Developmental Science 8:4 (2005), pp 333–343

REPORT

Sensitivity to triadic attention in early infancy

Tricia Striano[1,2,3] and Daniel Stahl[3]

1. *University of Leipzig, Center for Advanced Studies, Germany*
2. *Max Planck Institute for Human Cognitive and Brain Sciences, Germany*
3. *Max Planck Institute for Evolutionary Anthropology, Germany*

Abstract

In Study 1, 54 3-, 6- and 9-month-old infants interacted with an adult stranger who engaged in a face-to-face (dyadic) exchange. Dyadic interaction was halted when the adult turned away to look at an object. In a Joint Attention condition, the adult alternated visual attention between the infant and the object, and in a Look Away condition she looked away at the object only. Infants gazed and smiled more in the Joint Attention condition compared to in the Look Away condition. Infants' gazing to the target object interacted with age and condition. In Study 2, 37 3-, 6- and 9-month old infants interacted with an adult who coordinated visual attention and affect, affect only, visual attention only, or ignored the infant. Infants gazed reliably more at E when she coordinated both affect and attention and smiled reliably more when the adult coordinated affect and attention or attention only. The findings show a sensitivity to triadic attention by 3 months of age.

The transition from dyadic to triadic social relations buttresses important aspects of human culture such as imitative learning and language acquisition (Hobson, 2002; Tomasello, 1999). Despite the importance of a sensitivity to triadic relations, little is known regarding when such sensitivities emerge in early ontogeny, or the elements of interaction that determine joint attention. Joint attention can be defined as triadic interaction that involves monitoring:

1. another person's attention in relation to the self;
2. a second object;
3. the other person's attention toward the same object.

At birth infants are sensitive to direct eye to eye contact (Farroni, Csibra, Simion & Johnson, 2002) which implies some sensitivity to others' attention in relation to the self (see also Reddy, 2003). Soon after, infants shift their gaze toward external objects and events at which other people look (D'Entremont, Hains & Muir, 1997; Hood, Willen & Driver, 1998; see also Scaife & Bruner, 1975).

However, gaze following depends upon appropriate conditions that infants are placed in, such as whether the location of objects is within the infants' visual field (Butterworth & Jarrett, 1991; see also Moore and Corkum, 1998). According to Butterworth (1998) the mechanism of gaze following in early infancy is a 'two part process' (p. 152) that requires real-world objects upon which two minds can meet. The process involves one person changing their orientation. This carries information that a potential object or event will appear in visual space. It also involves a triangulation whereby the minds of two people meet when the object is encountered. According to this view, triangulation requires two people focused on some external object.

Research has highlighted the development of infants' understanding of gaze toward and away from the self, but not in relation to an object. For example, Hains and Muir (1996; see also Scaife & Bruner, 1975) tested 3- to 6-month-olds' sensitivity to changes in eye direction only, and to changes in both head and eye direction while interacting with an adult. Infants interacted with a stranger who was either live or displayed over a color television monitor placed at the infant's eye level. In a control condition, a stranger maintained eye contact throughout a normal interaction. For infants in the experimental conditions, the stranger maintained eye contact while interacting normally with infant-directed speech, smiling, and head movements or she continued to engage in a normal interaction (maintaining contingency by viewing the infant over a television monitor), but changed the direction of her gaze by (1) averting to one side the direction of her eyes only, (2) averting to one side the direction of her eyes and head or by (3) averting downward the direction of her eyes while

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

maintaining the en face position of her head. Infants did not discriminate among the three gaze-away conditions for gazing or smiling duration. Infants in the control and gaze-away (experimental) conditions gazed similarly, but responded with less smiling in conditions when the adult's eyes were averted.

In a related study, Caron, Caron, Roberts and Brooks (1997) evaluated whether 3- and 5-month-old infants use eye directionality as a cue to specify others' intentions. Infants viewed a pre-recorded adult over a television monitor while the adult either maintained eye contact with a frontal head position or averted eye contact by (1) averting eyes only, (2) averting head and eyes, (3) closing eyes or (4) averting the head alone. The results suggest that 3-month-old infants are primarily sensitive to head directionality, whereas 5-month-old infants start to manifest sensitivity to the eyes as a signal for social interaction. Together these results point to a sensitivity to the social significance of eye contact at least by 5 months of age, if not earlier.[1] While these studies suggest a sensitivity to eye contact as a cue to interaction, infants' sensitivity to triadic interactions could not be assessed in these paradigms given that the adult's attention was not directed at an object. The question thus remains when infants are sensitive to aspects of triadic attention.

In a recent study, Delgado, Messinger and Yale (2002) used a still-face paradigm to determine if 6-month-old infants differentially respond to a still-face that was directed at them or at a picture above the infant's head. Infants did not distinguish between these conditions, which suggests that the social dimension of the still-face (i.e. lack of communication) might override the cognitive dimension or the reason for breaking contact (object/event that the adult looked at). Confirming this idea, Striano (2004) compared 3-, 6- and 9-month-old infants' response to various still-face situations that were even more apparent. In one condition an adult broke interaction with the infant to look at someone who had walked into the room, and in another condition an adult broke contact to look away at a blank white wall. Infants at all ages manifested a robust still-face response regardless of the reason that contact was broken.

