Communication-induced memory biases in preverbal infants

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Human teaching, a highly specialized form of cooperative information transmission, depends not only on the presence of benevolent communicators in the environment, but also on the preparedness of the students to learn from communication when it is addressed to them. We tested whether 9-month-old human infants can distinguish between communicative and noncommunicative social contexts and whether they retain qualitatively different information about novel objects in these contexts. We found that in a communicative context, infants devoted their limited memory resources to encoding the identity of novel objects at the expense of encoding their location, which is preferentially retained in noncommunicative contexts. We propose that infants' sensitivity to, and interpretation of, the social cues distinguishing infant-directed communication events represent important mechanisms of social learning by which others can help determine what information even preverbal human observers retain in memory.

cognitive development | cultural transmission | social learning | visual short-term memory

Humans' facility for social learning enables us to obtain information from others that would otherwise be difficult, slow, or impossible to acquire solely on an individual basis (1–5). Much of this learning is accomplished through benevolent acts of information donation in which more experienced members of a community take an active role in passing on their knowledge through communication (2, 3, 6). Although transmitter competency, such as modification of behavior according to what the receiver does or does not know, is an important avenue of research (7–9) on its own, participation of a skilled information donor is not sufficient for successful information transmission. Here, we address the importance of receptivity to successful communication and ask whether even the youngest and least skilled of human learners, preverbal infants, are equipped to benefit from communication, such as teaching attempts, directed to them. Such a finding would add to the growing body of research on the evolution and development of social cognition suggesting that humans may be adapted to transfer information to, and receive information from, conspecifics.

Although we humans often share what we know through language, knowledge transfer in humans need not require linguistic communication, but may derive from more basic social cognitive abilities that enable us to understand or share intentions (1, 3, 5, 10, 11). We explore the hypothesis that early social learning mechanisms available before, and perhaps aiding in, the acquisition of language can enable even preverbal infants to benefit from communication when it is addressed to them. Specifically, we ask whether human preverbal infants are sensitive to the social cues that typically accompany infant-directed communicative interactions and whether the kind of information extracted by the infant in such communicative contexts differs from what is retained under noncommunicative but otherwise identical conditions.

We hypothesized that if human infants are sensitive to the signals that typically indicate communication addressed to them, they should be biased to perceive, attend to, or remember the referent of the communication in a particular way. This communicatively induced bias should be distinct from the way that infants' experience is shaped by superficially similar contexts where the social partner does not actively transmit information to (i.e., does not communicate with) the recipient.

To test this hypothesis, we capitalized on documented phenomena in the domain of object processing: dissociations between infants' use of action-relevant information (spatiotemporal features such as location or size) and recognition-relevant information (surface features specifying identity or kind), especially in representing hidden objects. Although infants below 1 year of age can bind action-relevant and recognition-relevant features after multiple familiarizations (12), this ability is fragile. Stimulus properties of the objects themselves (13), graspability (14), and specific linguistic labels (15) are all factors that can bias infants' object representations toward either action-relevant or recognition-relevant features.

Here, we asked whether social context alone could shape infants' representations of novel objects. Such a demonstration would assign a fundamental role for social contexts in determining how infants distribute their limited representational resources. If object representations are modulated by social context, we should find superior memory for object identity in certain social contexts and superior memory for object location in other contexts.

In accord with previous work, in which object representations were characterized in noncommunicative learning contexts, we predicted that the default bias for young infants would be to remember the location of an object rather than the surface features specifying object identity or kind (13, 15–18). In contrast, we reasoned that infants would be well positioned to benefit from a knowledgeable social partner's communication about an object (such as its valence, name, functional affordances, and other interesting nonobvious properties) if they are biased to remember surface features specifying the object's identity, even if it is at the expense of retaining the object's location. Location is normally a transient feature of objects, whereas the information conveyed in communication about an object should be bound to the features by which that object, or its kind, could later be recognized. Thus, we predicted that infants would be more likely to encode the surface features of an object than its location in a communicative context or to encode the surface features in a communicative than in a noncommunicative context.

