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Infants' Preference for Social Interactions Increases from 7 to 13 Months of Age

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This study examined 7-to-13.5-month-old middle-class Western infants' visual orienting to third-party interactions in parallel with their social attention behavior during own social interactions (Leipzig, Germany). In Experiment 1, 9.5- to-11-month-olds (n = 20) looked longer than 7- to-8.5-month-olds (n = 20) at videos showing two adults interacting with one another when simultaneously presented with a scene showing two adults acting individually. Moreover, older infants showed higher social engagement (including joint attention) during parent–infant free play. Experiment 2 replicated this age-related increase in both measures and showed that it follows continuous trajectories from 7 to 13.5 months (n = 50). This suggests that infants' attentional orienting to others' interactions coincides with parallel developments in their social attention behavior during own social interactions.

Human infants strongly rely on social interactions to acquire culturally relevant knowledge about their environment. Not only active social engagement but also the observation of others' social interactions represent an essential source of social learning opportunities (Paradise & Rogoff, 2009; Tomasello, 2016). Already 9-month-old infants can encode novel objects by merely observing triadic joint attention interactions between two adults (Thiele, Hepach, Michel, & Haun, in press). Moreover, 18-month-olds can learn novel words through overhearing conversations between two people (Floor & Akhtar, 2006) and imitate actions they have observed in a third-party demonstration directed toward another person (Herold & Akhtar, 2008; Matheson, Moore, & Akhtar, 2013). To learn from one's own or others' social interactions, infants first need to gain access to a potential learning opportunity. Theories highlighting the infant's active role in this process suggest that infants develop capacities and motivations guiding them toward social interactions.

Typically developing infants orient their attention to social information from early on. This preference is crucial for infants to detect potential interaction partners and to structure and filter the large amount of information they are confronted with (Reid & Striano, 2007). Newborns preferentially orient to face-like over nonface patterns (Goren, Sarty, & Wu, 1975), show enhanced neural processing of direct over averted gaze (Farroni, Csibra, Simion, & Johnson, 2002), spend more time looking at faces with opened than closed eyes (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000), and prefer looking at biological motion over random motion patterns (Simion, Regolin, & Bulf, 2008). During the first year of life, infants' social perception matures as their visual

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system, their practical experiences, and their understanding of others develop (Bertenthal & Boyer, 2015). For example, infants' preference for faces becomes increasingly robust from 3 to 6 months (Di Giorgio, Turati, Altoè, & Simion, 2012) and the face recognition system becomes attuned to human-specific features from 6 to 9 months of age (Pascalis, Haan, & Nelson, 2002).

In addition to identifying potential partners for direct interaction, infants can detect social relationships between other people. From 6 months onwards, they perform more gaze shifts between two people facing each other during a turn-taking conversation compared to two people standing back-to-back while talking, and their gaze-shifts become increasingly predictive toward the end of the first year (Augusti, Melinder, & Gredebäck, 2010; Bakker, Kochukhova, & von Hofsten, 2011; for equivalent findings with silent and still image stimuli, see Handl, Mahlberg, Norling, & Gredebäck, 2013). Other findings suggest that the sensitivity to face-to-face arrangements emerges slightly later: 10- but not 9-month-old infants show increased looking times when seeing two people facing each other during a conversation, after a habituation phase showing the same individuals standing back-to-back while talking (and vice versa, Beier & Spelke, 2012).

The second half of the first year of life is marked by significant changes in infants' active interaction behavior (Callaghan et al., 2011). While infants engage in dyadic face-to-face interactions from 2 months on (Aureli, Presaghi, & Garito, 2017; Striano, 2001), they begin to develop competencies for triadic social interactions in the second half of the first year (Carpenter, 2010; Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Striano & Reid, 2006). In addition to social cognitive developments (including an emerging understanding of others as intentional agents, Tomasello & Carpenter, 2007), infants' social attention is marked by significant changes in social motivation, including an increasing interest in coordinating attention with others. From 9 to 12 months of age, infants engage with an increasing frequency in joint attention and begin to initiate joint attention episodes themselves (Carpenter et al., 1998). Between 9 and 14 months, infants start to signal communicative intent toward an interaction partner (e.g., using ostensive gaze cues, gestures, vocalizations, Clearfield, Osborne, & Mullen, 2008), and 7- to 10-month-old infants make increasing attempts to re-engage a person who stops reacting to them (Striano & Rochat, 1999). The exact onset age of joint attention has been a matter of debate. Some researchers suggest an early onset and gradual increase starting around 6 months (Bakeman & Adamson, 1984; Striano & Bertin, 2005), while others argue that truly joint attention abilities do not emerge before 9 months of age (Carpenter et al., 1998; Tomasello, 1995). According to both perspectives, however, the second half of the first year of life marks a critical period in infants' social development and learning, as infants' emerging capacity to coordinate attention with others provides the necessary basis for teaching and cooperation (Csibra & Gergely, 2006; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Moreover, joint attention facilitates 7- and 9-month-old infants' processing of novel objects (Cleveland & Striano, 2007; Striano, Chen, Cleveland, & Bradshaw, 2006) and promotes future language learning (Morales et al., 2000). Combining these two strands of evidence, infants' increasing motivation to engage in joint attention enhances the availability of potential learning opportunities.

There is some indication from previous studies that infants' attention to third-party interactions is influenced by motivational factors as well. At least by the end of the first year of life, infants *prioritize* face-to-face interactions when choosing between attending to a face-to-face or a back-to-back scene with two human agents. Fourteen-month-olds look longer at biological motion of face-to-face interactions (point-light displays of two people engaging in a falling-catching or a pushing interaction) compared with biological motion of mirrored back-to-back scenes (two people performing the identical movements while standing back-to-back; Galazka, Roché, Nyström, & Falck-Ytter, 2014). Infants' looking preference disappears when seeing the same stimuli upside down, indicating that the longer looking times at upright face-to-face scenes do not reflect a response to the low-level perceptual features, but rather a greater interest compared to the "competing" back-to-back scene (Galazka et al., 2014). This interpretation is further supported by a previous study showing that 13-month-old infants organize their attention and associative learning in favor of predicting and actively approaching situations in which they can observe a face-to-face interaction (Thiele, Hepach, Michel, Gredebäck, & Haun, 2021).

Together, these findings suggest that, at least by 14 months of age, infants selectively attend to situations in which they can observe a third-party interaction. What remains unclear, however, is how this attentional preference develops during the second half of the first year of life, when infants' social attention in direct interactions undergoes decisive changes. In contrast to previous work, this requires a systematic investigation of both infants' attentional preference for others' social interactions, as well as of their social attention behavior during active social engagement. Infants' emerging awareness of others as communicators of learnable content and their increasing motivation to seek social interactions may not only contribute to their social attention behavior in own interactions, but also enhance their attention to others' interactions. Support for this idea comes from active-learning accounts highlighting the influence of motivational mechanisms on infants' behavior and learning (for a review see Raz & Saxe, 2020). Theories of curiosity-driven learning, for example, claim that infants are intrinsically motivated to acquire knowledge and to learn from others (for a review see Begus & Southgate, 2018). Since both active social engagement and observations of others' interactions represent potential sources of social learning opportunities, it would be functionally adaptive if infants increasingly oriented their attention toward both situations. Moreover, social motivation theories raise the possibility that infants' increasing intrinsic social motivation may modulate their interest in social interactions beyond situations in which they are directly involved (e.g., Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012).

