behavior in visit 2 of whether infants were held in the mothers' arm ($n = 14$) or placed in the infant seat ($n = 54$) during the normal interaction of visit 1.

they had said to their infant in visit 1 and to reflect the same feeling back to the infant, as reflected in their voice on the recorder.

Imitation Interaction: Mothers were instructed to imitate their infants' facial expressions, arm/hand gestures and vocalizations.

To verify task demands for mothers in the Non-Contingent interaction, maternal vocalizations on the audio recordings of visit 1 in Studies 1 and 2 were assessed in terms of frequency, amount in seconds, and mean duration in seconds of single vocalizations and of overall vocalizing in percent of time.[2] SDs are reported in brackets. Analyses showed that in the Non-Contingent interaction in Study 1, mothers were required to repeat an average of 25 (7.7) vocalizations, one every 2.4 seconds, with a mean duration of 1.1 (.5) seconds, and an overall 44.3 (14.8) percent of time of vocal behavior. Similarly, in the Non-Contingent interaction in Study 2, mothers were required to repeat an average of 35 (8.2) vocalizations, one every 2.6 seconds, with a mean duration of 1.3 (.8) seconds, and an overall 47.5 (12.6) percent of time of vocal behavior. Maternal speech on the recordings thus consisted of short utterances interspersed with pauses. It is interesting to note that maternal vocalizations were greater in 3-month-olds (1 vocalization every 2.4 seconds) compared to 1-month-olds (1 vocalization every 2.6 seconds), and that the mean duration of single vocalizations was greater in 3-month-olds (M = 1.33, SD = .1) compared to 1-month-olds (M = 1.1, SD = .06). However, these age differences were not significant, and likely did not differentially affect infants' affective response at each age (see also Henning, Striano & Lieven, in press, for evidence of greater interindividual differences in infant compared to maternal vocal behavior). Given the simplicity, rhythmicity and repetitiveness of infant-directed speech in general (e.g. Snow, 1977), we assumed that in the Non-Contingent interactions mothers were able to comply with the instruction to repeat their recorded vocalizations. In addition, mothers did not spontaneously report any difficulty with the task.

Coding

The main coder was not blind as to the experimental conditions given that she used a quad splitter image for coding, but was naïve as to the predictions of the study. Coding was done using a computerized coding system (Interact 6.8; Thiel, 2002). The coder activated the event recorder with different keys on the computer keyboard corresponding to the following behaviors:

Infant behaviors:

Gazing: looks to the mother's face.
Smiling: raised cheeks and corner of lips turned up.

Maternal behaviors:

Gazing: looks to the infant's face.
Smiling: toothy smiles or smiles that were more intense relative to their general display of positive affect.

Intercoder reliability

An independent coder scored a random 20% of the sessions using the same method as the main coder. To measure intercoder agreement, we used an adaptation of the Kappa to continuous data as recommended by Bakeman and Gottman (1997). Cohen's Kappas were .71 and .75 for infant gazing and smiling, respectively, and .98 and .75 for maternal gazing and smiling, respectively. Because it was sometimes difficult to establish if infants were fixating on the mother's face or elsewhere, a quad splitter image was used for coding purposes. Also, an additional 20% of randomly selected infants from the dataset for Study 1 and Study 2 (below) were coded with the images of the mother covered. Kappas assessing reliability between this blind coder and the original coding for infant gazing in Studies 1 and 2 were .73 and .76, respectively. Therefore, although coders naïve to the hypotheses of the studies reported that the image displaying both the mothers' and infants' face facilitates coding of infant gazing, it is also possible to obtain similar results using a coder who is blind to the experimental condition.

