Report

Current Biology

# The Social Origins of Sustained Attention in One-Year-Old Human Infants

## Highlights

- We used head-mounted eye tracking to record gaze data in child-parent free play
- Infants extend their sustained attention when a parent attends to the same object
- Parent-child social interactions influence the development of sustained attention
- The development of seemingly non-social competencies depends on social experience

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## In Brief

Using head-mounted eye tracking to record gaze data from both parents and infants, Yu and Smith find that infants extend their sustained attention to an object when a mature social partner also shows visual attention to that object, suggesting a pathway through which social interactions may influence the development of sustained attention.

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Current Biology
Report

# The Social Origins of Sustained Attention in One-Year-Old Human Infants

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## SUMMARY

**The ability to sustain attention is a major achievement in human development and is generally believed to be the developmental product of increasing self-regulatory and endogenous (i.e., internal, top-down, voluntary) control over one's attention and cognitive systems [1–5]. Because sustained attention in late infancy is predictive of future development, and because early deficits in sustained attention are markers for later diagnoses of attentional disorders [6], sustained attention is often viewed as a constitutional and individual property of the infant [6–9]. However, humans are social animals; developmental pathways for seemingly nonsocial competencies evolved within the social group and therefore may be dependent on social experience [10–13]. Here, we show that social context matters for the duration of sustained attention episodes in one-year-old infants during toy play. Using head-mounted eye tracking to record moment-by-moment gaze data from both parents and infants, we found that when the social partner (parent) visually attended to the object to which infant attention was directed, infants, after the parent's look, extended their duration of visual attention to the object. Looks to the same object by two social partners is a well-studied phenomenon known as joint attention, which has been shown to be critical to early learning and to the development of social skills [14, 15]. The present findings implicate joint attention in the development of the child's own sustained attention and thus challenge the current understanding of the origins of individual differences in sustained attention, providing a new and potentially malleable developmental pathway to the self-regulation of attention.**

## RESULTS

Voluntary control of attention becomes evident as early as an infant's first birthday, but even for 10- and 12-month-old infants, attention is often controlled by novelty, habituation, and distraction, with interest in one moment giving way in the next to some new object or event [2, 5, 16]. The duration of sustained attention grows incrementally and steadily from infancy through early childhood, becoming more extended in time and better able to withstand distraction [16–20]. While previous studies have identified internal factors to this incremental growth [21], the present study examined whether social interactions that extend the duration of attention to objects could also be a critical factor. If the infant's own attention is influenced by the attention of a social partner [14, 15, 22], then the attentional behavior of a mature partner could incrementally extend the duration of the infant's attention and in so doing support the development of the attentional pathways that underlie enduring concentration on an attention target. To test this hypothesis, we used the task of infant toy play with multiple objects, a context that has been widely used to assess sustained attention in late infancy and that yields measures of sustained attention predictive of later cognitive developments [16–18, 23].

The final sample consisted of 36 (19 male infants) parent-infant dyads, with the infants ranging in age from 11 to 13 months (mean = 12.52, SD = 1.15). In the task, infants and parents were given three highly engaging and novel toys (as determined by pre-testing) with which to play. In this free-flowing interaction, the infant's task was to engage and explore the toys (see Movie S1). The parent's task was to actively encourage their infant to play with the toys. As shown in Figure 1, head-mounted eye tracking technology was used to collect high-density real-time eye movement data from both infants and their parents during the task [24, 25]. The gaze data were analyzed with respect to four regions of interest (ROIs): each of the three toys and the partner's face. As shown in Figure 2B, infants' and parents' gaze dynamics were fundamentally different [13], befitting their different goals. Parents' gaze shifts were faster, generating 58.58 switches (SD = 10.21) per minute with a mean duration of 0.95 s (SD = 0.23), consistent with the parent's task of visually monitoring all the objects potentially in play and as well as their infant's face (and attention). Infants, in contrast, produced 30.57 switches (SD = 6.43) among ROIs (objects or the partner's face) per minute with a mean duration of 2.16 s (SD = 0.62) for each look. Overall, infants looked most frequently to the objects (proportion of time, M = 62.54%, SD = 8.23%) and not to their parent's face (M = 12.82%, SD = 3.71%). The infant pattern thus also fit their task: active engagement and play with the individual toys.