The Current Study

In this study, we aimed to investigate developmental trajectories of infants' attentional orienting toward third-party social interactions and, moreover, examine how these changes coincide with infants' social orienting behavior during active social interactions. For this purpose, we assessed both infants' visual attention to third-party interactions and their active social attention behavior within the same testing sessions. Like most of the previous studies cited above, this study was conducted in a Western, industrialized context where infants typically experience high levels of face-to-face interactions and direct pedagogy.

We conducted two experiments. In Experiment 1, we systematically investigated developments from before to after the previously suggested 9-month-threshold by comparing infants from two age groups (7–8.5 months and 9.5–11 months). All participants were tested in two experimental phases. First, we measured their looking times while they were simultaneously presented with two videos. One video showed two people turning toward one another while engaging in a social interaction, whereas the second video showed the same agents acting individually while standing back-to-back. To manipulate the relationship between the persons as interacting or noninteracting, we used the relative positioning of their bodies (face-to-face vs. back-to-back), gaze direction (eye contact vs. looking away), the execution of an action (coregulated vs. individually), and the amount of touch (mutual touch vs. no touch). In the second phase, we observed the participant's behavior during free play with their parent and coded four kinds of looks in the direction of their parent (general looks at their parent, looks at their parent's face, eye contact, and joint attention looks).

We hypothesized that if infants from before to after 9 months of age develop an increasing interest in observing others' interactions, infants in the older (vs. younger) age group should look relatively longer to the social interaction videos. Moreover, to probe infants' attentional preference for the social interaction videos, we tested infants' looking time score against chance level within the two age groups. We further hypothesized that if infants have an attentional preference for others' social interactions, they should spend more than 50% of their total looking time attending to the face-to-face interaction videos. Regarding infants' social attention during active social interaction, we hypothesized that if infants' social interest during active interaction increases with age, then infants in the older age group should perform more social looking behaviors during free play compared to the younger group. To examine the relation between infants' active social attention behavior and their attentional preference for others' interactions, we compared the developmental trajectories of both measures at the group level and explored the correlational relation at the individual level. Given the scarce literature about the immediate relation between infants' active social attention in direct interactions and their attentional orienting toward others' interactions, we did not preregister any specific predictions concerning the degree of correlation between the two modalities but sought to explore this relation in reference to parallel findings at the group level. We hypothesized that if infants' attention to third-party interactions relates to their social orienting behavior in direct interactions at the individual level, the two measures should be correlated.

In Experiment 2, we aimed to replicate our findings from Experiment 1 and build on them by testing infants at a broader and continuous age range between 7 and 13.5 months of age. This way, we aimed to gain a more comprehensive insight into the developmental trajectories in both modalities. We made analogous predictions as in Experiment 1, except that we did not test infants' looking preference against chance level. Specifically, we hypothesized that if infants' attentional preference for social interactions increases from 7 to 13.5 months of age, the proportional looking time to the social interaction videos should increase with age. If infants' social interest during active interaction increases during this period, then infants' social engagement score should increase with age. Our assumptions regarding the relation between the two measures were the same as in Experiment 1.

The study was approved by the ethics committee of the Medical Faculty of Leipzig University. We preregistered the hypotheses, methods, procedures, and the data analysis plans for both experiments at the Open Science Framework (OSF). The preregistration forms, all data, scripts for analyses, and supporting information are publicly accessible on the OSF (Experiment 1: https://osf.io/42nyv/ and Experiment 2: https://osf.io/s4uy7/).

Experiment 1

Methods

Participants

Forty infants from two age groups provided valid data for both eye tracking and free play measures. The younger sample consisted of 20 infants between 7 months, 2 days and 8 months, 14 days (n = 10 female; M = 240.4 days, SD = 13.24 days). The older sample consisted of 20 infants between 9 months, 15 days and 10 months, 25 days (n = 10 female; M = 313.6 days; SD = 11.65 days). Data from 13 additional infants were excluded due to technical error (n = 1), failure of calibration (n = 8), preterm birth (n = 2), or because they were older than the inclusion criterion (n = 2). The aimed sample size was based on the upper range of the sample sizes in previous similar studies (e.g., Augusti et al., 2010; Handl et al., 2013). For the separate analyses of the free play data, we included all participants who provided valid data in at least the free play phase, resulting in a larger sample of 27 participants in the younger age group (n = 15 female; M = 236.81 days, SD = 14.94 days). All infants were born full term (M = 40.4 weeks; SD = 1.32 weeks). The primary caregiver participated in the free play phase of the study, that is, the person spending most time of the day with their child at the time of testing. Five fathers (younger sample: n = 2; older sample: n = 3) and 42 mothers (younger sample: n = 25; older sample: n = 17) participated in the free play phase of the study. All participants came from Leipzig (Germany) or surrounding areas, an urban Western, industrialized context. They were recruited on a voluntary basis via phone from the database of the Max Planck Institute for Evolutionary Anthropology in Leipzig. We did not collect individual data regarding the participants' socioeconomic or ethnic background, but families in this database come from a predominantly white population with mixed, mainly mid to high socioeconomic backgrounds. Written informed consent was obtained from one parent of each infant prior to testing.

Stimuli and Design

To investigate infants' attentional preference for third-party social interactions, we measured their looking times while they were simultaneously presented with two video clips: one social interaction stimulus and one noninteractive control stimulus. Both videos were presented without sound against a black background. The social interaction stimulus showed two women initially facing forward before they turned toward one another and engaged in one of three social interactions while facing each other: playing an interactive clapping game, leaning toward one another, or touching their hands. The control stimulus showed the same two women facing forward before turning away from one another, performing the identical movements as in the social interaction scene while standing back-to-back. All actors were female, wore white t-shirts, and were visible from the waist up. To avoid actors between stimuli being interpreted as interacting with one another and to maximize the visual distance between the two videos, the videos were positioned diagonally on the screen.

Every trial lasted 12 s (see Figure 1). Before each trial, an attention-grabbing sequence was presented in the center of the screen until the infant looked at it. Every participant saw 12 trials in a randomized order: Each of the three interactions (and the corresponding control video) were shown in four possible diagonal arrangements on the screen. All four trials within one interaction showed a different dyad. The video stimuli were created by using Adobe Premiere Pro. Although seemingly acting in dyads, the actors were filmed individually. The control stimuli were created by horizontally mirroring the actions of the individual actors. All actors were filmed in front of a