Manipulation check

To verify that the mothers were in compliance with the conditions in Studies 1 and 2, we assessed whether an independent observer blind to the hypotheses of the study and order of conditions could reliably assign the correct condition to the three interaction phases (Normal, Imitation and Non-Contingent) of the mother–infant dyads. The observer was presented the video-taped interactions of all trials in a random order and then asked to classify each experimental trial to one. The reliability to correctly identify the experimental condition measured by Cohen's Kappa was 0.85. The Normal condition was correctly classified in 92.6%, Imitation condition in 97% and Non-Contingent condition in 77.9% of the trials. It is interesting to note that even the lowest correct classification rate of the Non-Contingent condition was still significantly higher than expected by chance. Chi-square goodness of fit test

[2] Maternal vocalizing was defined as any vocalization mothers produced. Cohen's Kappas measuring intercoder agreement on 20% of the sample were .80 and .77 for Studies 1 and 2, respectively.

Table 2 *Study 1: Means and standard errors for infant and maternal behavior (in percent of time) in conditions Normal, Imitation and Non-Contingent (N = 68)*

Condition	Normal	Imitation	Non-Contingent
	Infants		
Gazing			
M	68.7	63.2	64.9
SE	4.20	3.95	4.32
Smiling			
M	6.4	4.2	6.6
SE	1.33	1.76	1.59
	Mothers		
Gazing			
M	98.1	98.1	98.1
SE	0.76	0.51	0.38
Smiling			
M	21.3	16.9	24.9
SE	2.46	2.15	2.67

Table 3 *Study 2: Means and standard errors for infant and maternal behavior (in percent of time) in conditions Normal, Imitation and Non-Contingent (N = 66)*

Condition	Normal	Imitation	Non-Contingent
	Infants		
Gazing			
M	75.9	83.0	70.4
SE	3.02	2.07	3.31
Smiling			
M	12.4	5.9	9.3
SE	1.86	1.03	1.61
	Mothers		
Gazing			
M	99.7	99.2	98.3
SE	0.86	0.17	1.02
Smiling			
M	33.2	23.8	33.8
SE	1.97	2.56	2.67

yielded $\chi^2(1) = 60.89$, $p < .001$, $p = \frac{1}{3}$. Non-Contingent trials were more often misclassified as Normal (10 times) than as Imitation (4 times), although this difference was not significant, Chi-square goodness of fit: $\chi^2(1) = 2.87$, $p = .18$. In addition, coders were significantly more likely to classify Normal as Normal than as Imitation, Chi-square goodness of fit: $\chi^2(1) = 64$, $p < .001$, $p = .5$, and Imitation as Imitation than as Normal, Chi-square goodness of fit: $\chi^2(1) = 60.2$, $p < .001$, $p = .5$, or as Non-Contingent, Chi-square goodness of fit: $\chi^2(1) = 66$, $p < .001$, $p = .5$. These results suggest that mothers complied with the instructions. Interobserver reliability was conducted by a second independent observer, blind to the hypotheses and conditions of the study, for 100% of the sample and the Kappa was .72.[3] As shown in Tables 2 and 3, mothers smiled more than infants did in the Imitation condition, indicating that they did not fully comply with directions. There may have been several reasons for this difference. One possibility is that maternal smiles were longer lasting than infant smiles, and/or more easily detected by the coders of the study. It is possible that whereas mothers perceived their infant as smiling, the coders did not (and/or used a more rigid definition). A second possibility is than mothers' smiling may have reflected embarrassment when they had to copy their infants' behavior. Future studies will be needed to test these hypotheses. It is important to note, however, that despite these differences infants nevertheless received significantly different levels of maternal contingency as a function of condition. That is, for both studies (see results section) maternal smiling significantly differed as a function of experimental condition and independent of any relations between maternal and infant smiling.

[3] Note that the frequency of maternal and infant smiles showed a similar pattern of results. For study 1, Means (SD) for maternal and infant smiling were 3.80 (2.9) and .5 (1.25), respectively, and for Study 2 were 4.2 (2.40) and 1.6 (1.94), respectively.