While these various studies show that infants are sensitive to another's attention toward or away from the self, it has not been demonstrated when infants might become sensitive to triadic attention. In Hains and Muir's (1996) and Caron *et al.*'s (1997) studies this was because the experimental situation did not involve a third object to which to share attention. Delgado *et al.* (2002) and Striano (2004) set up a potential joint attention situation (i.e. infant, adult, object) but this potential was not fulfilled given that the adult simply looked away from the infant without ever monitoring the infant's attention. Thus, one of the key components of joint attention–monitoring the others' attention in relation to the object was lacking.

The current study was designed to assess the ontogeny of the human sensitivity to triadic attention. In Study 1, infants' reaction to breaks of dyadic interaction that contained all aspects of joint attention (Joint Attention condition) or that contained only some aspects of joint attention, such as an object that could be monitored and a person who could be monitored (Look Away condition), were assessed. Given evidence of gaze monitoring by 3 months of age (see D'Entremont *et al.*, 1997) and robust joint attention skills often reported by the end of the first year (see Carpenter, Nagell & Tomasello, 1998; see also Striano & Bertin, in press), infants were tested at 3, 6 and 9 months of age such that developmental patterns could be established.

It was predicted that for all ages, a shift from dyadic (face-to-face interaction) to triadic attention would not induce a still-face response, but that a shift from dyadic interaction to a look away situation would induce a traditional still-face response (i.e. less gazing and smiling and increased re-engagement efforts) as it did in prior studies. In contrast to the dyadic interaction conditions, it was predicted that infants would follow gaze toward the object that the adult was looking at in both the Joint Attention and Look Away conditions. As a working hypothesis, we predicted that this response would be more robust in the Joint Attention condition given that infants might continue to engage with the adult as she looked at the target object; whereas in the Look Away condition infants might sooner lose interest and look in other directions.

Given infants' developing capacity to coordinate attention by the end of the first year, we predicted that gaze following would become increasingly robust over development. In Study 2, a similar study was conducted in which various aspects of the joint attention such as movement cues and eye to eye contact were manipulated.

Study 1

Method

Participants

Fifty-four healthy, full-term infants were included in the final sample. There were 17 3-month-olds (M = 111.41

[1] In contrast to Hains and Muir (1996), the non-contingent display used by Caron *et al.* (1997) may account for the later sensitivity to eye contact at 5 months of age.

days, range = 90 to 135 days, 9 males and 8 females), 21 6-month-olds (M = 193.62 days, range = 182 to 217 days, 17 males and 4 females), and 16 9-month-olds (M = 267.50 days, range = 188 to 297 days, 2 males and 14 females). An additional 25 infants (six 3-month-olds, eight 6-month-olds and eleven 9-month-olds) were tested but not included in the final sample, 24 due to fussiness and 1 due to reported illness that may have prevented him from detecting the target object. Fussiness was defined as crying for 20 seconds. Infants were selected from a database of infants consisting of families who had expressed interest in volunteering for research in infant development. Infants were White and living in the east of Germany. Infants were given a small gift for participating.

Set-up

The procedure took place in a small child development laboratory room (approximately 8' × 16'). The room had white curtains placed around it resulting in a homogeneous background to prevent any visual distraction. Three- and 6-month-old infants were seated in a commercial infant seat. Nine-month-old infants were seated in a highchair without an attached tray. A small wooden stand was placed to the left of the infant and 45 degrees away from the infant and experimenter, approximately 3' away from the dyad. For half of the infants, a brightly colored plastic toy with small colorful balls on the inside was placed on the stand, and for the other half of infants a brightly colored stuffed-animal was placed on the stand. A female stranger (E1) interacted with the infant. Mothers sat behind the infant, out of view, and watched the procedure over a video monitor. A second experimenter timed the interaction and cued E1 when to start and stop each condition. Infants interacted with E1 for 5 minutes. Minutes 1, 3 and 5 consisted of normal interaction (NI) and minute 2 and 4 consisted of a *Joint Attention* or a *Look Away* episode. In the Joint Attention condition, the experimenter looked away at the object and smiled for 3–4 seconds and said phrases such as 'Oh, that is nice' or 'It is pretty' with a positive tone of voice. She then turned back to the infant, achieved eye contact, and repeated the same procedure for 1 minute. In the Look Away condition, the experimenter looked away at the object and smiled when she spoke and said phrases for 3–4 seconds such as 'Oh, that is nice' or 'It is pretty' (the experimenter spoke these phrases in German) with a positive tone of voice. The duration of the adult's smiling vocalizations was the same across the conditions, and the experimenter used the same phrase types in both conditions. What differed across conditions was that the adult coordinated visual attention with the infant in the Joint Attention condition and not in the Look Away condition. The order of the Joint Attention and Look Away conditions was counterbalanced across infants.

Coding and reliability

One coder who was blind to the experimental hypotheses analyzed all tapes for all measures. A second independent coder, blind to the hypotheses of the study, did reliability for a random 20% of all infants and measures. Cohen's Kappas were .77 or above for all measures. Measures were defined as follows:

Gazing:	any look to E1's face
Smiling:	cheeks raised and lips turn upward, with or without mouth open
Gaze following:	any look to the target object.

Results

Preliminary analyses yielded no significant effects of object, gender or order so these variables were collapsed in subsequent analyses. A 5-episode (N1, Joint Attention, N2, Look Away, N3) within-subject ANOVA was performed with age group as the independent factor. Alpha was set at $p < .05$. All significant effects are thus at $p < .05$ or better. For pairwise comparisons, Fischer's LSD procedure was applied following significant effects. For all analyses, unless otherwise specified, percent duration of time that infants engaged in a behavior was used as the dependent measure. All figures present marginal means and standard errors.