To test the hypothesis that parent attention (and thus joint attention) extends infants' visual attention to an object, we first independently measured joint attention (JA) and infant sustained attention (SA). Joint attention was objectively defined [26] as periods during which parents and infants were jointly fixated on the same object at the same time. Because meaningful shared

  

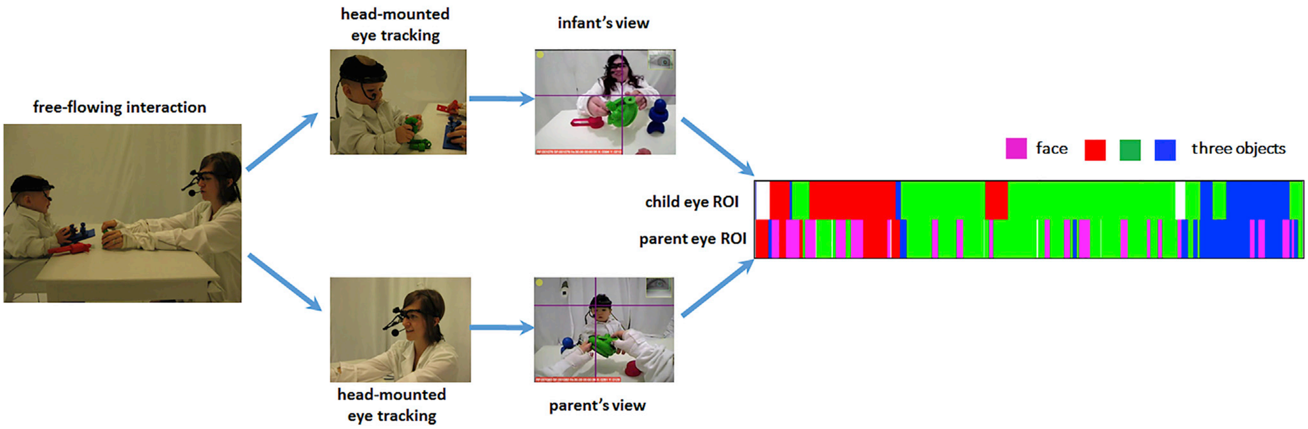


**Figure 1. Overview of the Experiment**

An infant and her parent played with a set of toys in a free-flowing interaction. Both participants wore a head-mounted eye tracker that recorded gaze data from the first-person view, with a crosshairs indicating gaze direction moment by moment. Two gaze streams collected from the parent and infant respectively were used for data analysis. See Movie S1.

attention should last some amount of time longer than a single video frame (33 ms) but also be inclusive of as many meaningful parent looks as possible (given their monitoring of the whole scene with frequent brief glances), a joint attention bout was defined as a continuous alignment of parent and infant fixation that lasted longer than 500 ms but that could include looks briefer than 300 ms elsewhere. Given that humans generate three saccades per minute, this threshold of 300 ms allowed one brief look away before switching back to the target. Examples of joint attention bouts are shown in Figure 2B. Parents and infants, on average, jointly attended to the same object 34.24% (SD = 6.04%) of the total toy-play time, which was composed of 9.37 (SD = 1.65) distinct JA bouts with an average duration per bout of 2.39 (SD = 0.61) seconds. Figure 3A shows a histogram of the duration of JA bouts across all infants.

Figure 3B shows a histogram of the duration of infant looks to an object, the majority of which were very brief, with an average duration of 2.16 s. Early work on sustained attention [17] defined the phenomenon in terms of a suite of behaviors, such as manual activities and facial expressions (viewed as indicative of focused concentration), and measured the duration of sustained looking when the infant's overall demeanor fit that definition. To more objectively define sustained attention, we turned the approach around and defined sustained attention as looks longer than 3 s, the average duration of concentrated attention for 1-year-olds reported in the earlier work [17]. This threshold ensures that the defined sustained attention bouts are on the tail of the distribution (exceeding the mean of the overall distribution) and thus are at the upper end of what children this age can do when visually focusing attention on a single object [17, 27]. More specifically, we operationally defined 3 s of consistent looking within the ROI for a single object *without any looks elsewhere* as the threshold for sustained attention by the infant. Given this definition, infants generated 4.72 sustained attention bouts per minute with a mean duration of 5.05 s, which is much longer than the observed average duration of looks to a single object when one considers all such looks ($t(35) = 12.54$, $p < 0.001$, $d = 4.24$). Analyses conducted on different thresholds for the duration defining SA (±1 s changes of the 3 s threshold) did not change the overall pattern of results reported below. In the following, we used linear mixed-effects models [28] with both subjects and items as random effects to examine the links between joint attention and sustained attention.