Results

The analyses focused on the following questions:

Did 1-month-old infants discriminate between Normal, Imitation, and Non-Contingent interactions? To assess this question, two 2-factorial Condition (within group factor: Normal, Imitation, Non-Contingent) × Order (between group factor: six different orders) repeated measures ANOVAs were performed on the percent of time infants gazed and smiled at their mother. Means and *SE*s are presented in Table 2. Following a significant main effect or interaction, we used planned pairwise comparisons for estimated marginal means (*t*-statistics) for both between- and within-subjects factors (Fischer's LSD Procedure).

Gazing: The ANOVA yielded no significant main effects or interactions, *p*s > .22.

Smiling: The ANOVA yielded no significant main effects or interactions, *p*s > .56.

Did infant behavior vary as a function of maternal behavior? To assess this question, a series of General Linear Mixed Models analyses (GLMMs) were performed to assess possible effects of maternal behavior (smiling or gazing) on infant's behavior as a function of condition and order. Covariates were included as main effects, and non-significant factors were removed from the final model. Adding maternal behaviors as covariates in the model, there was a significant positive relation between maternal smiling and infant gazing, GLMM: $F(1, 174.9) = 7.12$, $p = .008$, $\beta = .3$. Independent of condition, infants gazed more when mothers smiled more. There was also a significant positive relation between maternal and infant smiling, GLMM: $F(1, 174.6) = 6.72$, $p = .008$, $\beta = .13$. Independent of condition, infants smiled more when mothers smiled more. All other main effects or interactions were not significant, $ps > .28$.

Did maternal behavior vary as a function of experimental condition (Normal, Imitation and Non-Contingent)? To assess this question, two 2-factorial Condition (within group factor: Normal, Imitation, Non-Contingent) × Order (between group factor: six different orders) repeated measures ANOVAs were performed on the percent of time mothers gazed and smiled at their infant.

Gazing: Mothers gazed almost 100% of the time in all three experimental conditions. The ANOVA yielded no significant main effects or interactions, $ps > .39$.

Smiling: There was a significant main effect for condition, $F(2, 124) = 3.61$, $p = .03$. Pairwise comparisons showed that mothers smiled the same amount in the Normal and Non-Contingent conditions, $p > .18$. Mothers smiled reliably more during the Non-Contingent condition compared to the Imitation condition, $p = .004$. There were no other significant main effects or interactions, $ps > .14$ in all cases.

Did maternal behavior vary as a function of infant behavior? To assess this question, GLMMs were performed on maternal behavior. Adding infant behaviors as covariates in the model, there was a significant positive relation between infant and maternal smiling, GLMM: $F(1, 174.3) = 7.96$, $p = .005$, $\beta = .29$. Independent of condition, mothers smiled more when infants smiled more. The main effect of condition on maternal smiling remained significant when adding infant smiling as a covariate. GLMM: $F(2, 123.5) = 3.30$, $p = .04$. Pairwise comparisons revealed that, independent of infant behavior, mothers smiled significantly more in the Non-Contingent condition compared to the Imitation condition, $p = .012$. Interestingly, although mothers smiled reliably more in the Non-Contingent condition compared to the Imitation condition, infants' gazing and smiling still did not differ between conditions. There were no other significant main effects or interactions, $ps > .15$ in all cases.

Discussion Study 1

One-month-old infants interacted with their mother face-to-face and gazing and smiling was assessed across different interaction types. Infants did not appear to be sensitive to different types of imperfect contingencies. Although it is difficult to make firm conclusions based on null results, the findings suggest that a sensitivity to social contingencies likely develops sometime after 6 weeks of age. In Study 2, we assessed 3-month-olds' sensitivity in the same paradigm.

Study 2

Method

Participants

Sixty-six infants and their mothers participated in the study. Twenty-nine males and 37 females from the original sample were also included in Study 2 when they were 3 months of age ($M = 109.8$ days, range: 88–128). An additional 13 infants were tested but excluded because they were fussy or did not engage in at least one of the experimental conditions. Recruitment procedures, inclusion criterion and participant gifts were identical to Study 1.