We created social contexts that could be matched as closely as possible on nonsocial dimensions such as duration and object-directedness yet vary in the social dimension, with the condition of interest laden as richly as possible with cues that typify

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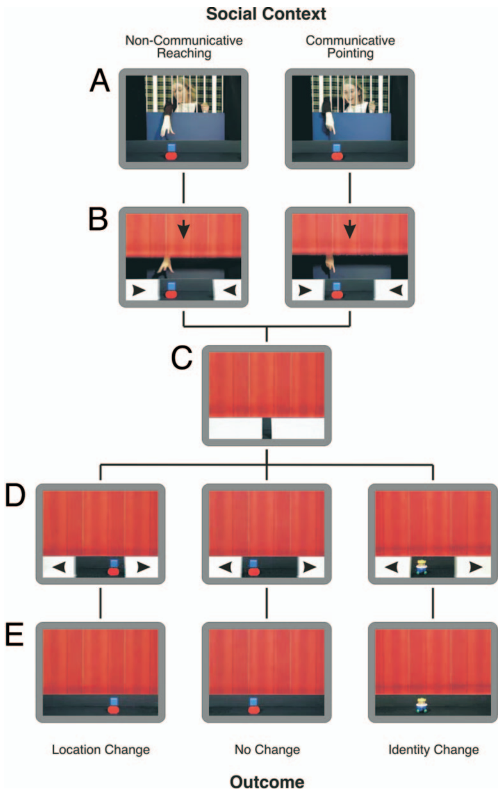

Fig. 1. Flow chart of stimuli in the test trials. Videos began with one of two object-directed actions (*A*). A red curtain then covered the actress, and two opaque sliding screens covered the two possible object locations (*B*) for a delay of 5 s (*C*). One of three outcomes followed, including a change in location but not identity, no change in either location or identity, or a change in identity but not location (*D* and *E*).

naturalistic, everyday infant-directed communication, including infant-directed speech and gestures. We therefore set out to contrast an object- and infant-directed communicative gesture such as pointing with an action like reaching. Reaching, like pointing, is object-directed and could be matched to pointing on low-level dimensions unrelated to our hypothesis while naturalistically portrayed as lacking in communicative intent.

Although reaching and pointing are actions that are familiar to, and frequently observed by, infants, previous findings suggest that infants' interpretations of the two actions are deeply different and that these differences are rooted in sociocommunicative function. In a habituation paradigm with ample time to encode all aspects of the scene, 9-month-olds have been shown to have different expectations about which objects actors should reach to and grasp, versus point to, next (19, 20). Informational properties of these actions also differ across social species, with dogs, but neither wolves nor apes, adaptively using human referential communicative signals, like pointing, in cooperative situations (21–23, but see also 24).

To determine whether the social signals that typically indicate human communication could bias infants to perceive, attend to, or remember the referent of a communication differently from what they would in a similar, but noncommunicative context, we showed 24 9-month-old infants a series of prerecorded videos. Each video contained an object-directed action (reaching or pointing), a delay during which both the actress and the object were hidden from view by curtains and screens, and an outcome assessing infants' memory for the hidden object by revealing the same object or an object that differed in either location or identity (Fig. 1). Because each action was paired with each

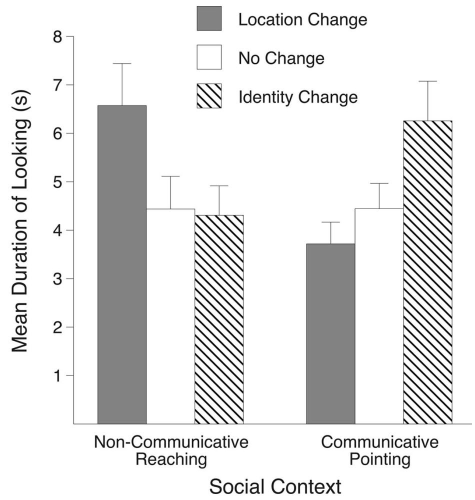

Fig. 2. Mean duration of looking with SE bars for each outcome grouped by social context.

outcome in a full factorial within-subject design, infants could not predict which type of change would occur or that a change would occur at all. It was therefore possible to measure whether infants' spontaneous representation of a novel object contained information about either location or identity, both location and identity, or neither. We assessed infants' representation of the object by measuring their looking time to the outcome in a violation of expectation paradigm. Because infants tend to look longer at events that violate their expectations (13, 20, 25–27), we could compare their looking times for outcomes containing an unexpected change with baseline outcomes containing no change at all. If infants look longer at the change outcome compared with the no-change baseline, they must have retained information about that feature in memory. Similarly, if infants find one type of unexpected change more interesting or surprising than another, they will respond with increased attention and longer looking time to this outcome.