We first divided the infant SA bouts into two categories: SA that overlapped with JA, and SA alone. On average, 65.38% of SA instances occurred with an accompanying parent look and thus with JA, while the rest were without JA. The average duration of SA-with-JA was much longer than the duration of SA-without-JA ($M_{SA\text{-}with\text{-}JA} = 5.33$ s, $M_{SA\text{-}without\text{-}JA} = 4.38$ s, $\beta = 1.27$, $SE = 0.11$, $p < 0.001$). Overall, the results are consistent with the hypothesis of the social extension of sustained attention. The results are not definitive, as longer bouts of sustained attention by the infant provide more time for parents to look to the same object, and thus joint attention could be a byproduct of longer attention bouts by the infant rather than due to the hypothesized mechanism that the parent's attention to the same object *extends* the infant's attention.

To test the "extension" hypothesis that parent attention to an object extends the duration of infant attention, we considered three key predictions. First, see Figure 4A: the time it takes the parent to join the child in attending to the object should not be systematically related to the duration of the SA bout; that is, the SA bout with JA should not be long, because children were already attending to the object for a long time before parents joined them. Second, see Figure 4B: if parents entrain child attention and extend the duration while they (the parent) also visually attend to the object, then SA bouts with longer JA bouts should be longer than SA bouts with shorter JA bouts. Third, see Figure 4C: if parent interest extends the child's interest beyond the period of joint attention, then the period of SA after JA ends should also be extended. That is, the sustained period should be dose dependent—longer when the accompanying JA portion is long than when it is short, and this dose-dependent influence should extend beyond the time of the parent's shared attention.

The first test focuses on the timing with which parents joined their infants' attention. If SA-with-JA bouts are longer because