Set-up and procedure

As in Study 1, in Study 2 mothers and infants interacted in two visits. The set-up for both visits in Study 2 was the same as in the second visit of Study 1. Also the procedure was the same as in Study 1, except that the duration of conditions was extended to 90 seconds. The mean number of days elapsed between the first and the second visit were $M = 7.3$ days. Order was originally counterbalanced across infants. However, some infants dropped out of the study and the final number of subjects differed between the order groups. The numbers of infants per order group are presented in Table 1.

Coding

The coding procedure was the same as in Study 1 and coded by the same observers.

Intercoder reliability

To assess intercoder reliability, an independent coder scored a random 20% of the sessions. Cohen's Kappas were .83 and .80 for infant gazing and smiling, respectively, and 1.0 and .76 for maternal gazing and smiling, respectively.

Manipulation check

To verify that the mothers were in compliance with the conditions we conducted the same analyses as in Study 1.

The reliability to correctly identify the experimental condition measured by Cohen's Kappa was .95. In the 3-months-old infant group, the correct classifications of trials for Normal, Imitation and Non-Contingent conditions were 98.4%, 98.4% and 93.9%, respectively. Interobserver reliability was conducted by a second independent observer, blind to the hypotheses and conditions of the study, for 100% of the sample. The Cohen's Kappa was .79.

Results

The analyses focused on the following questions:

Did 3-month-old infants discriminate between Normal, Imitation, and Non-Contingent interactions? To assess whether infant behavior differed across conditions two 2-factorial Condition (within group factor: Normal, Imitation, Non-Contingent) × Order (between group factor: six different orders) repeated measures ANOVAs were performed on the percent of time infants gazed and smiled. The means and *SE*s are presented in Table 3. Following a significant effect or interaction we conducted pairwise comparisons using Fischer's LSD procedure.

Gazing: There was a significant main effect for condition, $F(2, 120) = 8.44$, $p < .001$, but no effect of order and no interaction, *p*s > .29. Pairwise comparisons revealed that infants gazed more in the Imitation condition compared to both the Normal condition, $p = .018$, and Non-Contingent condition, $p = .001$. Additionally, there was a trend for infants to gaze more in the Normal condition compared to the Non-Contingent condition, $p = .055$.

Smiling: There was a significant main effect for condition, $F(2, 120) = 8.79$, $p < .001$. Pairwise comparisons revealed that infants smiled reliably more in the Normal condition compared to both the Imitation, $p < .001$, and Non-Contingent, $p = .052$, conditions. Additionally, infants smiled significantly more in the Non-Contingent condition compared to the Imitation condition, $p = .015$. There was no main effect for order, $p = .164$. There was a significant Condition × Order interaction, $F(10, 120) = 1.95$, $p = .048$. In all orders, infants smiled more in the Normal condition compared to the Non-Contingent and Imitation conditions, with the exception of order Imitation – Non-Contingent – Normal. In this order, infants smiled less in the Normal condition compared to the Non-Contingent and Imitation conditions. This result may reflect a carry-over effect from the preceding Non-Contingent condition.

Did infant behavior vary as a function of maternal behavior? To assess this question, GLMMs were performed on infant behavior. Adding maternal behaviors as covariates in the model revealed a significant positive relation between maternal and infant smiling, GLMM: $F(1, 176.8) = 8.49$, $p = .004$, $\beta = .13$. Independent of condition, mothers smiled more when infants smiled more. The effect of condition on infant smiling remained significant when statistically controlling for the effect of maternal smiling, $F(2, 122.6) = 5.86$, $p = .004$. Pairwise comparisons revealed that infants smiled more in the Normal condition compared to both the Imitation, $p < .001$, and Non-Contingent, $p = .043$, conditions. Infants did not smile significantly more in the Imitation condition compared to the Non-Contingent condition, $p = .163$. The Order × Condition interaction was not significant after adding maternal smiling as a covariate, $F(10, 119.7) = 1.75$, $p = .078$, suggesting that mothers' behavior may have contributed to the condition carry-over effect for infant smiling in order Imitation – Non-Contingent – Normal. There were no other main effects or interactions, *p*s > .15 in all cases.