Results

Infants detected a change in an object's identity (but not location) when the object was shown in the context of a pointing action, and they detected a change in an object's location (but not identity) when the object was shown in the context of a reaching action. The looking times were compared in a 2 × 3 ANOVA with action (reaching or pointing) and outcome (location change, identity change, no change) as within-subject factors (Fig. 2). There were no main effects of either action or outcome. Infants therefore did not find objects viewed in the context of one action more or less interesting than objects viewed in the context of another, nor did they find one type of change more or less surprising overall than the other type of change. Instead, a significant interaction between action and outcome consistent with our predictions: $F(2,46) = 16.155$, $P < 0.001$ [corrected significance levels are reported by using the Huynh–Feldt procedure to adjust degrees of freedom when necessary], $\eta_p^2 = 0.413$. Separate three-level one-way repeated-measures ANOVAs were computed for each action followed up by paired comparisons by parametric (Student's *t*) and nonparametric (Wilcoxon rank-sum) tests to assess the effect of each outcome on the looking times.

In reaching context trials, infants selectively retained information about a novel object's location but not its identity. A one-way ANOVA confirmed a main effect of outcome type: $F(2,46) = 5.823$, $P = 0.009$, $\eta_p^2 = 0.202$. Looking time for the location change was significantly longer than for no-change

[$t(23) = 2.527$, $P = 0.019$; Wilcoxon's $Z = -2.371$, $P = 0.018$] and identity change [$t(23) = 2.758$, $P = 0.011$; Wilcoxon's $Z = -2.373$, $P = 0.018$] outcomes, whereas looking time for the no-change and identity change outcomes did not differ significantly [$t(23) = 0.250$, $P = 0.805$]. In pointing context trials, infants instead remembered the object's identity but not its location. A one-way ANOVA confirmed a main effect of outcome: $F(2,46) = 7.276$, $P = 0.002$, $\eta_p^2 = 0.240$. Looking time for the identity change was significantly longer than for no-change [$t(23) = 2.683$, $P = 0.013$; Wilcoxon's $Z = -2.458$, $P = 0.014$] and location change [$t(23) = 3.311$, $P = 0.003$; Wilcoxon's $Z = -2.996$, $P = 0.003$] outcomes, whereas looking time for the no-change and location change outcomes did not differ significantly [$t(23) = 1.200$, $P = 0.242$].

A nonparametric McNemar test was also performed to verify whether looking time differences in individual infants reflected the patterns generated by the entire group. Fifteen infants displayed the predicted looking time relationship in both contexts (longer looking at location change than no-change after reaching and longer looking at identity change than no-change after pointing), 8 infants showed such an effect in one of the contexts, and 1 infant showed the opposite pattern in both contexts. This distribution is significantly different from chance (McNemar's $P = 0.0005$) [for additional findings, see supporting information (SI) *Results* and Fig. S1].

Discussion

Our results suggest that 9-month-old infants retain qualitatively different information about a novel object depending on whether their experience occurs in a communicative context or in a similar social context but without the specific cues associated with infant-directed communication. Infants detected a change in an object's identity (but not location) when the object was shown in the context of a pointing action with attendant signals indicating the actor's intent to communicate with the infant. They instead detected a change in an object's location (but not identity) when the object was shown in the context of a reaching action matched as closely as possible with the communicative context in parameters such as duration and distance of action termination from the object. The preverbal infants in our work were not only able to distinguish between the two contexts. The rich cues included in the communicative context biased them to remember qualitatively different information from what has been found to be the default mode of object encoding in infants (15, 18, 28) and our common primate ancestors when they themselves reach and search for them (13, 15, 17, 28). It was not just that they remembered more information in the communicative context, the effect was specific because they remembered different features of the object in the two contexts.

