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Infants infer potential social partners by observing the interactions of their parent with unknown others

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Infants are born into networks of individuals who are socially connected. How do infants begin learning which individuals are their own potential social partners? Using digitally edited videos, we showed 12-mo-old infants' social interactions between unknown individuals and their own parents. In studies 1 to 4, after their parent showed affiliation toward one puppet, infants expected that puppet to engage with them. In study 5, infants made the reverse inference; after a puppet engaged with them, the infants expected that puppet to respond to their parent. In each study, infants' inferences were specific to social interactions that involved their own parent as opposed to another infant's parent. Thus, infants combine observation of social interactions with knowledge of their preexisting relationship with their parent to discover which newly encountered individuals are potential social partners for themselves and their families.

social development | social cognition | relationships | cognitive development | social networks

Human infants are born into large cooperative social groups whose members depend on one another for their survival and collective well-being (1–3). Within the first year, infants have limited exposure to many of the members of this social world (4). How do they begin learning which individuals are potential social partners for themselves? Here, we test the hypothesis that infants combine inferences from observations of social interactions with prior knowledge of their preexisting close relationships. For example, imagine an infant is with her parent when a new person comes along. If her parent directs affiliative behavior toward this person, will the infant come to expect that this person is a potential partner of their own?

Many studies of infant cognitive development provide evidence that when infants observe social interactions between unknown individuals, they readily form expectations for those individuals' future social behaviors. For example, after seeing a previously unknown individual imitate (5, 6) or help (7, 8) a target, infants expect that individual to then approach the target. After learning that two individuals have the same food preference (9), clothing, group label (10–12), or language (13), infants and toddlers expect those individuals to be friendly toward one another and offer support. Similarly, after observing two individuals who both comfort or both are comforted by the same third character, toddlers expect those two individuals to engage with one another (14). In each of these studies, infants form expectations about new individuals based on brief third-party observations.

Infants seem to use similar inferences to identify potentially good social partners for themselves. Infants approach individuals who have imitated, deferred to, or helped other unknown individuals (8, 15, 16). Likewise, infants seem to identify individuals from the same group as the infant and their family as potential social partners. For example, infants more readily accept toys from people who speak in the native language and accent of their family (17) and from people who sing songs that the infants learned from their parents (18, 19). While infants take advantage of many converging sources of evidence, the social behavior of their own caregiver is likely to be an especially frequent, salient, and valid source of information for inferring which new individuals are potential social partners.

A distinct scholarly tradition in social development, founded on attachment theory, has characterized how an infant's early experiences with her own caregivers shapes her later expectations for social relationships (20, 21). Infants who have a secure attachment style expect a large, animated character to return to a crying small animated character, suggesting that infants have a generalizable schema for responsive caring relationships (22). Expectations for responsive caregiving that are established in infancy and childhood are correlated with people's expectations for relationships throughout their lifespan (22–24).

Yet neither of these lines of research can tell us what infants infer about a new person from her parent's behavior toward that person. In one experiment, conducted nearly 40 y ago, 10-mo-old infants with easy temperaments smiled more toward a

Significance

Despite decades of research on the development of social knowledge, few experiments have tested how infants learn about new individuals from the behavior of their caregivers. Here, we show that infants learn who is a potential social partner by observing their parents' interactions with previously unknown individuals.

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stranger after their mother communicated positive feelings about that stranger (25). However, this study did not compare infants' reactions to interactions involving their own parent versus those between two strangers.

Do infants make distinctive inferences from observed social interactions that involve their own caregivers? We tested this question using digitally edited videos showing 12-mo-old infants' own parent interacting with previously unfamiliar puppets. Studies 1 to 4 tested whether infants combine the known relationship between themselves and their parent together with their parent's social behavior toward unfamiliar puppets to infer which puppet is a potential social partner for themselves (Fig. 1A). For the parent's social behavior, we used imitation (26) because infants as young as 4 mo expect imitators to approach the target of their imitation, suggesting that infants understand imitation as an affiliative act (6). We used a yoked control design; each infant saw videos of their own parent and of another infant's parent, with each interacting with a different pair of puppets (see Fig. 2A). In study 1, we measured whether infants reached selectively for the puppet imitated by their parent. In studies 2 to 4, we measured whether infants inferred that the puppet imitated by their parent was the source of a voice that called to them by name. In study 5, we tested the reverse inference, as follows: do infants combine an unfamiliar individual's social behavior toward the infants themselves with knowledge of their relationship to their parent to infer that the individual is a potential social partner for their parent (Fig. 1B)? We measured whether infants expected a puppet who engaged with them and called their name to respond selectively to the distress of their own parent (see Fig. 4A).

Therefore, across five experiments, we tested the hypothesis that infants combine inferences from brief observations of social

behavior with knowledge of their preexisting relationships with their caregivers to infer which specific individuals are potential social partners for themselves and for their parents.

Results

Study 1 (preregistered <https://osf.io/t5mhp>) was conducted in the laboratory. Infants from a Northeastern American urban environment ($n = 20$, aged 11 mo, 15 d to 12 mo, 15 d) watched one set of videos of their parent and one set of videos of another infant's parent with each interacting with two puppets. Using their computer's camera at home, parents filmed themselves looking left or right and making noises. These videos were digitally merged with videos of two puppets. In the final video, two puppets appeared to flank the parent. The parent looked left, then one of the puppets made a noise (e.g., "whoop whoop"), and then the parent looked forward and made either the same noise or a different noise as the puppet depending on counterbalancing. Then the parent looked right, the other puppet made a new noise, and the parent looked forward and either made the same noise as this second puppet or a different noise. Thus, the parents appeared to look at and respond to both puppets but only to imitate one of the two puppets. Each adult in the study was the parent to one infant and an unfamiliar adult to another infant; we used a yoked control design.

