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Do toddlers reason about other people's experiences of objects? A limit to early mental state reasoning

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ABSTRACT

Human social life requires an understanding of the mental states of one's social partners. Two people who look at the same objects often experience them differently, as a twinkling light or a planet, a 6 or a 9, and a random cat or Cleo, their pet. Indeed, a primary purpose of communication is to share distinctive experiences of objects or events. Here, we test whether toddlers (14–15 months) are sensitive to another agent's distinctive experiences of pictures when determining the goal underlying the agent's actions in a minimally social context. We conducted nine experiments. Across seven of these experiments ($n = 206$), toddlers viewed either videotaped or live events in which an actor, whose perspective differed from their own, reached (i) for pictures of human faces that were upright or inverted or (ii) for pictures that depicted a rabbit or a duck at different orientations. Then either the actor or the toddler moved to a new location that aligned their perspectives, and the actor alternately reached to each of the two pictures. By comparing toddlers' looking to the latter reaches, we tested whether their goal attributions accorded with the actor's experience of the pictured objects, with their own experience of the pictured objects, or with no consistency. In no experiment did toddlers encode the actor's goal in accord with his experiences of the pictures. In contrast, in a similar experiment that manipulated the visibility of a picture rather than the experience that it elicited, toddlers ($n = 32$) correctly expected the actor's action to depend on what was visible and occluded to him, rather than to themselves. In a verbal version of the tasks, older children ($n = 35$) correctly inferred the actor's goal in both cases. These findings provide further evidence for a dissociation between two kinds of mental state reasoning: When toddlers view an actor's object-directed action under minimally social conditions, they take account of the actor's visual access to the object but not the actor's distinctive experience of the object.

In making sense of others' actions, we take account of their perspectives on the world. For example, we know that our companion will not turn to look at an interesting but silent event that took place behind her back or recognize a person who is a friend of ours but a stranger to her. The notion that people experience the same things differently lies at the heart of human communication and pedagogy (Clark, 1996; Grice, 1969), but the origins of this ability are obscure, despite many decades of study (Flavell, Everett, Croft, & Flavell, 1981; Masangkay et al., 1974; Surtees, Butterfill, & Apperly, 2012; Surtees, Samson, & Apperly, 2016; Tomasello, 2018). Research has revealed that human infants, young children and nonhuman primates appreciate differences between their own and others' perceptual access to objects and events (Call & Tomasello, 2011; Hamlin, Ullman, Tenenbaum, Goodman, & Baker, 2013; Kovács, Téglás, & Endress, 2010; Krupenye, Kano, Hirata, Call, & Tomasello, 2016; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Onishi & Baillargeon, 2005; Phillips et al., 2020; Scott & Baillargeon, 2009; Southgate, 2020; Southgate, Senju, & Csibra, 2007; Woo & Spelke, 2023; Woo, Steckler, Le, & Hamlin, 2017). In contrast, no study has revealed whether minimally verbal children understand that they and others, with equal perceptual access to objects, may experience those objects differently, and that the goals of others' actions will depend on their experiences. We tested for this understanding in 14- to 15-month-old toddlers and in 4- to 5-year-old children.

We focused on situations in which toddlers and an adult actor viewed the same pictures from different directions and therefore at different orientations. Such situations have been extensively studied in older children and adults, providing evidence for automatic processing of the visibility of objects from others' perspectives, but more difficult,

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controlled processing of others' mental states when the same visible object is perceived differently (see Apperly & Butterfill, 2009, for review). Here we presented toddlers with an actor who reached for pictures of faces, because a face's orientation dramatically affects the experiences and behavior of human infants, young children, and nonhuman animals (Carey & Diamond, 1977; Chien, 2011; Csibra & Gergely, 2009; Diamond & Carey, 1986; Geest, Kemner, Verbaten, & Engeland, 2002; Parr, Dove, & Hopkins, 1998; Thompson, 1980; Wang & Takeuchi, 2017). From birth, humans distinguish upright from inverted faces and look longer at the former (Valenza, Simion, Cassia, & Umiltà, 1996). Later in the first year, infants can anticipate the future orientations of rotating pictures (Frick, Möhring, & Newcombe, 2014). Accordingly, we first asked how toddlers would interpret the actions that an actor directs to pictures of faces that are visible both to the toddlers and to the actor but are experienced differently, because the face that is upright to the actor is inverted to the child (and vice versa).

1. Reasoning about others' perceptual access vs. others' perceptual experiences

Imagine you are facing a friend across a restaurant table, with just one menu. Although both of you can see the menu, its text will not be legible to both of you at once: If it is flat on the table and the text is upright to you, the text will be inverted to your friend. Now imagine that you hold the menu upright with its text facing you and the restaurant logo facing your friend. Now the text is perceptually accessible to you alone. Your friend cannot read the menu in either of these cases, but for different reasons. In the second case, your friend cannot see the text that you see. In the first case, you both can see the text but you experience it differently: For you it is legible and for your friend it is not. The present paper focuses on the distinction between reasoning about others' perceptual access and others' perceptual experiences.

To infer an agent's perceptual access to an object, one can follow a line-of-sight calculation, considering the position of the agent, the position of the object, the direction that the agent is facing, and the presence of any barriers occluding the agent's view. This calculation yields a dichotomous judgment: The object either is or is not accessible to the agent. In contrast, inferring an agent's perceptual experience goes beyond a simple yes-or-no judgment. An agent could experience an object in numerous ways. A menu, for example, could be experienced as upright, inverted, perpendicular, or even as meaningless if one cannot read English. Thus, reasoning about others' perceptual experiences may be more difficult than reasoning about others' perceptual access. Research on both children and adults confirms this prediction.

Young children appear to appreciate that what others do and do not know can depend on what they have and have not seen. For example, 3- and 4-year-old children attribute knowledge of an object's color to a person who has seen the object and ignorance of the object's color to a person who has not seen that object (Pillow, 1989). Thus, young children understand that others' perceptual access can influence their knowledge.

By contrast, longstanding research reveals that 3-year-old children often prioritize their own perspectives in verbal tasks. In some studies, children claim that someone who views a scene from a different direction will experience the scene in the same way as the children themselves (Birch & Bloom, 2004; Flavell et al., 1981; Masangkay et al., 1974; Piaget & Inhelder, 1956). These findings parallel findings regarding young children's false-belief understanding: Young children claim that someone who was absent when an object moved to its current location will nevertheless search for that object at that location (Baron-Cohen, Leslie, & Frith, 1985; Wellman, Cross, & Watson, 2001). In these situations, young children appear to focus on their own beliefs and experiences, failing to infer the differing beliefs or experiences of others.

Although 4- and 5-year old children can accurately answer questions about an experimenter's experiences of a picture (e.g., whether a picture is upright to the experimenter when it is inverted to themselves; Birch & Bloom, 2004; Masangkay et al., 1974), even older children have difficulty reasoning about others' understanding of ambiguous objects that have multiple identities (e.g., an object that looks like a die but functions as an eraser; Apperly & Robinson, 1998, 2003). Moreover, although some research suggests that adults spontaneously represent others' experiences of the same visible objects (Ward, Ganis, & Bach, 2019), research by Apperly, by Low, and by their collaborators has provided a wealth of evidence that reasoning about others' distinctive experiences of objects is more effortful than is reasoning about others' distinctive perceptual access to those objects (Edwards & Low, 2017, 2019; Surtees et al., 2012, 2016): Whereas adults automatically encode what objects are visible to another agent, they do not automatically encode another agent's distinctive experience of an object that is visible to them both (e.g., a written numeral that is read as a 6 or a 9, depending on its orientation). Thus, both children and adults have difficulty reasoning about others' experiences when those experiences differ from their own.

2. A signature limit to mental state reasoning

The difficulties that children and adults face when reasoning about others' perceptual experiences have been taken to reflect a signature limit to the ease and automaticity of mental state reasoning (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Carey, 2009; Spelke, 2022). Carey (2009) and Spelke (2022) argue that early-emerging core knowledge is grounded in perception and operates automatically and unconsciously, with key signature limits, in diverse domains, including two domains that pertain to people and their mental states. The first of these domains concerns a core conception of people as agents who cause their own motions and act efficiently to achieve their goals, guided by what they can see and by what they know; and the second domain concerns a core conception of people as social beings who experience the world, engage with one another, and share their experiences in states of engagement. Spelke (2022) suggests that these two conceptions begin to come together at the end of the first year, when infants begin to use language in their interactions with others and to share attention to objects (Bruner, 1974; Tomasello, 2010).

These considerations raise questions concerning toddlers' understanding of the mental states guiding an actor who acts on one of two objects. Because automatic perceptual mechanisms can serve to compute the visibility or occlusion of an object from another person's perspective, toddlers (and, indeed, infants) should be able to determine the goal of an agent whose action depends on the visibility or occlusion of an object. In contrast, determining how another person experiences an object typically requires processes beyond the limits of any automatic system, because it depends not on what a person can see but on how they interpret what they see (see Quine, 1960). If infants' understanding of the mental states of people who act as agents and the mental states of people who engage with each other have begun to come together by the end of the first year, then 14- and 15-month-old toddlers might be sensitive to the distinctive experiences of an actor who sees the same objects that they see but experiences them differently.

To test this possibility, the present studies focused on a situation like those studied by Flavell and by Apperly and Butterfill, in which an actor's experience of an object depends on the orientation from which the object is viewed. If toddlers' mental state reasoning is limited to an understanding of the mental states that young children can represent and that adults compute automatically, then they may fail to take account of the actor's distinctive experiences of objects. If toddlers transcend this limit, then they may succeed at reasoning about the actor's distinctive experiences.

3. Infants' and toddlers implicit understanding of others' mental states

At first blush, the possibility that toddlers might succeed at effortful mental state reasoning tasks may seem unlikely, since older preschool children fail such tasks. It is possible, however, that toddlers may have an early-emerging, implicit understanding of others' experiences that young children struggle to draw on in verbal tasks. Research on the development of false-belief understanding supports this possibility, because toddlers and young children implicitly take account of other agents' beliefs that differ from their own in nonverbal tasks before they manifest this understanding in verbal tasks (Carruthers, 2013; Scott & Baillargeon, 2017). Studies measuring toddlers' patterns of looking at events—an exploratory, information-seeking behavior (Fantz, 1958; Gibson, 1988; Stahl & Kibbe, 2022)—provide evidence that they expect an agent's action to be guided by information that was accessible to the agent. In some of these studies, toddlers looked longer at events in which an agent failed to act in accord with what she had seen (Onishi & Baillargeon, 2005; Song & Baillargeon, 2008). In other studies, when an object moved in an agent's absence and the agent later returned, toddlers and young children looked toward the original location of the object, as though in anticipation that the agent's future action would be guided by her false belief that the object had not moved (Southgate et al., 2007; see also Clements & Perner, 1994). Based on these and related findings, Southgate (2020) has hypothesized that infants and toddlers have an altercentric bias: They focus on others' perspectives rather than their own.

Consistent with these findings, some studies suggest that infants and children are sensitive to other people's distinctive experiences of objects. In studies using nonverbal measures, including EEG, toddlers have demonstrated sensitivity to others' false beliefs about objects' identities and infer, for example, that an object that appears to be a toy duck functions as a brush (Buttelmann & Kovács, 2019; Buttelmann, Suhrke, & Buttelmann, 2015; Forgács et al., 2019; Forgács et al., 2020; Scott & Baillargeon, 2009; Scott, Richman, & Baillargeon, 2015). In studies using verbal tasks, 3-year-old children correctly judged that an experimenter, who viewed a blue object through a yellow-tinted screen, would experience the object as green, in contrast to the child's own perception of the object's color (Moll & Meltzoff, 2011; Moll, Meltzoff, Merzsch, & Tomasello, 2013). These findings suggest that toddlers and young children are sensitive to other actors' experiences of the objects upon which they act.

Nevertheless, there are at least two reasons to doubt the robustness of young children's implicit understanding of others' beliefs and experiences. First, there have been multiple failures to replicate evidence that toddlers implicitly represent others' distinctive beliefs in nonverbal tasks (Kampis, Kármán, Csibra, Southgate, & Hernik, 2021; Phillips et al., 2020; Poulin-Dubois et al., 2018). Second, even in tasks relying on nonverbal measures (e.g., anticipatory looking, helping behavior), young children do not consistently succeed when reasoning about others' beliefs about objects' identities (Buttelmann et al., 2015; Fizke, Butterfill, van de Loo, Reindl, & Rakoczy, 2017; Low, Drummond, Walmsley, & Wang, 2014; Low & Watts, 2013; Oktay-Gür, Schulz, & Rakoczy, 2018; B. Wang, Hadi, & Low, 2015). If there are early capacities to represent others' false beliefs, therefore, they are fragile. It therefore remains an open question, whether toddlers implicitly reason about the differing experiences of agents who act on objects that are visible both to the actor and to the child but that are experienced differently, because the child and the actor view the objects from different directions.

4. Overview of the present experiments

In eight experiments, we modified a classic experimental method pioneered by Woodward (1998). In these experiments, we probed toddlers' understanding of the goals of an actor who viewed two pictures from a direction that differed from their own during familiarization, and who selectively reached for or pointed to one member of the pair of pictures, based on its orientation (upright vs. inverted) or visibility (in front of vs. behind an occluder). Like classic studies of action understanding and mental state reasoning in infants and toddlers (Onishi & Baillargeon, 2005; Woodward, 1998; Woodward & Guajardo, 2002), we used looking time as a measure of toddlers' interest in, and expectations about, the agent's actions. In one further experiment, we presented 4- and 5-year-old children with the same displays and probed their explicit understanding of these actions by means of verbal questions.