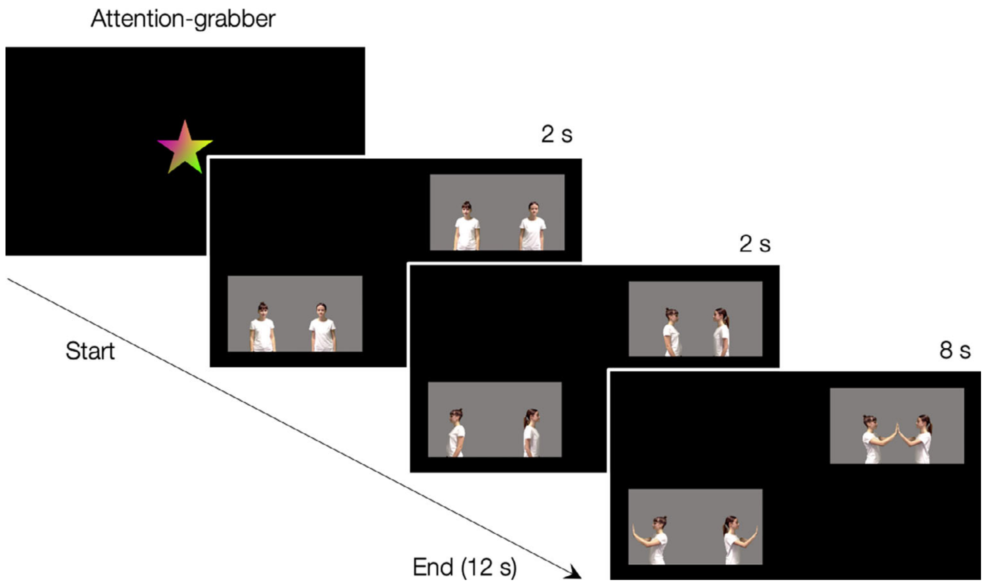

Figure 1. Exemplary sequence of one experimental trial (clapping interaction) with the social interaction stimulus in the upper right corner and the control stimulus in the lower left corner.

green screen to control for color and luminance differences between and within videos. Each video covered an approximate area of 13.9°width × 7.8°height (at a screen distance of 60 cm). In the Supporting Information, we provide detailed information regarding stimulus development.

To measure infants' looking time, an SMI eye tracker (RED250mobile, SensoMotoric Instruments, 8.2) and SMI eye tracking programs (Experiment Center 3.7.60 and BeGaze 3.7.42) were used. Data were recorded separately for the left and the right eyes at a sampling frequency of 250 Hz.

To investigate infants' social attention during own social interaction, we coded their looking behavior during a 5-min free play phase with their parent. We placed three toys (two rattles and a rubber duck) within reaching distance between the infant and their parent.

Procedure

The testing took place at the Leipzig Research Center for Early Child Development (Leipzig University) between July and December 2017. Each testing session was divided into two phases: eye tracking (10 min) and free play (5 min).

During the eye tracking phase, the parents sat down in front of a screen, holding their child on their lap. We used a 25″ monitor with 117.5 dpi and 1920 × 1080 screen resolution. The parents were instructed to close their eyes or lower their gaze during the experiment, hold their child as still as possible, and avoid any kinds of communication. We used SMI 5-point calibration to calibrate the eye tracker to the participant's eyes. To check the quality of the calibration, a manual calibration check was performed for each participant. Based on visual inspection, the experimenter evaluated the accuracy of each infant's gaze shifts, while they saw a colorful ball in the center of the screen and in all four stimulus regions of the preferential-looking task. A participant was only included if providing valid gaze data according to this assessment.

At the beginning of the free play phase, the experimenter instructed the parents to engage with their child and the toys in "normal play." The parents were further told not to touch the toys themselves during the first 90 s of play to allow infants to actively initiate joint engagement (Bigelow, MacLean, & Proctor, 2004). A short notification sound indicated the end of the 90-s interval. We did not find any statistically relevant differences in infants' social engagement scores from before to after the 90-s threshold (see Supporting Information for details). After instructing the parents, the experimenter left the room and came back after 5 min. All free play sessions were video recorded.

Data Analyses and Coding

Attentional Preference for Others' Social Interactions

By using SMI BeGaze 3.7.42, we defined rectangular-shaped areas of interest (AOI) for the social interaction and the control stimulus. Each AOI covered an area of 15.8°width × 9.7°height (at a screen distance of 60 cm). To accommodate for inaccuracies in calibration, the AOIs were defined 1° visual angle larger than the maximal dimensions of the stimulus (Gredebäck, Johnson, & von Hofsten, 2009). In a second step, we calculated the total duration of fixations within the social and the control AOI for each individual trial. Data for both the left and the right eyes of each participant were averaged. We included fixation data from the entire trial sequence. Results did not differ when including only the last 10 s of each trial (i.e., after the actors had started turning, see Supporting Information). To define the gaze events, we used the SMI BeGaze 3.7.42 high speed event detection filter. In a third step, we calculated the relative looking time at the social interaction stimulus for each individual trial:

$$\text{Proportional looking time at social stimulus} = \frac{\text{Cumulative length of fixations in social AOI}}{\text{Cumulative length of fixations in social AOI} + \text{control AOI}}$$

The score could take values between 0 and 1, with values above 0.50 indicating a relatively longer looking time at the social interaction stimulus. For statistical analyses, the proportion scores were averaged over all trials. A Shapiro–Wilk test of normality revealed that the proportion score was normally distributed (p = .72). A trial was excluded from the analysis if the participant did not look at the screen at all. To compare the averaged preference scores between the two age groups, we conducted a two-way analysis of variance (ANOVA) with age group as a between-subject factor. As some previous studies suggest gender differences in social attentional preferences in infancy (e.g., Lutchmaya & Baron-Cohen, 2002), we controlled for gender. To assess whether the proportion score significantly differed from chance level, we ran a one sample t-test (against .50) for both age groups.

Active Social Attention Behavior

The occurrence of four infant looking behaviors was coded from video recordings of the free play sessions (see Table 1). The reason for choosing these behaviors was to assess variability in different hierarchical levels of social attention (i.e., beginning with a very general social interest over face-to-face interactions up to joint attention looks). Note that the category "looking at the parent's face" was not included in the preregistered coding scheme. In aiming to get a more precise picture of infants' social attention behavior, we decided to differentiate general looks at the parent from looks at the parent's face after watching the recordings for the first time and prior to running any statistical analyses. In addition to the coding category "eye contact," infants' "looks at their parent's face" would consider situations in which infants made an attempt to engage in eye contact with their parent, without the parent looking back.

The coder watched every video recording in 5-s intervals (see also Hirshberg & Svejda, 1990). For each interval, she decided if the infant showed one of the four looking behaviors. If none of the behaviors was shown, the infant received a "0" in the respective interval. If an infant showed one of the four behaviors at least once, they received a "1" in the respective category. Based on the hierarchical structure of the coding behaviors, each interval was coded with the highest occurring looking behavior during this interval. The primary coding was done by the first author. For interobserver reliability, a second coder naive to any hypothesis coded a random 25% of the free play sessions after data collection was completed. The reliability coder was trained on a shared set of videos prior to coding. The inter-rater agreement was good (ICC = .85). The coding of the free play sessions was conducted in Microsoft Excel. For statistical analyses, the following preparatory steps were taken for each individual. First, we calculated the frequency of occurrence of the four relevant behaviors over all coding intervals (i.e., the number of intervals during which a behavior was shown). Then, the total frequencies of the individual behaviors were integrated in the following proportion score:

$$\text{Social Engagement Proportion Score} = \frac{\text{Frequency of occurence of behaviors } 2+3+4}{\text{Frequency of occurence of behaviors } 1+2+3+4}$$

Table 1
Infant Looking Behaviors Coded During Free Play With Their Parent

Infant looking behavior	Description
1. General look at the parent	Infant looks at their parent (including looks at objects, if the parent holds it in their hands).
2. Looking at the parent's face	Infant looks at the face of their parent but the parent does not look back.
3. Eye contact between parent and infant	Infant and parent look at each other's eyes.
4. Joint attention looks between parent, infant, and an object	Before or after infant and parent look at each other's eyes they both look at the same object.