The two familiarization videos of a single adult imitating one puppet and not the other were presented, in alternation, on five successive familiarization trials. Then infants were given a visual preference trial; the two puppets appeared onscreen side by side, jiggling silently, while infants' looking time toward each puppet was measured. Preferential looking can indicate social preferences in infants (15, 17, 28), but it can also index

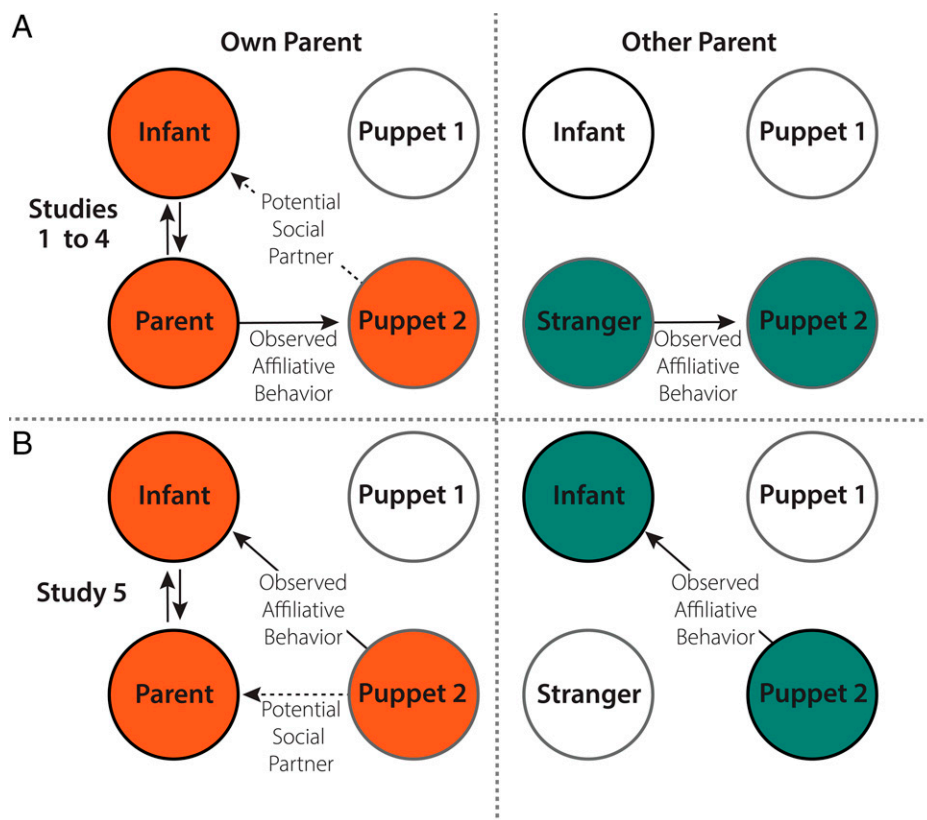


Fig. 1. Proposed inferences underlying the logic of studies 1 to 4 (A, Top) and study 5 (B, Bottom) in the own-parent condition (Left panels) and the other parent yoked control condition (Right panels).

wariness, fear, or curiosity (29). In the visual preference trial, infants looked equally at the two puppets both after seeing the puppets interacting with their own parent ($M = 0.467$, $SD = 0.168$, $BF_{01} = 3.00$) and in the yoked control condition ($M = 0.527$, $SD = 0.176$, $BF_{01} = 3.32$). Thus, infants were equally likely to look at the two puppets when they appeared on screen in silence.

The looking preference trial was followed by the critical reaching preference trial. Following the procedure of past studies of infant social evaluation (8, 15, 16, 30, 31), an experimenter who was unaware of the condition (imitation by mother vs. stranger) or of the particular puppet that the adult had imitated presented the real puppets to the infant, one in each hand, and asked, "Which one do you like?" We preregistered the prediction that infants would preferentially reach for the target of their own parent's imitation. Indeed, most infants (11/14) reached for the puppet that their parent had imitated. In contrast, consistent with past research (15), infants did not reach for the puppet imitated by another infant's parent (4/12 chose the puppet imitated by an unfamiliar adult; comparing parent and yoked control conditions, $BF_{10} = 10.95$; *SI Appendix* for more analyses).

What did the parent's imitation reveal about their relation to the puppet? It is possible that imitation revealed a preexisting affiliative relationship between the parent and the puppet or the successful creation of a new affiliative relationship between the parent and the puppet. In either case, we hypothesized that infants reached for the imitated puppet because they combined the newly revealed relationship between the parent and the puppet with the known close relationship between themselves and their parent to expect that the puppet whom their parent imitated was a potential social partner for themselves.

The present findings of infants' preferential reaching but not looking to the parent-imitated puppet accords both with the prior literature on infants' social preferences and with our preregistered predictions and hypotheses. Infants' equal looking at the imitated and nonimitated puppets suggests that they were equally interested in, or curious about, the two targets of the adults' social behavior (*SI Appendix* for a longer discussion). In contrast, their selective approach to and touching of the puppet imitated by their parent suggest a motive to affiliate with that puppet. However, fewer than two-thirds of the infants reached selectively for only one of the puppets—the other infants reached for neither or both puppets. For this reason, and because all subsequent studies were conducted by means of remote video conferencing during the COVID-19 pandemic, we used a different measure of infants' inference of a potential social partner in studies 2 to 4. We took advantage of infants' tendency to look toward a visual event that is the inferred source of an accompanying sound (32–35). After following the same procedure as in study 1, the reaching trial was replaced by a speaking trial; the two puppets from the previous interactions, side by side, moved their mouths in synchrony while a single voice, speaking with high and exaggerated pitch, addressed the infant by name (e.g., "Hi, Ashley! Hi!"). Infants recognize their own name by 4 mo of age (36, 37), and people who know one another's names are more likely to be social partners. We asked whether infants would infer that the voice calling to them by name came from the puppet imitated by their parent and therefore would look to that puppet in anticipation of future communicative behavior. We preregistered the prediction of longer looking to the parent-imitated puppet on this trial but not in the visual preference trial (*SI Appendix* for discussion).

In study 2 (preregistered: <https://osf.io/pbfzv>), infants ($n = 18$, aged 11 mo, 15 d to 12 mo, 15 d) looked toward the puppet

whom their own parent had imitated during the speaking trial ($M = 0.620$, $SD = 0.183$, $BF_{10} = 8.843$). This pattern selectively followed their own parent's social behavior; after seeing a different infant's parent imitate one of two puppets, infants did not look at the imitated puppet during the speaking trial ($M = 0.485$, $SD = 0.140$, $BF_{01} = 1.264$; difference between the own parent and other parent yoked control condition, $BF_{10} = 17.527$). Infants also did not look more toward the imitated puppet in the silent visual preference trial, either after watching their own parent ($M = 0.529$, $SD = 0.101$, $BF_{01} = 2.25$) or after watching the unfamiliar parent ($M = 0.484$, $SD = 0.133$, $BF_{01} = 3.70$; Fig. 2*B*).