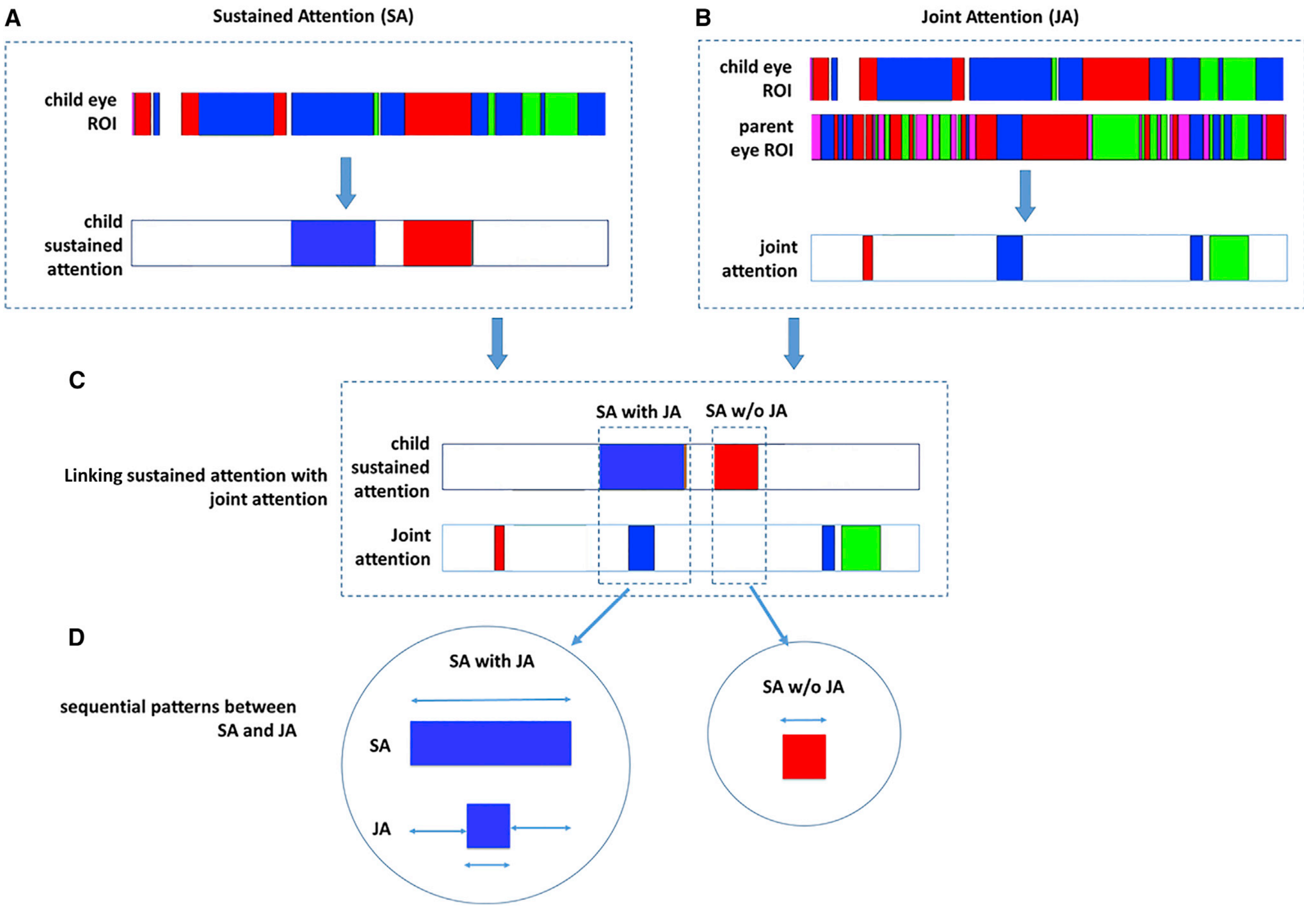


**Figure 2. Overview of Data Analysis**

(A) Sustained attention (SA) was defined based on infant eye region of interest (ROI).

(B) Joint attention (JA) was measured independently based on infant and parent eye ROI streams.

(C) SA instances were categorized as two types: SA with an accompanying JA and SA without any accompanying JA.

(D) Sequential patterns between SA and JA were examined for instances of SA with JA and were compared to the instances of SA without JA.

parents have more time to join, then long delays between the child onset of attention to an object and the onset of JA should be associated with longer SA bouts. This was not the case. As shown in Figure 4A, we divided all SA-with-JA instances into two groups based on median split of the lag duration between the onset of the infant's attention and parent's attention: long-lag SA ($M_{long\text{-}lag}$ = 2,308 ms) and short-lag SA ($M_{short\text{-}lag}$ = 548 ms). There was no difference in the total durations of the SA-with-JA bouts for long and short lags ($M_{long\text{-}lag}$ = 5,231 ms; $M_{short\text{-}lag}$ = 4,876 ms; $\beta$ = 0.07, SE = 0.17, not significant). The speed with which parents joined the infant was not the determining factor of the duration of infant sustained attention.

The second hypothesis concerns the length of the JA portion of the infant's sustained attention: by our hypothesis, longer JA should be associated with longer overall sustained attention. Accordingly, we categorized the SA-with-JA bouts into two groups according to the duration of the JA portion, above or below the median, yielding two groups of SA-with-JA bouts, with long-JA ($M_{long\text{-}JA}$ = 3,243 ms) versus short-JA ($M_{short\text{-}JA}$ = 1,835 ms) portions of those bouts. As predicted, SA instances with long JA were longer overall than were SA instances with short JA ($M_{long\text{-}JA}$ = 6,540 ms; $M_{short\text{-}JA}$ = 4,293 ms; $\beta$ = 0.87, SE = 0.17, $p < 0.001$), as shown in Figure 4B. A JA episode can be terminated by either the child or the parent. In cases when it was terminated by the infant (thereby also terminating SA), JA and SA durations were guaranteed to be correlated, without regard to parents' looks. To eliminate this possibility, we further selected a subset of SA with JA bouts that were terminated by the parent, divided those instances based on JA duration, and again found the predicted pattern ($M_{long\text{-}JA}$ = 5,825 ms; $M_{short\text{-}JA}$ = 4,762 ms; $\beta$ = 0.76, SE = 0.21, $p < 0.005$): the length of the JA period determined the overall length of infant sustained attention.