The primary experiments investigated whether toddlers appreciate an actor's distinctive experience of pictures of faces that appear at different orientations to the actor and to the child. In five experiments (Experiments 1, 3, 4, 7, and 8), we familiarized the toddlers to events in which an actor (a male adult) reached for one member of a pair of pictures of human faces that differed in orientation: from the actor's perspective, one was upright and the other was inverted. In Experiments 1, 3, 7, and 8, the actor faced the toddler, such that the face that was upright from his perspective was inverted from the toddler's perspective. In Experiment 4, the actor sat on the side of the room and faced the room's center, such that the faces were upright and inverted to him, but both faces were oriented sideways to the toddler.

Whereas Experiments 1, 3, 4, 7, and 8 focused on toddlers' understanding of an actor's distinctive experiences of the pictures on which he acts, Experiment 2 focused on toddlers' understanding of an actor's distinctive perceptual access, or lack of access, to the pictures on which he acts. In Experiment 2, the actor again faced the toddler in familiarization, but the visibility of the pictures, rather than their orientations, was varied by positioning two occluders such that one picture was visible to the actor but occluded from the toddler's perspective, and the other picture was occluded from the actor but visible to the toddler. The actor pointed either to the picture that he could see or over the occluder to the picture that he could not see.

In Experiments 5 and 6, we tested whether toddlers appreciate others' distinctive experiences of the heads of two different animals, based on the orientation of a classic ambiguous picture eliciting alternating perceptions of the face of a duck or a rabbit before and after 90° degree rotations (Carpendale & Chandler, 1996; Gopnik & Rosati, 2001; Jastrow, 1899; Sobel, Capps, & Gopnik, 2005). During familiarization, the actor reached for the rabbit from his perspective (and the duck from the toddler's perspective) or the reverse.

Experiments 1–7 and 9 were conducted in children's homes, via videoconferencing. Experiment 8 was conducted in the lab and replicated the previous findings. In Experiment 9, we presented 4- and 5-year-old children with versions of the videotaped events used in Experiments 1 and 5, involving the actor reaching toward the same pictures of human faces and animals.

Across Experiments 1–9, based on the actor's actions in familiarization, the toddlers and children viewing these events could attribute a goal to the actor: to act on pictures that were experienced in a certain way because of their orientation, or that were visible or hidden because of their positions relative to an occluding object (see Fig. 1, for a schematic of Experiments 1 and 2). To our knowledge, past research has not examined infants' and toddlers' understanding of goals to act on objects of a specific orientation or visibility. In the present experiments, an observer could infer the actor's perspective either by mentally rotating the visible arrays until their orientation corresponds to the orientation of at which it appears to the actor, or by simulating a walk through the array from one's current vantage point to the actor's vantage point. We tested whether the toddlers and children would encode the actor's goal in accord with the actor's perspective, with their own perspective throughout the event, or with neither perspective.

For this test, we introduced changes to the array after the familiarization trials, such that the actor's perspective became aligned with that of the participants. In Experiments 1–6, each test event began with the actor moving from his location in familiarization to his new location in alignment with that of the toddler. In Experiment 7, each test event began with the actor in the new location, and the test series was preceded by one orientation trial, in which the actor moved from his original position to the new test position. In Experiment 8, there was an orientation trial that presented a change in the toddler's perspective:

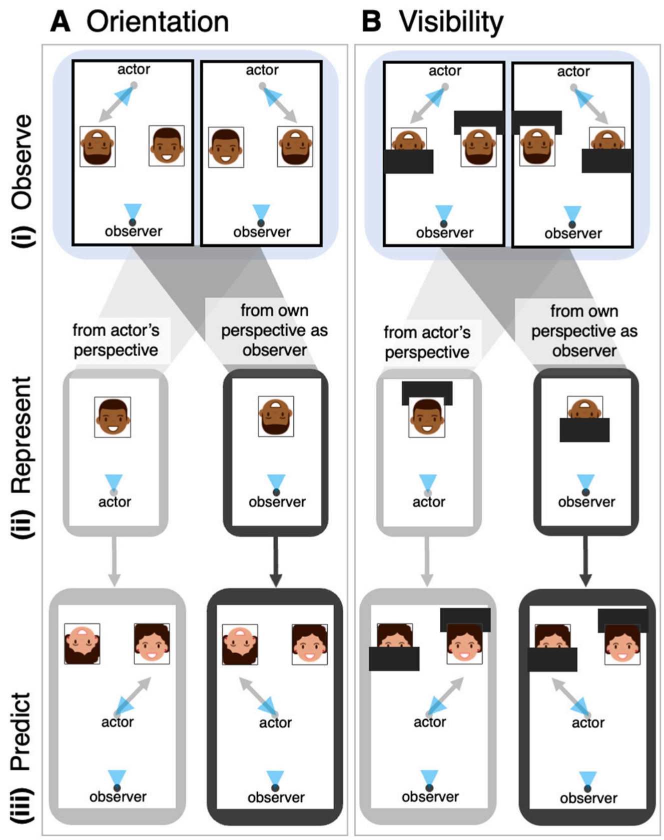

Fig. 1. A conceptual schematic of the spatial arrangements in Experiments 1 and 2. The arrows indicate the target of the actor's observed action (top figures) and predictions for the target's action (bottom figures). The toddler first observed the actor selectively reach for or point to pictures of faces that were either upright or inverted from his perspective (A, top) or were either visible or occluded from his perspective (B, top). In both cases, the actor's perspective was opposite to the perspective of the toddler throughout the familiarization sequence. If the toddlers expected the actor's actions to accord with his own perspective (middle figures), then they should expect that he will act on faces of the same orientation or visibility to himself on the test trials. If the toddlers instead represent the actor's action in relation to the toddler's perspective, then they should expect that the actor will act on faces of the same orientation or visibility to themselves on the test trials.

The toddler was led around the in-person actor and faced the actor's back, as the actor himself remained stationary. All these changes served to align the participant's perspective with that of the actor throughout the test trials.

In the experiments involving the toddlers, two pictures were displayed at the actor's left and right, differing in their orientation relative to the actor and to the toddler, and therefore in the experiences that they elicited in the actor and the toddler (Experiment 1 and 3–8), or in the actor's and the toddler's perceptual access to the pictures (Experiment 2). In alternating trials, the actor reached or pointed to one picture in each pair. To assess toddlers' inferences concerning the goal of the actor's reaching, we coded their looking times during each familiarization and test trial, on the assumption that they would look longer on test trials on which they perceived a change in the actor's goal, relative to the familiarization trials. In Experiment 9, we first showed 4- and 5-year-old children a subset of the familiarization videos of the earlier experiments; here, each video presented just one action with no repetition. At the end of the action, we probed children's explicit understanding of the actor's goal. As they viewed the actor in the test position, viewing two pictures from a new direction, we asked the children which of the two pictures they thought the actor liked more, and which of the two pictures they thought the actor would reach to. In all the studies, we assessed whether toddlers' expectations and children's inferences and predictions aligned with the actor's perspective or with their own perspective during familiarization.

5. Experiment 1

In Experiment 1, the participants viewed prerecorded videos depicting an adult male actor who sat on the floor facing but not looking at the participant (Fig. 2A). The actor first looked at two pictures of human faces: one upright and one inverted to him (and oppositely oriented to the toddler) and then reached for the face that was either upright or inverted from his perspective (counterbalanced between participants; see SI for analyses of toddlers' and children's behavior in relation to counterbalancing for Experiments 1–8). This action was presented repeatedly, on a loop, until toddlers looked away for 2 s; 6 familiarization trials were presented in total.

Test trials followed the familiarization sequence. On each loop of each test trial, the actor began in the same position as during familiarization, moved to the near side of the room, and turned around so that his back faced the toddler, aligning the actor's and toddler's perspectives. In alternating test trials, he reached for each picture: faces that appeared the same as, or different from, his perspective during familiarization. If toddlers infer that actions are guided by the perspective of the actor at the time the action occurs, then they should look longer when the actor's reaching aligns with the toddler's perspective rather than with his own. If toddlers instead are egocentric and attribute their own perspective to the actor, then they should show the reverse looking pattern. If they are unsure which perspective to use, or are insensitive both to their own and to others' perspectives, then they should look equally at the two reaching actions.

5.1. Method

The methods and analyses for Experiments 1–9 were preregistered on the Open Science Framework (OSF) at https://osf.io/6dvc2/. The stimuli, data, and code are hosted on the OSF.

5.1.1. Participants

Twenty full-term 14- and 15-month-old toddlers contributed data to the experiment (mean age = 14.68 months; range = 13;17–15;19; 10 girls, 10 boys). We recruited these participants from our lab database of children who had been based in the greater Boston area at the time of their birth. Two additional participants were excluded due to fussiness (n = 1) or inattentiveness (n = 1). All exclusions were decided by experimenters who were unaware of the events that the children saw, using preregistered criteria. For all the experiments, the caregivers provided consent for their children to participate. See SI for details about participant recruitment.

5.1.1.1. Demographics. About 55% of the participants' caregivers completed a demographic questionnaire. Approximately 42% of these participants were Asian, 25% were White, 17% were Black, 8% were Hispanic/Latino, and 8% were multiracial.

5.1.1.2. Sample size justification. For Experiment 1, we determined a sample size of 16 based on power simulations on the data from a pilot sample (n = 8). We found that with 16 toddlers, we would have 100% power (within machine precision) to detect a significant difference at test. We therefore decided to have at least 16 toddlers in our sample. More of the scheduled toddlers came to their appointments and completed the study than anticipated, resulting in a sample size of 20

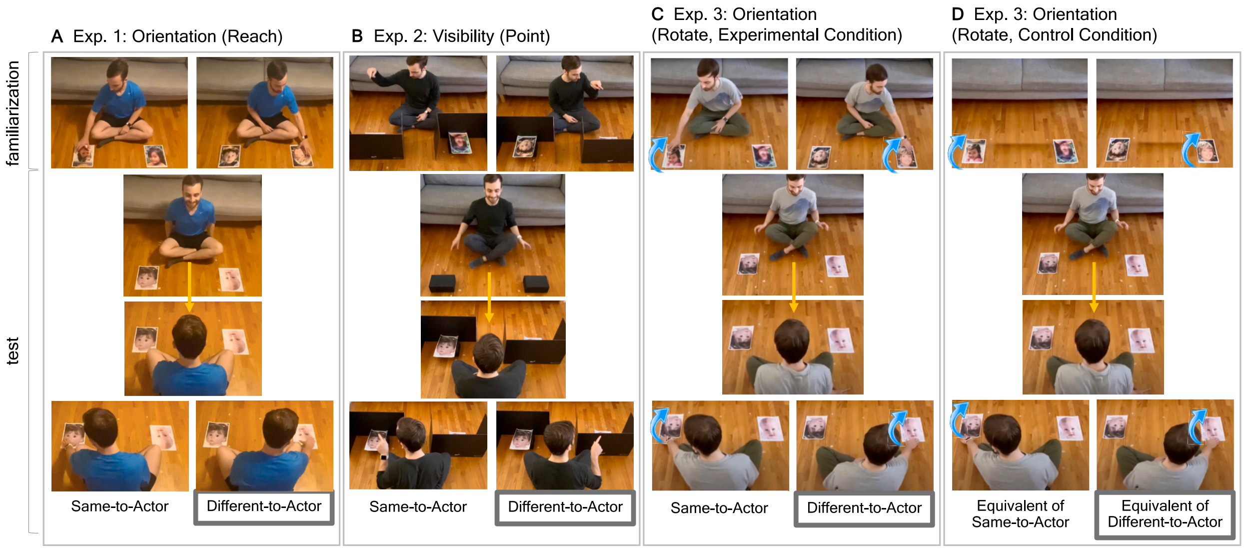

Fig. 2. Still frames from the displays in Experiments 1 (A), 2 (B), and 3 (C and D). In Experiment 3, the actor rotated one of the two pictures in each test trial. Curved arrows indicate that the orientation of a picture will change by 180° following that frame.

toddlers. Sample sizes similar to those of Experiments 1–8 have been used in recent research on toddlers' mental state reasoning (e.g., Burnside, Neumann, & Poulin-Dubois, 2020; Burnside, Severdija, & Poulin-Dubois, 2020).

5.1.2. Displays

Experiment 1 presented 6 familiarization trials, followed by 6 test trials. The events in each trial looped. Each trial presented toddlers with a pair of pictures of two different individuals, at opposite orientations. Toddlers viewed pictures of twelve individuals in total: Six individuals each appeared in two familiarization trials, and another six individuals each appeared in two test trials. The pictures in each pair of familiarization trials rotated 180° from the first trial to the second trial in the pair, while the identity and side (left vs. right of the actor) of each face remained the same. Because the actor consistently reached for pictures in a particular orientation on the familiarization trials, the toddlers received evidence that the actor chose between the pictures based on their orientation, rather than on their identity or side. In the test trials, the actor acted in alternation for the two pictures, which never rotated.

The familiarization trials began with an actor seated at the back of a room and facing the toddler and two pictures of faces on the floor, presented at opposite orientations (Fig. 2A). Because the actor faced the camera, the pictures were in the opposite orientations to the actor and to the toddler. The actor repeatedly reached for pictures of faces of a certain orientation to him (upright or inverted, counterbalanced across the toddlers): a different face on each trial. For all the experiments, see SI for analyses of looking time in familiarization.