Did maternal behavior vary as a function of experimental condition (Normal, Imitation and Non-Contingent)? To assess whether maternal behavior differed across conditions, two 2-factorial Condition (within group factor: Normal, Imitation, Non-Contingent) × Order (between group factor: six different orders) repeated measures ANOVAs were performed on the percent of time mothers gazed and smiled.

Gazing: Mothers gazed almost 100% of the time in all three experimental conditions. There were no significant main effects or interactions, *p*s > .22.

Smiling: There was a significant main effect for condition, $F(2, 120) = 8.47$, $p < .001$. Pairwise comparisons showed that mothers smiled significantly more in the Normal and Non-Contingent conditions compared to the Imitation condition, $p = .022$ and $p = .001$, respectively. There was no significant difference between the Normal and Non-Contingent conditions, $p = .793$. There was no significant main effect for order, $p > .29$, or an interaction between order and condition, $p > .76$.

Did maternal behavior vary as a function of infant behavior? To assess this question, GLMMs were performed on maternal behavior. Adding infant behaviors as covariates in the model revealed a significant positive relation between infant and maternal smiling, GLMM: $F(1, 176.9) = 8.39$, $p = .004$, $\beta = .35$. Mothers smiled more when infants smiled more, regardless of experimental condition. The main effect of condition on mother smiling remained significant when adding infant smiling as covariate, GLMM: $F(2, 123.3) = 5.79$, $p = .004$. Pairwise comparisons showed that mothers smiled significantly more in the Normal and Non-Contingent conditions compared to the Imitation condition, $p = .013$ and $p = .001$, respectively, regardless of infant behavior. There were no significant differences between the Normal and Non-Contingent conditions, $p = .517$. There were no other main effects or interactions, GLMM: all $ps > .16$.

Discussion Study 2

Three-month-old infants interacted with their mothers who presented different types of imperfect contingencies. Infants gazed more in the Imitation condition than in the Normal or Non-Contingent conditions but smiled more in the Normal condition compared to the Imitation and Non-Contingent conditions. Clearly, this finding suggests that infants discriminated among these different conditions, and contrasts with that of Study 1 with 1-month-olds. Furthermore, the different infants' gazing and smiling responses suggest that gazing and smiling serve different functions. These findings are in accordance with Bigelow and Birch's (1999) suggestion that infant attention and affect are regulated by two systems that may operate independently. Imitative responses did not impact the way that infants related on an affect level to their mother during the interaction. Rather, the imitative response captured infants' visual attention and may have modulated arousal by providing a higher degree of contingency compared to the more reciprocal Normal or Non-Contingent interaction. It has been proposed that imitation of facial and vocal behaviors regulates infant distress and plays an important role in sense of causality (e.g. Nichols, Gergely & Fonagy, 2001). One possibility is that this accounts for 3-month-old infants gazing more at their mother when she was engaged in an imitative compared to normal interaction. An alternative possibility is that infants gazed longer because their mothers' behavior was surprising and perhaps more novel.

Importantly, these effects both in terms of gazing and smiling held even when controlling for the amount of maternal behavior. The finding points to the proclivity of infants by 3 months to resonate to others who are attuned and reciprocate in terms of affect and timing. Such sensitivity at the affective and attentional level is an important step in the direction of communicative development (Jaffe, Beebe, Feldstein, Crown & Jasnow, 2001).

General discussion

The findings of the current series of studies provide support for theories on the role of contingency detection in social development between 1 and 3 months of age. Watson and colleagues (e.g. Gergely & Watson, 1996; Watson, 1994) have proposed that in the first 2–3 months of life, human infants prefer perfect contingencies, whereas after 3 months of age they seek out high but imperfect contingencies. Consistent with this hypothesis, results show a general developmental trend of a sensitivity to social contingencies by 3 months of age as 3-month-olds distinguished between social interactions that differed in their degree of imperfect contingency, whereas 1-month-olds did not.

