

Who's in the Mirror? Self–Other Discrimination in Specular Images by Four- and Nine-Month-Old Infants

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This research investigated the early determinants of self–other discrimination in infancy. Ninety-six 4- and 9-month-old infants were placed facing a live image either of themselves or of another person (experimenter) mimicking them. The specular image was either contingent (on-line), or contingent with a 2-s delay. After a first 1-min presentation, the video image of either the self or the other was suddenly frozen for 1 min (still-face episode). This was followed by a last minute of live presentation. From 4 months of age, infants appeared to perceive and act differentially when facing the specular image of themselves or the mimicking other. In general, infants tended to smile more, look more, and have more protracted first-look duration toward the mimicking other compared with the self. Developmentally, 9-month-olds showed markedly more social initiatives toward the mimicking other compared with the self during the still–face episode. In all, these results indicate that infants develop self–other discrimination in specular images long before mirror self–recognition, which is typically reported by the second year. Discrimination of the self from other is interpreted as a precursory ability and a perceptual foundation of later conceptual self development.

INTRODUCTION

Seeing oneself in a mirror or in a live video projection is a significant and profoundly revealing psychological experience. The way in which infants, children, and even adults react and behave while contemplating their specular image reveals not only how they construe their bodily self, but also how they might construe others in relation to themselves. Recognizing oneself in a specular image is more than overcoming the sudden experience of spatial dislocation between the proprioceptive and visual sense of one's own body. It entails some synthesis of "coexistence with others" (Merleau-Ponty, 1964/1989, p. 140). In other words, it entails the realization that the specular image is standing for the identified or conceptual self (i.e., "Me"), not somebody else (Rochat, 2002). Self-recognition is the realization that one's own specular image is nothing but my one's bodily self: the self as seen by others.

Questions remain as to what are the developmental origins and determinants of self–other discrimination in specular images. Much research documents the emergence of behaviors by 14 to 18 months that indicate explicit self-awareness in mirrors or any other reflecting surfaces. Self-referencing activities, self-labeling, and emotional expression of embarrassment after discovering some rouge on the face are typically taken as unambiguous signs of self-recognition, namely that children begin to construe their specular image as standing for their own body and how it appears to others (Bertenthal & Fisher, 1978; Guillaume, 1926; Lewis & Brooks-Gunn, 1979; Zazzo, 1981). If such behaviors express conceptual self-awareness, namely

the child's construal that what is reflected in the specular image is nobody else but Me, then how does this conceptualization come about? Is it a sudden developmental emergence or is it progressive? If it is progressive, do infants already show some basic perceptual abilities in discriminating what pertains to themselves and what pertains to others in specular images, long before they manifest conceptual and explicit self-awareness? Recent research seems to support this concept.

From at least 3 months of age, when placed in front of mirrors, infants tend to engage in long bouts of self-exploration, observing their own movements and seemingly enjoying the experience of visual–proprioceptive contingency afforded by mirrors. They manifest positive affect, including smiling, cooing, reaching for the part of the body reflected in the mirror, and often demonstrating sudden bursts of joyful activities (Amsterdam, 1972). There is some evidence that from 3 months of age, when mirror reflections become potent objects of exploration, infants can discriminate whether they are looking at a mirror image of themselves or that of a peer. Field (1979) observed that 3-month-olds tended to look significantly more at themselves in a mirror compared with when attending to another, noncontingent infant to whom they smiled and vocalized more. Other research has shown that young infants are responsive to particular aspects of their own specular image. Placing 1- to

24-month-old infants in front of two mirrors that were either flat, blurred, or distorted, Schulman and Kaplowitz (1976) showed that prior to 6 months of age, infants tended to look more often at the clear rather than the blurred image of themselves, and showed less interest in the distorted image compared with the flat nondistorted mirror image. Interestingly, Schulman and Kaplowitz noted that compared with older infants, 1- to 6-month-olds were not yet showing complex behavior such as looking at a particular body part, followed by an immediate inspection of the body part's reflection in the mirror.

Lewis and Brooks-Gunn (1979) have suggested that what determines early specular image exploration is the discovery by the young infant of the contingency between visual and proprioceptive feedback from body movements (see also Guillaume, 1926; Wallon, 1942/1970). This suggestion, however, does not account for the observations of Schulman and Kaplowitz (1976), in which infants discriminated between specular displays of themselves that were equally contingent, but spatially transformed. One possibility is that in addition to visual–proprioceptive contingency, young infants might already be able to discriminate between specular images that are spatially more or less eccentric relative to what they calibrated of their own body via direct visual exploration of limb movements. Another possibility is that experimentally transforming the specular image (e.g., blurred), aside from making it perceptually less salient, might also eliminate important features of the mirror reflection that are potentially social in nature—in particular, eye contact between self and specular image.