Each test trial presented a change in the actor's position and facing direction, followed by a reach to one of the two pictures. The test trials began with the actor seated at the far side of the room, with two pictures in front of him, but he did not look at them at that time. Instead, he looked at the camera and then moved to the room's front and turned 180°, so that the face that were upright to him from his earlier position in familiarization was now inverted, and vice versa. Next, the actor looked down at the faces. In alternating trials, he reached for each of the faces: one of which had the same orientation to him as during familiarization and the start of the test trial (Same-to-Actor trials) and the other that had a different orientation to him, relative to familiarization and the start of each loop of the test trial (Different-to-Actor trials). Because the actor and the toddler had opposite perspectives during familiarization (and also at the start of every test trial), the test trials that were the same to the actor were different to the toddler, and the reverse.

We counterbalanced, across the participants, the orientation of the pictures that the actor reached for during the familiarization trials, the side of the picture that the actor reached for during odd-numbered vs. even-numbered familiarization trials, and the order of the two types of test trials. At test, half the participants viewed the test trials in each order (i.e., same-to-actor first vs. second) and with initial reaches to each side (left vs. right).

5.1.3. Procedure

Data collection occurred in the toddlers' homes, with the toddlers observing videos displayed via screen-sharing over Zoom video conferencing on a caregiver's personal electronic device (e.g., laptops). The toddlers either sat on a caregiver's lap or on a highchair, with the caregiver not in their view. The caregivers received instructions to set up the experiment and optimize data collection by making the displays full screen, ensuring the toddlers' eyes were visible on camera, hiding the toddlers' webcam view of themselves, reducing caregiver influence (e.g., asking caregivers to avoid looking at the screen displaying the events at test).

5.1.4. Coding

In all trials, after the actor reached for a face, a bell sounded to cue an experimenter (naïve to all events) to begin coding, and the videos looped. The experimenter coded looking time using the coding program jHab (Casstevens, 2007). Each trial ended when a toddler had looked away for 2 consecutive seconds, or 30 total seconds had elapsed. (See SI for reliability analyses for all the experiments.) Looping has been implemented in some studies of infants' and toddlers' understanding of actions and mental states (e.g., Liu, Ullman, Tenenbaum, & Spelke, 2017, Liu et al., 2022; Southgate, Johnson, & Csibra, 2008). See SI for an analysis of whether the amount of looping differed across experiments.

5.1.4.1. Excluded and repeated trials. We preregistered that we would exclude trial-level data for an individual test trial (i) if the toddler was not looking as the actor reached for or pointed to a picture, (ii) if a specific localized event (e.g., a doorbell) or a member of the household caused the child to disengage from the screen, or (iii) if there were technical issues that were detected by the experimenter during a trial. When these events occurred, the trial was discarded and repeated. If a disruption was discovered after the test phase (e.g., upon learning new information from the caregiver), then we excluded the data from that trial. Trial-level exclusions were determined by experimenters who were unaware of the events that the children saw. See SI for full details about trials that were excluded, missing, or repeated in Experiments 1–9. The mixed-effects models that we used for our analyses are tolerant to missing data (Wu, 2009).

5.1.5. Analyses

We ran a mixed-effects model (Bates, Mächler, Bolker, & Walker, 2015) to determine whether the toddlers expected the actor to behave consistently from his perspective or from the perspective of the toddler. In this model, the dependent variable was looking time during the test trials, the fixed effect was trial type (Same-to-Actor/Different-to-Actor),

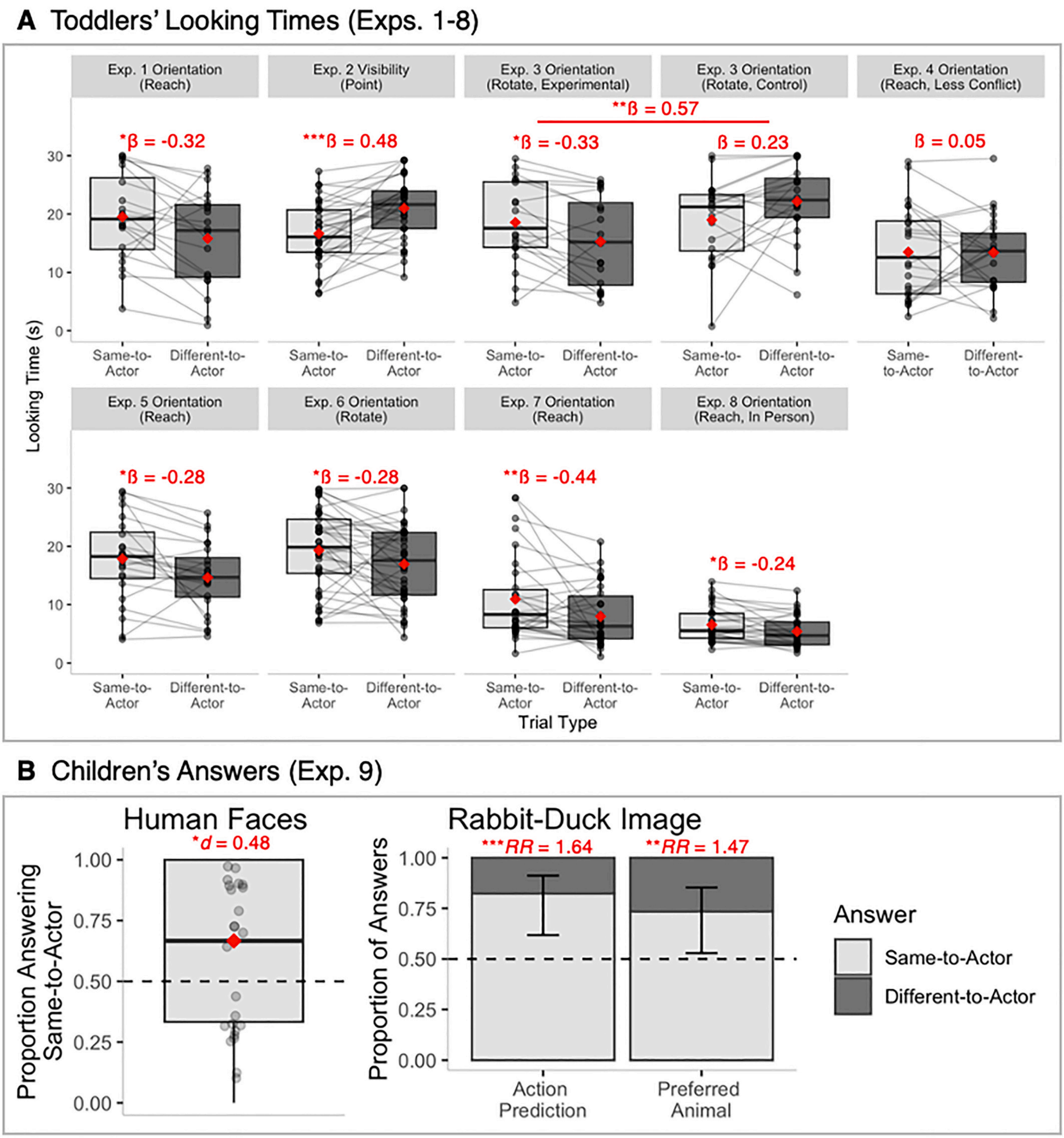

Fig. 3. Box plots depicting the time that the toddlers looked to test trials for Experiments 1–8 (A) and a box plot and a bar graph depicting the children's verbal answers in Experiment 9 (B). In the box plots, the horizontal lines within the boxes indicate the medians, the red diamonds indicate means, the boxes indicate the interquartile ranges, and the whiskers indicate 1.5 times the interquartile range. In the bar graph, the whiskers indicate the 95% bootstrapped confidence intervals. The connected and jittered dots indicate data from individual participants in the box plots of A and B, respectively. The beta coefficients (β), *d*, and relative risk (RR) indicate standardized effect sizes. The asterisks indicate significant effects (**p* < .05, ***p* < .01, ****p* < .001). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and the trial pair and participant ID were random intercepts. (We did not include trial type as a random slope because its inclusion led to overfitting of the data.) Because a normal distribution fit the looking time data better than did a lognormal distribution, we did not log-transform the data for the model. (See SI for exploratory analyses on the data from just the first test trial.)

5.2. Results and discussion

At test, the toddlers looked longer at actions that were consistent with the actor's perspective during the familiarization trials ($\text{mean}_{\text{same-to-actor}} = 18.84$ s; $SD = 9.62$ s) than at actions that were inconsistent with the actor's perspective during those trials ($\text{mean}_{\text{different-to-actor}} = 16.05$ s; $SD = 10.30$ s) ($\beta = -0.32$, 95% of β [-0.62, -0.01], $b = -3.22$, $t(77) = -2.07$, $p = .041$; Fig. 3). These findings provide evidence that the action that was consistent with the actor's perspective was unexpected: The toddlers failed to interpret the actor's actions in accord with his own distinctive perspective on the pictures and instead expected the actor to act in accord with the toddlers' perspective on the pictures.

What might account for this pattern of findings? Although the present findings suggest that the toddlers did not appreciate the actor's distinctive perspective on the pictures, they are open to multiple alternative explanations, including the following four possibilities. First, toddlers may see others' actions as communicative, and therefore as undertaken with the toddler's perspective in mind. Second, toddlers may encode an actor's goal with respect to the room, rather than the perspective of any individual. For example, when the actor reached for a picture of a face that was upright to the actor and faced the back of the room, the toddlers may have interpreted the actor's goal as being to act on pictures that face the back of the room. Third, toddlers may have failed to appreciate that the actor's movement changed the direction from which he viewed the array. Fourth, the toddlers may have defaulted to their own perspective because the experiment placed high demands on their executive functions, given that each trial presented multiple actions (i.e., the actor rising, turning 180°, looking at each picture, and reaching), and the actor's perspective changed repeatedly during every test trial.

Experiment 2 addressed these potential reasons for toddlers' responses, by using the same physical arrangements and experimental method to test whether toddlers appreciate the goal of an actor whose perspective differs from theirs with respect to the visibility of a picture rather than its orientation. As reviewed above, adults automatically encode others' diverse states of perceptual access to objects but reason more slowly and deliberately about others' diverse experiences of accessible objects (Surtees et al., 2012, 2016). Although much of the evidence for false-belief understanding in toddlers has failed to replicate (Poulin-Dubois et al., 2018), infants and toddlers have demonstrated sensitivity to whether someone is ignorant vs. knowledgeable about an event or an object (e.g., if a barrier occludes an object) (Choi, Mou, & Luo, 2018; Hamlin et al., 2013; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Woo et al., 2017), and the evidence for early sensitivity to states of ignorance and knowledge has replicated more consistently than the evidence for early reasoning about false beliefs (Holland & Phillips, 2020; Phillips et al., 2020). Thus, toddlers may more readily reason about others' perceptual access than about others' experiences.

That said, in past experiments on infants' and toddlers' understanding of states of ignorance and knowledge, the position and facing direction of the actor did not change between the familiarization and test phases. In some of these experiments, an actor's position changed from present to absent, so that events that were visible to the toddler were instead hidden from the actor (Hamlin et al., 2013; Woo et al., 2017). Moreover, in past experiments involving perceptual access and goal attribution, agents' goals were based on differences in objects' kinds (e.g., a bear vs. a ball), rather than in their visibility. Because of these differences in methods, it remained an open question whether toddlers would be sensitive to the actor's perceptual access to pictures of faces in the present paradigm involving goal attribution, with the present spatial arrangements, in which the actor's position changed at the start of each loop in each test trial.

6. Experiment 2

Experiment 2 presented toddlers with the same pictures of faces, and the same positions, facing directions, and displacements of the actor, as in Experiment 1. In contrast to Experiment 1, Experiment 2 varied the visibility rather than the orientation of the pictures from the actor's and the toddler's perspectives (Fig. 2B). On all the familiarization trials, the pictures differed in their visibility, rather than in their orientation, relative to the toddler and the actor. The same actor and pictures now appeared in the same positions as in Experiment 1 but with opaque occluders positioned in front of one picture and behind the other picture, rendering one picture visible only to the toddler and the other picture visible only to the actor. During familiarization, the actor pointed consistently either to the picture that was visible to him or to the picture that was hidden from him by the occluder (counterbalanced between participants). On each test trial, the actor began by moving to the near side of the room and turning around, such that his perspective on the two pictures was now aligned with that of the toddler, and then he pointed to one of the two pictures: either the visible picture or the occluded picture, on alternating test trials.

If the toddlers in Experiment 1 had seen the actor's actions as communicative, had encoded the relative positions of the occluder and picture that the actor had acted on with respect to the room, had failed to take account of how the actor's changing facing direction influenced what he would see, or had been overloaded by the looping sequence of actions at test, then looking patterns should be the same in Experiment 2 as in Experiment 1, because both studies presented the same social context, spatial context, and looping event structure, and both required that the toddlers take account of the actor's movements and their effects on his perspective. If the toddlers' behavior in Experiment 1 instead reflected difficulty with understanding others' experiences, then the toddlers might succeed in Experiment 2, because it tests for an understanding of what is visible to others, rather than an understanding of the distinctive experiences of faces that arise when they are viewed at different orientations.

6.1. Method

6.1.1. Participants

Thirty-two full-term 14- and 15-month-old toddlers contributed data to the experiment (mean age = 14.84 months; range = 13;17–15;27; 20 girls, 12 boys). One additional participant was excluded due to technical issues on the participant's computer.