Gazing

As shown in Figure 1, there was a significant main effect of episode, $F(4, 192) = 15.16$. As predicted, infants gazed

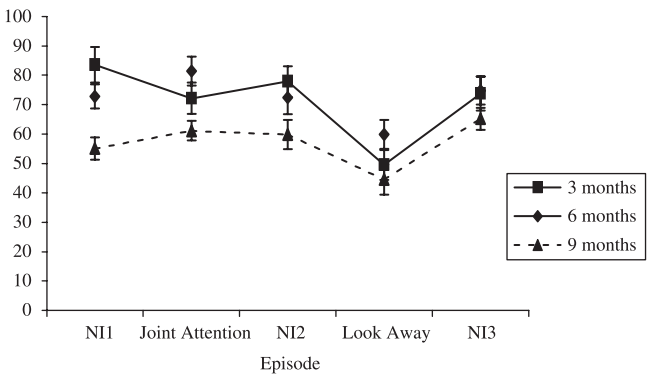

Figure 1 *Percent of time gazing as a function of age group and episode.*

reliably less in the Look Away episode compared to the Dyadic (N1, N2, N3) and Joint Attention episodes. There was a significant linear, quadratic, cubic and order 4 component. There was a significant age main effect, $F(2, 48) = 4.87$, such that 9-month-olds gazed reliably less than 3- and 6-month-olds ($M = 57.10$, 71.09 and 72.09, respectively). As shown in Figure 1, gazing interacted with age. There was a significant age × episode interaction $F(8, 192) = 2.00$. Infants at all ages manifested a significant episode effect. Pairwise comparisons for 3-month-olds revealed reliably less gazing in the Look Away episode, compared to all Dyadic (Normal) episodes and the Joint Attention episode.

For the 6-month-olds, there was reliably less gazing in the Look Away episode compared to the Joint Attention episode, and compared to the Normal 3 episode. For the 9-month-olds there was the same trend as with the 6-month-olds. Six- and 9-month-olds gazed significantly less in the Look Away episode compared to the Joint Attention episode and compared to the Normal 3 episode.

Smiling

As indicated in Figure 2, across ages there was significant main effect of episode, $F(4, 192) = 13.56$, with a significant linear, quadratic and order 4 trend. There were no age effects, and thus data are collapsed for age. As predicted, there was significantly more smiling in the Joint Attention condition compared to the Look Away episode. There was also more smiling in the Dyadic (NI) interaction conditions compared to the Joint Attention and Look Away episodes. In relation to smiling response, infants distinguished between others' dyadic and triadic attention. All contrasts were significant, with the exception of Normal interaction 1 and Normal interaction 2, and between Normal interaction 2 and Normal interaction 3.

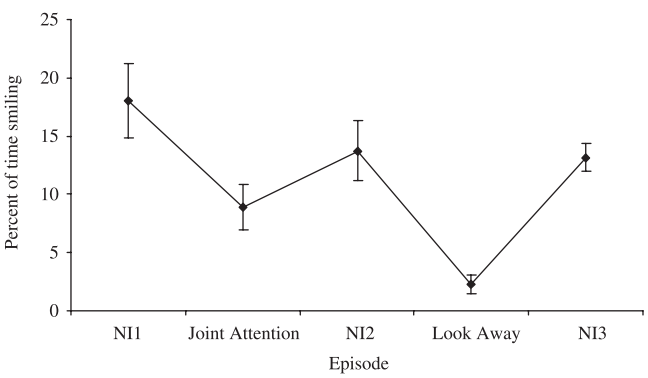

Figure 2 *Percent of time smiling as a function of age group and episode.*

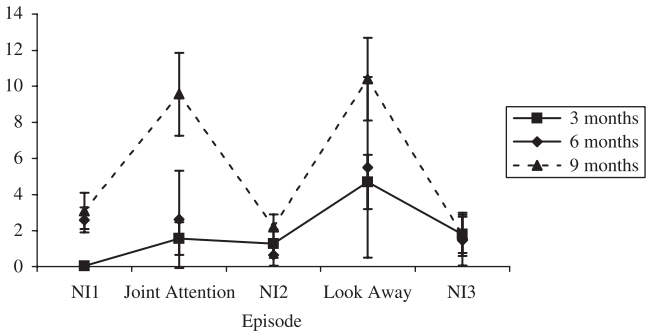

Figure 3 *Percent of time gazing to object as a function of age group and episode.*

Gazing to object

As shown in Figure 3, there was a significant main effect of gazing to the target object, $F(4, 192) = 13.65$, with a significant quadratic, cubic and order 4 trend. As predicted, infants gazed reliably more at the object in the Joint Attention episode and Look Away episode compared to all the Normal interaction conditions. Pairwise comparisons revealed that infants also looked at the target object significantly longer in the Look Away episode compared to the Joint Attention episode ($M = 6.92$ and $M = 4.56$, respectively).