Papousek and Papousek (1974) introduced an experimental paradigm based on video recordings rather than mirrors. They placed 5-month-olds in front of two different video images presented side-by-side: one of themselves and one of another infant. By measuring preferential looking of the infant, this method allowed for the assessment of what the infants discriminated between the two video images. Papousek and Papousek reported that infants preferred to look at images of the self or at images of others that allowed for eye contact. Eye contact as a social factor appears to play a role in determining the exploration of specular images, whether they are of the self or of another child. Both are apparently treated by the infant as social rather than self objects. This apparent social treatment of the specular image, whether it refers to the self or to another infant, might only hold for situations in which specular images include faces and facial displays, however. Much research indicates that from birth, infants demonstrate particular attention to facelike displays and are capable, within hours after birth, of discriminat-

ing subtle differences among faces, depending on the familiarity of the faces (Walton, Bower, & Bower, 1992) or whether they have organized or disorganized internal features (Fantz, 1963; Johnson & Morton, 1991). By 2 months of age, the internal features of faces increasingly become focal aspects of infants' visual scanning of faces (Haith, Bergman, & Moore, 1977); and as early as 3 to 5 months, infants appear remarkably sensitive to eye contacts and eye direction in facial displays (Hains & Muir, 1996; Hood, Willen, & Driver, 1998).

Bahrnick and Watson (1985) demonstrated the early detection of proprioceptive–visual contingency in nonfacial images. In their study, infants were simultaneously presented with either a noncontingent, prerecorded view of their own legs or the view of another baby's legs wearing identical booties. These views were presented on two adjacent TV screens for preferential looking analysis. Bahrnick and Watson showed that 5-month-olds looked preferentially to the noncontingent view. They also observed this phenomenon in a situation in which an occluder prevented infants from seeing their legs directly. Three-month-olds showed split preferences, looking much longer at either the contingent or the noncontingent view. These findings indicate that perceptual discrimination of own versus someone else's specular image does not rest solely on the display of faces, but can also pertain to nonfacial parts of the body (i.e., moving legs). From 3 to 5 months, young infants appear to be sensitive to visual and proprioceptive contingency in general, and not just to the contingency of eye contact, as suggested by previous researchers who emphasized the social context in which first discrimination between self and others takes place (Dixon, 1957; Papousek & Papousek, 1974).

Follow-up studies using the video paradigm introduced by Bahrnick and Watson indicate that from 3 months, infants are not only sensitive to the presence or absence of temporal contingency between visual and proprioceptive feedback in specular images, but also to the spatial calibration of their own bodily movements that are reflected in these images. From 3 months of age, infants are sensitive to a left–right reversal of their own legs seen on-line on a TV screen (Rochat, 1998; Rochat & Morgan, 1995). Converging observations were made using a similar paradigm that involved infants' hands and arms instead of legs (Schmuckler, 1996).

In summary, existing research suggests that by 3 to 5 months, infants are able to discriminate differences in visual–proprioceptive temporal contingency (Bahrnick & Watson, 1985), changes in the spatial calibration of visual and proprioceptive feedback (Rochat & Morgan, 1995), as well as to the presence or absence of eye contact (Papousek & Papousek, 1974) in the sponta-

neous exploration of their own specular image. These findings show that young infants are discriminant of spatial, temporal, and configurational aspects of their specular image. They do not, however, demonstrate that infants construe the specular image as either standing for themselves or someone else.

Recent studies began testing this issue more directly by assessing infants' differential responding to prerecorded (i.e., noncontingent) video views of their own face or the face of another infant, controlling for age, gender, head posture, and clothing. Bahrick, Moss, and Fadil (1996) found that infants as young as 3 months prefer to look at the dynamic video of another infant's face. Infants at this age appear to be able to discriminate their own facial features, probably based on previous mirror experience (Bahrick et al., 1996). The preferential looking at the display of the other infant suggests that 3-month-olds might already construe the other infant as a putative social partner with whom to engage. This interpretation, however, is highly speculative, because aside from gazing, Bahrick et al. did not record any social responses, such as smiling, cooing, or other socially oriented behaviors. Their interpretation was limited to the idea that infants probably learned to discriminate and detect invariant feature characteristics of their own face via previous mirror exposure.

Legerstee, Anderson, and Schaffer (1998) replicated the findings of Bahrick et al., providing further evidence that by 5 months, infants do differentiate between the dynamic specular image of self, others, or a puppet. Such discrimination appears to hold in the auditory presentation of prerecorded sounds made by a peer, an object, and the infants themselves. In general, infants show preference for social faces and social sounds. Interestingly, this preference is not restricted to gazing, but also to responses such as vocalizing and smiling. Overall, Legerstee et al. showed that from 5 months of age, infants attended to their own face and voice as familiar and differentiated from other social or nonsocial facial and auditory events. If these findings confirm that by 5 months there is an early perceptual discrimination between images and sounds reflecting either the self, others, or physical objects (i.e., a puppet), it is still not clear whether such discrimination is purely perceptual or whether such discrimination might also entail some early signs of self-recognition, in the sense of a construal of the self as differentiated from someone else. On the one hand, the discrimination reported by Bahrick et al. (1996) and Legerstee et al. (1998) could rest merely on differential feature or vitality detection that more or less matches what infants might be familiar with when feeling their own body moving or visually exploring their own face in mirrors. On the other hand, this dis-

crimination might also entail higher categorization of the self as an entity differentiated from others.