We replicated the results from the own-parent condition in an independent group of infants in study 3 (preregistered: <https://osf.io/52bx4>, $n = 23$ infants, aged 11 mo, 15 d to 12 mo, 15 d). Upbeat infant-friendly music played in the visual preference trial to more closely match the positively valenced auditory input in the speaking trial. As in study 2, infants looked toward the puppet whom their own parent had imitated in the speaking trial ($M = 0.600$, $SD = 0.144$, $BF_{10} = 23.38$). In the visual preference trial of study 3, music played and both puppets danced by moving their bodies, and again, infants looked at the puppets equally ($M = 0.476$, $BF_{01} = 7.145$, comparing speaking and visual preference trials, $BF_{10} = 26.21$; Fig. 2; *SI Appendix* for a description and results of the yoked control condition in study 3). In summary, infants looked toward the puppet imitated by their parent when seeking the source of a voice calling to them (study 2 and 3), but not when watching the puppets jiggle silently (Studies 1 and 2) or dance to music (study 3).

Why did infants match the friendly voice with the imitated puppet in studies 2 and 3? We hypothesized that infants inferred that the puppet imitated by their parent was specifically a potential social partner for themselves. However, an alternative possibility is that infants inferred that the puppet imitated by their parent was more likely to be friendly or prosocial and thus would be more likely to socially engage with anyone. Study 4 was designed to disambiguate these possibilities. In study 4, the familiarization trials and experimental design were similar to study 2. In the own-name trial, two puppets appeared side by side, faced forward, and one voice addressed the infant by name. In the other-name trial, the two puppets faced to the left or right, appearing to attend to a person located offscreen, while the voice called the name of a different infant participant (see Fig. 3*A*). The audio was yoked across participants to ensure that the friendly prosody was matched across conditions. Therefore, in both trials, infants were tasked with finding the source of a friendly voice calling an infant's name, but only in the own name trial was this voice engaging with the infant herself by looking toward the infant and using her name.

In study 4 (preregistered: <https://osf.io/n8y9v/registrations>) infants ($n = 22$, aged 11 mo, 15 d to 13 mo, 15 d) looked longer at the puppet their parent imitated, in the own-name trial ($M = 0.596$, $SD = 0.1392$, $BF_{10} = 25.5$). In the other-name trial, infants did not look more at the puppet their parent imitated ($M = 0.425$, $SD = 0.120$, $BF_{01} = 13.0$, comparing own-name and other-name trials $BF_{10} = 391$). Again, infants made this inference selectively; after seeing a different infant's parent imitate one of two puppets, infants did not look at the imitated puppet in the own-name trial ($M = 0.43$, $SD = 0.197$, $BF_{01} = 11.96$; comparing own-name trials in the own-parent and other-parent yoked control condition, $BF_{10} = 101.64$) or the other-name trial ($M = 0.531$, $SD = 0.197$, $BF_{01} = 2.31$).

We also measured the infants' first look toward a puppet upon hearing a name. Infants looked first toward the puppet whom

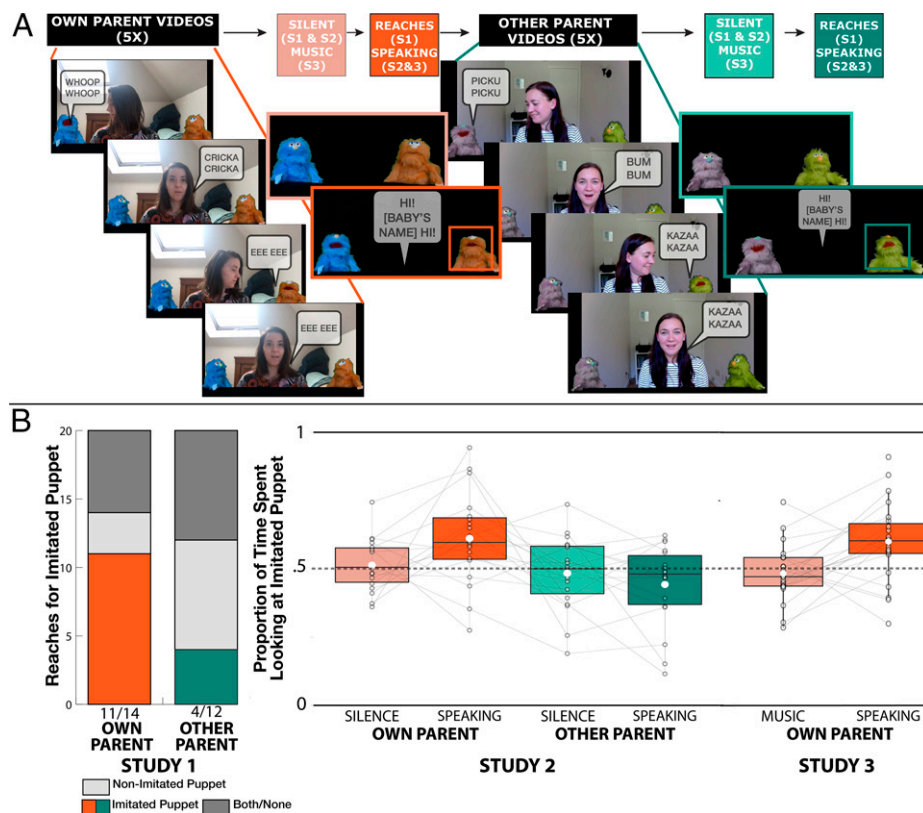


Fig. 2. (A) Events presented in studies 1 to 3. The order of the presentation of the videos (parent first or other parent yoked control condition first) was counterbalanced across infants, as was the puppet that was imitated and the pair of puppets that appeared with each adult. In study 2, the puppets appeared on screen in silence following the parent videos. In study 3, the puppets appeared with music in the background instead of in silence. In both studies 2 and 3, the puppets then appeared facing the infant and a voice spoke in a friendly manner using the infant's name. (B) Infants' reaching for the imitated puppet (study 1, stacked bars) and proportion of time looking at the imitated puppet (studies 2 and 3, box plots; white dots are means, black bars are medians; connected dots are a single infant's data; boxplots made with ggplot2 (27).

their parent had imitated upon hearing their own name (17/21 looked first toward the imitated puppet, $BF_{10} = 31.75$) but not upon hearing a different name (only 7/20 looked first at the imitated puppet, $BF_{01} = 8.24$). After the other parent imitated one puppet, infants were equally likely to look first toward either puppet upon hearing either their own name (10/21 looked at the imitated puppet; $BF_{01} = 3.16$) or another infant's name (11/21 looked first at the imitated puppet; $BF_{01} = 3.86$) (see Fig. 3B).

Altogether, studies 1 to 4 provide evidence that infants infer who is a potential social partner for themselves by observing their parents' social behavior toward two previously unknown individuals. After making this inference, infants were more likely to reach for that puppet (study 1), and they expected social engagement from that puppet (studies 2 to 4). These findings suggest that infants came to view that puppet as a potential member of their social world. The last experiment tested a prediction that follows from this suggestion.