The third hypothesis is that parent attention extends infant attention, increasing the duration even after JA ends. This dose-dependent extension predicts that the period during which the infant attended to the object after JA ends should be longer, given immediately prior and longer shared attention with the parent. This was the pattern obtained as shown in Figure 4C. Infant attention to the target after JA ended was longer for longer JA periods than for shorter ones ($M_{long\text{-}JA}$ = 2,146 ms; $M_{short\text{-}JA}$ = 959 ms; $\beta$ = 0.82, SE = 0.09, $p < 0.001$). Thus, even after joint

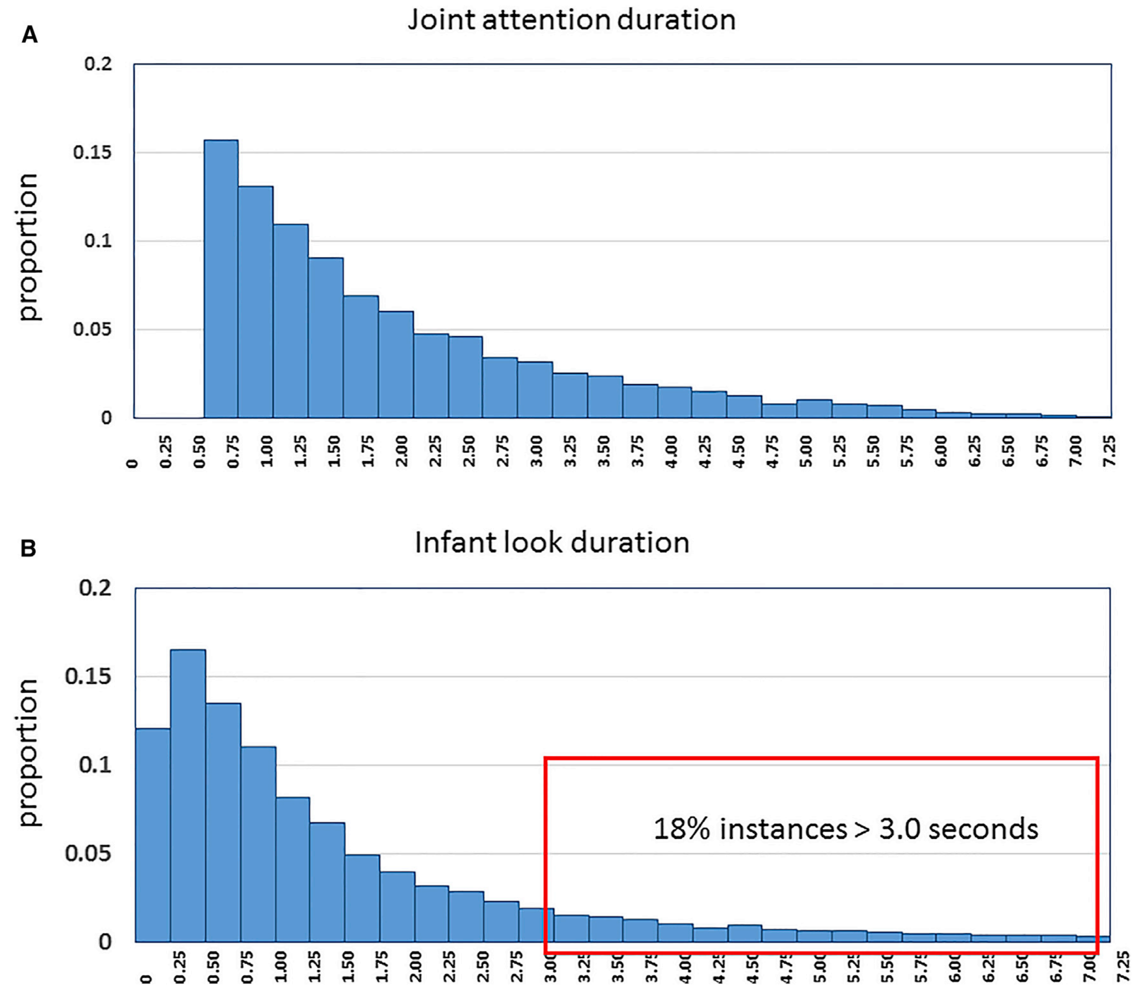


**Figure 3. Histograms of Durations of Joint Attention and Infant Looks**

(A) Histogram of JA duration. Note that JA bouts are defined as lasting longer than 500 ms.

(B) Histogram of infant gaze duration. Infants generated many brief gazes, but fewer than 20% were longer than 3 s, which was the threshold used to define sustained attention.

attention, infants tended to look at the target longer after a period of long joint looking with the parent than after a period of short joint looking. Parent looks to the target of the infant's interest not only sustained that interest during parent attention but extended it after parents had shifted attention elsewhere. At a surface level, the phenomenon bears some similarity to what is known as "attentional inertia" observed in the context of older children watching television [21]: the longer the child looks, the more likely they are to keep learning. The present results suggest that parent interest extends infant looking and may similarly (through inertial processes) extend infant attention in time.