Relevant to the developmental emergence of such higher processing are the observations of Meltzoff and Moore (1999) on infants' ability to detect mirroring from a social partner. Infants were tested while facing two experimenters, one imitating systematically the action they performed on an object, as in a specular image, and the other responding contingently but without any exact mirroring of the infant's own action. The authors reported that by 14 months, infants began to show clear signs of discrimination between the two social partners. By 9 months, infants were reported to spend more time looking at the imitating rather than the contingent experimenter (Meltzoff & Moore, 1999). It is not clear, however, whether such tendency might entail self-recognition in the action of the imitating experimenter.

The aim of the present research was to investigate further the emergence and determinants of self-other discrimination, by systematically manipulating temporal and featural characteristics of on-line specular (video) images. Two basic questions guided the research:

1. When do infants start to show signs of a discrimination between self and others in on-line specular images?
2. What are the featural and temporal determinants of such discrimination?

To address these questions, both visual attention and infants' social responses to the specular image with varied featural characteristics (self versus experimenter) as well as varied temporal characteristics (on-line versus delayed contingency) were measured. To enhance the assessment of self-other discrimination, testing in each condition included a still-face period in which the specular image became momentarily frozen. Past research indicates that from approximately 2 months of age, infants react to a sudden still-face from a social partner with marked negative behaviors such as gaze aversion and diminished smiling (Toda & Fogel, 1993; Tronick, Als, Adamson, Wise, & Brazelton, 1978). This robust phenomenon is typically considered as indexing infants' sensitivity to social contingency and early social attunement as well as emerging social expectations in face-to-face protoconversations (Muir & Hains, 1993; Rochat & Striano, 1999; Trevarthen, 1979). Furthermore, by 7 to 9 months, infants begin to manifest clear attempts to re-engage a social partner who has adopted a sudden still-face (Striano & Rochat, 1999). Such attempts are clearly social in nature, oriented toward changing the behavior of the social partner. Thus, in the context of the present research, such responses

were considered as an index of infants' construal of the specular image as standing for a social (nonself) partner with communicative intents. Our rationale was that if infants manifested enhanced social re-engagement toward nonself compared with self specular images (either on-line or delayed), this would further support self versus other discrimination.

In all, the present research added to previous investigations that used prerecorded specular images (Bahrick et al., 1996; Legerstee et al., 1998). It was specifically designed to address the question of whether and when infants might treat an on-line specular image as a social partner, or as referring to the self. In addition, the research was designed to assess more directly the possible determinants of such discrimination in infancy. Infants were presented with on-line specular images while temporal (simultaneous versus delayed visual-proprioceptive feedback) and featural aspects of the specular image (image of the self versus the image of a mimicking other) were covaried.

As a general working hypothesis, and in the context of the recent body of findings showing a major transition in social-cognitive development at around 9 months of age (Tomasello, 1995, 1999), we expected that 9-month-old infants would start demonstrating differential responding between self and an imitating other. By this age, and not prior (i.e., 4 months), infants should begin to show reliable signs that they do not respond to their own image on the TV as if it were another infant, even when the image of the self is presented with a temporal delay that might resemble the time-lagged but synchronized turn-taking format of early social exchanges (Gergely & Watson, 1999; Stern, 1985; Trevarthen, 1979). In addition to enhanced visual attention, when facing the imitating experimenter on the TV, infants were expected to manifest social responses—in particular, explicit attempts at social re-engagement of the kind documented in 9-month-olds during still-face episodes that interrupted normal face-to-face social exchanges (Striano & Rochat, 1999). Compared with the group of 9-month-olds, we expected 4-month-olds to respond to their own image as if it were another infant. We expected them to show less explicit attempts at social re-engagement, however.

METHOD

Participants

Ninety-six healthy, term infants were tested and included in the final sample, divided equally into two age groups: forty-eight 4- to 5-month-olds (referred to as the group of 4-month-olds; *range* = 110–150 days;

23 males, 25 females) and forty-eight 8- to 9-month-olds (referred to as the group of 9-month-olds; *range* = 240–289 days; 26 males, and 22 females). Fifty-one additional infants were tested but not included in the final sample: 49 for fussiness prior to completion of testing and 2 for technical errors. The infants were recruited from a participant pool consisting of over 500 infants born at the Northside Maternity hospital of Atlanta, Georgia. Races were representative of the Northeastern Greater Atlanta population, predominantly of Caucasian middle class.

Apparatus and Setup

Participants were seated on an upright infant seat placed on a table and facing a black enclosure made of a metal frame structure holding a 45° inclined one-way mirror that faced the infants (see Figure 1). A 50-cm TV monitor rested horizontally (facing down) on top of the metal frame structure so as to project its image onto the mirror that faced the infants approximately 1.5 m away. The TV image appeared to the infants as if it was seen on a regular monitor facing the infants, with no particular inclination or deformation. The mirror technique was meant to allow for the projection of an on-line image of self or of the experimenter, with the possibility in both instances for precise eye-to-eye contacts between the specular image and its viewer (the same as viewing oneself in a frontal and parallel mirror). This technique was originally established by Murray and Trevarthen (1985) and later used by Rochat, Neisser, and Marian (1998) to account for eye contacts as an important social variable from the outset of development (see Papousek & Papousek, 1974; Symons, Hains, & Muir, 1998). A video camera,