In study 5 (preregistered: <https://osf.io/5qeuv>, $n = 29$, aged 11 mo, 15 d to 13 mo, 15 d), we tested whether infants who were given evidence that one of two unfamiliar puppets engaged socially with themselves would infer that that puppet was a more likely potential social partner for their own parent (Fig. 1B). During familiarization, one puppet, presented alone on screen, moved its mouth while a voice spoke in exaggerated pitch and called to the infant by name (e.g., "Hi, Ashley! Hi"). In alternating videos, the other puppet appeared alone, facing the infant, and danced to child-friendly music.

To measure whether infants inferred that the puppet who called to them was a potential social partner for their parent, we focused on a different aspect of social relations, as follows:

when a person is in distress, their close affiliates are expected to offer comfort (14, 38, 39). Human infants expect closely related individuals to respond to one another's distress (39), as do nonhuman primates (40). Accordingly, on the test trials, infants saw a digitally edited video in which the infant's parent (or the yoked control parent), flanked by both puppets, expressed distress and lowered their head into their hands, whereupon both puppets turned toward the adult. Infants' anticipatory looking toward the puppets was measured.

When infants saw their own parent expressing distress, they looked first toward the puppet that had called to them by name (23/29 first looks at the speaking puppet, $BF_{10} = 24.570$). Infants also looked longer at this puppet ($M = 0.780$, $SD = 0.254$, $BF_{10} > 1000$). When infants saw another infant's parent in distress, they did not look first toward the speaking puppet (11/29, $BF_{01} = 2.72$), and overall, infants looked less at the puppet that had called to them ($M = 0.311$, $SD = 0.312$, $BF_{10} = 9.887$) comparing own- and other-parent conditions ($BF_{10} > 1,000$; Fig. 4B).

Study 5 thus provides evidence that infants combine the observation of unfamiliar puppets' social behavior directed toward the infant with the previously known relationship between the infant and their own parent to infer which puppet was a potential social partner for their parent.

Discussion

Five studies provide evidence that 12-mo-old infants use knowledge of their existing relationship with their parent together with observations of social interactions to determine

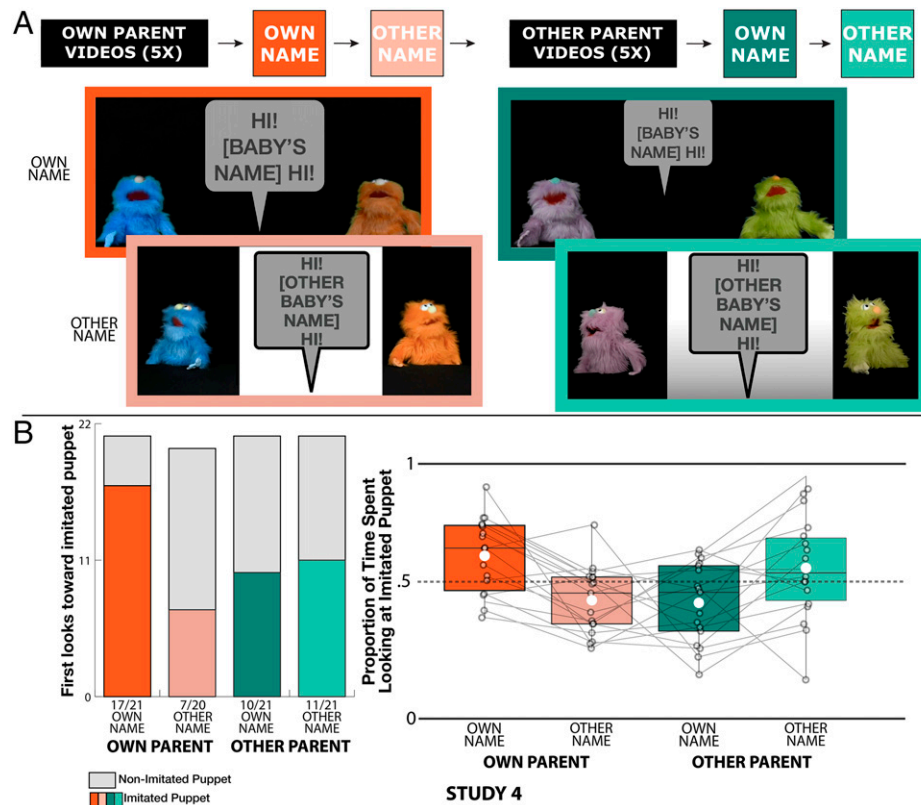


Fig. 3. (A) Speaking trials presented in study 4. These trials were presented after familiarization trials in which either the infant's own parent (own-parent condition) or another infant's parent (other-parent condition) imitated one of the puppets. Each infant saw five familiarizations, two speaking trials, then the 5 familiarizations in the other condition, and two speaking trials. The order of these two trials was counterbalanced across participants, as well as whether infants participated in the own-parent condition or the other-parent condition first. (B) Infants' first looks toward the imitated puppet (stacked bars) after hearing a name and proportion of time infants spent looking at the imitated puppet during the speaking trials (box plots; large white dots are means, black bars are medians; connected dots are a single infant's data; boxplots made with ggplot2 (27)).

which previously unfamiliar individuals are potential social partners for themselves or their parent. Infants reached preferentially for a puppet that was imitated by their parent (study 1). Infants also inferred that such a puppet was the source of an engaging voice calling to the infant by their own name (studies 2 to 4) but not a voice calling a different name while appearing to look offscreen (study 4). These inferences depended on the infant's relationship with their parent; infants did not reach for, or look toward, a puppet that was imitated by the unfamiliar parent of another infant (studies 1, 2, and 4). Finally, infants expected that a puppet that had called to the infant using their name was more likely to respond to the distress of their own parent (study 5).

A central assumption of the current experimental methods is that infants accept puppets as meaningful potential social partners. We used puppets because their simplified social repertoire allows for precise experimental control of the depicted interactions (14) and because puppets cannot induce social expectations based on gender, age, or ethnicity. The home environments of the infants in the current sample likely include many representational toys, including puppets and dolls. Prior research shows that toddlers from this population are willing and able to treat puppets as social partners and interactions with puppets as socially meaningful events (14, 30).