The score could take values between 0 and 1, whereby higher scores indicated greater levels of social interest. The specific equation for calculating the proportion score was not preregistered prior to data collection. We based it on our observation that infants' general looks at their parent were mainly looks at toys in their parent's hand. As a consequence, infants' "general looks" at their parent (category 1) seemed to be confounded by the parents' activity level. To include all preregistered infant behaviors while extracting infants' "real" social looking behaviors from the overall number of coded behaviors, we relativized the sum of the higher order social looking behaviors at the total amount of all coded behaviors for each individual infant. Our results remained stable when including the sum of frequencies of the behaviors "look at parent's face" (category 2), "eye contact" (category 3), and "joint attention" (category 4) without relativizing them at the total amount of behaviors (see Supporting Information).

A Shapiro–Wilk test of normality revealed that the social engagement score ($p = .14$) was normally distributed. To compare the social engagement scores between the two age groups, we ran a two-way ANOVA, controlling for gender. We explored the data further by running separate analyses for each of the four behaviors. Four Mann–Whitney *U*-tests for independent samples were conducted to compare the mean frequency of occurrence of the behaviors between the two age groups.

Relation Between Attentional Preference for Others' Interactions and Active Social Attention Behavior

We correlated the proportional looking time at social interactions with the social behavior score by using Pearson's *r* correlation. In addition to the preregistered plan, we calculated separate Pearson's *r* correlations for both age groups.

All statistical tests were two-tailed with an alpha-level of .05, except the exploratory pairwise comparisons of the four infant looking behaviors during free play (Bonferroni-corrected $\alpha = .0125$). R software environment was used for processing and analyzing the data.

Results

Attentional Preference for Others' Social Interactions

We found no effects for gender, neither as main effect ($F(1, 36) = 0.05$, $p = .83$, $\eta^2 = .001$) nor in interaction with age group ($F(1, 36) = 2.40$, $p = .13$, $\eta^2 = .06$) and thus excluded gender from the following analyses. The mean proportion of looking time at social stimuli was significantly greater in the older compared to the younger sample ($F(1, 38) = 7.50$, $p = .009$, $\eta^2 = .16$, Figure 2a). Only infants in the older age group preferentially looked at the social interaction stimuli ($M = .54$, $SD = .07$; $t(19) = 2.38$, $p = .03$, $d = 0.53$), whereas infants in the younger age group did not show any preference ($M = .47$, $SD = .08$; $t(19) = -1.56$, $p = .13$, $d = 0.35$, Figure 2a).

We ran the following analyses in addition to the preregistered analysis to explore the data further. First, we repeated our main analysis after excluding trials in which infants exclusively looked at one stimulus, revealing the same pattern with even stronger effects (older sample: $M = .57$, $SD = .06$, $t(19) = 5.32$, $p < .001$, $d = 1.20$; younger sample: $M = .47$, $SD = .07$, $t(19) = -1.63$, $p = .12$, $d = 0.36$; difference between age groups: $F(1, 38) = 21.11$, $p < .001$, $\eta^2 = .36$). The average number of trials discarded in this way per infant was 1.40 ($SD = 1.79$, total = 27) for the younger age group and 1.60 ($SD = 1.64$, total = 32) for the older age group. Second, we explored possible intertrial variability over the course of the experiment. We did not find any effect of trial on infants' preference score, neither in interaction with age group ($\chi^2(1) = 1.12$, $p = .29$, estimate = −0.03, $SE = 0.03$), nor as overall main effect ($\chi^2(1) = 2.11$, $p = .15$, estimate = 0.01, $SE = 0.01$).

Active Social Attention Behavior

We found no effects of gender, neither as main effect ($F(1, 43) = 1.71$, $p = .20$, $\eta^2 = .03$) nor in interaction with age group ($F(1, 43) = 1.02$, $p = .32$, $\eta^2 = .02$) and thus removed gender from the following analyses. Social engagement scores were

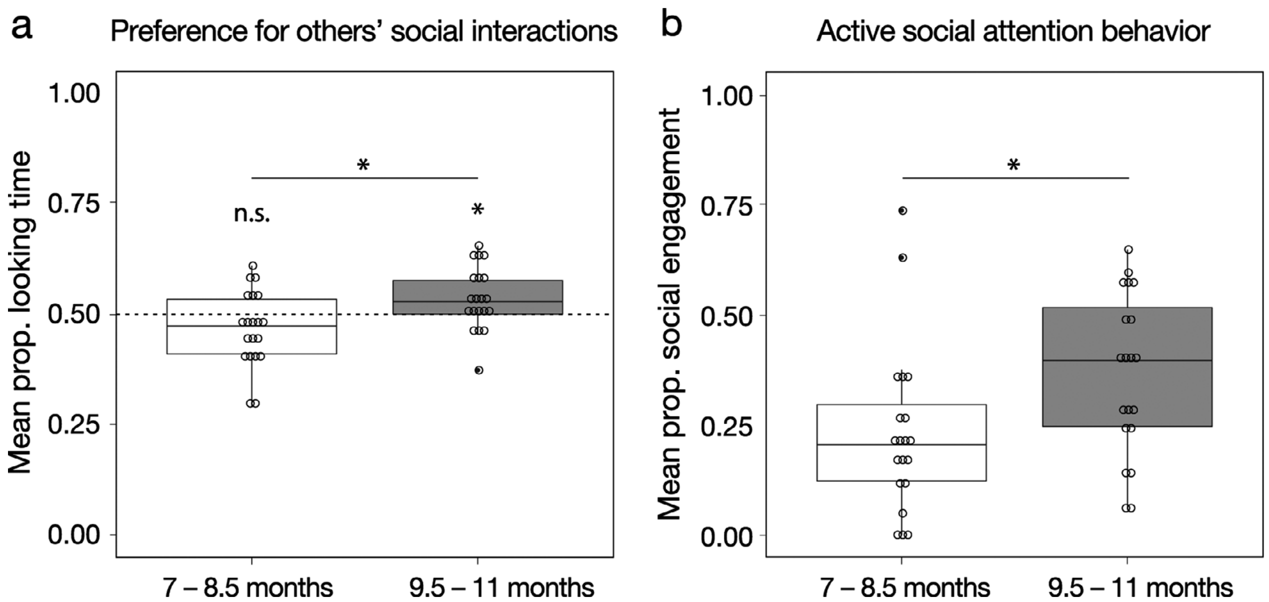

Figure 2. Boxplots with individual data points. (a) Mean proportional looking time to social interaction stimuli for both age groups tested against .50 and compared between age groups. The dashed line at .50 represents chance level. (b) Mean proportion score of active social engagement compared between age groups. n.s. = not significant. $^{*}p < .05$.