There was also a significant age × gazing to object interaction, $F(8, 192) = 59.41$, with a significant order 4 trend. Performing the ANOVAs separately for each age group revealed a significant main effect of episode on 3-month-olds' gazing to the target object, $F(4, 64) = 4.09$, with infants looking significantly more to the target in the Look Away condition compared to all others. A similar effect was found for 6-month-old infants, $F(4, 80) = 2.97$, such that they gazed significantly more at the target object in all conditions except Normal 1. At 9 months of age, there was also a significant episode effect, $F(4, 60) = 9.40$, such that infants gazed significantly longer at the target object in the Joint Attention episode and Look Away episode compared to the normal interaction conditions. Unlike the younger age groups, there was no difference in looking to the target object in the Joint Attention and Look Away condition. To better understand the meaning of this developmental effect, we also performed non-parametric tests and considered the duration of time that it took infants to look to the target object as a function of condition. Assessing the mean duration of time in seconds that it took for infants to look to the target object was also one way to assess how information processing capacities might influence gaze following. The numbers of infants and their mean duration of time before looking to the target object are presented in Table 1. The mean duration

Table 1 *Number of infants who gaze followed and the mean (SD) duration of time in seconds it took for infants to gaze follow as a function of condition*

	Condition			
	Joint Attention		Look Away	
Age	*N*	Mean duration to gaze follow (SD)	*N*	Mean duration to gaze follow (SD)
3 months	4	16.75 (10.5)	11	15.72 (14.72)
6 months	9	15.77 (15.80)	12	19.75 (10.74)
9 months	12	8.83 (9.72)	12	14.00 (13.75)

of time before looking to the target object was calculated by taking the mean duration of time in seconds that it took for infants to first look at the target object once a given condition began.

The number of infants who looked to the target object as a function of condition varied across ages. Among the 3-month-old infants, 11 infants looked to the target object in the Look Away condition, compared to four infants in the Joint Attention condition. That is, at 3 months of age, significantly more infants followed gaze in the Look Away compared to the Joint Attention condition, $\chi^2(1) = 5.84$. The pattern for the 6- and 9-month-old infants was different, with no significant difference for the number of infants who looked to the target object as a function of condition (at 6 months of age, nine infants followed gaze in the Joint Attention condition and 12 infants followed gaze in the Look Away condition, and at 12 months of age 12 infants followed gaze in both conditions).

In addition, we performed *t*-tests for each age group to determine if infants were faster to follow gaze (i.e. mean duration of time in seconds that it took for infants to first look to the target object) as a function of condition. We also assessed if there were age effects for the Look Away or Joint Attention condition. Although the means presented in Table 1 are suggestive and might be used to guide future research on the topic, results were not significant for any analysis.

Discussion Study 1

Several results point to a developing sensitivity to triadic attention in the first year. Gazing to the social partner in dyadic and triadic contexts was influenced by age. At 3 months of age, infants gazed significantly more at the adult in the Joint Attention condition compared to the Look Away condition; whereas at 6 and 9 months of age, infants gazed reliably more at the experimenter in both the Normal Interaction and Joint Attention conditions compared to the Look Away condition. In general, these findings show a sensitivity to triadic attention by 3 months of age, but point to a probable inclination for dyadic interaction. Whereas at 6 and 9 months of age, given that they gazed at the adult just as much in a dyadic or triadic interaction, infants may be becoming more flexible in interaction type.

Across ages, infants' gazing and smiling during the Joint Attention condition relative to the Look Away condition shows that alternating visual attention and/or making eye contact is one key element of interpersonal communication. In contrast to the studies of Delgado *et al*. (2002) and Striano (2004) in which infants manifested a robust still-face effect when the adult looked away from them to focus on something else, in the current study, infants did not manifest a still-face response (i.e. reduced gazing and smiling) when the adult broke dyadic contact but continued to engage in a triadic interaction. This still-face effect in the Look Away condition occurred even though the adult emoted with a positive tone of voice and smiled when talking about the object.

The amount of gazing to the target object also interacted with age. At 3 and 6 months of age, infants reliably followed gaze in the Look Away condition only, whereas at 9 months of age infants followed the adult's gaze in both the Joint Attention and Look Away conditions. The analysis of individual infants' performance was also revealing. At 3 months of age reliably more infants followed gaze in the Look Away condition compared to the Joint Attention condition. At 6 and 9 months of age, infants followed gaze just as readily in both conditions. These findings point to a transition period at around 6 months of age where infants might begin to follow others' attention in both contexts. These findings suggest that attentional or information processing developments may be a key factor in 3-month-olds' ability to disengage from an adult's face to follow another's gaze (see also Hood *et al*., 1998; Ruff & Rothbart, 1997). Compared to older infants, 3-month-olds may also require more time to process an adult's behavior. This processing would have been more difficult in the Joint Attention condition because the adult's behavior was changing every few seconds, compared to the Look Away condition

in which the adult's behavior stayed constant. Future research is needed to disentangle the relation between information processing and attentional constraints in infants' developing attention-following skills and how this might relate to a sensitivity to other's triadic attention in general. Given that information processing was not controlled in the current study, the mechanisms that may account for developmental changes observed remain for future studies.

Overall, the results of the study suggest that regardless of age, infants detect when someone is attuned to them whether communicating in a dyadic (face-to-face interaction) or triadic context (joint attention). This is a first demonstration of a sensitivity to triadic attention already by 3 months of age. This skill is certainly a prerequisite for more mature forms of joint attention. The critical question that remains from the study is the degree to which infants were simply influenced by the re-engagement (i.e. eye contact) of the social partner, rather than to the adult's communicative behavior per se. Study 2 was designed to address this question by manipulating the amount of movement and re-engagement cues (eye contact and smiling) directed at the infant.