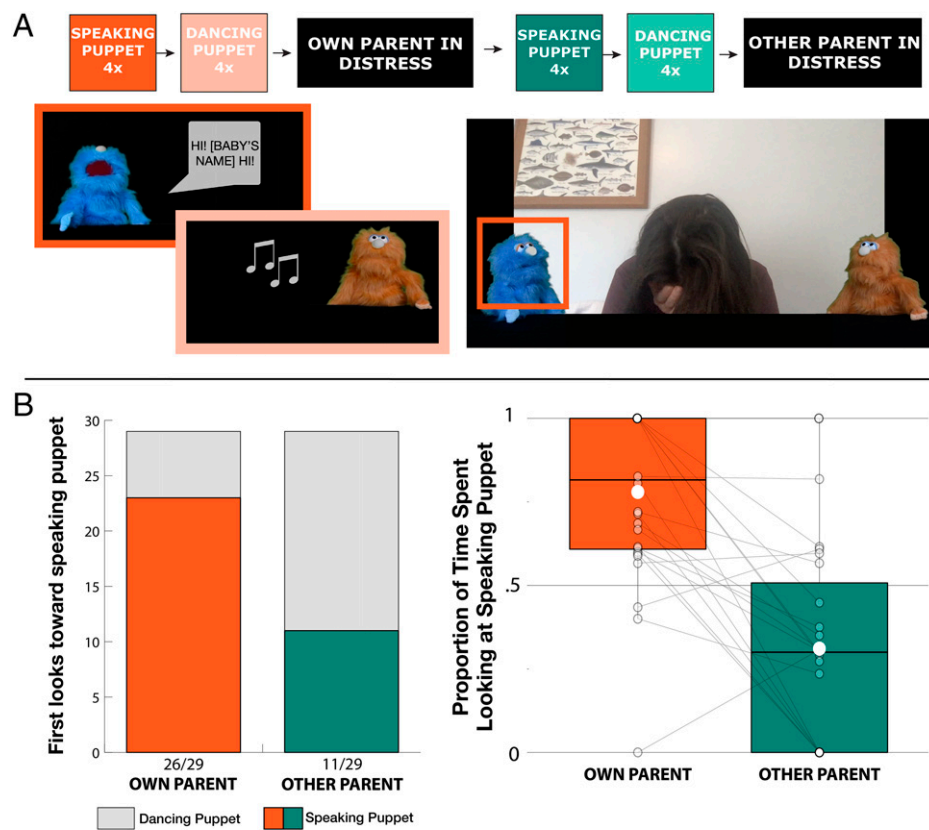
The yoked control design of these experiments and the pattern of results rule out a variety of alternative interpretations of the findings. The selectivity of infants' behavior indicates that the puppet who interacted with the infant or their parent was not simply more interesting to the infant since infants only looked at the imitated puppet during trials in which the

puppets socially engaged the infant. Infants' behavior cannot be explained by associations between positively valenced puppets and events nor by expectations that the target of their parent's imitation would be more generally friendly or prosocial because the infants did not look more toward the imitated puppet when it spoke in a friendly voice but turned away from the infant and spoke another infant's name. Thus, infants selectively inferred that the puppet whom their parent imitated was a potential social partner for themselves.

Identifying potential social partners contrasts with learning the names and functions of objects or the norms and conventions of a social group. Infants readily learn names, functions, and norms by observing the choices of adults with whom they have no preexisting relationship (41–45). The few studies that have directly compared learning from parents versus strangers have found that older children learn from knowledgeable or confident strangers as effectively as they learn from their parents (46, 47). Learning about one's own social relationships may be different because of the small-world structure of human social networks (48, 49); an individual who has an affiliative relationship with the infant's parent is more likely to be a social partner of the infant and vice versa.

In summary, five experiments provide evidence that infants combine observations of social interactions with knowledge of their own existing relationships to identify potential social partners for themselves and their family. These inferences guide infants' expectations for future interactions with previously unknown individuals.

The current results are consistent with the view that infants, like adults, represent their social world as a network of relationships, a



STUDY 5

Fig. 4. (A) Example events from one condition in study 5. All infants saw two puppets with their parent and two other puppets in the other-parent condition; the order of these two conditions was counterbalanced across infants. (B) Results of study 5. First looks toward speaking puppet after parent expresses distress (stacked bars); proportion of time spent looking at speaking puppet during pause after parent distresses (box plots; large white dots are means; black bars are medians; connected dots are a single infant's data).

core aspect of a naive sociology (50, 51). However, we did not directly test this hypothesis. It is possible that infants inferred a preexisting social connection between the parent and the imitated puppet and infants expected that an individual who was connected to the parent was more likely to be connected to the infant. Another possible interpretation is that infants inferred that the parent accepted one puppet's bid to form a new affiliative relationship and infants expected that an individual who had formed an affiliative relationship with their parent was more likely to engage with the infant. Thus, when we describe infants as inferring potential social partners in our studies, these inferences could reflect either the discovery of a preexisting social connection or expectation of future social engagement.

The present studies raise additional questions that future research could address. First, how early in development do infants make these inferences? Both the ability to recognize their own parents and to make inferences from observed social behaviors originate well before the age of 12 mo. Infants recognize their mother's voice at birth (52) and her face by 3 mo later (53). By at least 4 mo of age, infants predict that an imitator will approach the target of their imitation (6). Thus, two key aspects of these inferences are available very early in development, and yet combining the two may be substantially more cognitively challenging. An interesting possibility is that infants begin to use their caregiver's behavior to identify potential social partners toward the end of the first year, when infants show dramatic increases in many aspects of social engagement (54–57).

Second, how are these inferences influenced by the infant's relationship with the caregiver? The security of infants' attachment to their caregiver may influence how readily they use the

caregiver's behavior to infer potential social partners for themselves. Future studies could also investigate the breadth of preexisting relationships from which infants infer potential social partners. Infants might make these inferences only from their closest and strongest preexisting relationships, i.e., with primary caregivers. Infants as young as 8 mo do distinguish cooperative interactions that tend to occur in close relationships (39). Alternatively, infants may learn about potential social partners from observed social interactions of other family members, of familiar caregivers who are not family members, or even of individuals to whom they have just been newly introduced (58).

Third, how variable are these inferences across infants and social contexts? The social behaviors used in the present studies (i.e., imitation and infant-directed speech) are common and salient in the Western cultural context in which these participants live. Both cultural and individual differences could affect whether infants interpret imitation as evidence of an affiliative relationship (59). In some societies, adults are less likely to speak directly to infants and to use high and exaggerated pitch while doing so (60); and infants with less experience of infant-directed speech may be less likely to interpret it as evidence of social engagement (61, 62). Infants with more inhibited temperaments may be generally less open to new potential social partners (63). Finally, infants in more isolated communities may rarely encounter previously unknown individuals and thus may have less experience using social cues to distinguish potential social partners. Thus, future research could explore the determinants and consequences of variability in the inferences described here.