## DISCUSSION

An infant's first year marks the beginning of a period of steady incremental growth in the ability to sustain attention on a single target of interest. Sustained attention, in turn, is linked to object exploration, language development, and problem solving [1]. Emerging individual differences in sustained attention during this period predict later developmental outcomes in many domains [18, 19]. While the infant's own internal system (what is sometimes called temperament [7, 29]) surely determines the nature and rate of individual growth in attentional skills, the infant's internal system is itself changing during this period of time and thus potentially malleable through its own intrinsic and evoked activity [30]. The results provide evidence for a pathway through which social interactions may influence the development of sustained attention, a pathway through which individual differences in the development of sustained attention may emerge and through which atypical patterns of attention development may be addressed. The results here show that the duration of infant attention to an object is extended by a mature social partner's visual attention to and interest in that object, and that this socially shared attention extends the infant's own attention both during and after the joint attention portion, so that the infant continues to focus on the object after the adult has shifted attention elsewhere. The present evidence consists of in-the-moment effects on the duration of attention, not the long-term training of

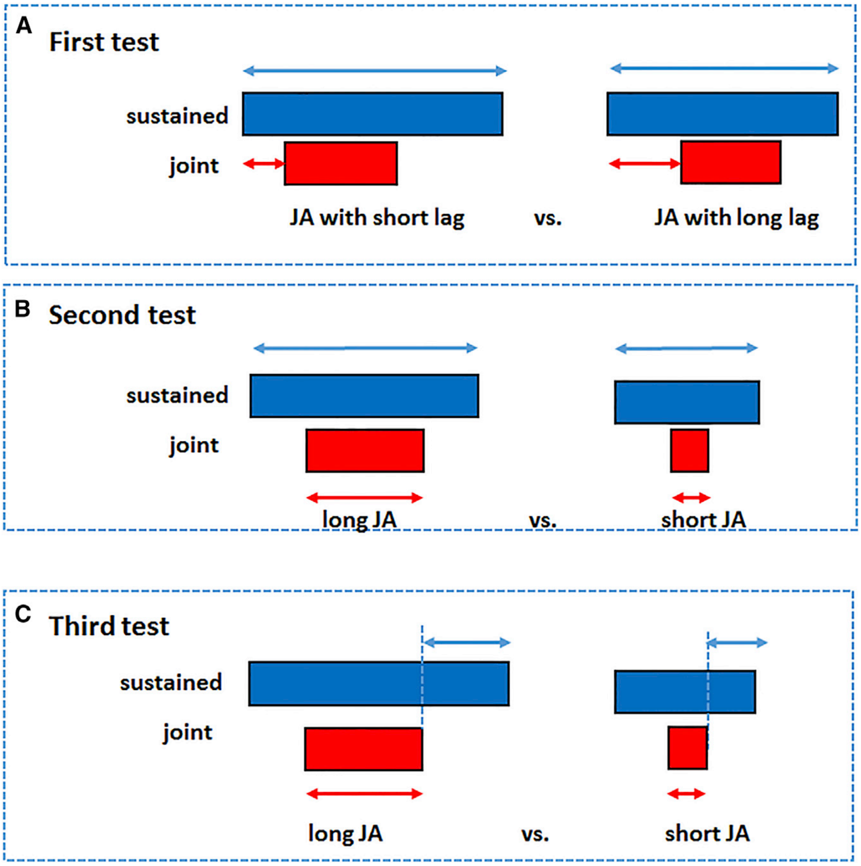


**Figure 4. Overview of Data Analysis to Test Three Hypotheses**

In all three cases, SA instances are divided into two groups based on the accompanying JA instances (red arrows), and SA durations (blue arrows) in the two groups are compared.

(A) SA instances are divided into SA instances with short-lag JA and those with long-lag JA. SA durations in the two groups show no significant difference.

(B) SA instances are divided based on JA duration, and the results show that longer JA is associated with longer overall SA.