Study 2

Participants

A total of 37 infants were included in the study. Twelve 3-month-old infants (7 females and 5 males; M = 95.2 days, SD = 8.78, range = 72 to 105 days), 12 6-month-old infants (6 females and 6 males; M = 177.2 days, SD = 8.21, range = 165 to 191 days) and 13 9-month-old infants (6 females and 7 males; M = 275.4 days, SD = 14.48, range = 262 to 316 days) participated. An additional 3-month-old infant, 4 6-month-old infants and 9 9-month-old infants were tested but not included due to fussiness. The sample had the same characteristics and was taken from the same subject pool as in Study 1.

Method

The set-up was very similar to Study 1. Four cameras filmed the interaction and the resulting image was fed into a digital quad splitter and recorded onto a mini-digital VCR. The set-up also differed in that infants sat between two objects instead of one. The objects were two plastic frog toys approximately 4 inches tall that were placed on an orange block and a pink bowl. The objects were then placed on two buckets that were about 14 inches high and therefore approximately at the infant's eye level when the infant was sitting in the chair.

Figure 4 *Experimental set-up in Study 2 (3-month-old gazing at target).*

The buckets were placed approximately 40 degrees and 16 inches away from the infant on either side of his/her head as shown on Figure 4.

Infants interacted with E in four 30-second conditions that were embedded within normal interactions. Between each 30-second episode, E engaged the infant in a normal interaction for 5–10 seconds and waited until the infant made eye contact. Infants received all four conditions. In each of the conditions, E always looked to just one of the objects. For half of the infants, E looked to the object on the right side and for the other half of the infants E looked to the object on the left side. The order of conditions was counterbalanced across infants. A second experimenter stood behind the curtains, timed the interaction, and cued E1 by beeping the stopwatch when the 30 seconds were over for each interaction period. The conditions are as follows.

Joint Attention

E turned her head and eyes to look at one of the objects. She then looked back and forth between the object and the infant's face. She held her gaze at the object for about 3 seconds and then looked at the infant's face for about 2 seconds before repeating the procedure. She smiled and talked while looking at the infant and then she turned to look at the object. The procedure was repeated for 30 seconds.

Alternate only

The procedure was the same as the Joint Attention condition except that no affect was provided. Therefore, E

alternated her gaze but did not smile or talk. This condition was designed to assess the role of movement/alternating in infants' response.

Affect only

The procedure was the same as in the Joint Attention condition, except E broke eye contact with the infant for 1 second before looking to the object. That is, after looking at the infant and smiling and talking for 2 seconds, E looked up above the infant's head for 1 second and then immediately turned to look at the object. The rationale was that E's smile and vocalization would not be interpreted as about the object that E was looking at. This is because when E turned to look at the object it was not following eye contact with the infant, but rather after a brief break in contact while looking above the infant's head.

Ignore

E turned to look at the object for 30 seconds. She did not vocalize or smile. E held this position for 30 seconds.

Coding and reliability

The procedure for coding was the same as in Study 1. Cohen's kappa was above .80 for all measures.

Results

Preliminary analyses yielded no significant effect of age, gender, side, or order of condition and thus these variables were collapsed in subsequent analyses. Alpha was set at $p < .05$. All significant effects are thus at $p < .05$ or better. For pairwise comparisons, Fischer's LSD procedure was applied following significant effects. For all main analyses, a 4 Episode (Joint Attention, Alternate, Affect, Ignore) × 3 Age (3-, 6- and 9-month infants) mixed design ANOVA was performed. For pairwise comparisons, Fischer's LSD procedure was applied following significant effect. As with Study 1, the percent duration of time that infants engaged in each behavior was used at the dependent measure. All graphs present marginal means and standard errors.

Gazing

As shown in Figure 5, there was a significant main effect of episode, $F(3, 102) = 29.103$. Pairwise comparisons confirmed that infants gazed significantly more at the experimenter during the Joint Attention episode compared to all other episodes (all p-values ≤ .006). Infants also gazed significantly more at the experimenter in the Alternate and Affect episode compared to the Ignore episode (both p-values ≤ .001). There were no other significant main effects or interactions.