The present studies merge two long-standing traditions in developmental psychology. Scholars of infants' social development

have long argued that infants' relationships with their caregivers are the foundation of lifelong expectations for responsiveness in relationships (64); (23, 65), but this tradition has not directly investigated infants' inferences from their caregiver's behavior toward previously unknown individuals. In contrast, many experiments in the field of cognitive development have asked how infants use observed social interactions between unknown individuals to predict the future behavior of those individuals (5, 8, 14), but this tradition has not yet studied infants' selective learning from their own caregivers. By combining the strengths of both traditions, we find that infants infer which individuals are potential social partners for themselves and their parent, which is a skill essential for navigating the larger social landscape and developing new social and emotional relationships.

Materials and Methods

All studies were approved by the Harvard institutional review board office under protocol IRB18-0986. Parents provided informed consent before the study.

Study 1.

Participants and exclusions. Participants were 20 full-term infants ($M = 369.3$ d; $SD = 9.53$ d). When asked about their child's gender/sex, 12 parents said male and 8 parents said female. Infants were recruited from the greater Boston area. Data collection was cut short due to the COVID-19 pandemic, which halted in-person laboratory testing.

In this and all subsequent experiments, decisions concerning participant exclusions were determined before any measures were coded. Participants were excluded from the analysis based on a set of preregistered criteria including fussiness, parental interference, inattention, and technical failure. Infants were excluded from the reaching analysis if they failed to choose a puppet or if they chose both puppets at the same time (details can be found in the preregistration at <https://osf.io/t5mhp>, note the original preregistration was removed because of potentially identifiable information in it; this information was removed and reposted). Six babies were excluded in the reaching analysis in the own-parent condition (4 chose neither puppet; 2 chose both puppets). Eight babies were excluded in the yoked control condition (6 chose neither puppet, 1 chose both puppets, and one test session was cut short because of fussiness). No infants were excluded for other reasons.

Materials. All the familiarization events and the visual preference trials appeared on films featuring 14" monster puppets, purchased from <https://www.thepuppetstore.com/>. Prior to coming into the laboratory, parents were sent instructions on how to make videos at home using their webcams on their computers. The instructions can be found on the OSF page at <https://osf.io/z8r7t/>. The previously filmed videos of the puppets were then cropped into the parent videos, so it appeared as though the parents were interacting with the puppets. An example video can be found on the OSF page at <https://osf.io/z8r7t/>. These same puppets were used in the visual preference trial and the reaching trial.

Displays. In each video, one puppet was imitated by the adult in the video and the other was not. First, one puppet vocalized (e.g., whoop, whoop). Next, the adult looked forward and responded by making the same or a different sound (e.g., "cricka cricka"). Lastly, the other puppet vocalized, and the adult looked forward and made a final sound that differed from the previous sound the adult had made, either matching the second puppet's sound or not depending on counterbalancing. Thus, one of the two sounds made by each adult matched the sound made by one of the puppets.

Design. Each infant saw one set of videos featuring their own parent and another set of yoked control videos featuring another parent interacting with a different set of puppets making a different set of vocalizations. When possible, the parent featured in the yoked control condition was matched to the child's participating parent on gender and ethnicity, based on the judgment of a research assistant who was assigned to compile the presentations. Infants saw each familiarization video repeated five times. After each set of familiarization videos, infants saw the visual preference trial and then participated in the reaching trial for that pair of puppets. We counterbalanced the order of the conditions in which the infant saw their parent and the other parent, the sets of puppets that each parent interacted with, and the particular member from each set that

the parent imitated. Each condition (own parent and other parent) included five familiarization trials followed by one visual preference trial and one reaching trial.

Procedure. Before the study began, parents were briefed about the hypothesis of the study and consented to participate. Infants sat on their parent's lap in a room with a large projection screen. Parents were asked to close their eyes for the duration of the study. The familiarization trials came first; as described above, infants saw one video repeated five times, preceded by a star that rotated and made a noise to draw infants' attention. The visual preference trial came next; the two puppets from the preceding video appeared on opposite sides of the screen, without the human actor, for two 10-s intervals for a total of 20 s. The puppets appeared in consistent positions (left and right of center) during the familiarization trials, visual preference trial, and the reaching trial that concluded the condition.

During the reaching trial, an experimenter, who did not know the identity of the imitated puppet or the condition (own parent or yoked control), brought out the two puppets featured in the prior videos, held them in front of the screen, said, "Hi!" to get the attention of the infant and then said, "Look!" and brought the puppets together in front of the infant but out of reach until the infant looked at both puppets. Next, the experimenter moved the puppets toward the infant and said, "Which one do you like?" while presenting the two puppets to the infant ~12" apart from one another. If a baby did not make a choice within 10 s, the experimenter further prompted the baby by saying, "Which one do you like?" or "It's okay to choose one." They repeated one of these prompts every 10 s until the infant chose a puppet or the experimenter had given three prompts to the infant. If an infant had still not made a choice after the third prompt, the experimenter repeated the choice procedure up to three times (on average, infants received 2.7 of the 9 possible prompts; *SI Appendix*). If an infant reached for both puppets at the same time, the choice was coded as both and was not included in the analysis. If an infant failed to reach for either puppet after three attempts, the choice was coded as none. This procedure and these criteria for exclusion were preregistered. At the end of the study, parents were invited to ask questions and were given the opportunity to view the stimuli.

Coding, stopping rule, and analyses. Coders who were unaware of the identity of the imitator (own parent versus yoked control) coded which puppet the infant looked at in 0.10-s intervals in each visual preference trial. Looks were coded as left, right, or away from both puppets (which included the center of the screen). The dependent measure was the proportion of time that infants spent looking at the puppet whom their parent had imitated (time spent looking at imitated puppet/total time looking at one of the puppets).

Reaching preferences were coded at the time of the study and then recoded by a second experimenter who did not know the condition or the hypothesis of the study. When the two coders disagreed, the reaching preference that was coded by the person watching the videos was used as the final decision. We planned to stop data collection after collecting preference data from at least 16 participants per condition or obtaining a Bayes factor of 8 for the proportion of infants who chose the imitated puppet in the own parent condition. However, because of the outbreak of COVID-19, in-person data collection was halted prior to attaining either criterion. Accordingly, all analyses for study 1 reported in the main text and *SI Appendix* should be viewed as preliminary. The program JASP was used to analyze the data (66).

Study 2.

Participants and exclusions. Participants included 22 full-term infants ($M = 363.6$ d; $SD = 14.17$ d). Infants were recruited from the greater Boston area and from an online recruitment website (<https://childrenhelpingscience.com/>). When parents were asked about their child's gender/sex, 10 parents said female and 12 parents said male.