Most participants ($n = 24$) had been based in the greater Boston area at the time of their birth, and their caregivers had responded to mailings from our lab to express interest in participating in studies with their children; these children were then added to our lab database. After Experiment 1, we had posted information about this study on ChildrenHelpingScience.com, a website that connects caregivers with labs that conduct online research on infants and children. The remaining participants contacted our lab based on a posting at this website.

6.1.1.1. Demographics. About 59% of the participants' caregivers completed demographics questionnaires. Approximately 53% of these participants were Asian, 21% were White, and 26% were multiracial.

6.1.1.2. Sample size justification. We determined a sample size of 32 based on power simulations on the data from a pilot sample ($n = 15$). We found that with 32 toddlers, we would have 100% power (within machine precision) to detect a significant difference at test. We therefore decided to test 32 toddlers in our sample. The larger sample size was needed because, in piloting, the effect was both smaller and opposite in direction to that of Experiment 1.

6.1.2. Displays

The familiarization displays were like those of Experiment 1, except that the critical difference between the toddler's and actor's perspectives was based on the visibility, rather than the orientation, of the pictures of faces. The trials began with two pictures of faces on the floor, initially without an actor present (Fig. 2B). Both faces were inverted to the toddler (and upright from the back of the room). The display faded to black, and when the room reappeared, one face was occluded by an upright black occluder that had been placed in front of it from the toddler's perspective, and the other face was visible to the toddler with a similar occluder behind it. The display faded to black again, and the actor appeared, seated facing the toddler such that faces that were visible and occluded to the toddler were occluded and visible, respectively, to the actor.

The actor first looked in the direction of the visible and occluded faces and then pointed either to the face that he could see or over the occluder to the face that he could not see (counterbalanced between toddlers). The actor pointed, rather than reached, so that his hand would be equally visible regardless of whether he acted on the face that he could or could not see. Importantly, past research suggests that infants see pointing as goal-directed by 12 months of age (Woodward & Guajardo, 2002). Thus, similar reaching trajectories, hand positions, and pointing actions were used throughout familiarization.

The test trials began with the actor moving to the front of the room by scooting forward, initially without pictures of faces and without occluders present, and sat cross-legged while continuing to face in the same forward direction, while looking downward and away from the camera to avoid any appearance of social engagement with the toddler. Before the actor turned around to face the room's center, the screen faded to black. When the room reappeared, there were two pictures of faces, both upright to the toddler. The screen faded to black once more, and when the room reappeared, two occluders were present, as in familiarization. The actor turned around while remaining seated, so that faces that would have been visible to him from his position in familiarization were now occluded (as they had been for the toddler in familiarization), and vice versa, he again looked in the direction of the visible and occluded faces, and then, in alternating trials, he pointed to faces that were either of the same visibility to him as before (Same-to-Actor trials) or of a different visibility to him than before (Different-to-Actor trials). The actor's movements and hand positions were identical except for their direction (left vs. right) on the test trials. On all the test trials, the pictures that were of the same visibility to the actor, relative to familiarization, were of the opposite visibility to the toddler.

The counterbalancing in Experiment 2 was the same as in Experiment 1, except that the counterbalanced variables were the visibility of faces (rather than their orientation) and the direction and order of acts of pointing (rather than reaching). In each trial, toddlers again saw the actor act on one member of six pairs of pictures of faces (3 pairs during familiarization and 3 pairs at test). In this experiment, however, the pictures differed in their visibility rather than their orientation, and the actor pointed to a picture on each trial rather than reaching for and contacting the picture.

6.1.3. Procedure, coding, and analyses

The procedure and coding were the same as those for Experiment 1. Coding began when the actor pointed to a picture for the first time in each trial. We ran a mixed-effects model exactly like that of Experiment 1.

6.2. Results and discussion

The toddlers in Experiment 2 showed the reverse pattern of looking relative to those of Experiment 1: They looked longer at the actions that were inconsistent with the actor's perspective (and consistent with their own) ($\text{mean}_{\text{different-to-actor}} = 21.16$ s; $SD = 8.38$ s) than at the actions that were consistent with the actor's perspective, relative to familiarization ($\text{mean}_{\text{same-to-actor}} = 16.85$ s; $SD = 9.32$ s) ($\beta = 0.48$, 95% of β [0.24, 0.71], $b = 4.33$, $t(137) = 4.02$, $p < .001$; Fig. 3). These findings provide evidence that the toddlers appreciated how the actor's perceptual access to objects varied as he moved from one side of the room to the other. Moreover, the toddlers evaluated the actor's goal in accord with his own perspective on the array, rather than with their own perspective on the array.

The findings of Experiment 2 replicate longstanding evidence that infants and toddlers are sensitive to what others can and cannot see, even when what is visible to them is occluded to others and the reverse. These findings speak against the four alternative interpretations of the findings of Experiment 1. First, it is unlikely that toddlers viewed the actor's actions as communicative with themselves, and therefore as appropriate to their own perspective in Experiment 1, because the actor's social behavior toward the toddler was the same in Experiments 1 and 2. Although the actor reached in Experiment 1 and pointed in Experiment 2, pointing is even more likely than reaching to be viewed as communicative, yet the toddlers did not attribute altercentric motives to the actor when he pointed to a hidden or visible object: Instead, they expected him to act in accord with his own perspective on the visibility of the objects. Second, it is unlikely that the toddlers encoded the actor's goal in familiarization with respect to the room in Experiment 1 (e.g., a goal to act on pictures that faced the back of the room), because the change in the actor's position and facing direction were the same in both studies, but the toddlers were able to encode the actor's goal in accord with the actor's perspective in Experiment 2. Third, it is unlikely that the toddlers failed to appreciate the change in perspective that occurred when the actor changed his position and facing direction between familiarization and test in Experiment 1, for the same reason: The same changes in position and facing direction occurred in Experiment 2, where they were used by the toddlers in interpreting the actor's actions. Fourth, it is unlikely that the looping structure of Experiment 1's events confused toddlers, because the toddlers in Experiment 2 also watched looping test sequences.

There remain, however, two possible reasons why toddlers failed, in Experiment 1, to interpret the actor's goal in accord with his own perspective. First, toddlers may successfully infer the differing face orientations but they may fail to realize that the orientation of a face affects the ease with which the face is perceived. Although toddlers have surely seen many faces both in natural scenes and in pictures and drawings, all these faces typically appear upright and rarely are rotated before the toddler's eyes. Toddlers may assume, therefore, that faces will look the same however they are viewed. Second, because the actor moved from the far side of the room (where his perspective was the same as in familiarization) to the near side of the room (where his perspective changed), the toddlers may have inferred that the actor formed an action plan from the far side of the room and kept to that plan throughout the test trial. Because the actor did not look at the pictures until he was seated on the near side of the room, we consider the last possibility to be unlikely, but it cannot be excluded. Experiment 3 addresses these possible reasons for toddlers' egocentric mental state attributions in Experiment 1.

7. Experiment 3

Experiment 3 presented toddlers with an action that emphasized the relevance of a face's orientation to the actor. Throughout familiarization, the actor sat facing two pictures of faces at opposite orientations, reached for the picture that was inverted from his own perspective and upright to the toddlers, and rotated it 180° so that it became upright to him and inverted to the toddlers (Fig. 2C). These changes aimed to facilitate toddlers' performance in several ways. First, because the toddlers saw the picture rotate, they were alerted, on each familiarization trial, to the importance of orientation for face perception. Second, because rotations of the pictures of faces occurred in every trial, toddlers likely became more familiar with this transformation, rendering a similar mental transformation of the pictures at test easier to perform. Third, because the actor caused the pictures of faces to rotate from inverted to upright for himself, his action revealed his preference for upright faces more clearly, it emphasized his experience of the faces; instead of revealing preferences both for upright and for inverted faces (in the two counterbalanced conditions of Experiment 1), Experiment 3 presented all the toddlers with an actor who, like themselves, preferred upright faces during familiarization (Valenza et al., 1996). If these changes rendered the task more comprehensible and easier to perform, then the toddlers should be able to infer the actor's own perspective at familiarization and expect him to act on the object that looked the same to him at test.

Because the actor had reached for faces that were initially inverted to him in familiarization, the test trials in which the actor acted consistently from his perspective always involved the actor rotating pictures of faces from inverted to upright. Thus, this experiment required a control condition to assess toddlers' baseline preferences and expectations for the test events. The toddlers were therefore randomly assigned to either the Experimental Condition (described above) or a Control Condition (n = 20 per condition), in which the actor was not present during familiarization, and the picture of a face that would have been inverted to the actor had he been present (i.e., was upright to the toddlers) changed its orientation from upright to inverted from the toddlers' perspective, providing toddlers with the opportunity to experience the effects of this change in both conditions (Fig. 2D). The two conditions presented the same actions at test and the same pictures of faces and stationary orientations throughout the study, but the control condition's familiarization events provided no information about the actor's goals during the familiarization period.

7.1. Method

7.1.1. Participants

Forty full-term 14- and 15-month-old toddlers contributed data to the experiment (mean age = 14.71 months; range = 13;12–15;21; 18 girls, 22 boys). No participants met the preregistered exclusion criteria.

7.1.1.1. Demographics. In Experiment 3, most participants (n = 35) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants were recruited via ChildrenHelpingScience.com. About 52% of the participants' caregivers completed demographics questionnaires. Approximately 33% of these participants were White, 29% were Asian, 5% were Black, and 33% were multiracial.

7.1.1.2. Sample size justification. We determined a sample size of 40 based on power simulations over the data from a pilot sample (n = 16) and from Experiment 1. Based on simulations over just the pilot data from the Experimental Condition (n = 8), we found that with 20 toddlers in the Experimental Condition, we would have 94% power to detect a significant difference at test. Based on simulations over the combined data from the pilot's Experimental Condition and Experiment 1, we found that with 20 toddlers in the Experimental Condition, we would have 85% power to detect a significant difference at test.

Finally, we ran a power analysis over pilot data from both the Experimental and the Control Conditions, to assess the power to detect a difference in patterns of looking between conditions. We found that with 20 toddlers per condition, we would have 100% power (within machine precision) to detect a significant interaction. We therefore decided to test 20 toddlers per condition in our sample.

7.1.2. Displays

The familiarization trials of the Experimental Condition were like those of Experiment 1, except that the actor rotated the pictures that he reached for on each familiarization trial, changing its orientation from inverted to upright from his own perspective. The familiarization trials of the Experimental Condition (Fig. 2C) began with the actor at the back of the room, facing the toddler and looking down at two pictures of faces: one upright and one inverted to him. Different pairs of pictures of faces again appeared on each pair of trials, and the actor repeatedly reached for pictures that were inverted to him (and upright to the toddler) and rotated them 180° so that they became upright to him (and inverted to the toddler).

The Control Condition's familiarization trials (Fig. 2D) were like those of the Experimental Condition in timing and sound, but the actor was absent and no rotation of any picture was visible. Instead, the screen faded to black, and a bell sounded at the time when the actor in the Experimental Condition would have rotated one picture, corresponding to the moment that the experimenter began coding looking time. Then the room reappeared, revealing that one face (the one that was initially inverted to the actor in the Experimental Condition) was now upright. Thus, the toddlers in the Experimental and Control Conditions saw the same pictured faces at the same starting and final orientations.

The test trials of both conditions were like those of Experiment 1, except that the actor rotated the picture that he reached for on each test trial. In the test trials, the actor alternately reached (i) for pictures of faces that were inverted to rotate them upright, as he had from his perspective in the Experimental Condition's familiarization (Same-to-Actor trials) and (ii) for pictures of faces that were upright to invert them, as he had from the toddler's perspective in the Experimental Condition's familiarization (Different-to-Actor trials). Although the actor was absent in the Control Condition's familiarization, the test events in the Control Condition were identical to those of the Experimental Condition, and they are therefore designated by the same labels.

The counterbalancing was the same as in Experiment 1, except that there was no actor in the Control Condition's familiarization, and in the Experimental Condition, the actor only reached for and rotated faces that were initially inverted to him in familiarization.

7.1.3. Procedure, coding, and analyses

The procedure and coding were the same as those of Experiment 1. We ran a mixed-effects model like that of Experiments 1 and 2 but with the additional variable of Condition (Experimental vs. Control, reflecting the presence vs. absence of the actor, respectively, in familiarization trials). The fixed effects were trial type, Condition (Experimental/Control), and the interaction between the trial type and the condition. These fixed effects were centered.

7.2. Results and discussion

As in Experiment 1, the toddlers in the Experimental Condition looked longer at actions that were consistent with the actor's perspective at familiarization ($\text{mean}_{\text{same-to-actor}} = 18.87$ s; $SD = 9.95$ s; $\text{mean}_{\text{different-to-actor}} = 15.58$ s; $SD = 10.33$ s; $\beta = -0.33$, $b = -3.39$, $t(185) = -2.37$, $p = .018$; Fig. 3), providing evidence that this event was unexpected. Although the actor had rotated the pictures in that condition, the toddlers appeared to encode his goal from their own perspective during the familiarization trials, not the perspective of the actor. This difference could not be explained by a preference for events in which inverted pictures became upright, because it was not exhibited by the toddlers in the Control Condition, who viewed the same test events but did not see the actor on the familiarization trials ($\text{mean}_{\text{same-to-actor}} = 19.76$ s; $SD_{\text{same-to-actor}} = 10.10$ s; $\text{mean}_{\text{different-to-actor}} = 22.32$ s; $SD_{\text{different-to-actor}} = 8.98$ s; $\beta = 0.23$, $b = 2.38$, $t(184) = 1.65$, $p = .100$). The interaction was significant, indicating that looking patterns differed reliably across the two conditions ($\beta = 0.57$, 95% of β [0.18, 0.96], $b = 5.77$, $t(180) = 2.85$, $p = .004$).