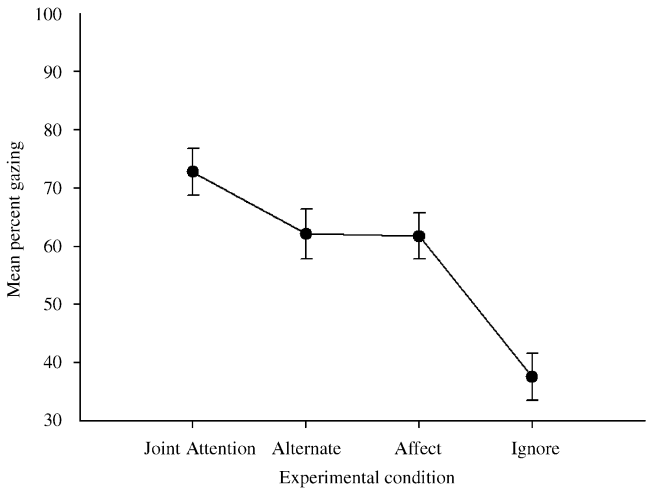

Figure 5 *Percent of time gazing as a function of age group and episode.*

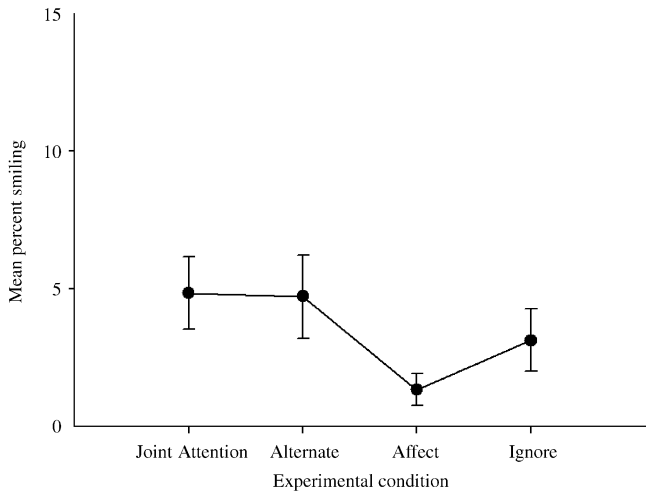

Figure 6 *Percent of time smiling as a function of age group and episode.*

Smiling

As shown in Figure 6, there was a significant main effect of episode, $F(3, 102) = 3.124$. Pairwise comparisons showed that infants smiled significantly more in the Joint Attention and the Alternate episode compared to the Affect and Ignore episode. There were no other significant main effects or interactions.

Table 2 *Means and standard deviations for percent duration of time for infant behavior as a function of age*

Age	Behavior	JA	(SD)	Alternate	(SD)	Affect	(SD)	Ignore	(SD)
3 months	Gazing	77.5	(29.28)	71.3	(29.58)	68.3	(24.78)	38.7	(32.72)
	Smiling	7.0	(7.74)	7.0	(9.58)	1.3	(2.34)	2.4	(4.17)
	Gaze following	0.0	(0.00)	2.3	(5.60)	−0.1	(2.92)	−0.9	(4.16)
6 months	Gazing	77.6	(24.05)	64.9	(19.22)	64.2	(26.21)	34.0	(18.60)
	Smiling	0.7	(1.99)	0.3	(0.97)	0.1	(0.19)	1.9	(6.75)
	Gaze following	2.5	(8.68)	3.3	(7.69)	2.8	(8.41)	5.2	(17.86)
9 months	Gazing	63.2	(18.81)	50.3	(27.93)	52.8	(20.63)	40.0	(19.57)
	Smiling	6.8	(11.04)	6.9	(12.39)	2.7	(5.36)	5.1	(8.70)
	Gaze following	6.4	(11.31)	1.9	(14.24)	0.4	(10.43)	10.8	(15.28)

Gazing to object

The means for gazing to the target object (i.e. gazing to target object minus gazing to non-target object) are presented in Table 2. There were no significant main effects or interactions for gaze following. However, it is important to note that unlike in Study 1, infants' gazing during the four experimental (triadic) conditions were compared to each other and not to a normal (dyadic) interaction. As indicated by the means in Table 2, infants did look to the target object in many of the conditions, but there were not differences as a function of age and condition. This may also have been due to the addition of a second object that competed for infants' attention and the shorter condition times (30 rather than 60 s) in comparison to Study 1.

Discussion Study 2

Infants interacted with an adult and various aspects of joint attention were manipulated when the adult looked away at an object. The results show that by 3 months of age infants are sensitive to both movement and affect cues as aspects of joint attention. That is, infants across ages gazed significantly more at the adult when she coordinated both affect and attention (i.e. joint attention condition) than when she provided affect cues only, attentional (i.e. movement) cues only, or when she ignored the infant. That infants gazed reliably longer in the Affect only and Attention only conditions compared to the Ignore condition, also suggests that both aspects may be essential parts of joint communication. The smiling results were also revealing in this regard and mirror what is generally found in interpersonal contingency studies. Research conducted with young infants using closed circuit video procedures shows that by 2 months of age infants are sensitive to more than the mere presence or absence of movement of an interactive partner. Infants are sensitive to small and subtle perturbations in the timing and structure of interaction, and respond to their mother with more gazing and positive affect when they see her live rather than replayed over a monitor (Murray & Trevarthen, 1985; Nadel, Carchon, Kervella, Marcelli & Reserbat-Plantey, 1999). Such sensitivity suggests that the infants' behavior in the current studies is likely due to a loss of contact that involves much more than vocal or movement cues. Although infants received more smiling directed at them in the Affect only condition – in return, they smiled at the adult reliably less in this condition than in the Alternate only and Joint Attention conditions. Future research will be needed to replicate this effect and explore this finding in more detail. One working hypothesis is that infants are tuned into the presence or absence of *relevant* communicative cues from an early age – and hence respond to perturbations in the normal flow of interaction whether in dyadic or triadic contexts. Unlike in Study 1, we did not find that infants reliably followed the experimenter's gaze more in the Joint Attention condition compared to the Ignore condition or vice versa. However, this result was most likely due to the shorter time period of the episodes in Study 2 compared to Study 1.