Participants were excluded based on a set of preregistered criteria, including fussiness, parental interference, inattention, and technical failure such as internet connectivity (details can be found in the preregistration at <https://osf.io/t5mhp>). These criteria were similar to those used in study 1, with the addition of technical failures that would specifically affect online studies. Data from four infants were excluded because of the following reasons: the parent told the experimenter that there was a significant lag in the audio relative to the video ($n = 2$), because the video quality was inadequate for coding ($n = 1$), or because there was an echo in the room where the video was being played ($n = 1$).

Materials. The same puppets were used in the videos as those used in study 1. The adults who participated in the videos were primary caregivers for the infant participants of study 2. The familiarization events were created using the same process as in study 1.

Displays. The displays were the same as in study 1, except there was an additional trial, namely, the speaking trial, in which both puppets moved their mouths simultaneously while one voice spoke in a friendly manner (high and exaggerated pitch) through the audio system of the parent's tablet or computer using the name or nickname by which the infant was most frequently addressed, as reported by the parent. This trial was custom-made for each infant and lasted roughly 14 s (the exact time differed for each child because of variations in the length of the infant's name). Each puppet appeared in a constant position (left or right) during the familiarization, the visual preference trial, and the speaking trial.

Design. The design was the same as in study 1, except the reaching trial was replaced with the speaking trial. As in study 1, each infant saw one set of videos featuring their own parent and another set of yoked control videos featuring another parent interacting with a different set of puppets making a different set of vocalizations. As in study 1, infants saw each familiarization video repeated five times. After each set of familiarization videos, infants saw the visual preference trial followed by the speaking trial for that pair of puppets. Between the two conditions (own parent and yoked control), there was a short filler video that featured an actress playing peek-a-boo and a person playing a drum. The order of presentation of the puppets (i.e., green/purple or blue/orange), the identity of the imitated puppet within that pair, and the order of presentation of the own parent and yoked control conditions were all counterbalanced.

Procedure. The study was conducted during the COVID-19 pandemic, over video chat. Before the session, parents were given information about the study and asked to place their child on their lap or in a highchair for the session. They were also asked to choose a room in their house free of distractions, including other children and pets if possible. During the beginning of the video chat call, before the testing session began, the experimenter asked parents to put the video chat in full-screen mode, turn their computer on do not disturb, and hide the videos of themselves and the experimenter. Therefore, the only display on the parent's screen was the keynote presentation that was shared from the experimenter's computer via screen sharing and a gray bar that said, "[name] is talking." The experimenter also asked parents to remain neutral during the experiment, refrain from having any reaction to the videos, and not redirect their child's attention to the screen. All parents were compliant.

At the end of the study, the experimenter briefed the parents about the hypothesis of the study, answered parents' questions, and asked parents about the video and sound quality during the experiment.

Coding, stopping rule, and analyses. Coders who were unaware of the condition (own parent versus yoked control) and unaware of the identity of the imitated puppet, coded which puppet the infant looked at in 0.10-s intervals for both the visual preference and speaking trials. The dependent measure was the proportion of time that infants spent looking at the puppet whom their parent had imitated relative to the total time looking at either of the puppets.

As specified in the preregistration, default priors were used. Bayesian, one sample, one-sided *t* tests were used to determine whether infants spent more time looking at the puppet whom the adult had imitated compared to the puppet whom the adult had not imitated for each condition. A Bayesian paired *t* test was used to directly compare the parent and yoked control conditions.

As per our preregistration, participant recruitment stopped when a Bayes factor of 8 was achieved for comparison across these conditions.

Study 3.

Participants and exclusions. Participants were 23 full-term infants ($M = 366.64$ d; $SD = 8.892$ d). When parents were asked about their child's gender/sex, 14 parents said male and 9 said female. Infants were recruited in the same way as in study 2.

Participants were excluded based on preregistered criteria that were the same as in study 2 (details can be found in the preregistration at <https://osf.io/t5mhp>). No infant's data were entirely excluded in this study. However, parts of four infants' data were excluded from the analysis, as follows: half of one infant's data were excluded because the parent reported that the internet connection was bad for that half of the experiment such that the audio and visual were not synched; half of one infant's data were excluded because their parent adjusted

the screen during the test portion of that condition; half of one infant's data were excluded because they were inattentive during the familiarization trials that preceded the preference trial, and half of one infant's data were excluded because the experimenter played the wrong stimuli during that portion of the experiment.

Materials. The materials used in study 3 were the same as those used in study 2 in the own-parent condition. The only difference was the visual preference trial; instead of jiggling silently, both puppets jiggled to an upbeat instrumental song. See <https://osf.io/z8r7t/> for stimuli.

Displays. The familiarization events were made using the same process as in the own-parent condition of studies 1 and 2. Infants also saw another condition in which a different set of puppets imitated another infant's parent; *SI Appendix* for more details. Infants then saw two trials. The first was the visual preference trial. In study 3, in the visual preference trial, both puppets appeared on screen and made small jiggling motions to music. Then infants saw the same speaking trial as in study 2, during which both puppets moved their mouths while a single voice addressed the infant in a friendly manner using the infant's own name or nickname as specified by the parent.

Design. The design in study 3 was similar to the design in study 2. As in study 2, each infant saw one set of videos featuring their own parent and another set of videos featuring another parent interacting with a different set of puppets making a different set of vocalizations. These videos were repeated five times and were followed by the visual preference trial, this time featuring music, and then the speaking trial. Like the yoked control condition of study 2, the unreported condition presented the parent of another infant in the study who engaged in imitative interactions with a second set of puppets. Thus, infants' exposure to people, puppets, and imitative events across studies 2 and 3 were equal. The nature of the imitative events and the findings from this condition are presented in *SI Appendix*. The order of presentation of the puppets (i.e., green/purple or blue/orange), the identity of the imitated puppet within that pair, and the order of presentation of the own parent and yoked control conditions were all counterbalanced.

Procedure. The procedure was the same as described for study 2.

Coding, stopping rule, and analyses. The coding procedure was the same as described for study 2. The only difference was the preregistered stopping rule; participant recruitment stopped after at least 16 infants or when a Bayes factor of 8 was achieved when comparing the visual preference and speaking trials in the own parent condition. One-tailed Bayesian *t* tests were preregistered. We mistakenly tested several infants outside of the intended age range; thus, we include an analysis of all tested infants in the *SI Appendix*, as well as the analysis and results for the other condition that infants saw in this study.

Study 4.

Participants and exclusions. Participants were 22 full-term infants ($M = 387$ d; $SD = 20.1$ d). When parents were asked about their child's gender/sex, 12 parents said male and 10 said female. Infants were recruited in the same way as in studies 2 and 3, except that we recruited infants up to age 13 mo 15 d because of age effects we found in study 2 (*SI Appendix*).