Table 2
Mann–Whitney U*-Tests for the Mean Frequency of Occurrence of the Four-Coded Infant Behaviors in Experiment 1*

	7–8.5 months		9.5–11 months		
	Total N = 27		Total N = 20		
Looking behavior	N	M (SD)	N	M (SD)	U
General look at parent	27	21.81 (11.06)	20	20.0 (8.35)	292
Look at parent's face	0	—	5	0.35 (0.67)	202.5
Eye contact	20	3.0 (2.87)	18	4.65 (3.80)	202
Joint attention look	19	3.41 (4.33)	20	6.05 (4.30)	154.5**

Note. N = Number of participants showing the behavior at all. $^{**}p = .011$.

significantly higher in the older age group ($M = .36$, $SD = .18$) compared to the younger age group ($M = .24$, $SD = .20$; $F(1, 45) = 5.06$, $p = .03$, $\eta^2 = .10$, Figure 2b). Exploratory pairwise tests regarding the mean frequency of occurrence of the separate looking behaviors revealed an age group difference in only joint attention looks, with infants in the older group performing more joint attention looks compared to the younger age group ($U = 154.5$, $p = .01$, see Table 2). The proportional looking time at others' social interactions did not correlate with the social engagement scores—neither in the total sample ($N = 40$; $r(38) = .15$, $p = .36$) nor in both age groups separately (younger sample: $r(18) = .30$, $p = .19$; older sample: $r(18) = -.34$, $p = .15$).

Discussion

We found an increase in infants' attentional preference for third-party social interactions from before to after 9 months of age. Infants at 9.5 to 11 months, but not at 7 to 8.5 months, showed a preference to watch others' social interactions over individual actions. Moreover, 9.5- to 11-month-olds showed more social looking behaviors during active social engagement compared to younger infants. At the individual level, infants' social attention behavior during own social interaction was not correlated with their attentional preference for others' interactions.

Together, these findings are in line with the idea that the age of 9 months represents a critical age in infants' social-motivational development (Tomasello, 1995). By comparing infants from two age groups close to before and after 9 months, we could demonstrate that infants do not only show an increasing interest in direct interaction partners (Carpenter et al., 1998) but also develop an increasing visual preference for others' social interactions. The developmental differences that we found are particularly relevant given the small difference of a minimum of 4 weeks between the age groups. It remains unclear, however, *how* infants' social behavior and especially their attention toward others' interactions develop during the critical transition period—abruptly, or following a gradual and continuous increase (e.g., Striano & Bertin, 2005).

To gain a more comprehensive insight into developmental trajectories, we ran a second experiment using exactly the same tasks as in Experiment 1 but including infants at a broader and continuous range between 7 and 13.5 months of age. We aimed to test whether we could replicate our findings from Experiment 1 and extend them in three regards. First, by measuring age continuously and throughout the 9-month-period, we aimed to get an insight into the kind of transition taking place around 9 months. Moreover, by including infants up to 13.5 months of age, we aimed to broaden our understanding of developments after 11 months since infants' active social engagement has been previously found to continue increasing after 11 months (Adamson & Bakeman, 1985; Carpenter et al., 1998). Finally, we aimed to examine the non-significant correlation further by testing an additional and bigger sample.

Experiment 2

Methods

The experimental design, procedure, data preprocessing, and coding procedures were identical to Experiment 1. The testing took place between July and October 2019 at the Max Planck Institute for Evolutionary Anthropology. To measure infants' looking time in the eye tracking task, we used a different SMI eye tracking hardware compared to the first experiment (RED-m, SensoMotoric Instruments, 8.2), recording data at a sampling frequency of 120 Hz. The eye tracking model did not have an effect on the results of the merged analyses (see Supporting Information). Other deviations from Experiment 1 are described in the corresponding sections.

Participants

Fifty infants between 7 months, 0 days and 13 months, 13 days provided both eye tracking and free play data and were included in the correlation analysis ($n = 21$ female; $M = 316.9$ days, $SD = 58.42$ days). Another 24 infants were tested but excluded due to calibration error or technical failure during eye tracking ($n = 14$), technical failure during free play ($n = 5$), or because the infant did not remain in the camera field during free play ($n = 5$). For the separate analyses of the eye tracking and free play data, we included all infants who contributed valid data for either of the two measures. Accordingly, 51 infants were included in the eye tracking analyses ($n = 21$ female, $M = 318.43$ days, $SD = 58.86$ days) and 64 infants in the free play analyses ($n = 30$ female; $M = 311.9$ days, $SD = 57.79$ days). All infants were born full term ($M = 40.09$ weeks; $SD = 1.40$ weeks). The primary caregivers, that is, 5 fathers and 59 mothers participated in the free play phase of the study. Participants were partly recruited from the database described in Experiment 1 ($n = 39$) and partly from the database of the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig ($n = 35$). The general sample characteristics and contexts are similar between the two databases. The sampling plan was planned in the preregistration and is available on the OSF. We ran additional analyses over a merged sample combining all participants from Experiment 1 and 2. A total of 90 infants between 7 months, 0 days and 13 months, 13 days ($M = 299.17$ days, $SD = 54.27$ days) were included in the overall correlation analysis, 91 infants in the overall eye tracking analysis ($M = 300.22$ days, $SD = 54.89$ days), and 111 infants in the overall free play analysis ($M = 293.95$ days, $SD = 55.21$ days).

Data Analysis and Coding

The coding of the free play sessions was identical to Experiment 1, except that a different second coder performed the inter-reliability coding. The inter-rater agreement between the first and second coder was good (ICC = .88). Shapiro–Wilk tests revealed that both dependent variables were normally distributed ($p > .05$). To investigate the effect of age on infants' visual preference for third-party social interactions, we ran a linear model for the mean proportional looking time to the social interaction videos in the eye tracking task, using age (in days) as a continuous predictor. To investigate the effect of age on infants' social attention behavior during own social interaction, we ran a second linear model for infants' active social engagement score, including the same predictor as in the first model. To assess the relation between the two measures, we correlated the proportional looking time at the social interaction scenes with the social engagement score by using Pearson's r correlation. We did not include gender in any of our analysis as we did not find any effect of gender in

Experiment 1. As planned in the preregistration, we repeated all analyses over a merged sample combining participants from both experiments.

Results

Attentional Preference for Others' Social Interactions

The mean proportional looking time to the social interaction stimuli increased with age (β =-.04 ± SE = .01, t(1, 49) = 3.73, p < .001, η^2 = .22, Figure 3a). In addition to the preregistered analysis, we repeated our main analysis after excluding trials in which infants exclusively looked at one stimulus, revealing the same pattern (β = .04 ± SE = .01, t(1, 48) = 2.61, p = .01, η^2 = .12). The average number of trials discarded in this way per infant was 2.5 (SD = 2.2). We found the same pattern when repeating our analysis over a merged sample including participants from both Experiments (β =-.04 ± SE = .01, t(1, 89) = 5.09, p < .001, η^2 = .23).

Active Social Attention Behavior

The social engagement score increased with age both in the separate sample (β = .09 ± SE = .03, t(1, 62) = 3.35, p < .001, η^2 = .15) and in the merged sample (β = .09 ± SE = .02, t(1, 109) = 4.49, p < .001, η^2 = .16, Figure 3b). Exploratory analyses of the separate looking behaviors revealed that infants with increasing age produced more joint attention looks (β = 2.80 ± SE = .85, t(1, 62) = 3.28, p < .001, η^2 = .15) and fewer general looks at their parent (β = −2.71 ± SE = 1.0, t(1, 62) = −2.71, p = .01, η^2 = .11, see Table 3a). Additional analyses including infants from both experiments revealed a similar pattern (see Table 3b). The proportional looking time at others' social interaction did not correlate with infants' social behavior scores at the individual level (N = 50; r(48) = .23, p = .11).