General discussion

Triadic interactions are essential for many aspects of human cultural learning. For instance, skills such as language learning and imitation could never come about without an appreciation of the things to which others are attending. Most research assessing infants' sensitivity to triadic attention has considered infants only by the end of the first year (see Carpenter *et al.*, 1998). Research with infants younger than 9 months of age has not distinguished between dyadic and triadic sensitivities. As a result, the ontogeny of sensitivity to triadic attention – so critical for human cultural learning – is remarkably unknown. In the current studies, infants' sensitivity to triadic attention was assessed for the first time. The studies also present original descriptive data on the early ontogeny of triadic sensitivities by assessing infants at 3, 6 and 9 months of age.

Study 1 was motivated by prior studies in which infants did not respond differently toward an adult social partner as a function of the reason or underlying motive that she stopped communicating with them. One possibility is that despite the different reasons or motives behind the break of dyadic contact in these studies, infants were influenced similarly in these situations because these were not *shared* situations. Assuming that infants are primarily motivated by the social rather than the cognitive aspect of interaction (see Delgado *et al*., 2002; Striano, 2004), they might not manifest a still-face response if dyadic contact is broken but the underlying motive or reason behind the break is shared as in a triadic interaction.

In contrast to prior studies in which dyadic contact was broken and triadic interaction was not established, infants did not manifest a still-face reaction in the Joint Attention condition in the current study. Across all ages, infants only manifested a still-face response when the adult looked away at an object and not back at them. This still-face effect occurred even though the adult emoted with a positive tone of voice and smiled when talking about the object.

While some suggest that it is not until the end of the first year that infants tune into others' attention (i.e. Tomasello, 1999; Carpenter *et al*., 1998), the current findings show that a sensitivity to shared attention starts well before the end of the first year. The mechanisms that drive more robust forms of joint attention are unknown, but the gaze following results from Study 1 suggest that information processing skills may play a major role (see also Hood *et al*., 1998; Ruff & Rothbart, 1997). At 3 months of age, infants were reliably more likely to follow the adult's gaze toward an external object when she continued to stare at the object rather than when she continued to coordinate attention. This finding suggests that attention following is within the infants' repertoire well before 9 months of age. It is important to note that prior studies did not consider infants' development before 9 months of age and included only attention following tasks that involved alternation of gaze (see Carpenter *et al*., 1998). Thus, task demands might account for some inconsistent results across various studies. Along these lines, recent research shows that among 18-month-old infants, verbal information promotes joint attention toward unfamiliar but not to familiar target objects (Flom & Pick, 2003). This study suggests that task demands interact with joint attention. The same might hold true for the current study, for instance, in explaining facilitated gaze following at 3 months of age in the Look Away compared to the Joint Attention condition. It is also interesting to note that the adult vocalizations may have led to enhanced gaze following in the Look Away condition of Study 1 compared to the Ignore condition of Study 2. Given that the duration of conditions was not the same in these two studies, it is difficult to make firm conclusions about this pattern of findings. However, it is possible to speculate that this pattern of results would be consistent with that reported by Flom and Pick (2003) with 18-month-old infants, and suggests that multimodal information might even facilitate joint attention in early infancy. Assessing the role of multimodal cues in establishing joint attention in infancy is clearly one important avenue for future research. In future research it may also be useful to assess inter-individual differences in the capacity for joint attention. Research suggests that joint attention skills may be related to self-regulatory processes (Raver, 2004), and these processes may have related to the attrition rate of the current study. The causes and consequences of attrition and inter-individual profiles should therefore be considered when interpreting the findings of the studies and when designing future studies on the topic.

The results of the current study show that already by 3 months of age, infants manifested more attention and positive affect when someone broke dyadic contact to engage in a triadic interaction. Beyond a sensitivity to the presence or absence of dyadic contact or the presence or absence of eye contact (e.g. Hains & Muir, 1996), infants were sensitive to the other's visual attention in relation to an external object. When someone looked away and continued to speak, infants manifested reliably less positive affect and tried to re-engage the adult more. When the adult coordinated attention with the infant, therefore completing what might be called the 'referential' or 'relatedness triangle' (see Hobson, 2002; Tomasello, 1999), infants gazed and smiled as they did in the normal face-to-face interaction.

While the results of Study 1 suggest a sensitivity to triadic attention, other interpretations were still possible due to the nature of the experimental conditions. For instance, in the Joint Attention condition the adult looked at the infant's face and moved as she alternated her attention between the infant and the object. In contrast, in the Look Away condition, there were no movement or facial cues provided. Therefore in Study 2, we controlled for these various aspects of interaction.

The findings from Study 2 showed that both alternating visual attention and positive affect are aspects of joint attention to which 3- to 9-month-old infants are sensitive. In general, the study confirms young infants' sensitivity to head and gaze direction by 3 months of age (Caron *et al*., 1997; Hains & Muir, 1996) which is a necessary precursor to more systematic triadic interaction in later ontogeny. More robust triadic skills most likely await further experiential, neural, and motor developments

(see Campos, Anderson, Barbu-Ruth, Hubbard, Hertenstein & Witherington, 2000; Elman, Bates, Johnson, Karmiloff-Smith, Parisi & Plunkett, 1996; Mundy, Card & Fox, 2000).

Overall, the results of the study suggest that a sensitivity to joint attention does not emerge in some sort of abrupt way, but gradually develops over the first year (see also Striano & Bertin, in press; Striano & Rochat, 1999). Regardless of the form, whether in dyadic or triadic contexts, the current findings suggest that human infants are attuned to others. This sensitivity to others' triadic attention expresses itself at least by 3 months of age.