The findings of Experiment 3 weigh against the possibility that toddlers' failures to base their predictions on the actor's perspective stem from a failure to realize that the rotation of a picture of a face changes the way that the face is experienced. The toddlers in the Experimental Condition of Experiment 3 had considerable opportunity to experience this phenomenon and to learn from it, as they watched both the rotating pictures and the actor's acts of rotating them. Nevertheless, representing the actor's perspective still may have been difficult for the toddlers because it conflicted with their own perspective during the critical familiarization trials in which the actor revealed his preference. Experiment 3 required that toddlers actively disregard, during familiarization, their own intrinsic preferences for upright faces (Valenza et al., 1996). In Experiment 4, we removed this difficulty.

8. Experiment 4

In Experiment 4, we familiarized toddlers to an actor who viewed pictures of the faces from Experiments 1–3 from the side rather than the back of the room, such that the two faces were viewed by the actor in the canonical upright and inverted orientations, whereas both faces were viewed sideways by the toddlers; neither picture appeared upright to the toddlers (Fig. 4A). On each loop of each test trial, the actor moved from his position during familiarization to the near side of the room, and he rotated 90° to align his perspective with the toddlers' perspective. Then two pictures (one upright, one inverted) appeared, and the actor reached for pictures at each orientation on alternating trials, as in Experiments 1 and 3. None of the test trials presented faces at the orientations that the toddlers previously viewed, but as in the previous studies, one of the pictures in each test trial appeared at the same orientation to the actor, relative to familiarization. This experiment therefore simplified the toddler's task in two ways: It presented a smaller change in the perspective of the actor (a change in the face's orientation of 90° rather than 180°), and it removed the salient distractor of a face that was upright to the toddler during the critical familiarization phase. Because no action by the actor accorded with the toddlers' perspective during familiarization, the toddlers should look longer at the test events presenting a change in the actor's goal if, during familiarization, they represent the actor's goal in accord with his own perspective. In contrast, toddlers should look equally at the two test events if they are not able to infer the actor's goal from his own perspective.

8.1. Method

8.1.1. Participants

Twenty-four 14- to 15-month-old toddlers contributed data to the experiment (mean age = 14.80 months; range = 13;18–15;26; 11 girls, 13 boys). No participants met the preregistered exclusion criteria.

8.1.1.1. Demographics. In Experiment 4, most participants (n = 18) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants were recruited via ChildrenHelpingScience.com. About 58% of the participants' caregivers completed demographics questionnaires. Approximately 36% of these participants were White, 36% were Asian, 14% were Hispanic, and 14% were multiracial.

8.1.1.2. Sample size justification. In pilot data ($n = 8$) using the methods for Experiment 4, we found no evidence that the toddlers looked differently to the different test events. We therefore used the results of Experiment 2 for a power analysis, given that in Experiment 2, toddlers demonstrated sensitivity to the difference between their own and the actor's perspective. We found that with 24 toddlers, we would have 93% power to detect a significant difference at test. We therefore decided to have 24 toddlers in our sample.

8.1.2. Displays

The displays were like those of Experiment 1, except that the actor in familiarization was seated on the room's right side, facing pictures of faces that were upright and inverted to him in the room's center but were both sideways to the toddler (Fig. 4A). As in Experiment 1, the actor always reached for faces of a certain orientation to himself.

On each test trial, the actor began on the right side of the room, without any pictures in front of him. (We removed the pictures to make it easier for the actor to move to the front of room.) Then, as in Experiment 1, the actor moved to the front of the room. Two pictures of faces appeared, and in alternating trials, the actor reached for the face in the same orientation to himself (Same-to-Actor trials), and for the face in a different orientation to himself (Different-to-Actor trials).

8.1.3. Procedure, coding, and analyses

The procedure and coding were the same as those of Experiment 1. We ran a mixed-effects model like that of Experiment 1 on the looking times in the test trials. The data were log-transformed before inclusion

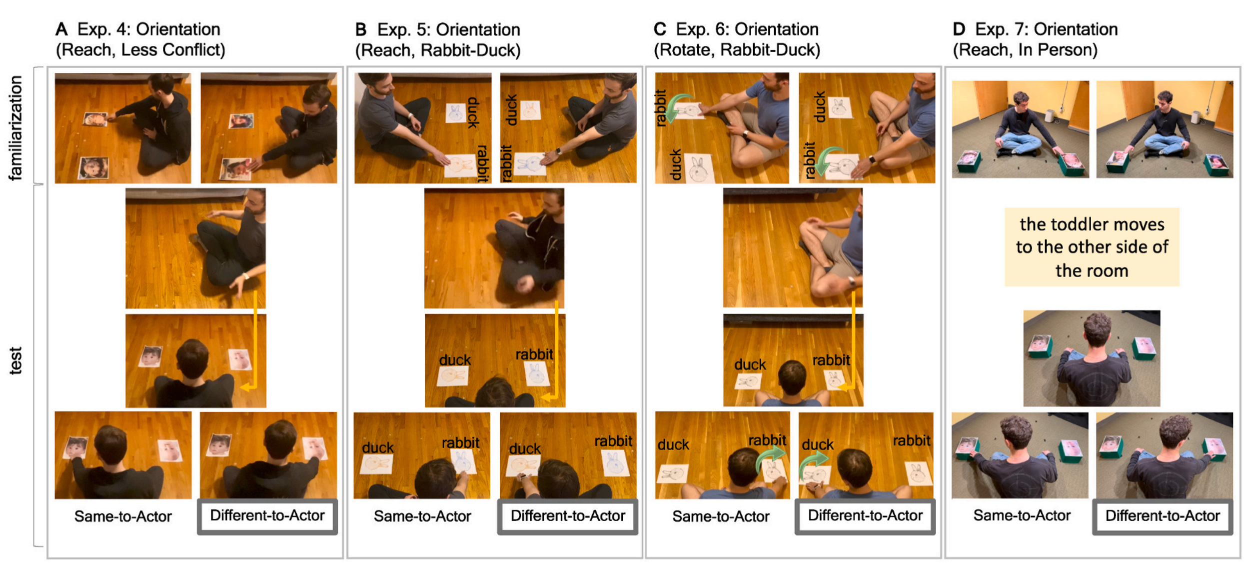

Fig. 4. Still frames from the displays in Experiments 4 (A), 5 (B), 6 (C), and 8 (D). The green curved arrows indicate that a picture will rotate 90° following that frame. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

into the model because a lognormal distribution fit the data better than did a normal distribution.

8.2. Results and discussion

At test, the toddlers looked equally when the actor acted inconsistently ($\text{mean}_{\text{different-to-actor}} = 13.67$ s; $SD = 9.61$ s) and consistently ($\text{mean}_{\text{same-to-actor}} = 13.73$ s; $SD = 10.23$ s) from his perspective from familiarization ($\beta = 0.05$, 95% of β [−0.24, 0.33], $b = 0.04$, $t(111) = 0.353$ $p = .736$; Fig. 3). Given the null finding of the effect of trial type, we conducted a Bayesian mixed-effects model (Goodrich, Gabry, Ali, & Brilleman, 2020) to probe this null finding further, with default, weakly informative priors and with the same fixed and random effects as our frequentist model. This Bayesian analysis revealed that these data provided strong evidence for the null hypothesis ($BF_{10} = 0.036$). Thus, the toddlers failed to appreciate that the actor's actions during the familiarization period were guided by his own experiences of the faces, even though the toddlers experienced no faces as upright during that period.

Taken together, Experiments 1–4 reveal that early in the second year, toddlers do not readily infer the goals of another actor whose perceptual experience of a goal object differs from their own. The experiments used pictures of human faces as goal objects, because faces are in some ways ideal displays for studies of the sensitivity of minimally verbal beings to others' experiences of objects. The orientation of a picture of a face greatly affects infants' perceptions, looking preferences, and attentive tracking even as neonates (Morton & Johnson, 1991; Slater et al., 2010). These effects have been found throughout infancy (Chien, 2011; Csibra & Gergely, 2009; Valenza et al., 1996), throughout childhood (Carey & Diamond, 1977; Diamond & Carey, 1986), into adulthood (Chien, 2011; Thompson, 1980; Valentine, 1988), and across many species (Adachi, Chou, & Hampton, 2009; Guo, Robertson, Mahmoodi, Tadmor, & Young, 2003; Kendrick, Atkins, Hinton, Heavens, & Keverne, 1996; Parr et al., 1998; Racca et al., 2010; Rosa-Salva, Regolin, & Vallortigara, 2010; Tomonaga, 1994; M.-Y. Wang & Takeuchi, 2017).

Nevertheless, human faces at all orientations are likely perceived as faces: instances of a common kind. The toddlers in Experiments 1, 3, and 4 therefore may have failed to attend to the actor's distinctive experiences of the orientations of the faces, but only to their own, and the actor's, shared experience of looking at a face. In Experiments 5 and 6, we tested whether toddlers would recognize an actor's distinctive experience of pictures if the rotation of a picture changed one's impression of the kind of animal that it depicted. To this end, the experiment presented an actor who reached for a well-known ambiguous drawing that elicits representations of two different animals, depending on the orientation at which it is viewed.

9. Experiment 5

Experiment 5 presented toddlers with pictures eliciting perceptions of the heads of two different animals, viewed in profile, when rotated by 90°: a duck versus a rabbit. These pictures were drawings that were either monochrome blue or monochrome orange in color: a feature that contributed to their distinctiveness but did not affect the perception of one or the other animal. During familiarization, an actor sat facing a picture that was oriented to look like a rabbit to the actor but like a duck to the toddler, and a second picture that was oriented to look like a duck to the actor but like a rabbit to the toddler. Across a series of trials, the actor viewed the two pictures from the left and the right sides of the room in alternation, and he reached consistently to one of the two orientations (the duck orientation for half the participants and the rabbit orientation for the others; Fig. 4B). On each loop of each test trial, the actor began in the same position as during familiarization, and he moved to the near side of the room. The actor turned around, such that his and the toddler's perspectives coincided, and two rabbit-duck pictures appeared (one as a rabbit, one as a duck). In alternating trials, the actor reached for each animal. If toddlers are sensitive to the actor's perspective on the pictures, then they should expect the actor to reach for the picture that looked like the same animal to him, relative to familiarization. If toddlers fail to appreciate the actor's perspective on the drawings, then they might either have no expectation or expect the actor to reach for the other picture, which looked like the same animal to the toddlers themselves.

9.1. Method

9.1.1. Participants

Twenty-four 14- to 15-month-old toddlers contributed data to the experiment (mean age = 14.54 months; range = 13;10–15;25; 10 girls, 14 boys). One additional participant was excluded due to technical issues on the participant's computer.

9.1.1.1. Demographics. In Experiment 5, most participants ($n = 20$) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants, recruited via ChildrenHelpingScience.com. About 45% of the participants' caregivers completed demographics questionnaires. Approximately 46% of these participants were White, 27% were Asian, 9% were Indigenous, and 18% were multiracial.

9.1.1.2. Sample size justification. We determined a sample size of 24 based on power simulations on data from a pilot sample ($n = 8$). We found that with 24 toddlers, we would have 98% power to detect a significant difference at test.

9.1.2. Displays

During the familiarization trial sequence, the actor sat on the left and right sides of the room on alternating trials, where there were two pictures (one oriented like a rabbit to the actor, one like a duck to the actor; Fig. 4B). These pictures were created by Darren Allen and adapted with his permission. We deliberately made the pictures mirror reflections of each other, so that the picture that looked like a rabbit to the actor looked instead like a duck to the toddler and the reverse, consistent with the 90° difference in facing direction between the toddler and the actor. Because the rabbit-duck drawing is asymmetrical, it was necessary that the drawings be presented as reflections of each other, or else the toddlers and the actor would not simultaneously see each picture as different animals.

The actor always reached in familiarization for the picture that was presented in an orientation that appeared to adults to elicit the perception of an upright rabbit (for half the participants) or an upright duck (for the other participants) from the positions at which the actor viewed the pictures, and as the opposite animal from the toddlers' position. The two pictures differed in color (orange/blue), so that they appeared distinct. We intentionally made the actor alternate between the room's two sides in familiarization, so that he would reach for pictures that appeared like one of the two upright animal heads regardless of their color or location relative to himself, and so that his goal was tied to a specific animal rather than a specific image. From the standpoint of an adult, therefore, the actor consistently reached for pictures of the duck for half of the participants and for pictures of the rabbit for the other participants, and these pictures varied in color, facing direction, and orientation.

In each loop of each of the test trials, the actor began on the right side of the room, where there were no pictures present. He moved to the front of the room, where two pictures of the duck and the rabbit appeared, differing in color, one to his left and the other to his right. He and the toddler viewed the two pictures on each of the test trials. As in Experiment 4, but in contrast to Experiments 1 and 3, the pictures did not appear until after the actor had moved to the front of the room. In alternating test trials, the actor reached for pictures of the same animal from the actor's perspective (Same-to-Actor), and for pictures of the same animal from the toddlers' perspective (Different-to-Actor), relative to familiarization. Thus, the actor reached for the same animal and for the different animal on alternating test trials.