Overall Analysis of Individual Differences Across Both Experiments

Probing the relation between infants' visual preference for others' interactions and their active social engagement score with a higher-powered analysis, revealed a statistically relevant relation (N = 90; r(88) = .24, p = .03, R^2 = .06, see Figure 4). These findings complement the pattern of group-level differences in both measures by showing an increase in social attention and behavior on the individual level. To explore the impact of age on this relation, we ran a linear model for the active social

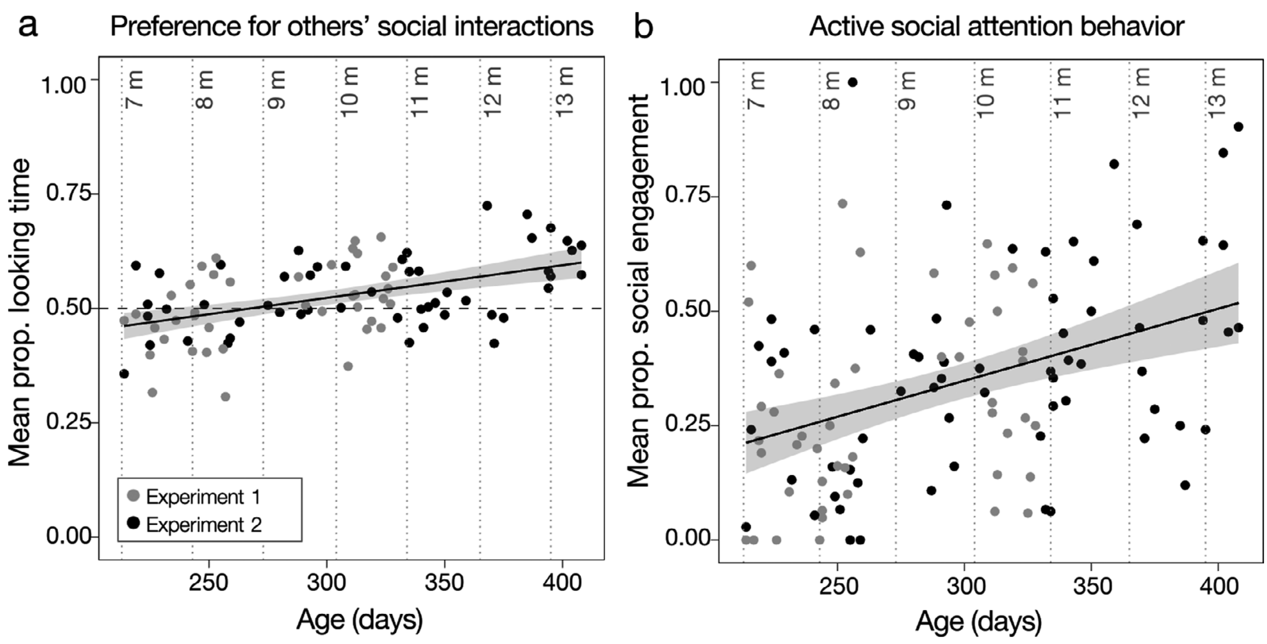

Figure 3. Scatterplots with individual data points including participants from both experiments. (a) Effect of age on mean proportional looking time to social interaction videos (p < .001). The dashed line at .50 represents the chance level. (b) Effect of age on mean proportion score of active social engagement (p < .001). The vertically dashed lines indicate age in months. The linear regression lines with confidence ribbons fit to the overall data of the plots. The lower variance in infants' preference for social interactions compared to their active social behavior represents a methodological artefact, no systematic developmental difference between the constructs.

Table 3

Results from Exploratory Linear Models for the Effect of Age (Days) on the Absolute Frequency of the Four Infant Behaviors (a) in Experiment 2, and (b) for a Merged Sample Including Participants from Experiment 1 and 2

	(a) Experiment 2 (total N = 64)				
Looking behavior	N	β	SE	t	p
General look at parent	63	−2.71	1.00	−2.71	.01**
Look at parent's face	8	−0.03	0.04	−0.71	.48
Eye contact	49	0.03	0.33	0.08	.93
Joint attention look	58	2.80	0.85	3.28	<.01***
	(b) Experiment 1 & 2 (total N = 111)				
Looking behavior	N	β	SE	t	p
General look at parent	110	−2.20	0.84	−2.62	.01**
Look at parent's face	13	0.04	0.04	0.97	.33
Eye contact	87	0.06	0.29	0.22	.82
Joint attention look	97	2.93	0.56	5.20	.00***

Note. N = Number of participants showing the behavior at all. Figure S3 in the Supporting Information provides visualizations of the data for all four infant behaviors.
$^{**}p < .01$. $^{***}p < .001$.

engagement score, including the interaction between proportional looking time to the social interaction stimuli and age (in days). The interaction did not reveal a significant effect ($\beta = -.36 \pm SE = .23$, $t(3, 86) = -1.61$, $p = .11$, $\eta^2 = .03$) and was therefore dropped from the model. The same model including proportional looking time and age as main effects revealed a significant effect of age ($\beta = .08 \pm SE = .02$, $t(2, 87) = 3.54$, $p < .001$, $\eta^2 = .12$), not proportional looking time ($\beta = .13 \pm SE = .28$, $t(2, 87) = 0.48$, $p = .63$, $\eta^2 = .003$).

Discussion

We found a continuous increase in both infants' preferential orienting toward third-party social interactions and their social attention during active social interaction (especially joint attention looks). We found analogous patterns when repeating our analyses over a merged sample of Experiment 1 and 2. Infants' proportional looking time at others' interactions was not correlated with their social engagement scores in Experiment 2, but the two measures were correlated in a merged sample including infants from both experiments. Further analyses suggested that this correlational relation was predominantly driven by age, indicating that the two measures were not directly related at the individual level.

In contrast to the increase in infants' overall social engagement score and joint attention, infants' general looks at their parent decreased with age. This finding is in line with our observation, that infants' "general looks" were mainly looks at toys in their parent's hand (see "Data analysis and coding," Experiment 1). Based on our impressions during video coding before running statistical analyses, we speculate that a decrease in parent-toy interaction may have caused the age-related decrease in infants' general looks at their parent. With the increasing age of their child, parents appeared to make fewer attempts to engage their child with the toys as children began exploring the toys by themselves.

General Discussion

Previous work on infants' social attention did not assess whether infants' preferential orienting to third-party social interactions coincides with their social attention during active social engagement, which undergoes a significant development during the second half of the first year of life. In Experiment 1 we found that, in contrast to 7.0- to 8.5-month-olds, older infants at 9.5 to 11 months of age (a) show an increasing preference to watch social interactions over individual actions, and (b) show a higher attentional interest in an interaction partner during active participation in social interaction. In Experiment 2, we could replicate this increase at both levels and show that it develops in a continuous manner from 7 to 13 months of age. In a merged sample over both experiments, infants' orienting toward others' interactions was positively correlated with their social attention during own social engagement, but this correlation was mainly driven by infants' age. Our findings suggest that infants' social attention is driven toward social interactions toward the end of the first year of life.