That the infants detected change in either location or identity but not in both may reflect a limitation of information processing (29) or of retention leading to selective "change blindness" (30). Nine-month-olds' visual representations of objects appear to become quite sparse after a brief delay, which places important constraints on developmental accounts of object cognition. The consequence of this limitation, however, is neither random loss of information nor selective preservation of only one type of information. Rather, infants' memory appears to be biased to retain the kind of information that is most relevant in the given context. For incomplete goal-directed actions like reaching, the location of goal-objects can be thought of as more relevant than their identity because the goal-directed reaches infants typically observe are often part of a larger plan intended to culminate in some action on the object by the actor herself (i.e., grasping, throwing, eating, etc.). It may thus be profitably retained to help the infant to predict what will happen next (27). In contrast, for a communicative pointing gesture, the identity of the object-referent is more relevant than its location because the content of the communication must be anchored to those features that allow future recognition of the object and proper generalization to like kinds (2, 31). That context-irrelevant changes produced looking times indistinguishable from the no-change outcome supports the interpretation that relevance-specific encoding may result from limited representational resources.

Dissociable memory for location and identity also suggests that infant object processing may involve a lack of integration between dorsal and ventral visual processing streams (12, 13, 28, 32, 33), the functionally and structurally distinct neural systems thought to subserve "where" versus "what" (34) or "perception for action" versus "perception for recognition" (35) in human adults and non-human animals. Our results may be explained by a perceptual bias in which observed actions serve to prime or activate preferentially either the dorsal or ventral visual processing streams, just as executed or planned actions are thought to (36–38). This priming may even persist into adulthood (39).

The social contexts in which the objects appeared in our experiment were different in many ways. We created videos that differed in terms of what communicative cues were presented, whereas we matched low-level aspects of the events such as duration of object exposure, number of utterances, and distance from the object that the observed action terminated. Besides the object-directed gesture of pointing, the communicative context that we presented to the infants also included multiple opportunities for direct eye contact (the actor looked into the camera several times), infant-directed speech with greeting content ("Hi baby!") and an evaluative comment ("Wow!"). Communicative context vocalizations, in contrast to the vocalizations in the noncommunicative context, were provided concurrently with direct gaze toward the viewer and infant-directed speech prosody. Our results do not allow us to tell which of these communicative cues triggered the shift of object representation from encoding locations toward encoding surface features or whether the cues influenced processing directly or more indirectly by modulating infants' eye movements or attentional focus, consequently resulting in differential memory biases. Any or all of these cues might have contributed to the effect, and the nature of each cue's specific contribution will have to be assessed in further studies.

Another important question is the generalizability of the current results to live social interactions or to interactions with non-human interactants. Although we refer to the presence of communicative cues typical of a social interaction between adult and infant, we decided to show infants video recordings of human actions to gain control over low-level perceptual factors (duration, distance from object, etc.) in the stimuli. Presenting the films on a large plasma screen certainly deprived infants of the subtle cues, like temporal contingency, that are characteristic for live interactions (40). However, our results do show that the cues present in the recorded action were causally sufficient for biasing the infant to encode a novel object in terms of its identity. Further research is need to clarify which of these cues are essential in facilitating this effect and whether the kind of agent (human or non-human) providing these cues is an important factor in triggering this bias.

Our results indicate that action contexts can have a profound effect on what information is retained about a novel object, even by preverbal infants. Object representation and action understanding are often discussed as separate domains in cognitive development. These results also suggest that action understanding during development is not solely a question of whether an action is construed as goal-directed or not (19, 20). We propose that infants are sensitive to cues indicating specific intentions and that our results show that even preverbal infants distinguish communicative–referential intent from other kinds of object-specific goals (20, 41). This ability may be subserved by an action interpretation system that is distinct from that underlying goal attribution and that fulfills unique social learning functions (2, 31).

When put into the context of previous research on goal-directed action understanding and object individuation, the present result refines our perspectives on infant object representation. In a well known paradigm of infants' interpretation of goal-directed actions, infants are habituated to an actor's hand repeatedly reaching for and grasping the same object in the same location in a display with two graspable objects. Then, the locations of the objects are switched, and the actor's hand grasps either a new object in the old location or the old object in a new location. Infants in this situation look longer when the hand grasps the new object, thus suggesting that they expected the actor to continue to reach for the same object and that they encoded its identity in the absence of communication (20). However, there are several differences between this paradigm and the current work. In the current work, the actor reaches for a new object on each trial, and the infant only views the actor reaching for a given object once. Moreover, infants see an actor reach for a different object each time she reaches, whereas in the Woodward study, infants see an actor reach repeatedly for the same object, ignoring a second object of a different identity. Therefore, in paradigms designed to assess infants' expectations about goal-directed actions, infants have the opportunity (number of trials) and information (repeated action that selects one particular object over another) to predict that the action they are seeing should be specific to an object of a particular identity. Taken with the goal-directed action encoding literature then, our data suggest that infants must view several, stable interactions between an actor and object to infer that the intention behind an actor's reach and grasp is directed to a specific goal object or that infants require multiple exposures to encode the identity of a novel reached-for object.