We propose that by 3 months of age, infants are selectively attuned to their mothers. Bigelow (1998) showed that 4–5-month-old infants distinguished between familiar and unfamiliar levels of social contingencies and were more responsive to familiar levels. In the current study, 3-month-olds smiled more at their mothers in the Normal compared to the Imitation and Non-Contingent conditions. In the Normal interaction mothers likely provided a familiar degree of contingency, whereas magnitude of contingency was likely higher than the familiar level in the Imitation and lower in the Non-Contingent condition. Notably, sensitivity to differing degrees of social contingency is necessary for developing a preference for parental contingency levels.

The current findings highlight important developmental transitions taking place within the dyad and demonstrate such changes at the behavioral level. However, it is important to note that the experimental session was short in general, and that future research should assess if such sensitivities can be manifested in infants younger than 3 months of age using a longer interactive period. Also, given the short duration of the conditions, the design of the study is not optimal to assess directionality and reciprocal imitation in general.

Clearly, further research is needed to assess how dyadic reciprocal interactions, based in part upon a sensitivity to social contingencies, engender an awareness of intentional relations, and aspects of social learning that may be unique to humans (see Tomasello, Kruger & Ratner, 1993). Recent studies on the neural mechanisms of affect sharing between individuals (e.g. empathy) show high similarity between imitation and observation of various emotions (e.g. Carr, Iacoboni, Dubeau, Mazziotta & Lenzi, 2003). Assessing how such networks develop in ontogeny and as a function of dyadic interaction will likely be key in understanding how unique aspects of human cognition emerge. It has been suggested that the motivation to share affect and attention with others is unique to humans and might precipitate skills such as language and imitation (Hobson, 2002). The current studies suggest a transition in the sensitivity to various aspects of social contingencies, including imitation and affective-reciprocal attunement. The findings might be instrumental in establishing when infants might be at risk for social cognitive impairments in general.

For instance, research showed that children with autism prefer to attend to perfect compared to imperfect contingencies. Typically developing children, however, prefer to look at imperfect contingencies at least by the middle of the first year (Gergely *et al.*, 2000). Thus, understanding these early developmental transitions between 1 and 3 months of age might be key in predicting understanding of some social-cognitive deficits. Interestingly, autism is generally related to deficits in a range of social cognitive skills such as language, imitation and joint attention (Carpenter, Pennington & Rogers, 2002; Charman & Baron-Cohen, 1994; Mundy, Sigman & Kasari, 1994; Rogers, 1999), all of which require a sensitivity to social contingencies to some degree.

The current study highlights a possible transition in development between 1 and 3 months of age. Research is needed to further document this transition, for instance to establish if the finding is due to the nature of the paradigm or to development. This is especially important given the null results of Study 1 with 1-month-olds (see also Bigelow & DeCoste, 2003; Rochat *et al.*, 1998).

If the general phenomenon is replicated in other experimental contexts, and if these findings suggest that a sensitivity to social contingency develops between 1 and 3 months, the obvious and essential question remains – what developmental processes account for this social transition? Does social experience play an integral role, or might more general maturational factors precipitate these changes, likely in interaction with social experience? The current findings provide some direction for future research on the topic of social contingencies and on the motivation to communicate with others in general.

Overall, the current work provides further evidence for a hypothesized shift in infant sensitivity to social contingencies that is clearly manifested at 3 months and not at 1 month of age (at least not in the paradigm employed here). Further research is needed to determine the mechanisms that are responsible for this transition, and the possible relation between these sensitivities and later emerging social cognitive skills.

Acknowledgements

The project was supported in part by the Sofja Kovalevskaja Award from the Alexander von Humboldt Foundation to T. Striano. Thank you also to the Cultural Ontogeny Group for help with running the study, especially to Caterina Böttcher and Kerstin Träger, for coding. We are grateful to Michael Tomasello for comments on an earlier version of the manuscript. We are also thankful to the staff of the Universitätsfrauenklinik in Leipzig for their support with infant recruitment and especially to the parents and infants who participated in the study.