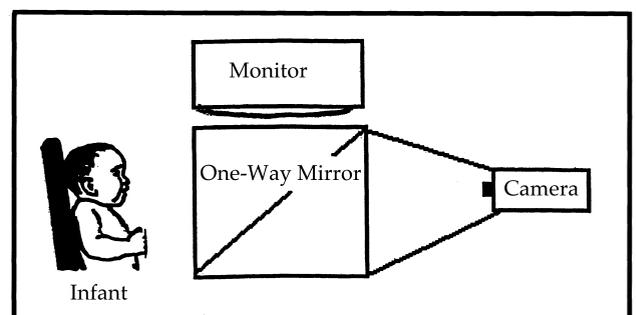


Figure 1 Diagram of the experimental setup. Infants were seated facing their own or the mimicking experimenter's specular image from a TV, which was reflected on a one-way mirror placed diagonally in a metal frame structure. A video camera, which was placed behind the one-way mirror, was invisible to the infants and filmed them at eye height through the mirror projecting the TV image seen by the infants.

which was placed behind the one-way mirror, was invisible to the infants and filmed them at eye height through the mirror projecting the TV image seen by the infants. The mirror reflected to infants either an on-line view of themselves—including face, shoulders, and arms—recorded by the camera behind the mirror (self condition), or the view of a female experimenter mimicking the infant on-line (other condition), see Procedure and Design section below).

Figure 1 presents a diagram of the apparatus and setup used in the self or in the other condition. A white curtain surrounded the infant and the frame structure holding the mirror. The TV and camera were invisible to the infant who sat across from the 45°-inclined mirror framed by a black curtain that hid the faced-down TV as well as cables and other pieces of equipment. Infants could not kick or touch the framed mirror, or lean forward and look up directly at the TV.

In the other condition, the experimenter was placed on the other side of the table, facing another, identical metal frame and one-way mirror apparatus. To mimic the infants, the experimenter viewed the on-line image of the infants as reflected in the mirror. Infants were simultaneously presented with the on-line specular image of the mimicking experimenter filmed at eye height. The specular image of the mimicking experimenter included face, shoulders, and arms, as in the self condition (see Figure 2). The experimenter was always the same person, trained to mimic on-line the infants' slightest head, facial, arm, and trunk movements with comparable magnitude. Facial movements included mouth opening and emotional expressions such as smiling or frowning. Limb movements were matched to appear on the ipsilateral side of the specular image relative to the infants. In other words, the mimicking by the experimenter was reflected in the same way the infants would see their own actions on a mirror (left/right reversal).

In addition to the self or other condition, each infant was tested with a mirror reflection of the TV that was either on-line (on-line contingency) or delayed by 2 s (delayed contingency). In the delayed contingency situation, prior to being projected onto the TV facing the infant, the image was fed into a special effect broadcasting device (Primeimage Pipeline Video Delay SN 5066), which allowed for short-term storage and adjustable delayed output of on-line video recording. In addition, prior to being projected onto the TV, the image was also fed into a video mixer (Videonics mx-1 NTSC), which allowed for the freezing of the recording of the current image at the push of a button. This device was used for the still-face episode in each experimental condition (see Procedure section below).



Self Condition



Other Condition

Figure 2 Example of own specular image (self condition) and specular image of the mimicking experimenter (other condition) viewed by infants in the current research.

For later coding, this device was also used for the synchronized recording of one final split image composed of the infant's face recorded by the camera behind the one-way mirror, and the TV image (self/other in on-line or delayed contingency) projected onto the mirror and seen by the infant.

Procedure and Design

Infants of each age group were further divided into four equal experimental subgroups of 12 infants. Each subgroup was tested separately in one of four experimental conditions combining self versus other and the two types of video feedback contingency, respectively:

1. self condition with on-line contingency.
2. self condition with delayed contingency.
3. other condition with on-line contingency.
4. other condition with delayed contingency.

Each experimental condition lasted a total of 3 min divided into three successive 1-min episodes. During the first minute, infants saw a view of either themselves or the mimicking experimenter in either one of the two contingency conditions (on-line or delayed). Following this first minute of free interaction and exploration, the video image projected onto the mirror was frozen for a second minute (still-face episode). Following the still-face episode, infants were tested

for a third and last minute of free interaction and exploration of the dynamic mirror reflection. The three 1-min episodes occurred with no interruption.

Coding and Analysis

Video recordings of the infant were coded separately by two naive observers using a computerized event recorder. While viewing the on-line video recording of the infants' frontal view and pressing on a particular key of a computer corresponding to a specific behavior, observers activated a channel of the event recorder. Once coded, a program computed the cumulated occurrences of a particular behavior and its proportion (percentage) over total trial time. First-look duration (see below), was measured directly on the printout of the computerized event recording, with .5-s precision (1 cm long deflection of the signal on paper = 1 s in duration). The coding corresponded to the occurrence of the following five behaviors that indexed infants' visual attention (proportion in percentage of gazing at the specular image and duration in seconds of first look at the specular image) and infants' social responding to the specular image (proportion in percentage of smiling, vocalizing, and social re-engagement). These behaviors were operationally defined as follows:

1. Visual attention:

Gazing: Infant gaze oriented toward the specular image.