In another line of research, infants younger than 1 year of age appear to fail to individuate objects on the basis of their visual features, although verbal labeling of the objects helps them to overcome this limitation (16, 28). Our results suggest that an unambiguous communicative–referential context, established primarily through nonlinguistic means, can facilitate preverbal infants' encoding of objects in terms of their identity without requiring specific linguistic input or language-related concepts. Spatiotemporal or action-relevant encoding has been proposed to serve as a "default," or automatically privileged, processing mode (16, 17, 28), although the kind of objects occluded may also have an effect on infants' object representation (42). The present result suggests that communicative–referential contexts succeeded in switching object processing from this default mode, whereas the reaching contexts did not. Further studies could clarify whether communicative–referential contexts could also contribute to numerical individuation of objects.

This finding also highlights the importance of viewing the process of knowledge acquisition during development not solely as a matter of enrichment and change in distinct domains (43) but also as fundamentally influenced by social partners who can guide learning in many domains. Whether or not human conceptual organization is committed to an ontological divide between the world of people and the world of objects, the world of everyday experience is a jumbled mix of the two. Whereas the divided worldview of domain specificity directs us to study social cognitive mechanisms that serve the function of helping us learn *about* people, the guided worldview of social learning leads directly to the investigation of mechanisms that serve the function of allowing us to learn *from* people (44), a preparedness for learning from teaching (2, 31). Learning mechanisms that are important in the development of "theory of mind" and help us to understand how mental representations relate to behavior may not be required for acquiring social information through communication. Independently operating social learning mechanisms that are not rate-limited by theory of mind development could allow for the effective acquisition of information and guidance from others by automatically triggering implicit learning mechanisms (31). In this view, it could be that we learn from people by virtue of having foolproof mechanisms that ensure that we pay attention to those around us who are supplying communicative information rather than by relying on an individual learner's realization that people, as intentional agents with mental states, are useful sources of information (45). These mechanisms can impose specific and flexible constraints in learning. By focusing the learner's attention on just what is most relevant in a given learning situation, a knowledgeable social partner can help the learner sift the most relevant information from the ever-shifting clutter of details that would otherwise be left to obstruct the course of knowledge acquisition. Thus, with just a limited set of initial biases and constraints, those that will enable the learner to benefit from social learning, even preverbal infants can start to acquire knowledge rapidly and efficiently in a wide variety of domains.

This conclusion implies that the social environment, and especially the infant-directed interactions provided by people, can strongly influence what infants learn from a situation. Human infants are known to seek and exploit social information about novel entities and ambiguous or unexpected situations (46–49). Our results provide a specific demonstration of adults' potential to play an active role in shaping infants' experiences. Thus, human infants seem prepared to profit from the intentional communicative transmission of information by other humans, an aptitude that may underlie their ability to learn from even more sophisticated teaching experiences later in life.

Methods

Participants. Twenty-four full-term 9-month-old infants participated in the study (mean age: 9 months, 0 days; range: 8 months, 19 days to 9 months, 14 days; 12 male and 12 female). Parents and infants were recruited through local advertising and referrals. An additional 31 infants were excluded from the analysis. Of these, 12 infants were excluded because of excessive fussiness preventing completion of the study ($n = 4$) or resulting in uncodable eye movement ($n = 1$), experimenter and equipment error ($n = 4$), or caretaker interference ($n = 3$). The other 19 infants were excluded based on design-specific criteria.

Ceiling. Infants who reached the 15-s maximum looking time for multiple trials, obscuring possible looking time differences between trials, were excluded ($n = 3$). This 15-s maximum is consistent with similar published procedure (13) and was designed to ensure that infants could proceed from trial to trial in a timely fashion and increase the likelihood that they would successfully attend to all six events, given the within-subject design.

Occlusion. Infants who looked off-screen during an occlusion event were excluded ($n = 14$) because full viewing of this event was necessary for observers to conclude that objects were not transformed in any way and therefore should retain their original identity and location. More infants missed occlusion events during only-reaching trials ($n = 7$) than during both reaching and pointing trials ($n = 6$) or only-pointing trials ($n = 1$). This suggests that infants were less likely to pay attention to occlusion events during reaching trials and may indicate overall differences in attentiveness to reaching trials. However, global differences in attentiveness between reaching and pointing conditions cannot explain the interaction obtained in the results because infants were less likely to remember one aspect of the object (identity) during reaching trials but more likely to remember another one (location).