While these results suggest a sensitivity to triadic attention, they certainly do not imply an awareness of the underlying motives, desires and intentions that guide others' behavior. That being said, there is very scant evidence that *any* triadic social skill (even if it emerges at 9 months of age or later) is a very solid index of an awareness of intentions in others. To our knowledge there is no study that has successfully linked triadic social skills (i.e. gaze following, blocking, teasing; see Carpenter *et al*., 1998; Striano & Rochat, 1999; Striano & Bertin, in press) to an unequivocal awareness of others' intentions or rationale for action – for instance of the sort elegantly demonstrated by Gergely, Bekkering and Kiraly (2002) with 14-month-old infants.

The key is to establish exactly what this early sensitivity to triadic attention means. One way to tackle this problem is by relating this early sensitivity to triadic attention to other social cognitive skills (see Morales, Mundy & Rojas, 1998). Here we show an early sensitivity to triadic attention – the mechanism that drives such sensitivities and whether these sensitivities are necessary precursors for a unique aspect of human cultural learning are just some of the essential questions that need to be addressed in future research.

Acknowledgements

The research was supported in part by the Sofja Kovalevskaja Award, granted by the Alexander von Humboldt Foundation, to T. Striano and the Max Planck Society. Thank you to Michael Tomasello, Vincent Reid, Anne Henning, Evelin Bertin for comments on the paper. Thank you 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 research.

References

Butterworth, G. (1998). Origins of joint visual attention in infancy. *Child Development*, **63** (4), 114–166.

Butterworth, G., & Jarrett, N.L.M. (1991). What minds have in common is space: spatial mechanisms for perspective taking in infancy. *British Journal of Developmental Psychology*, **9**, 55–72.

Campos, J.J., Anderson, D.I., Barbu-Roth, M.A., Hubbard, E.M., Hertenstein, M.J., & Witherington, D. (2000). Travel broadens the mind. *Infancy*, **1**, 149–219.

Caron, A.J., Caron, R., Roberts, J., & Brooks, R. (1997). Infant sensitivity to deviations in dynamic facial-vocal displays: the role of eye regard. *Developmental Psychology*, **33**, 802–813.

Carpenter, N., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence. *Monographs of the Society of Research in Child Development*, **36** (4, Serial No. 176).

Delgado, C.E.F., Messinger, D.S., & Yale, M.E. (2002). Infant responses to direction of parental gaze: a comparison of two still-face conditions. *Infant Behavior and Development*, **137**, 1–8.

D'Entremont, B., Hains, S.M.J., & Muir, D.W. (1997). A demonstration of gaze following in 3- to 6-month-olds. *Infant Behavior and Development*, **20**, 569–572.

Elman, J.L., Bates, E.A., Johnson, M.A., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development (Neural networks and connectionist modelling series)*. Cambridge, MA: MIT Press.

Farroni, T., Csibra, G., Simion, F., & Johnson, M. (2002). Eye contact detection at birth. *Proceedings of the National Academy of Science*, **99**, 9602–9605.

Flom, R., & Pick, A. (2003). Verbal encouragement and joint attention in 18-month-old infants. *Infant Behavior and Development*, **26**, 121–134.

Gergely, G., Bekkering, H., & Kiraly, I. (2002). Rational imitation in preverbal infants. *Nature*, **415**, 755.

Hains, S.M.J., & Muir, M.W. (1996). Infant sensitivity to adult eye direction. *Child Development*, **67**, 1940–1951.

Hobson, P. (2002). *The cradle of thought: Exploring origins of thinking.* Oxford: Oxford University Press.

Hood, B.M., Willen, D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science*, **9**, 131–134.

Moore, C., & Corkum, V. (1995). The origins of joint visual attention. In C. Moore & P. Dunham (Eds.). *Joint attention: Its origins and role in development* (pp. 61–85). Hillsdale, NJ: Erlbaum.

Morales, M., Mundy, P., & Rojas, J. (1998). Following the direction of gaze and language development in 6-month-olds. *Infant Behavior and Development*, **21**, 373–377.

Mundy, P., Card, J., & Fox, N. (2000). EEG correlates of the development of infant joint attention skills. *Developmental Psychobiology*, **36**, 325–338.

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., & Reserbat-Plantey, D. (1999). Expectancies for social contingency in 2-month-olds. *Developmental Science*, **2**, 164–173.

Raver, C. (2004). Placing emotional self-regulation in socio-cultural and socio-economic contexts. *Child Development*, **75**, 346–354.

Reddy, V. (2003). On being an object of attention: implications for self–other-consciousness. *Trends in Cognitive Science*, **7** (9), 397–402.

Ruff, H.A., & Rothbart, M.K. (1996). *Attention in early development: Themes and variations*. New York: Oxford University Press.

Scaife, M., & Bruner, J. (1975). The capacity for joint visual attention in the infant. *Nature*, 265–266.

Striano, T., & Bertin, E. (in press). Social cognitive skills between 5 and 10 months of age. *British Journal of Developmental Psychology.*

Striano, T., & Rochat, P. (1999). Developmental link between dyadic and triadic social competence in infancy. *British Journal of Developmental Psychology*, **17**, 551–562.

Striano, T. (2004). Direction of regard and the still face effect in the first year: does intention matter? *Child Development*, **72**, 468–479.

Tomasello, M. (1999). *The cultural origins of human cognition.* Cambridge, MA: Harvard University Press.

Received: 9 December 2003
Accepted: 18 October 2004