The increase that we found in infants' active social attention, specifically their joint attention, aligns with prior work suggesting changes in infants' social interaction behavior toward the end of the first year of life (Carpenter et al., 1998; Striano & Reid, 2006). More specifically, the continuous trajectory supports previous studies suggesting that infants' social engagement skills develop gradually rather than changing abruptly from before to after 9 months of age (see also Bakeman & Adamson, 1984; Striano & Bertin, 2005). This is further in line with the assumption that triadic attention results from multiple continuous developments unfolding

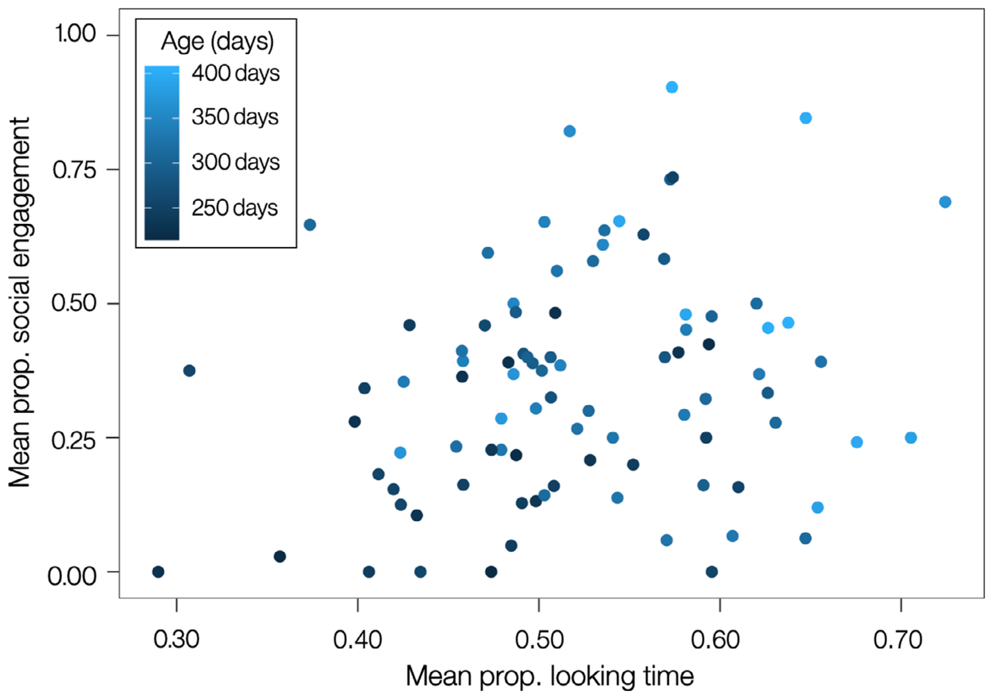

Figure 4. Scatterplot illustrating the mean proportional looking time to social interaction stimuli plotted against the mean proportional social engagement score for a merged sample of Experiment 1 (N = 40) and Experiment 2 (N = 50). The dots represent individual data points of participants from both experiments. The color gradient represents the participant's age ranging from 7 months, 0 days (dark blue) to 13 months, 13 days (light blue). In a merged sample over both experiments, the two measures were spuriously correlated through infants' age (N = 90, p = .03).

over time and in interaction with the environment, rather than being the result of one isolated emerging social skill causing a sudden change (de Barbaro, Johnson, & Deak, 2013). The age-related increase that we found in both experiments does not imply that younger infants did not show any joint attention behaviors at all. Indeed, we found infants at all ages, including 7-month-olds, engaging in at least one joint attention episode with their parent (97 out of 111 infants over both Experiments). This finding corresponds with previous studies demonstrating early joint attention behaviors emerging already before 9 months of age (e.g., Bakeman & Adamson, 1984; Mundy & Newell, 2007; Striano & Bertin, 2005).

Our findings regarding infants' attentional preference for others' interactions extend previous studies by revealing a continuous increase throughout the second half of the first year of life. When probing infants' preferential looking score against chance level in Experiment 1, only infants older than 9 months showed a statistically relevant preference for the face-to-face interaction videos (even though individual infants in the younger age group showed a preference as well). Our finding that older infants preferred attending to third-party interactions corresponds with prior work demonstrating a preference for face-to-face interactions in 9-month-old infants or older (Beier & Spelke, 2012; Galazka et al., 2014; Handl et al., 2013). Based on previous findings, it is rather unlikely that the absence of preferential orienting in 7.0- to 8.5-month-old infants resulted from a lacking ability to differentiate between the two scenarios. Already 6-month-old infants use others' body orientation to infer an interactive relationship between two people (Augusti et al., 2010). Accordingly, we suggest that the younger participants in the current experiments did identify a difference between the two scenarios, but did not prioritize one over the other scenario. Another possibility would be that our preferential-looking task was too demanding for the younger participants, as two videos were shown at the same time (in contrast to studies using a one-by-one stimulus presentation, e.g., Augusti et al., 2010). However, even if the higher complexity of our procedure had undermined the onset age of infants' above-chance preference for social interactions, the findings from both experiments point to an increasing orienting toward the end of the first postnatal year. During the same period, previous studies with geometrical shape agents have shown that infants develop representations of different kinds of third-party social relationships, and that they use these representations to make inferences about the future. Seven-month-old infants represent affiliative relationships and expect social group members to perform similar actions (Powell & Spelke, 2013), 9-month-old infants use intergroup representations to make moral evaluations about others (Hamlin, Mahajan, Liberman, & Wynn, 2013), and 10-month-olds represent dominance relationships and use this information to predict competition outcomes (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011).

Comparing the developmental pathways of both modalities at the group level suggests that infants' attentional orienting to others' interactions indeed follows a similar increase as their active social attention behavior. In addition, we found a spurious relation at the individual level in a merged sample over both experiments, in that infants with a higher attentional preference for others' interactions showed more social attention behaviors during interaction with their parent. However, and importantly, additional analyses revealed that this effect was driven by an underlying effect of age. While the current findings show that both modalities are related in terms of concurrent developmental trajectories, future studies will need to examine the specific underlying processes and mechanisms explaining this relation. It is likely that an interplay of multiple mechanisms is involved, as the absence of a correlational relation speaks against the notion that one single construct underlies the development of both social attention behaviors (see also Slaughter & McConnell, 2003).

One possible interpretation of our findings would be that social behavior and perception are both driven by motivational systems guiding infants to situations in which they can engage in or observe others' interactions. One specific mechanism could be an intrinsic motivation to acquire knowledge and to learn from others (e.g., Litman, 2005). Even though our study did not focus on learning per se, our finding that infants increasingly engage in coordinated attention and increasingly prefer attending to face-to-face interactions raises the possibility that information-seeking motivations steer infants' attention toward situations in which they can gather knowledge. Both situations provide opportunities to acquire culturally relevant knowledge, including knowledge about content in the environment (e.g., information about novel objects, Csibra & Shamsudheen, 2015) or knowledge embodied in interpersonal interaction (e.g., coordinated action rituals, Legare & Nielsen, 2020). Another candidate mechanism could be infants' intrinsic social motivation (e.g., Chevallier et al., 2012). Previous studies have shown that infants find it intrinsically rewarding to engage in social interactions, and that this social motivation increases during the second half of the first year of life (Striano & Bertin, 2005; Venezia, Messinger, Thorp, & Mundy, 2004). Considering the possibility that infants find it also intrinsically valuable to observe others' interactions (e.g., Thiele et al., 2021), it would be possible that social reward-seeking mechanisms underlie the parallel increase in infants' attention to direct interaction partners and others' interactions. Another factor that may influence infants' behavior at the broader level is a more general motivation to establish and foster social bonds with social group members (Over, 2016). Early affiliative motives may not only modulate infants' behavior in direct interactions but also increase their sensitivity to social relationships between others (for related evidence with 18-month-olds, see Over & Carpenter, 2009).