First look: First gazing bout oriented toward the specular image from the onset of a presentation episode.

2. Social responding:

Smiling: Infants' cheeks raised and sides of the mouth raised up while gazing at the specular image.

Vocalizing: Positive (i.e., cooing) or neutral (i.e., babbling) vocalization expressed while looking at the specular image. Negative vocalization such as fussing and crying were not included.

Re-engagement: Clapping, banging, or reaching toward the specular image while gazing at it.

Interobserver reliability measured on 20% of all tested infants in every condition yielded κ s on all measures ranging from .79 to .89.

RESULTS

Table 1 presents the means and standard deviation for the visual attention measures (percentage of gazing and first-look duration) and social responding measures (percentage of smiling, vocalizing, and re-engagement

behaviors) as a function of age, condition, contingency, and episode.

Each dependent measure was analyzed by performing a 2 (age: 4 months versus 9 months) \times 2 (condition: self versus other) \times 2 (contingency: on-line versus 2-s delayed) \times 3 (episode: first minute, still-face episode, third minute) mixed-design analysis of variance (ANOVA). In this design, episode was the within-subjects factor, and all other variables were entered as between-subjects factors. The results of the visual attention measures are reviewed first.

Visual Attention Measures

Gazing. The ANOVA yielded a significant main effect of age, $F(1, 88) = 9.43, p < .003$, with 4-month-olds tending overall to look significantly more at the specular image, regardless of condition, contingency, or episode. The ANOVA also yielded a significant episode main effect, $F(2, 176) = 23.01, p < .001$, with all infants tending overall to look less during the still-face episode, regardless of age, condition, or contingency. More interesting, the ANOVA revealed a significant main effect of condition, $F(1, 88) = 5.34, p < .023$, whereby infants, regardless of age, contingency, or episode, tended to look significantly more at the specular image when it reflected the mimicking other compared with the self. The analysis also revealed a contingency main effect approaching significance, $F(1, 88) = 3.87, p < .052$. This effect rested on the fact that overall, infants tended to gaze more at the specular image displaying on-line contingency.

First-look duration. The ANOVA yielded a significant main effect of age, $F(1, 88) = 14.12, p < .001$, with younger infants displaying, overall, a longer first-look at the duration specular images. The analysis also revealed a significant condition main effect, $F(1, 88) = 5.13, p < .026$, with infants demonstrating a significantly longer first-look duration at the specular image when it reflected the mimicking other rather than the self. In addition, the analysis yielded a significant episode effect, $F(2, 176) = 4.93, p < .008$. This effect was due to a significant overall drop in first-look duration during the still-face episode compared with the first and last minute of interaction. Furthermore, the ANOVA revealed a marginally significant Condition \times Contingency interaction, $F(1, 88) = 3.71, p < .057$, and a significant Condition \times Contingency \times Episode interaction, $F(1, 176) = 3.33, p < .038$. Analysis of the simple effects of the latter three-way interaction indicated that in the other condition and Delayed contingency, infants showed more decline in first-look duration during the still-face episode, $p < .05$. Finally, the ANOVA also yielded a significant Age \times Condition \times

Table 1 Means for Each Dependent Measure as a Function of Age (4- and 9-Month-Olds), Condition (Self versus Other), Contingency (On-Line versus Delayed), and Episode