The counterbalancing for Experiment 5 was the same as in Experiment 1, except that the pictures appeared as an upright duck or rabbit head (rather than as upright or inverted human face) to the actor. Additionally, we counterbalanced the direction toward which the actor reached for pictures across the familiarization trials. Importantly, throughout familiarization, the actor reached for pictures on his left and right, and for displays of different colors in different positions, with equal frequency (see SI for details).

9.1.3. Procedure, coding, and analyses

The procedure and coding were the same as those of Experiment 1. We ran a mixed-effects model like that of Experiment 1, but with trial type as a random slope; here, the inclusion of a random slope did not lead to overfitting of the data. Because each picture was viewed from opposing perspectives by the actor and the toddler during familiarization, as in Experiments 1–3, the analyses and predictions were the same as in those experiments.

9.2. Results and discussion

Once again, the toddlers looked longer on the test trials in which the actor acted consistently from his own perspective during familiarization ($\text{mean}_{\text{same-to-actor}} = 17.61$ s; $SD = 10.02$ s) than when the actor acted inconsistently from his own perspective during familiarization ($\text{mean}_{\text{different-to-actor}} = 14.78$ s; $SD = 10.21$ s) ($\beta = -0.28$, 95% of β [-0.55, -0.01], $b = -2.89$, $t(84) = -2.06$, $p = .042$; Fig. 3), providing evidence that they interpreted the actor's goal in accord with their own perspective on the pictures. Thus, toddlers failed to rely on the actor's experiences of the ambiguous pictures when interpreting the actor's actions, even though the differences in the orientation of the two drawings led to differences in the different kinds of animals that older children and adults see (Carpendale & Chandler, 1996; Gopnik & Rosati, 2001; Jastrow, 1899; Sobel et al., 2005).

This experiment provides evidence against the possibility that toddlers failed to take account of the actor's distinctive experiences in Experiments 1–4 because the pictures were experienced as human faces at all orientations. In Experiment 5, the experience of each picture changed dramatically with the changes in orientation: from one kind of animal to another. Despite this change, toddlers failed to appreciate the actor's distinctive experiences of the pictures during the familiarization period: They drew on their own experience of a duck or rabbit, rather than the actor's experience, in inferring the actor's goals. Additionally, Experiment 5 provides indirect evidence against the possibility that the toddlers in Experiments 1 and 3 had only failed to appreciate the actor's distinctive experience because the pictures were present throughout each test trial, and the actor therefore had two different perspectives on each test trial (from before and after he had moved across the room). In Experiment 5, although the pictures were absent until after the actor had moved across the room, toddlers still failed to appreciate the actor's distinctive experience. It is possible, however, that the toddlers failed to recognize the pictures in Experiment 5 as depicting the animals that adults perceive, or to realize that the same image could be experienced as either of two different animals upon being rotated 90°. Experiment 6 addressed these concerns.

10. Experiment 6

In Experiment 6, we first presented toddlers with a word recognition task, following methods used in research on language acquisition (Golinkoff, Ma, Song, & Hirsh-Pasek, 2013). Two rabbit-duck pictures appeared in different orientations, as a duck and a rabbit, on opposite sides of the screen, and we measured toddlers' selective looking at the two pictures as they heard "a duck" and "a bunny" in alternating trials (Fig. S4A). If toddlers recognized the drawings as depicting a duck and a bunny, then they should look at the corresponding picture after hearing each word.

Next, we presented the toddlers with videos in which two rabbit-duck pictures appeared and rotated in front of them, from the orientation at which adults perceive a duck to the orientation at which adults perceive a rabbit, and the reverse. By showing these videos, we aimed to provide toddlers with evidence that the same picture would be experienced as either a duck or a rabbit, depending on its orientation, and that the experience of the picture would change when it was rotated by 90°.

Following the rotation phase, we familiarized the toddlers with the actor's actions using videos that were similar to those used in Experiment 5, with modifications that aimed to simplify the toddler's task and increase the meaningfulness of the actor's actions. First, the variability in the colors and facing directions of the pictures and in the position of the actor during familiarization was eliminated (see SI for details). Second, each time the actor reached to one of the two pictures, he rotated the picture so that its appearance changed from one animal to the other for himself, and so that its appearance changed from a meaningful, upright animal to a drawing that was less meaningful for the toddler, for it no longer appeared as either upright animal to the toddler. This rotation aimed to emphasize the actor's perspective and make clear that the actor was not acting for the toddler's benefit. In each loop of each of the test trials, the actor moved to the near side of the room, where two pictures appeared as in Experiment 5, and he reached for and rotated each picture in alternation. Finally, we asked caregivers for their estimates of their child's language exposure, their child's knowledge if the words "duck" and bunny", and the frequency with which the child heard these words.

10.1. Method

10.1.1. Participants

Thirty-eight 14- to 15-month-old toddlers contributed data to the experiment (mean age = 14.82 months; range = 13;14–15;25; 20 girls, 18 boys). One additional participant was excluded entirely due to caregiver interference, and one of the 38 toddlers was excluded during the test trials due to fussiness.

10.1.1.1. Demographics. In Experiment 6, most participants ($n = 33$) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants, recruited via ChildrenHelpingScience.com. About 45% of the participants' caregivers completed demographics questionnaires. Approximately 53% of these participants were White, 6% were Asian, and 41% were multiracial. Of the 38 toddlers who participated, 36 came from homes where English is spoken at least 50% of the time.

10.1.1.2. Sample size justification. We determined a sample size of 24 based on power simulations on data from a pilot sample. In pilot data for the word recognition task ($n = 7$), the toddlers preferentially looked to the rabbit orientation of the picture as they heard the word "bunny." We used the effect size ($d = 1.20$) here to determine the sample size necessary to detect a significant effect: a preference for the picture that matched the word being said. We found that with a sample size of 24, we would have 99% power to detect a significant effect.

Additionally, we ran power analyses over data from the pilot sample's test trials ($n = 15$), when the actor acted in a way that was consistent vs. inconsistent from his perspective. We found that with a sample size of 24, we would have 82% power to detect a significant effect: a difference in looking time at test. We therefore decided on a sample size of 24 toddlers whose caregivers reported that they knew at least one of the words "duck" or "bunny." Because 13 toddlers' caregivers reported that their toddlers did not know those words and because one toddler was too fussy to participate in the test trials, we tested a total of 38 toddlers.

10.1.2. Displays

In the word recognition task, two pictures (one oriented like a rabbit, one like a duck) appeared on opposite sides of the screen. These pictures were mirror images of each other, as in Experiment 5. There were three 10-s trials in the word recognition task: one beginning with a tone that was followed by silence, and two trials on which a woman's voice alternately and repeatedly said "a bunny" or "a duck", once per second (Golinkoff et al., 2013; Tincoff & Jusczyk, 2012) (Fig. S4A). The tone trial always came first; the order of the two trials with words was counterbalanced across participants. Before the first trial and between trials, an animation appeared in the center of the screen; the toddlers were required to fixate on the screen before each trial began.

Next, the toddlers watched four videos in which two rabbit-duck pictures appeared, with one initially appearing as a duck and the other as a rabbit. In each of these videos, one picture rotated by itself, such that it appeared to be the same kind of animal as the other one. For two videos, the picture initially appearing as a rabbit rotated so that it appeared as a duck. For the other two videos, the picture initially appearing as a duck rotated so that it appeared as a rabbit. This pre-familiarization rotation phase provided evidence that the same picture can change its appearance between a duck and a rabbit upon being rotated 90°.

The familiarization trials were the same as in Experiment 5 except as follows: First, both pictures appeared in the same color (black) in Experiment 6. Second, the actor sat in a constant position on the right side of a room, facing two pictures that looked respectively like a rabbit and a duck to the actor and like the other animal to the toddler, on all the familiarization trials (Fig. 4C). With these changes, we aimed to simplify the toddler's task by reducing the variability in the pictures that the actor acted upon and in the actor's position. Third, the actor consistently reached to one of the pictures of animals (counterbalanced across participants) and rotated the picture so that it appeared as the other animal to himself and as a less meaningful, non-upright drawing to the toddler. With this action, we aimed to (i) call toddlers' attention to the actor's goal, as in Experiment 3; (ii) reduce competition from the toddler's perspective by presenting no meaningful animal from that perspective; and (iii) make clear that that the actor was not acting for the toddler's benefit, because his rotation presented no animal for the toddler to view.

In each loop of each of the test trials, the actor began on the right side of the room, where there were no pictures present; he then moved to the near side of the room, where he rotated 90° so that his facing direction aligned with that of the toddler, and the two pictures appeared. As in Experiments 4 and 5, the pictures did not appear until after the actor had moved to the near side of the room. In alternating trials, he reached for and rotated each picture so that it changed from an orientation depicting one animal (e.g., a rabbit) to an orientation depicting the other animal (e.g., a duck), and toddlers' looking time was measured. After the test trials, we asked the caregivers about the child's language exposure, whether their toddler knew the words "duck" and bunny", and the familiarity of these words to the child.

The counterbalancing for familiarization and test trials was the same as in Experiment 5, except that the actor stayed on the right side of the room throughout familiarization. The side of the duck in the test phase was the same as the side of the duck in the word recognition task, and the order in which the actor acted on the duck in the test trials was the same as the order in which the toddlers heard the "duck" trial in the word recognition task.

10.1.3. Procedure, coding, and analyses

For the word recognition task, a researcher (naïve to the events each toddler had seen) used jHab (Casstevens, 2007) to code the toddlers' looking to the pictures of the rabbit and the duck in each trial of the word recognition task. We used these data to determine whether toddlers looked differently to the pictures of the rabbit and the duck when they heard a tone and no words, and when they heard the phrases "a duck" vs. "a bunny." The procedure and coding of the familiarization and test trials was the same as that of Experiment 1.

We preregistered analyses of the data from the word recognition task separately for (i) toddlers from homes where English is spoken at least 50% of the time and whose caregivers reported that the toddlers knew at least one of the words "duck" and bunny," and (ii) all toddlers from homes where English was spoken at least 50% of the time, regardless of their knowledge of the words "duck" or "bunny". Likewise, we preregistered analyses of the data from the test trials separately for (i) toddlers from homes where English is spoken at least 50% of the time and whose caregivers reported that the toddlers knew at least one of the words "duck" and bunny," and (ii) all toddlers.

10.1.3.1. Analyses of the word recognition task. To determine whether the toddlers saw the picture as a rabbit and a duck in different orientations, we ran a mixed-effects model based on the data from the word recognition task. In the model, the dependent variable was preferential looking time; the fixed effects were the target (rabbit/duck), the trial type (tone/"bunny"/"duck"), and the interaction between the two, and participant ID was a random effect. We used dummy coding, with the preferential looking time in the trial with the tone as the reference group.

10.1.3.2. Analyses of looking in the test events. We ran mixed-effects models exactly like those of Experiment 1.

11. Results and discussion

We first asked whether the toddlers recognized the different orientations of the picture as a rabbit and as a duck. For the toddlers who came from homes where English was spoken at least 50% of the time and whose caregivers reported that the toddlers knew at least one of the words "duck" and "bunny" ($n = 25$), we compared looking in the word recognition task at the pictures of animals that matched vs. mismatched the accompanying word. The toddlers' looking to the duck and rabbit orientation of the pictures differed depending on whether they heard a tone, "a duck", or "a bunny" (Fig. S4B). When the toddlers heard only the tone, they did not look differently to the drawings that adults see as a duck ($mean_{duck} = 3.46$ s, $SD = 1.30$ s) and a rabbit ($mean_{rabbit} = 3.08$ s, $SD = 1.08$ s), showing no preference between them ($\beta = -0.23$, $b = -0.48$, $t(128) = -0.86$, $p = .391$). When the toddlers heard the word "bunny", by contrast, they looked more to the rabbit ($mean_{rabbit} = 4.53$ s, $SD = 1.76$ s) than to the duck ($mean_{duck} = 3.00$ s, $SD = 1.33$ s) orientation of the pictures ($\beta = 0.92$, $b = 1.53$, $t(128) = 3.47$, $p < .001$). Finally, when the toddlers heard the word "duck", they showed a trend to look more at the duck ($mean_{duck} = 3.64$ s, $SD = 2.00$ s) than at the rabbit ($mean_{rabbit} = 2.84$ s, $SD = 1.80$ s) but no significant preference ($\beta = -0.48$, $b = -0.80$, $t(128) = -1.83$, $p = .069$). When examining all toddlers from homes where English is spoken at least 50% of the time ($n = 36$), regardless of knowledge of the words "duck" and "bunny", the same pattern of findings emerged (see SI).

Next, we examined the toddlers' expectations for the actor's actions in the test phase. As a group ($n = 38$), the toddlers looked longer when the actor acted consistently from his own perspective ($mean_{same\text{-}to\text{-}actor} = 20.12$ s, $SD = 10.46$ s) than when the actor acted inconsistently from his own perspective ($mean_{different\text{-}to\text{-}actor} = 17.35$ s, $SD = 9.58$ s) ($\beta = -0.28$, 95% of β [-0.50, -0.07], $b = -2.87$, $t(153) = -2.56$, $p = .011$; Fig. 3), providing evidence that they drew on their own perspective, not the actor's perspective, in inferring the actor's goal. This finding remained significant when examining the toddlers from English-speaking homes whose caregivers reported that they knew at least one of the words "duck" and "bunny" ($n = 24$, after the session of one participant was terminated early; $\beta = -0.39$, 95% of β [-0.67, -0.11], $b = -3.79$, $t(98) = -2.70$, $p = .008$).