References

Bahrick, L.E., & Watson, J.S. (1985). Detection of intermodal proprioceptive-visual contingency as a potential basis of self-perception in infancy. *Developmental Psychology*, **21**, 963–973.

Bakeman, R., & Gottman, J.M. (1997). *Observing interactions*. New York: Cambridge University Press.

Barresi, J., & Moore, C. (1996). Intentional relations and social understanding. *Behavioral & Brain Sciences*, **19**, 107–154.

Bigelow, A.E. (1998). Infants' sensitivity to familiar imperfect contingencies in social interaction. *Infant Behavior and Development*, **21**, 149–162.

Bigelow, A.E. (2001). Discovering self through other: infants' preference for social contingency. *Bulletin of the Menninger Clinic*, **65**, 335–346.

Bigelow, A.E., & Birch, S.A.J. (1999). The effects of contingency in previous interactions on infants' preference for social partners. *Infant Behavior and Development*, **22**, 367–382.

Bigelow, A.E., & DeCoste, C. (2003). Sensitivity to social contingencies from mothers and strangers in 2-, 4-, and 6-month-old infants. *Infancy*, **4**, 111–140.

Bigelow, A.E., MacLean, B.K., & MacDonald, D. (1996). Infants' response to live and replay interactions with self and mother. *Merrill-Palmer Quarterly*, **42**, 596–611.

Carpenter, M., Pennington, B.E., & Rogers, S.J. (2002). Interrelations among social-cognitive skills in young children with autism. *Journal of Autism & Developmental Disorders*, **32**, 91–106.

Carr, L., Iacoboni, M., Dubeau, M.-C., Mazziotta, J.C., & Lenzi, G.L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences*, **100**, 5497–5502.

Charman, T., & Baron-Cohen, S. (1994). Another look at imitation in autism. *Development and Psychopathology*, **1**, 1–4.

Fogel, A. (1993). *Developing through relationships: Origins of communication, self, and culture.* Chicago, IL: Harvester Press.

Gergely, G., Koos, O., & Watson, J.S. (2000). Contingency perception and the role of contingent parental reactivity in early socio-emotional development: some implications for developmental psychopathology. In J. Nadel & J. Decety (Eds.), *Imitation, action et intentionnalité.* Paris: Press Universitaires de France.

Gergely, G., & Watson, J.S. (1996). The social biofeedback theory of parental affect-mirroring: the development of emotional self-awareness and self-control in infancy. *International Journal of Psycho-Analysis*, **77**, 1181–1212.

Gergely, G., & Watson, J.S. (1999). Early socio-emotional development: contingency perception and the social-biofeedback model. In P. Rochat (Ed.), *Early social cognition: Understanding* *others in the first months of life* (pp. 101–136). Mahwah, NJ: Lawrence Erlbaum Associates.

Hains, S.M.J., & Muir, D.W. (1996). Effects of stimulus contingency in infant–adult interactions. *Infant Behavior and Development*, **19**, 49–61.

Haith, M., Bergman, T., & Moore, M. (1997). Eye contact and face scanning in early infancy. *Science*, **198**, 853–855.

Henning, A., Striano, T., & Lieven, E.V.M. (in press). Maternal speech to infants at 1 and 3 months of age. *Infant Behavior and Development*.

Hobson, P. (2002). *The cradle of thought.* London: Macmillan.

Iacoboni, M. (2005). Understanding others: imitation, language, empathy. In S. Hurley & N. Chater (Eds.), *Perspectives on imitation: From cognitive neuroscience to social science* (pp. 77–99). Cambridge, MA: MIT Press.

Jaffe, J., Beebe, B., Feldstein, S., Crown, C.L., & Jasnow, M. (2001). Rhythms of dialogue in infancy: coordinated timing in development. *Monograph of the Society for Research in Child Development*, **66** (2, Serial No. 131).

Lewis, M., Sullivan, M.W., & Brooks-Gunn, J. (1985). Emotional behavior during the learning of contingency in early infancy. *British Journal of Developmental Psychology*, **3**, 307–316.