Measure	Condition	Episode		
		N1	SF	N2
4-month-olds on-line contingency				
Gazing	Self	65.30 (21.98)	54.53 (29.59)	62.20 (27.10)
	Other	81.69 (13.00)	70.11 (27.46)	86.52 (13.94)
First-look duration	Self	6.53 (8.27)	5.19 (4.50)	8.34 (6.78)
	Other	12.85 (20.36)	19.15 (18.09)	26.8 (25.08)
Smiling	Self	1.37 (1.92)	.39 (1.25)	1.70 (3.36)
	Other	6.00 (10.08)	.76 (.90)	3.84 (6.42)
Vocalizing	Self	5.28 (7.88)	5.65 (9.70)	6.60 (8.84)
	Other	.08 (.20)	1.07 (2.14)	.92 (1.16)
Re-engagement	Self	1.44 (2.28)	.28 (.71)	.99 (2.24)
	Other	.05 (.16)	6.40 (21.93)	.03 (.09)
4-month-olds delayed contingency				
Gazing	Self	65.96 (25.80)	46.83 (28.54)	58.18 (34.89)
	Other	71.35 (25.24)	41.86 (25.82)	52.67 (29.72)
First-look duration	Self	8.09 (7.84)	5.74 (8.27)	13.79 (20.39)
	Other	10.07 (10.04)	3.58 (2.92)	9.73 (11.08)
Smiling	Self	.41 (1.18)	.09 (.22)	.59 (2.06)
	Other	2.81 (4.34)	1.39 (4.00)	1.93 (4.32)
Vocalizing	Self	2.52 (5.81)	3.22 (9.33)	1.50 (3.48)
	Other	.79 (.89)	.21 (.43)	.92 (2.82)
Re-engagement	Self	.10 (.24)	.07 (.25)	.18 (.61)
	Other	.47 (1.02)	.68 (1.47)	.42 (1.00)
9-month-olds on-line contingency				
Gazing	Self	49.66 (19.31)	37.43 (22.51)	48.43 (26.03)
	Other	64.47 (13.92)	49.50 (20.42)	61.70 (28.22)
First-look duration	Self	3.31 (4.53)	4.70 (4.53)	5.11 (4.07)
	Other	4.90 (2.29)	4.82 (6.10)	4.56 (4.22)
Smiling	Self	2.65 (3.86)	1.00 (2.27)	1.20 (2.13)
	Other	1.11 (3.83)	.91 (2.27)	1.53 (3.78)
Vocalizing	Self	6.10 (7.76)	4.32 (6.98)	5.22 (4.71)
	Other	.27 (.32)	.40 (1.09)	.67 (1.33)
Re-engagement	Self	4.85 (6.75)	1.13 (1.63)	6.85 (10.86)
	Other	7.86 (17.66)	14.05 (22.66)	26.45 (30.86)
9-month-olds delayed contingency				
Gazing	Self	54.89 (18.82)	38.86 (17.52)	49.84 (20.23)
	Other	62.31 (22.99)	44.33 (16.52)	53.01 (21.28)
First-look duration	Self	1.77 (1.95)	2.92 (3.24)	7.07 (6.71)
	Other	10.02 (14.89)	3.76 (4.19)	5.44 (3.64)
Smiling	Self	1.74 (4.19)	2.16 (4.90)	2.67 (5.89)
	Other	7.05 (17.94)	4.56 (7.63)	3.41 (6.67)
Vocalizing	Self	3.31 (3.68)	3.07 (4.83)	2.27 (2.81)
	Other	.84 (1.16)	2.17 (3.00)	1.66 (3.73)
Re-engagement	Self	5.37 (6.08)	6.62 (12.00)	6.90 (9.04)
	Other	6.54 (16.05)	14.74 (22.58)	8.71 (16.03)

Note: Values in parentheses are standard deviations. N1 = first normal interaction; SF = still-face; N2 = second normal interaction.

Contingency interaction, $F(1, 88) = 6.71, p < .001$. This interaction rested on the fact that the group of 4-month-olds in the on-line contingency tended to have a markedly longer first-look duration at the specular image of the other compared with the self, $p < .015$.

Overall, the analysis of both gazing and first-look durations revealed that infants' visual attention varied in significant ways as a function of age and episode, but also as a function of condition (self versus other) and the kind of contingency displayed in the specular image.

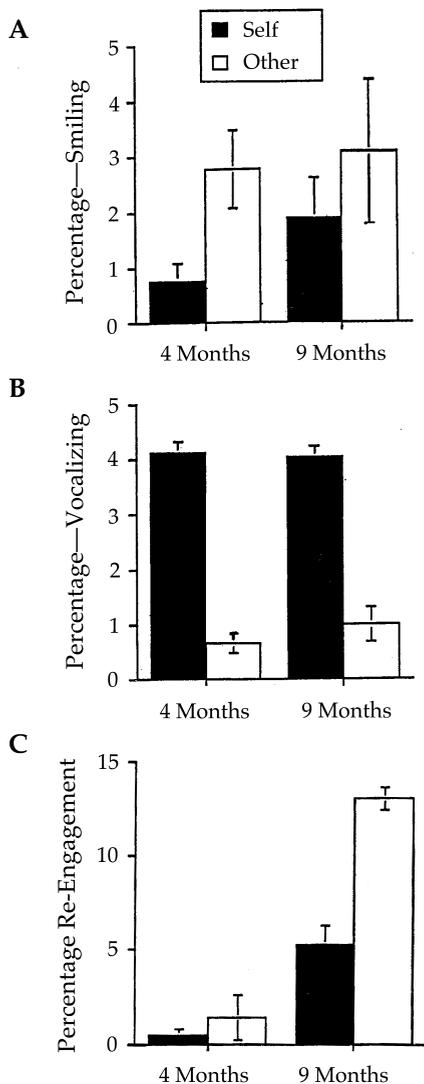


Figure 3 Average percentage of time (and SEs) that infants smiled (A), vocalized (B), or manifested attempts to re-engage the specular image (C), as a function of the two age groups (4- and 9-month-olds) and two experimental conditions (self versus other).

Social Responding Measures

Smiling. The ANOVA yielded a marginal main effect of condition, $F(1, 88) = 3.77, p = .055$, with infants tending overall to smile more at the specular image of the mimicking other compared with the self (see Figure 3A). The analysis also revealed a significant Age \times Contingency interaction, $F(1, 88) = 4.05, p < .047$. Nine-month-olds tended to smile more in the delayed compared with the on-line contingency condition; whereas 4-month-olds showed the reverse. No other significant main effects, nor any significant interactions were found.

Vocalizing. The ANOVA yielded only a significant main effect of condition, $F(1, 88) = 13.20, p < .001$,

whereby infants who faced their own specular image (self condition) tended to vocalize significantly more compared with those who faced the specular image of the mimicking other (other condition, see Figure 3B). The analysis also yielded a close to significant Condition \times Contingency interaction, $F(1, 88) = 3.62, p < .06$. This marginal interaction rested on the fact that infants tended to vocalize more in the self condition when the specular image displayed an on-line compared with a delayed contingency.