(C) SA instances are divided again into long-JA and short-JA cases, as in (B). Infant SA to the target after JA ended is longer for longer-JA periods than for shorter ones.

sustained attention. However, day-in and day-out interactions with mature social partners that stretch the duration of the child's concentration on an object may, over time, strengthen the internal networks responsible for the self-regulation of attention. By analogy, just as a parent may hold onto and balance a two-wheel bike for a young rider, letting go so that the young rider experiences (at first, a product of the body's inertia) balancing a bike on their own, so may sustained joint attention help infants' attentional systems experience and then discover the means to concentrate on their own. One key open question is the parent behaviors that support this sustained attention and its extension in time. Here we measured parent looking to the attended object, but previous work [26, 31] shows that looking is associated with multiple other behaviors, including handling of the object and talking about the object, and these behaviors could play an important contributory role.

The role of the mature partner in these interactions is to be responsive to the infant's visual attention. Parental responsiveness is a construct that emerged in the study of infant temperament [32, 33] and refers to the degree to which parents respond contingently and appropriately to their child's emotional, social, and cognitive needs. Usually measured at a global level and conceptualized as a stable characteristic of a dyad's interaction, parental responsiveness measured when the child is either an infant or toddler has been shown to be predictive of long-term developmental outcomes [34]. Responsiveness may also be conceptualized as real-time behavioral adjustments by the parent that are made in seconds and fractions of seconds [34, 35]. The present findings may help unify these two senses of responsiveness and provide a mechanistic pathway through which long-term predictions from the quality of early interactions play out. In brief, parents who are more "tuned" to their children's momentary interests, and who are "responsive," may coordinate their visual attention with that of the infant and thereby entrain and train the child's self-regulation of attention, setting up a cascade of "down-the-road" effects. The present results determined from free-flowing interactions are at their core correlational and thus require experimental tests for confirmation, for example, studies in which parents either are instructed to follow infants' attention all the time (and thus be responsive) or are cued to only sometimes attend to the object of infants' attention.

Sustained attention and joint attention are two well-studied phenomena with important development consequences [1, 36]. To our knowledge, they have never been jointly studied, primarily because sustained attention is conceptualized as a characteristic of individuals and joint attention as a social phenomenon among partners. The present findings thus also suggest that the pathway through which joint attention is positively associated with language learning and other outcomes may need to be reconsidered. Currently, shared social attention is considered a marker of the infant's ability to build mental models and make inferences about the mental states of social partners [15]. However, socially shared attention with a partner may not be solely a marker of more mature social understanding but may more directly affect learning by entraining and stabilizing the infant's attention on the object of interest.

In conclusion, the self-regulation of attention may have social origins, because human development occurs in a social environment in which invested parents are part of evolutionarily expected experiences. Infants' socially shared attention with a mature partner has real-time consequences on infant sustained visual attention to an object and may have a very long reach into developmental outcomes beyond social interactions, in non-social and core cognitive skills such as the self-control of attention.

## SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures and one movie and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2016.03.026.

## AUTHOR CONTRIBUTIONS

C.Y. and L.B.S. designed the experiment, collected and analyzed the data, interpreted the results, and wrote the manuscript.

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## Supplemental Information

# The Social Origins of Sustained Attention in One-Year-Old Human Infants

**Chen Yu and Linda B. Smith**

**Supplemental Experimental Procedures**

**Participants.** The final sample consisted of 36 (19 male infants) parent-infant dyads with the infants ranging in age from 11 to 13 months (mean = 12.52, SD= 1.15); 10 additional dyads began the study but the infants refused to wear the measuring equipment throughout the entire procedure. The sample of infants was broadly representative of Monroe County, Indiana: 84 % European American, 5% African American, 5% Asian American, 2% Latino, 4% Other) consisting of predominantly working- and middle-class families.

**Stimuli.** There were 6 unique novel "toys" constructed in the laboratory and pilot-tested to be interesting and engaging to infants. Each novel toy was a complex object made from multiple and often moveable parts and were of similar size, on average, 288 $cm^3$. These were organized into two sets of three so that each object in the set had a unique uniform color.

**Experimental setup.** As shown in Figure 1, parents and infants sat across from each other at a small table (61cm × 91cm × 64cm). Parents sat on the floor such that their eyes and heads were at approximately the same distance from the tabletop as those of the infants, a posture that parents reported to be natural and comfortable. Both participants wore head-mounted eye trackers (positive science, LLC http://www.positivescience.com/). The positive science eye-tracker was designed for use with infants and was designed to be attached to head so as to be stable on the head (even in self-locomoting infants and infants, see [S2, S3]. The tracking system has been widely and successfully used in both infant and adult research [S1, S4-S8]. Both parent and infant eye-tracking systems include an infrared camera – mounted on the head and pointed to the right eye of the participant – that records eye images, and a scene camera that captures the events from the participant's perspective. The scene camera's visual field is 108 degrees, providing a broad view to approximate the full visual field [S9]. Each eye tracking system recorded both the egocentric-view video and eye-in-head position (x and y) in the captured scene at a sampling rate of 30 Hz.