In addition to motivational mechanisms, it would be possible that the two modalities are causally or reciprocally related to one another. For example, infants' practical experience and active exploration in social interactions may influence the detection and understanding of others' interactions (Gredebäck & Melinder, 2010; Henderson, Wang, Matz, & Woodward, 2013). Vice versa, infants' experience and knowledge gained through observation of others may have an impact on their own behavior as well (Matheson et al., 2013). Importantly, this study was not designed to detect and disentangle such immediate relations between the two levels. This would require longitudinal study designs, together with a closer matching between infants' natural interactions and the observed interactions, for example, by including touch as an interactive behavior, or by matching the knowledge that can be potentially learned from the interaction (e.g., object-related information, coordinated action rituals). Moreover, to assess infants' *understanding* of others' interactions, it would require different measures, such as predictive saccades (e.g., Bakker et al., 2011) or outcome measures of learning (e.g., object encoding, Cleveland & Striano, 2007; or manual actions, Matheson et al., 2013).

Limitations

The findings obtained from this study need to be considered against some limitations. First, since we investigated infants' social orienting capacities under controlled experimental conditions, the videos depicted third-party interactions in a very simplified and in some sense restricted way. This was intended given that our primary goal was to match the videos from both conditions with regard to perceptual salience (e.g., motion, synchronicity, luminosity). Since the control scenes were created by mirroring the social interaction scenes, the rational meaning of the actions in the control videos was lower compared to the social interaction videos (e.g., performing the clapping movements without a social partner). Our findings suggest that infants with increasing age were not distracted by this issue, as they preferentially looked at the social interaction videos. For younger infants, however, we cannot rule out the possibility that they were distracted by the lower rational meaning in the control videos (Houston-Price & Nakai, 2004). Another difference between the videos was that only the social interaction scenes contained movement toward the center of the screen. Based on our data, we cannot completely exclude the possibility that infants' looking behavior was influenced by a preference for perceptually grouped content. However, based on the finding by Galazka and colleagues (2014), that infants' preferential looking at social interactions disappeared in a control condition with inverted stimuli, we consider it rather unlikely that infants' looking pattern in the present study has been driven by low-level perceptual features. Future studies should systematically disentangle what visible features of social interactions underlie infants' visual preference (e.g., eye contact, face-to-face orientation, proximity, touch, rationality). Moreover, additional measures should be used to examine whether infants' attentional preference for others' social interactions is driven by affective-motivational mechanisms. Looking times alone do not provide direct information about motivational processes and should be complemented with measures of emotional arousal and valence, for example, by measuring infants' facial expressions (Steckler et al., 2018) or pupil dilation (Hepach & Westermann, 2016). In contrast to the current study design, this would require a one-by-one presentation order of stimuli. In addition, neuroimaging methods could complement the current findings regarding possible cortical specialization processes with regard to social interaction processing (Isik, Koldewyn, Beeler, & Kanwisher, 2017). Additionally and more generally, future studies are required to complement laboratory findings with infants' natural orienting in their everyday environment.

Another limitation is that we did not directly control for the impact of parental activity on infants' behavior during free play. To investigate reciprocal dependencies between interaction behaviors of infants and their parents, it would require a correspondingly detailed coding procedure considering the specific duration of behaviors and a setup with multiple cameras, allowing to record both interaction partners from different perspectives. In addition, a more advanced setup would allow to account for social attention behaviors going beyond the eye contact-based behaviors measured in this study. Mobile eye-tracking studies, for example, have demonstrated that 1-year-olds' joint attention behaviors are not restricted to eye contact and gaze following. Infants and parents increasingly coordinate their attention by mutually following manual actions on objects, without necessarily looking at each other's eyes (Yu & Smith, 2013). Another limitation is that our findings are restricted to interactions between infants and their primary caregiver. Since we did not investigate differences between mothers and fathers as primary caregivers, we cannot draw inferences regarding the influence of parental gender (Lewis et al., 2009). Moreover, our findings cannot not account for systematic differences in infants' behavior toward other interaction partners such as siblings (Teti, Bond, & Gibbs, 1988), peers (Bakeman & Adamson, 1984), or strangers (Dixon et al., 1981). In addition, we did not control for possible third factors that may have an effect on either of the two measures or mediate their relation. For example, an infant with an insecure attachment style may avoid eye contact with their mother during free play but show preferential orienting to interactions between strangers (Claussen, Mundy, Mallik, & Willoughby, 2002). Other possible influential factors could be, for example, infant temperament (Todd & Dixon, 2010), motor ability and activity level (Clearfield et al., 2008), or own previous experience with an observed interaction (e.g., Gredebäck & Melinder, 2010). Furthermore, infants' developing receptive language abilities (Frank, Braginsky, & Marchman, 2021) may increase their interest in self-experienced and observed social turn taking. Moreover, given the great number of studies suggesting impairments in social attention and motivation in children with Autism Spectrum Disorders (Chevallier et al., 2012), it would be important to investigate the visual preference for social interactions in a high-risk sample. Finally, our findings are restricted to typically developing infants growing up in a Western, industrialized context. Given the substantial variation in the extent to which children in different cultural contexts rely on direct pedagogy and observational learning (e.g., Callaghan et al., 2011; Mesman et al., 2018), it would be interesting to investigate cross-cultural differences in the development of infants orienting toward both situations. This would enable conclusions regarding the evolution of infants' attentional preference for social interactions.

Conclusions

In summary, we could show that infants' social behavior and attention are increasingly driven toward social interactions throughout the second half of the first year of life. From 7 to 13 months of age, infants do not only show increased active social engagement but are additionally increasingly biased to attend to third-party interactions. Our findings suggest that infants develop capacities and preferences, enabling them to approach social interactions through multiple pathways, including first-hand experience and third-party observation. This indicates that, toward the end of the first year of life, infants take an increasingly active role in maximizing the availability of situations in which they can potentially learn from others. Thus, at a broader level, infants' increased orienting toward own and others' social interactions represents an important development on their way to becoming a competent member of their cultural community.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Statement

The study was approved by the ethics committee of the Medical Faculty of Leipzig University (title of the overall approval: "Investigating the nonpathological development of social behavior and competences in children and adults by using behavioral, peripheral physiological, and psychometric methods"; reference number 169/17-ek).

Data Availability Statement

All raw data, the preregistrations as well as scripts for data processing and analysis are openly accessible on the Open Science Framework (non-blinded link Experiment 1: https://osf.io/42nyv/, Experiment 2: https://osf.io/s4uy7/).

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. Supplementary materials including a document with additional analyses, tables, figures, and information about the eye tracking and free play task, and seven exemplary videos illustrating the video stimuli that were used in the preferential looking task.