Re-engagement behavior: The ANOVA yielded a significant main effect of age, $F(1, 88) = 17.864, p < .001$, with 9-month-old infants manifesting markedly more re-engagement behavior compared with the group of 4-month-olds. The analysis also yielded a condition main effect, $F(1, 88) = 4.86, p < .03$, with infants manifesting significantly more re-engagement behavior in the other compared with the self condition (see Figure 3C). The analysis also yielded a significant Age \times Contingency \times Episode interaction, $F(1, 88) = 3.41, p < .035$. Analysis of simple effects revealed an Age \times Episode interaction in the on-line contingency condition only, $p < .032$. In this latter condition, 4-month-olds tended to show increased re-engagement behavior during the second minute still-face episode, whereas 9-month-olds showed a marked increase of such behavior by the third minute of interaction.

DISCUSSION

The aim of the present research was to investigate the emergence and determinants of self–other discrimination in specular images, manipulating temporal and featural characteristics. Two basic questions guided the research: (1) When do infants begin to show signs of a discrimination between self and mimicking others in on-line specular images? and (2) What is the relative role of featural and temporal factors in such discrimination?

Overall, the research indicated that by 4 months of age, infants showed signs of self–other discrimination in specular images. As a working hypothesis, we speculated that 9-month-olds who begin to understand others as intentional agents of communication (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Bruner, 1983; Tomasello, 1995) would perceive the specular image of others as intentional and communicative, and, hence, as socially more engaging compared with the self. The present research provides new evidence supporting this hypothesis. It also provides more direct evidence supporting previous findings from which it was inferred that by 5 months, infants show signs of a discrimination between the specular image of self and someone else

(i.e., the prerecorded view of another infant; see, e.g., Barhrick & Watson, 1985; Schmuckler, 1996).

The analysis of behaviors indexing infants' overall visual attention to the various specular images (gazing and first look) indicated that infants tended to pay relatively more visual attention to the specular image of the other compared with the self. Both age groups manifested reliable visual discrimination and preference for the specular image that was potentially social and communicative. Analysis of the social responding measures provided convergent and more direct support for this contention.

In general, infants at both ages displayed differential smiling, vocalizing, and re-engagement toward the specular image of the other compared with the self. They tended to smile and re-engage more in the other condition, whereas they vocalized more in the self condition. The increased smiling and re-engagement behaviors in the other condition clearly points to infants' enhanced social responding when facing the specular image of the mimicking experimenter compared with the self. Interpreting the reversed tendency with regard to vocalizing is less straightforward. The marked increase of infants' vocalizing while facing their own specular image corroborates what has previously been reported by Legerstee et al. (1998) in 5-month-old infants. The reliable increase of vocalizing in the self condition could be part of self-exploration and the spontaneous self-production of redundant visual, proprioceptive, and auditory stimulation afforded by their own specular image. An analogous interpretation is offered by Legerstee et al. (1998). This interpretation is in resonance with Bahrick and Lickliter's (2000) suggestion and empirical demonstration of a tendency by infants to consolidate and maximize learning via increased redundancy of intermodal information.

Although both 4- and 9-month-olds expressed such discrimination, some results indicate that they do so in different ways. In general, the older group of infants devoted reliably less time to exploring and giving a first glance at the specular image in either the self or other condition. Between 4 and 9 months, visual monitoring becomes markedly more fleeting and less protracted, probably as part of documented changes in visual attention and performance—in particular, the development in the course of the first year of inhibitory mechanisms that reduce gazing inertia or attentional "stickiness" (Colombo & Mitchell, 1990; Johnson, 1990; Ruff & Rothbart, 1996).

In accord with the rationale for our developmental hypothesis, the data confirmed that by 9 months, infants developed a new propensity toward social initiatives, attempting to re-engage a social partner (see also Striano & Rochat, 1999). In general, 9-month-olds

tended to demonstrate more re-engagement behaviors (i.e., social initiatives) compared with 4-month-olds. However, both 4- and 9-month-olds tended to manifest greater social re-engagement toward the specular image in the other compared with the self condition. The analysis points toward an age effect, with the impact of condition tending to be greater for older compared with younger infants (see Figure 3C). In general, the differential re-engagement behavior as a function of condition (cardinal main effect of the present analysis) is a clear expression of self–other discrimination in specular images. As suggested in the Introduction, re-engagement behavior can be construed as attempts by infants to initiate social responses and change the behavior of a social partner (Striano & Rochat, 1999). In the context of the present research, we propose that such behavior probably reflects an understanding of other's specular image as a social communicative partner.

Infants also demonstrated self–other discrimination when one considers the other dependent measures. Both 4- and 9-month-olds tended to smile more, look larger in general, and have more protracted first-look duration at the specular image in the other compared with the self condition.

Smiling and looking are the most common measures of social monitoring and emotional regulation used in documenting early social attunement of infants in face-to-face protoconversation (Rochat, Querido, & Striano, 1999; Toda & Fogel, 1993; Tronick, Als, Adamson, Wise, & Brazelton, 1978). The self versus other condition effect regarding these measures demonstrates infants' inclination at both ages to be more socially engaged in interacting with the mimicking experimenter compared with their own specular image.