Thus, despite some evidence that the toddlers recognized the pictures as animals of different kinds in different orientations, and despite the evidence they received that the perceived animal changed upon rotation of the picture, the toddlers failed to take account of the actor's distinctive perspective on the pictures, and therefore his distinctive experiences of the pictures. Experiment 6's findings conceptually replicate those of Experiments 1 and 3–5, and they provide further evidence that when the toddler's own perspective differs from that of an actor, they interpret the goal of the actor's action in accord with their own perspective rather than the actor's perspective.

It is possible, however, that toddlers are more sensitive and attentive to human faces than to animal faces, and that two aspects of the methods of Experiments 1 and 3 served as barriers to their ability to infer the actor's goal from his own perspective. First, in Experiments 1 and 3, the test trials presented not only the actor's new perspective but his familiar perspective on the pictures: Both perspectives occurred on every loop of every test trial, as the actor moved from his initial position to his new test position while the pictures were present. It is possible that this aspect of our design confused the toddlers, hindering their ability to reason about other actors' experiences of objects that differ from their own. This explanation cannot account for the results of Experiments 4–6, in which the pictures were not present at the beginning of the test trials, but it could account for the findings of Experiments 1 and 3. Second, in all the experiments described thus far, the actor's perspective changed while the toddler's perspective remained the same. It is possible that toddlers will take account of an actor's perspective if that perspective is constant and it is the toddler rather than the actor who moves. Experiments 7 and 8 were conducted to test these possibilities.

12. Experiment 7

The method of Experiment 7 was the same as that of Experiments 1 and 3 except as follows: A single orientation trial was interposed between the familiarization trials and the test trials. In this orientation trial, the actor moved from the far to the near side of the room, just once, with no pictures present. Thus, in each test trial, the actor appeared only at the new position and facing direction: his final position at the end of the orientation trial. If toddlers infer the actor's goal in accord with their own perspective, then they should look longer at the test event in which the actor behaved consistently from his perspective, rather than their own perspective, at test. In contrast, if toddlers appreciate others' distinctive experiences but failed to do so in Experiments 1 and 3 because the test events presented the actor as having two perspectives on each test trial, then the toddlers in this experiment should look longer when the actor behaves inconsistently from his own perspective at test.

12.1. Method

12.1.1. Participants

Thirty 14- to 15-month-old toddlers contributed data to the experiment (mean age = 14.91 months; range = 13;11–15;28; 17 girls, 13 boys). No participants met the preregistered exclusion criteria.

12.1.1.1. Demographics. In Experiment 7, most participants (n = 27) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants, recruited via ChildrenHelpingScience.com. About 37% of the participants' caregivers completed demographics questionnaires. Approximately 45% of these participants were White, 36% were Asian, and 18% were multiracial.

12.1.1.2. Sample size justification. We used the data (n = 40) from Experiment 1 and Experiment 3's Experimental Condition for a power analysis to determine an appropriate sample size. We found that with 28 toddlers, we would have 80% power to detect a difference in looking times based on trial type. More caregivers responded than anticipated, resulting in the present sample.

12.1.2. Displays

The displays were the same as those of Experiment 1, except as follows. First, immediately after familiarization, there was a single orientation trial, involving no pictures. Here, the actor began sitting on the far side of the room and facing the center of the room, as in familiarization. Then, while facing forward, the actor moved from the far to the near side of the room and turned 180° to again face the center of the room. This video took 4 s, and all action then paused for a fixed duration of 10 s before moving on to the test trials.

Second, relatedly, the actor was positioned on the near side of the room, facing the center of the room, throughout the test trials.

12.1.3. Procedure, coding, and analyses

The procedure and coding were the same as those for Experiment 1 for the familiarization and the test trials. Coding began when the actor reached for a picture for the first time in each trial. The orientation trial was not toddler-controlled in length; it was shorter to reduce fussiness in toddlers. Some previous studies of goal attribution have similarly not involved infant-controlled orientation trials (Luo & Johnson, 2009; Woodward, 2003). We ran a mixed-effects model exactly like that of Experiment 1. The data were log-transformed before inclusion into the model because a lognormal distribution fit the data better than did a normal distribution.

13. Results and discussion

As in Experiment 1, the toddlers looked longer at actions that were consistent with the actor's perspective ($\text{mean}_{\text{same-to-actor}} = 11.36$ s; $SD = 8.97$ s; $\text{mean}_{\text{different-to-actor}} = 8.48$ s; $SD = 7.59$ s; $\beta = -0.44$, $b = -0.40$, $t(122) = -3.11$, $p = .002$; Fig. 3), providing evidence that they had inferred the actor's goal in accord with their own perspective on the pictures. These findings provide evidence against the possibility that toddlers in Experiments 1 and 3 had failed to appreciate the actor's distinctive experiences because the actor had exhibited two different perspectives on each test trial. Instead, toddlers privilege their own egocentric perspective in attributing goals to other actors.

We next tested the possibility that toddlers would interpret the actor's actions in accord with his own distinctive experience of the object on which he acts if the experiment were simplified in one further respect. Older children have been found to perform less egocentrically in reasoning about another individual's perspective on a picture if they themselves move to the location of that individual (Huttenlocher & Presson, 1973), instead of attempting to imagine how the world looks from that individual's position. Accordingly, it is possible that toddlers will reason better about an actor's experience if it is the toddler, rather than the actor, who moves to a new position in the room and experiences the change in the picture's appearance. Experiment 8 was undertaken to test this possibility.

14. Experiment 8

In Experiment 8, we adapted the methods of Experiments 1 and 7 for in-person testing. Instead of moving to the near side of the room in each test trial, the actor remained in a constant position throughout the experiment. Because the experiment occurred in person, we were able to move the toddlers around the room after the last familiarization trial, so that it was their perspective, rather than that of the actor, that changed between familiarization and test (Fig. 4D).

This procedure preserves the essence of the procedures used in the previous experiments, because the perspectives of the actor and toddler continue to differ during familiarization and to align at test. The procedure likely makes the toddlers' task more comprehensible and easier to perform, however, for two reasons. First, it allows them to experience a change in their own perspective on the pictures from familiarization to test. Second, the actor's perspective remains constant from familiarization to test. Thus, Experiment 8 served as a crucial test of toddlers' understanding of others' experiences. If they possess such understanding and use it to infer the goals of other agents' actions, then they should expect the actor to act consistently from his own perspective. In contrast, if they lack such understanding and infer other actors' goals from what they have and have not seen (Experiment 2) but not from how they have and have not experienced what they have seen (in Experiments 1 and 3–7), then they might expect the actor to act consistently from their current perspective.

14.1. Methods

14.1.1. Participants

Thirty 14- to 15-month-old toddlers contributed data to the experiment (mean age = 14.40 months; range = 13;15–15;30; 14 girls, 16 boys). No participants met the preregistered exclusion criteria.

14.1.1.1. Demographics. In Experiment 8, all participants were part of our lab database of children who were based in the greater Boston area at the time of their birth. About 73% of the participants' caregivers completed demographics questionnaires. Approximately 50% of these participants were White, 23% were Asian, and 27% were multiracial.

14.1.1.2. Sample size justification. We decided on a target sample size of 28, as in Experiment 7 (see above for power simulations). More caregivers responded than anticipated, resulting in the present sample.

14.1.2. Displays

As in Experiments 1–7, there were 6 familiarization trials and 6 test trials. In contrast to Experiments 1–7, the present displays were presented live and in person, rather than in prerecorded videos, and the test trials involved a change in the toddler's position and facing direction, rather than a change in the position of the actor.

The use of a live actor necessitated some changes to the displays and procedure, as described here. The familiarization trials began with the actor seated facing the toddler, facing two pictures of faces, one upright and one inverted. The actor was present in the room before the caregiver and the toddler entered the room. The pictures (each 8.5 by 11 in.) lay on small green boxes (5.5 in. in height) to make them more visible from the toddler's position in both familiarization and test. Because the actor had been a stranger in Experiments 1–7, we did not introduce the toddlers to the actor for this experiment, and the actor never looked at or spoke to the toddler or caregiver. The toddler and their caregiver were seated in a chair either ~40 in. in front of the actor (in familiarization trials) or ~ 25 in. behind the actor (in test trials). (We increased the space between the toddler and the actor in familiarization so that the pictures could fit in that space and be visible from the toddler's sitting position.)

We used the same pairs of faces as in Experiments 1–4 and 7. As in Experiments 1, 3, 4, and 7, toddlers viewed each pair of faces in one pair of trials, and in familiarization, the pictures of faces in each pair of trials rotated 180° from the first trial to the second trial in the pair. Because this experiment took place in person, an experimenter entered the room to rotate the pictures (in even-numbered familiarization trials) and to put down new pictures (in odd-numbered familiarization trials and before each test trial). The pictures remained stationary throughout each trial.

As in previous studies, the actor repeatedly reached for faces of a certain orientation to him (upright or inverted, counterbalanced between toddlers during familiarization and alternating between the two orientations at test). After contacting one picture, the actor remained stationary until the child looked away from the actor for 2 s. The actor reached only once on each trial in Experiment 8, as in the experiments by Woodward (1998).

Before the test phase, the last pictures were removed and the toddler and caregiver moved to the other side of the room, behind the actor, approximately aligning the child's perspective with that of the actor. Thus, during the test phase, pictures that would have been upright to the toddler from the toddler's earlier position were now inverted, and vice versa. In alternating test trials, new faces appeared, and the actor reached for faces that were either of the same orientation to him (Same-to-Actor trials) or a different orientation to him (Different-to-Actor trials), relative to the familiarization trials. Different-to-Actor trials involved the actor acting on faces that were the same in orientation to the toddler as the faces that the toddler had seen the actor reach for during familiarization.

Counterbalancing was identical to that of Experiment 1.

14.1.3. Procedure

There were several differences in procedure due to the use of live events. First, data collection occurred in person, with the toddlers observing a live actor who reached for the pictures. The toddlers sat on their caregiver's lap, with the caregiver's eyes closed. Each caregiver received instructions to reduce their influence on their toddler's behavior. Following the familiarization phase, an experimenter removed the pictures from the room and asked the caregiver to open their eyes and then stand up with their toddler. The experimenter then moved the caregiver's chair to the part of the room behind the actor, the caregiver and toddler moved to the new chair and the experimenter asked the caregiver to sit back down with the toddler on their lap and to close their eyes again. There were two cameras capturing the toddler's face throughout familiarization and test, allowing for live looking time coding.

14.1.4. Coding and analysis

Immediately before both the familiarization phase and the test phase, before there were any pictures but after the toddler was seated, an experimenter used a squeaky toy to help the coder determine how the toddler looked when looking at the actor or at the location of the pictures. The coder observed a live video feed in an adjacent room.

On all trials, after the actor reached for a face, he produced a clicking sound with his tongue and the roof of his mouth, all motion stopped, and the coder (naïve to all events) coded looking time, using jHab (Casstevens, 2007). Coding was otherwise like that of Experiment 1: The coder observed a live video feed of the toddler, and the trials continued until the toddler had looked away for 2 consecutive seconds or 30 total seconds had elapsed. When the trial was over, the actor retracted his hand before the experimenter re-entered the room to rotate or replace the pictures. We ran a mixed-effects model like that of Experiment 1. The data were log-transformed before inclusion into the model because a lognormal distribution fit the data better than did a normal distribution.

14.2. Results and discussion

The toddlers in Experiment 8 showed the same pattern of looking as in the previous experiments: They looked longer at the actions that were consistent with the actor's perspective (and inconsistent with their own) ($mean_{same\text{-}to\text{-}actor} = 6.46$ s; $SD = 3.88$ s) than at the actions that were inconsistent with the actor's perspective (and consistent with their own) ($mean_{different\text{-}to\text{-}actor} = 5.50$ s; $SD = 3.57$ s) ($\beta = -0.24$, 95% of β [−0.47, −0.02], $b = -0.15$, $t(139) = -2.13$, $p = .034$; Fig. 3). These findings conceptually replicate the evidence, from Experiments 1 and 3–7, that toddlers interpret the actor's action in accord with their own experience of the pictures on which he acts, rather than in accord with the actor's experience.

In Experiment 8, we had sought to simplify the toddlers' task, by use of a method in which the actor's perspective was constant throughout and the toddlers themselves experienced a change in their own perspective. Nevertheless, the toddlers interpreted the actor's actions in familiarization in accord with their own perspective rather than in accord with the perspective of the actor. In contrast to the findings of studies with older children (Huttenlocher & Presson, 1973), toddlers remain egocentric even when they move to new positions in the array and reason about an actor whose position and actions do not change.

Across seven experiments, therefore, toddlers gave egocentric interpretations to the actions of an actor on pictures of faces and animals that were visible both to the toddlers and to the actor but that should have been experienced differently. These experiments nevertheless raise a further question: Would older children also fail to interpret an agent's actions in accord with his own distinctive experiences, when presented with the events from the present experiments? Although past research has tested children's understanding of others' experiences of objects and pictures from different facing directions (Birch & Bloom, 2004; Flavell et al., 1981; Masangkay et al., 1974; Piaget & Inhelder, 1956; Surtees et al., 2012), no experiment, to our knowledge, has involved upright and inverted faces or the present version of the rabbit-duck illusion. The use of the present stimuli may be especially difficult for children, because inverted faces are hard to process for adults and children alike (Morton & Johnson, 1991; Slater et al., 2010; Thompson, 1980; Valentine, 1988), and because ambiguous pictures like the rabbit-duck illusion are likely unfamiliar to children, who rarely encounter them. Toddlers' failures to infer the perspective of the actor therefore may have stemmed from the novelty or difficulty of the displays used in these studies. In an initial attempt to address this concern, we presented the displays and remote testing procedures of a subset of our experiments to a group of 4- and 5-year-old children, and we assessed their interpretations of the actions by means of simple verbal questions.