Maurer, D., & Salapatek, P. (1976). Developmental changes in the scanning of faces by young infants. *Child Development*, **47**, 523–527.

Muir, D.W., & Hains S.M.J. (1993). Infant sensitivity to perturbations in adult facial, vocal, tactile, and contingent stimulation during face-to-face interactions. In B. de Boyssons-Bardies & S. de Schonen (Eds.), *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 171–183). Amsterdam: Elsevier.

Mundy, P., Sigman, M., & Kasari, L. (1994). Joint attention, developmental level, and sympton presentation in autism. *Development and Psychopathology*, **6**, 389–401.

Murray, L., & Trevarthen, C. (1985). Emotional regulations of interactions between two-month-olds and their mothers. In T.M. Field & N.A. Fox (Eds.), *Social perception in infants* (pp. 177–197). Norwood, NJ: Ablex.

Nadel, J., Carchon, I., Kervella, C., Marcelli, D., & Réserbat-Plantey, D. (1999). Expectancies for social contingency in 2-month-olds. *Developmental Science*, **2**, 164–173.

Nichols, K., Gergely, G., & Fonagy, P. (2001). Experimental protocols for investigating relationships among mother–infant interaction, affect regulation, physiological markers of stress responsiveness, and attachment. *Bulletin of the Menninger Clinic*, **65**, 371–379.

Rochat, P., Neisser, U., & Marian, V. (1998). Are young infants sensitive to interpersonal contingency? *Infant Behavior and Development*, **21**, 355–366.

Rochat, P., & Striano, T. (1999). Social-cognitive development in the first year. In P. Rochat (Ed.), *Early social cognition: Understanding others in the first months of life* (pp. 3–34). Mahwah, NJ: Lawrence Erlbaum Associates.

Rogers, S.J. (1999). An examination of the imitation deficit in autism. In J. Nadel & G. Butterworth (Eds.), *Imitation in infancy* (pp. 254–283). Cambridge: Cambridge University Press.

Snow, C.E. (1977). Mothers' speech research: from input to interaction. In C.E. Snow & C.A. Ferguson (Eds.), *Talking to children* (pp. 31–50). Cambridge: Cambridge University Press.

Stern, D.N. (1985/2000). *The interpersonal world of the infant*. New York: Basic Books.

Thiel, T. (2002). Manual for INTERACT version 6.8 [Computer software]. Munich, Germany: Mangold Software & Consulting.

Toda, S., & Fogel, A. (1993). Infant response to still-face situation at 3 and 6 months. *Developmental Psychology*, **29**, 532–538.

Tomasello, M., Kruger, A.C., & Ratner, H.H. (1993). Cultural learning. *Behavioral and Brain Science*, **16**, 495–552.

Trevarthen, C. (1979). The foundations of intersubjectivity: development of interpersonal and cooperative understanding in infants. In D. Olson (Ed.), *The social foundations of language and thought* (pp. 316–342). New York: W.W. Norton & Co.

Tronick, E.Z., Als, H., Adamson, L., Wise, S., & Brazelton, T.B. (1978). The infant's response to entrapment between contradictory messages in face-to-face interaction. *Journal of the American Academy of Child Psychiatry*, **16**, 1–13.

Watson, J.S. (1972). Smiling, cooing, and 'The Game'. *Merrill-Palmer Quarterly*, **18**, 219–229.

Watson, J.S. (1994). Detection of self: the perfect algorithm. In S. Parker, R. Mitchell, & M. Boccia (Eds.), *Self-awareness in animals and humans: Developmental perspectives* (pp. 131–149). New York: Cambridge University Press.

Watson, J.S., & Ramey, C.T. (1972). Reactions to response-contingent stimulation in early infancy. *Merrill-Palmer Quarterly*, **18**, 219–227.

Wolff, P.H. (1987). *The development of behavioral states and the expression of emotions in early infancy: New proposals for investigation*. Chicago, IL: University of Chicago Press.

Received: 3 November 2003
Accepted: 23 February 2005