Familiarization. Infants who saw only one familiarization trial and thus were familiarized to only one actress were excluded ($n = 2$).

Stimuli. Stimuli were presented as short videos on a computer screen. The test trials started with one of two object-directed actions toward a single object that occupied one of two possible locations (see Fig. 1*A*). In reaching trials, the actor looked at the object eagerly (vocalizing "What's that!") and then reached for it unsuccessfully ("Hmm!"). In pointing trials the actor greeted the viewer by making eye contact and vocalizing ("Hi baby!") and then pointed to the object approvingly ("Wow!"). Reaching and pointing actions were matched for several superficial characteristics that might produce action-

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unrelated differences in object representation. Actions were terminated at equivalent distances from the object, with bars included to provide a plausible reason for the reaching action to end at a distance from the object rather than in a grasp. The speed, timing, and duration of each action were matched, and each action was repeated twice. Two different actresses demonstrated each action with actress–action pairings and trial order counterbalanced across infants. The actions lasted for 14 s. Then a curtain came down in front of the actor while two opaque screens slid from the sides occluding the object (Fig. 1*B*). After a 5-s delay (Fig. 1*C*), the screens slid out uncovering a single object (Fig. 1*D*). This object was either the same object at the same place as during the action (no-change outcome), or the same object reappeared from behind the other screen (location change outcome), or a different toy occupied the location where the object had been during the action (identity change outcome) (see Fig. 1*E*). The last frame of the video, showing a single object, was frozen on the monitor until the trial terminated. The total duration of each video was 19 s.

Pretest familiarization trials exposed infants to each of the two actresses and to the action–occlusion–outcome structure of the subsequent trials. Familiarization action consisted only of the actress moving slowly back and forth behind the bars while directing her gaze either at the infant or at the object. The actress who gazed at the infant during familiarization performed pointing actions during the test, whereas the actress who gazed at the object performed reaching actions. Postocclusion outcomes during familiarization included no change in the object's location or identity. Familiarization videos lasted 6 s and were accompanied by an upbeat soundtrack.

Each trial featured a novel object, with objects counterbalanced by action and outcome type and side of appearance across infants. Actions were digitally combined with other video elements so that each action context was identical across all objects and outcomes. The objects were $\approx 6 \times 9$ cm in size ($3.4° \times 5.2°$ visual angle), and their two possible positions were 7 cm (9.7°) apart. The height of the occluding screen was 11 cm, and the gap between them during the delay was 6 cm (3.4°). The faces of the actresses were nearly life size (15×11 cm, $8.6° \times 6.3°$ visual angle). In between trials, small animations were used to attract the infants' attention to the stimulus display.

Procedure. Infants sat on a parent's lap facing the plasma screen from a 100-cm distance. The stimuli appeared on a 69- $\times$ 51-cm area of the monitor. The experimenter initiated trials when the infant visually fixated on the screen. Two familiarization trials preceded the test trials. Familiarization trials were followed by six test trials that represented all possible pairings of two action types and three outcomes. The order of test trials was counterbalanced across infants. Trials concluded when the infant looked off-screen for 2 consecutive s or when 15 s elapsed. A mixer combined the image of the infants' eye movements with the image that the infant was viewing into a single, synchronized digital video.

Coding. Looking times for each outcome were measured from the first video frame in which the two sliding screens started to move away to reveal the hidden object and terminated when the infant made his or her first look off-screen. We chose to measure duration of first looks rather than total looking times because when an infant looks away from the screen, he/she has no evidence of the continuing existence of the object (i.e., that it has not changed location or identity while it was not observed). Thus, measuring the duration of the first look before any looks away should be more sensitive to perceptual change and more interpretable as reflecting change blindness than total looking times. Nevertheless, we also report total looking times in *SI Results* and Fig. S1. The length of infants' first looks was coded off-line by an experimenter who covered the portion of the image that displayed the action films while scoring and was therefore blind to the trial type. A second coder analyzed eight (33%) randomly selected recordings. The intercoder correlation of looking times was 0.93.

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