Considering that both 4- and 9-month-old infants showed self–other discrimination, questions remain as to what determines such discrimination. Our results indicate that it is probably based on a complex combination of featural, movement dynamic, and temporal information. Infants at both ages showed some evidence of being sensitive to all of these in their discrimination.

Physical and dynamic features of what was reflected in the specular image need to be considered as the basis of the self–other discrimination expressed by the infants. Adult (specular other) and infant (specular self) did not look the same, and obviously did not move in exactly the same way. Although the experimenter was trained to mimic the infant to the best of her ability, the on-line mimicking could never perfectly equate the copied facial and limb movements of the infant in amplitude, vitality, general dynamic, and timing. It is thus reasonable to think that the self–other discrimination manifested by the infant was

based primarily on a combination of featural and dynamic information. On the one hand, infants could already have some template featural representation of their own reflection in a mirror based on past experience (see Bahrack et al., 1996; Legerstee et al., 1998). On the other hand, they could also have an intermodal (i.e., visual–proprioceptive) and dynamic sense of their own body reflected in the specular image. This dynamic sense of the body would be based on previous visual–proprioceptive calibration arising from early self-exploration. Such calibration is evident in infants as young as 3 months of age who showed signs of discriminating on-line views of their own body on a TV, which violated familiar spatial arrangements of the directly perceived body (Rochat, 1998). Further research is needed to isolate the relative importance of featural detection and visual–proprioceptive calibration as the basis of self–other discrimination in specular images.

Because the mimicking experimenter could only approximate the movements and gestures of the infants, she provided them with analogous but imperfectly contingent behaviors, whether in the on-line or delayed contingency condition. Considering that by at least 3 months infants are particularly interested in exploring imperfect contingency even when it comes from inanimate sources (Watson, 1979), it is feasible that an early preference for imperfect temporal contingency could be the basis of self–other discrimination. Results regarding the re-engagement behavior however, show that there is probably more than the involvement of an imperfect contingency detection, with infants perceiving the experimenter as a social partner with communicative intents.

Other results point to infants' sensitivity to the temporal contingency displayed in the specular image (i.e., on-line versus 2-s delayed contingency). Self–other discrimination expressed in the analysis of visual attention (gazing and first look), as well as social responding (i.e., vocalizing and re-engagement) tended to depend on whether the specular image was on-line or delayed. This dependence, however, was marginal. By manipulating the contingency variable, we expected to find more evidence of its role as a determinant of self–other discrimination in the specular image across our measures. In fact, only one marginally significant condition-by-contingency interaction was observed, $p < .057$, for the measure of first-look duration. It may be that infants are not sensitive to delays smaller than 2 s. Some have suggested that imperfect contingency detected by infants might begin with at least 3-s delays (Watson, 1984, 1995). For adults, preliminary testing with the apparatus demonstrated that a 2-s delay in a specular image was highly noticeable. It is

feasible, however, that more delay is necessary for an analogous discrimination by young infants.

In general, we observed what is typically reported in a still-face procedure. Infants at both 4 and 9 months tended to decrease their overall proportion of gazing at the specular image during the still-face episode. This observation is consistent with previous still-face experiments using live adults (Toda & Fogel, 1993; Tronick et al., 1978) or on-line specular (reflected video) images of the mother (Rochat et al., 1998). From 4 months, infants reacted to the specular still-face in ways resembling those observed with the sudden still-face of live adults. Interestingly, for the gazing response, we found that when the specular image had a 2-s delayed contingency, infants overall tended to look significantly less at the image, $p < .052$. The tendency toward greater visual attention paid to the on-line compared with the delayed specular image is difficult to interpret. One possibility, however, is that the on-line specular image tended to be viewed by the infant as more novel compared with the contingent but delayed visual feedback typically characterizing familiar face-to-face exchanges (e.g., affective mirroring as depicted by Gergely & Watson, 1999).

In all, this research provides converging evidence, on the basis of multiple measures, that infants from 4 months of age are able to discriminate between the specular image of themselves and the specular image of a mimicking other. This discrimination becomes particularly evident by 9 months of age, when infants display a propensity toward social initiatives at the specular image of the mimicking adult, apparently construed by the infant as a social partner who is differentiated from the self. This discrimination appears to have multiple determinants, including featural and dynamic, as well as temporal dimensions.

Early self–other discrimination in specular images cannot be equated to mirror self-recognition indexed, for example, by the passing of the rouge task. Signs of such discrimination do not mean that infants from 4 months actually recognize themselves or express conceptual self-awareness. Despite the fact that this discrimination is primarily perceptual, however, it is the foundation from which children can eventually develop the conceptual and explicit sense of themselves expressed by the middle of the second year.

Our research confirms the idea that there is a long and probably continuous development from the early perceptual sense of one's own body as differentiated from the body of others, to the actual recognition and explicit identification of the self in specular images. More research is needed to capture this development; in particular, the functional link between early self–

other discrimination as demonstrated in the present study, and later conceptual self-awareness.

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