In addition to head-mounted eye tracking, three additional video cameras were used to record the interaction from three different viewpoints that was independent of participants' movements: a bird's-eye camera mounted on the top of the interaction tabletop, a camera pointing to the infant, and a camera pointing to the parent. In total, 7 video streams were recorded in a geovision video capture card (Model 1480B) which automatically synchronized multiple video streams. Synchronization was verified by using a standard camera flash procedure. An experimenter triggered a camera flash both at the beginning and end of each interaction which was captured in one frame in all cameras. Before data processing, coders compared the frame numbers across all the video streams to confirm synchronization. The flash-marked frames were used for resynchronization, if necessary.

**Placing the head gear and eye tracker calibration**. Prior to entering the testing room, in the waiting area, the first experimenter desensitized the infant to touches to the head and hair by lightly touching the hair several times when the attention and interest of the infant was directed to a toy. Both the parent and the infant entered the experimental room, and a second experimenter and the parent engaged the infant with an enticing toy with buttons to push that make animals pop up. The infant's head gear was placed while the infant was engaged with the toy. This was done in one movement and care was taken by the experimenter to ensure that the infant remained engaged with the toy and that the infant's hands didn't go to the head gear. The first experimenter then adjusted the scene camera to ensure that the button being pushed by the infant was in the center of the scene camera. We have used this procedure in multiple head-camera and head-mounted eye-tracking experiments [S10-S14] with an overall 70% success rate.

**Instructions and procedure.** Parents were told that the goal of the experiment was to study how parents and infants interacted with objects during play and therefore they were asked to engage their infants with the toys and to do so as naturally as possible. Each of the two sets of toys was played with twice for 1.5 min, resulting in 6 minutes of play data from each dyad. Order of sets (ABAB or BABA) was counterbalanced across dyads.

**Data processing.** During post-processing and before coding, the quality of the eye tracking video (with eye images superimposed) for each infant and parent was checked to ensure the quality of calibration at the end as well as the beginning of the session. Re-calibration would be conducted if necessary. ROI coding was done by human coders. These coders were highly trained and code these variables for many different experiments and projects. They were naïve to the specific hypotheses or experimental questions of this study. The four regions-of-interest (ROIs) were defined in the head-camera videos: the three toy objects and the partner's face. To determine gaze that fell within these ROIs, coders watched the first-person view video with a cross-hair indicating gaze direction, frame-by-frame, and annotated when the cross-hair fell on a pixel identified as any part of the four ROIs. Because the experimental room is white and all participants wore white clothing that covers all but faces and hands, and because the three toys in play were three different primary colors that are different from skin tones, it was straightforward for coders to identify the three object and face regions in view. In addition, using the eye tracking software, we rendered eye images via picture-in-picture superimposed at the upper-right corner of a scene frame (see Figure 1), which allowed coders to constantly use them as a reference to verify reliability of cross-hair indicating gaze direction in view. If coders detected from an eye image that the eye tracking software failed to detect the pupil correctly due to image quality or eye blinks, coders disregarded that frame for any ROIs because the cross-hair was incorrect. Thus, we measured infants' and parents' visual attention in terms of gaze directed at any of the three objects or the partner's face. In implementation, coders went through each video four times wherein one of the four ROIs was focused in each round and they needed to make a yes/no decision (whether the cross-hair was on the ROI) based on the overlap of the cross-hair with the ROI. In previous studies with the same setup, we've also developed an image processing algorithm to automatically separate the three objects in play from each other and the background (see [S13 S14] for details). We've applied automatic object detection to this dataset and calculated object sizes in view. We found that on average, each object took 3.25% of the scene image in the infant's view and 1.82% in the parent's view. Thus, relatively large objects in view with the clean background made ROI coding highly reliable when compared with coding ROIs from more naturalistic and complex visual scenes. From gaze ROI coding, each dyad provided two gaze data streams containing the four ROIs as shown in Figures 1 and 2. A second coder independently coded a randomly selected 10% of the frames with the inter-coder reliability ranged from 82% to 95% (Cohen's kappa = 0.81).

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