Participants were excluded based on preregistered criteria that were the same as in studies 2 and 3 (details can be found in the preregistration at <https://osf.io/z8r7t/>). No infant's data were entirely excluded in this study. However, portions of five infants' data were excluded from the analysis; half of one infant's data were excluded because the parent pointed at the screen during two of the test trials and a portion of three infant's data were excluded because they did not attend to at least 50% of the familiarization trials, and one trial was excluded for one infant because the infant never looked at the screen during the test trial.

Materials. The materials used in study 4 were similar to those used in studies 1 to 3. The key innovation in study 4 was the comparison of the own-name versus the other-name trial. The own-name trial was very similar to the speaking trial in study 2; both puppets moved their mouths while a single voice addressed the infant in a friendly manner using the infant's own name or nickname (specified by the parent). In the other-name trial, both puppets faced away from the infant and moved their mouths while a single voice called a different infant's name. The audio that was used in these two trials was yoked across infants (i.e., the same audio was used in the own-name trial for one infant and in the other-name trial for another infant) to control for friendliness of prosody across conditions. Before the experiment began, we checked to make sure that the infant did not know anyone personally with that name.

Displays. The familiarization events were made using the same process as in studies 1 to 3. As in studies 2 and 3, infants saw two trials after each set of familiarization videos. However, in study 4, they saw two speaking trials, namely, one other-name trial and one own-name trial. At the start of each trial, a spinning diamond at the center of the screen was used to attract infants' attention to the center, until the name in the trial was first spoken ("Hi, Ashley"). This allowed us to measure the infant's first looks upon hearing a name (see *Coding, stopping rule, and analysis* below).

Design. The design was the same as in study 2 except that the visual preference trial was replaced by an additional speaking trial. As in study 2, each infant saw one set of videos featuring their own parent and another set of yoked control videos featuring another parent interacting with a different set of puppets making a different set of vocalizations. These familiarization trials were repeated five times and were followed by the two speaking trials. The order of presentation of the puppets (i.e., green/purple or blue/orange), the identity of the imitated puppet within that pair, the order of presentation of the own parent and yoked control conditions, and the order of the speaking trials (other-name trial and own-name trial) were all counterbalanced.

Procedure. The procedure was the same as described in study 2.

Coding, stopping rule, and analyses. The coding procedure was the same as described for studies 2 and 3. The only difference was the preregistered stopping rule; participant recruitment stopped after at least 16 infants or when a Bayes factor of 8 was achieved when comparing the own-name trial and other name trial in the own-parent condition. One-tailed Bayesian t tests were preregistered. We report evidence for the alternative hypothesis BF_{10} , that infants spent more than half of the time looking at the imitated puppet or the null hypothesis BF_{01} that infants spent half or less than half of the time looking at the imitated puppet. We also preregistered a new measure in this study: which puppet the infants looked toward first upon hearing the spoken name during the test trials. We preregistered the hypothesis that infants would look first at the puppet their parent had imitated upon hearing their own name, but not upon hearing another name, and not at the imitated puppet in the yoked control condition upon hearing their own name.

Study 5.

Participants and exclusions. Participants were 29 full-term infants ($M = 383.86$ d; $SD = 16.9$ d). When parents were asked about their child's gender/sex, 16 parents said male and 13 said female. Infants were recruited the same way as in studies 2 to 4.

Exclusion criteria were the same as in studies 2 to 4, except that infants were also excluded if they did not look at either puppet after the pause in the test trial. One infant in the own parent condition and two infants in the yoked control condition were excluded from analysis for this reason. No other infants were excluded from the analysis.

Materials. The same puppets were used in study 5 as in studies 1 to 4. In study 5, parents were instructed to make a video that showed them expressing distress. Parents were instructed to say "oh no" and then lower their head to their hands and then down into their lap or onto a table. The instructions sent to parents for this study can be found at <https://osf.io/z8r7t/>. Again, puppets were cropped into the videos so it appeared as though the parents were with the puppets. An example video can be found at <https://osf.io/k3udb/>.

Displays. Each familiarization event in study 5 presented one puppet at a time onscreen. In one familiarization video, a puppet (e.g., green) talked in infant-directed speech and used the infants' names (e.g., "Hi Ashley, Hi!"). This video was custom-made for each infant and lasted ~14 s (the time was slightly different depending on the infant's name). In the other familiarization video, the

other puppet (e.g., purple) appeared on screen and was jiggled in time to the infant-friendly music that was used in study 3.

During the test trial, the parent (either the infant's own parent or another participant's parent) appeared onscreen alone. Next, two black boxes disappeared revealing the two puppets from the familiarization videos. There was a 2-s pause so that infants had time to notice the three characters on screen. Then the parent said "oh no" and put their head in their hands and then down toward their lap or a table. At the end of this action, the two puppets simultaneously turned toward the adult. This action was followed by a 6-s pause during which infants' looking at the puppets was recorded.

Design. The design was like the previous studies; each infant participated in both the own-parent condition with one set of puppets and the yoked control condition with another set of puppets. Infants were familiarized to one pair of puppets, followed by one test trial, and then familiarized to the other pair of puppets, followed by the other test trial. The familiarization videos were repeated four times in an ABBABAAB pattern with an attention-grabbing animation between each trial (a star rotated and made a noise). The order of presentation of the speaking and dancing puppets, the pair of puppets (i.e., green/purple or blue/orange) that was shown with the infant's parent, the identity of the speaking puppet within that pair, and the order of presentation of the own parent and yoked control conditions were all counterbalanced.

Procedure. The procedure was the same as described in studies 2 to 4 except for differences described in the Displays and Design sections above.

Coding, stopping rule, and analyses. A coder, who did not know which puppet was the speaking puppet, coded which puppet infants looked at first and for how long. They coded 1) which puppet the infant looked at first after the adult in the test video expressed distress and 2) how long the infants looked at each puppet during the 6-s pause that came after the parent expressed distress. Bayesian tests of proportion served to determine whether infants were more likely to look first at the puppet who previously had spoken to them. One-tailed t tests analyzed whether infants spent more time looking at that puppet during the pause at the end of the test trial. A Bayesian paired t test was used to compare the amount of time infants spent looking at the puppet who had spoken to them in the two conditions (parent versus yoked control). Default priors were used, and all tests were preregistered at <https://osf.io/5qebv>.

The preregistered stopping rule specified that we would test between 18 and 45 infants and that we would stop after obtaining a Bayes factor of at least 8 for either of the two different looking measures. This criterion was met for both the first look and the total looking time measures.

Data Availability. Anonymized looking time data data were deposited in the Open Science Framework (OSF) at https://osf.io/z8r7t/?view_only=921080948168470a89f788e8d0518849 (67).

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