15. Experiment 9

Experiment 9 used remote video conferencing to present 4- and 5-year-old children with a subset of the displays from our previous experiments. We chose to test children of this age, because this is the youngest age at which children have consistently succeeded in previous studies probing their explicit understanding of others' experiences; children a year younger have failed (Birch & Bloom, 2004;Flavell et al., 1981; Masangkay et al., 1974). For example, 4- and 5-year-old children, but not 3-year-old children, correctly infer that a picture of a turtle that is upright to them is inverted to a person who views the picture from the opposite direction (Flavell et al., 1981; Masangkay et al., 1974).

Nevertheless, there are at least five differences between the methods of Experiments 1 and 3–7 and the methods of previous experiments by Flavell, Masangkay, and colleagues. First, whereas the present experiments presented toddlers with two pictures per trial, the previous experiments often presented toddlers with a single picture per trial: arguably, a simpler situation. Second, whereas the present experiments probed toddlers' nonverbal expectations of action at test, the previous experiments include verbal tasks in which children answer questions about what the experimenter sees (e.g., "Do I see the turtle right side up, or do I see the turtle upside down?"). Third, whereas Experiments 1 and 3–7 involved the actor moving so that his perspective changed between familiarization and test (from different to consistent with the actor's perspective), the experimenter in the previous experiments maintained a constant position during the verbal tasks (always with a different perspective from that of the child). Fourth, as noted above, the present studies manipulated the orientations of faces and heads: Stimuli for which non-canonical orientations can be hard to process. Finally, the classic experiments were conducted in person, before the emergence of methods for testing children via remote video conferencing. In light of these differences, children may have greater difficulty reasoning about the actor's perspective in our tasks. Experiment 9 tested that possibility by presenting the displays of the previous experiments to children over video conferencing and probing their understanding of the events by verbal questions similar to those used in the literature cited above.

Experiment 9 had two phases: one focused on upright and inverted pictures of human faces and one focused on the rabbit-duck pictures. In familiarization for the human faces phase, we used the familiarization events from Experiment 1. An actor sat facing two pictures of human faces: one upright and one inverted to him (and oppositely oriented to and experienced by the child). The actor repeatedly reached for faces in a particular orientation. In each test trial, the actor moved so that his perspective aligned with that of the child, and an experimenter asked the child to predict for three pairs of pictures of faces which one the actor would like more and reach to. That is, the test trials of Experiment 9 did not depict reaching by the actor; instead, we asked the children to predict the actor's actions. The experimenter did not ask children to explain their predictions and did not refer to the pictures' orientations, so as to avoid unintentionally influencing children's behavior. We did, however, ask children to explain their predictions for the rabbit-duck phase (see below).

In familiarization for the rabbit-duck phase, we used the familiarization events from Experiment 6, except that the videos were paused before the actor rotated the pictures; children therefore saw no rotated pictures. By using the videos from Experiment 6 (involving only black pictures), rather than Experiment 5 (involving multicolored pictures), we reduced the variability in the pictures that the actor acted upon and in the actor's seating position. During familiarization, the actor repeatedly reached for pictures at a particular orientation to him that was distinct from the orientation of those pictures to child: The picture that appeared as a rabbit to the child instead appeared as a duck to the actor, and vice versa. In the single test trial, the actor moved so that his perspective on two rabbit-duck pictures aligned with that of the child, and an experimenter asked the child (i) to predict which picture the actor would like more and reach to, and (ii) why the actor would do so (i.e., whether the actor preferred ducks or rabbits). We asked children to explain their predictions for the rabbit-duck phase because there was only a single trial, so this question would not influence children's responses in other parts of the experiment.

15.1. Method

15.1.1. Participants

Thirty-five 4- and 5-year-old children contributed data to the experiment (mean age = 5.24 years; range = 4.19–5.99; 19 girls, 19 boys). All children who participated heard English at least 50% of the time in their homes. Three additional participants were excluded entirely due to technical issues on the participant's computer ($n = 1$), caregiver interference ($n = 1$), and inattentiveness ($n = 1$). Additionally, 6 participants only contributed data to one of the two phases due to technical issues on the participant's computer ($n = 2$), caregiver or sibling interference ($n = 2$), and inattentiveness ($n = 2$). In addition to the caregivers' written and verbal consent, the children provided assent to participate.

15.1.1.1. Demographics. In Experiment 9, most participants ($n = 31$) were part of our lab database of children who were based in the greater Boston area at the time of their birth. The remaining participants were recruited via ChildrenHelpingScience.com. About 63% of the participants' caregivers completed demographics questionnaires. Approximately 59% of these participants were White, 27% were Asian, 5% were Hispanic, and 9% were multiracial.

15.1.1.2. Sample size justification. We determined a sample size of 24 based on power simulations on data from a pilot sample ($n = 8$) that had completed the human faces phase. We found that with 24 children, we would have 92% power to detect a significant difference at test. We therefore decided to have at least 24 children in our sample who had completed both phases of the experiment. More caregivers responded than anticipated, resulting in the present sample.

15.1.2. Displays

The children were presented with the familiarization videos used with the toddlers, but with distinctively colored bars adjacent to each of the two pictures (see below). In the human faces phase, there were three pairs of different pictures of faces in familiarization (as in Experiment 1), and the actor reached for a different face on each trial. The colored bars that were next to pictures allowed both the experimenter and the children to refer to them by their color (e.g., "the one on the purple side"). We varied the colors that were present in each trial, so that a color preference could not support the children's answering.

During each familiarization trial in the human faces phase, the experimenter described the actor as "Chad" (a name not shared by any of the participants nor their caregivers). At the end of each trial, the experimenter (whose face was hidden on the child's computer) asked the child: "Chad really likes how one of these pictures looks. Which picture does [he] like more: the one on the [color on the left] side or the one on the [color on the right] side?" The child's verbal answer served to confirm that the child paid attention on that trial.

Each of the test trials for the human faces phase began with the actor moving to the room's front and turning around, as in Experiment 1, and then looking down, where there were two faces, one upright and one inverted. The experimenter then asked: "Chad really likes how one of these pictures looks. Which picture do you think Chad likes more and will reach to: the one on the [color on the left] side or the one on the [color on the right] side?" There were three pairs of different pictures of faces in test (as in Experiment 1), all different from those of familiarization, and there were therefore three test trials. In each trial, we examined whether each child selected the picture that was the same in orientation to themselves or to the actor, relative to familiarization.

In the rabbit-duck phase, we again used colored bars to foster communication about the pictures. In two pre-familiarization rotation trials for the rabbit-duck phase, two pictures (one oriented like a rabbit, one like a duck) appeared on opposite sides of the screen (as in Experiment 6). The experimenter said: "One of these looks more like a [duck/rabbit]. Which one looks more like a [duck/rabbit]: the one on the [color on the left] side or the one on the [color on the right] side?" After the children identified one orientation as a duck and the other as a rabbit, the experimenter asked the child to predict whether each animal would look like the other upon being rotated (e.g., "If we turn this duck around, will it look like a rabbit?"). (The sides of the animals and the order of these questions were counterbalanced.) The experimenter then rotated the pictures. These pre-familiarization trials served to introduce the children to this version of the rabbit-duck illusion and to show the children that the picture could look like a duck or a rabbit, depending on its orientation.

In the familiarization trials for the rabbit-duck phase, the actor sat on the right side of a room (as in Experiments 5 and 6) where there were two rabbit-duck pictures: one oriented like a rabbit, one like a duck to the actor. Because the actor faced the center of the room, the pictures were in the opposite orientations to the child. The actor reached for pictures that were in a certain orientation to him. After he had reached for a picture in each trial, the experimenter asked the children: "Chad really likes how one of these pictures looks. Which picture does [he] like more: the one on the [color on Chad's left] side or the one on the [color on Chad's right] side?" These questions served to confirm that the children had been paying attention. Because there was only one pair of rabbit-duck pictures and the experimenter was able to confirm that children inferred the actor's preference, we only had four familiarization trials for the rabbit-duck phase.

The test trial for the rabbit-duck phase began with the actor moving to the room's front and turning around, as in Experiments 5 and 6, while no pictures were present. The actor then looked down, where two rabbit-duck pictures appeared, one oriented as a rabbit and the other as a duck. The experimenter then asked: "Chad really likes how one of these pictures looks. Which picture do you think Chad likes more and will reach to: the one on the [color on the left] side, or the one on the [color on the right] side?" Finally, the experimenter asked why the children made their predictions, and if they did not spontaneously mention that Chad prefers ducks or rabbits, the experimenter asked which animal Chad liked more. Because there was only one rabbit-duck picture, there was only one test trial, for which the experimenter asked these two questions. After the experimenter asked about which picture Chad liked more and would reach to, we examined whether each child selected the picture that was the same in orientation to Chad or in a different orientation to Chad (but the same in orientation to themselves), relative to familiarization. After the experimenter asked the child to explain their predictions, we recorded whether each child said that Chad liked the animal that he had reached to from his perspective or from the child's perspective, relative to familiarization.

15.1.3. Counterbalancing

The order of the two phases of this experiment was counterbalanced across the participants in this study. Otherwise, the counterbalancing for the familiarization trials of the human faces and rabbit-duck phases was the same as in Experiments 1 and 6. The test trials followed the counterbalanced design of Experiments 1 and 6, except that there were no reaching actions by the actor in the test trials to counterbalance. As mentioned above, instead of presenting reaching actions at test (as in the toddler experiments), we asked the children to predict which picture the actor would like more and reach to.

15.1.4. Procedure

The data collection occurred in children's homes, with the children observing stimuli displayed via screen-sharing over Zoom on a caregiver's personal electronic device (e.g., laptops). The children sat independently of their caregivers. The caregivers received instructions to set-up the experiment and optimize data collection: making the displays full screen, minimizing the videos of the experimenter and of the self, and reducing caregiver influence.

15.2. Results and discussion

We analyzed the human face and rabbit-duck phases separately. For the human faces, we first calculated the proportion of test trials on which each child demonstrated sensitivity to the actor's distinctive experience of the pictures: choosing the face that was consistent from the actor's perspective over the face that was inconsistent from the actor's perspective (but consistent with their own perspective). We examined using a one-sample t-test whether the proportion of answers on which the children ($n = 30$) chose the picture that was consistent from the actor's perspective differed from chance (50%). Here, the children demonstrated sensitivity to the actor's distinctive experience in 66.6% ($SD = 34.5\%$) of their answers ($t(28) = 2.60$, $p = .014$, $d = 0.48$).

For the rabbit-duck pictures, we ran binomial tests to determine whether children demonstrated sensitivity to the actor's distinctive experience above chance in their predictions and preference attributions (50%). We preregistered that we would analyze these data differently from the data from the human faces phase, because there was only one pair of rabbit-duck pictures in the test trials for this phase but three pairs of faces in the test trials of the human faces phase. In the rabbit-duck phase, children demonstrated sensitivity to the actor's experience in both their predictions (28/34; binomial $p < .001$; relative risk $= 1.64$) and preference attributions (25/34; binomial $p = .009$, relative risk $= 1.47$). Thus, unlike the toddlers in Experiments 1 and 3–8, the 4- and 5-year-old children succeeded at understanding how the actor's experience of the pictures differed from their own.

These findings provide evidence that the present displays and online methods are understood by preschool-aged children. Moreover, the children were able to consider the actor's experiences of pictures in their responses to the displays and events shown to the toddlers in the previous experiments. Because both the ages of the children and the outcome measure differed between Experiments 1–8, on the one hand,

and Experiment 9 on the other, we do not know whether one or both of these factors produced the change in children's responding. In either case, however, the findings of Experiment 9 suggest that the scenarios that we presented to toddlers were no harder to understand than are the classic scenarios used in explicit perspective-taking tasks that children first begin to pass at 4 or 5 years of age.

16. General discussion

The present experiments provide evidence for a limit to toddlers' early-emerging understanding of others' mental states. When the toddlers and an actor viewed the same pictures of human faces or animal heads from different directions, we found that the toddlers interpreted the actor's actions on the pictures in accord with their own, rather than the actor's, experiences of the pictures. In contrast, using the same method, pictures, and spatial arrangements, we found that toddlers appreciated when objects that were visible to themselves would be hidden from others, and they leveraged this understanding in inferring the actor's goal over a change in his position and direction, consistent with previous research (Choi et al., 2018; Luo & Baillargeon, 2007; Luo & Johnson, 2009). These contrasting findings ruled out many potential sources of toddlers' failure to take account of the actor's distinctive experiences of the pictures in inferring his goal.

The toddlers' failure to appreciate the actor's visual experiences of the objects is striking, because it manifested itself not as random responding but as systematic responding in the wrong direction: The toddlers used their own perspective in reasoning about the actor's goals. The toddlers' performance was highly systematic in Experiments 1 and 3–8: The toddlers interpreted the actor's actions in accord with their own visual experiences of the pictures that he acted on, even when the actor actively rotated the pictures (Experiment 3 and 6), the actor's actions did not conflict with toddlers' intrinsic preferences for upright faces (Experiment 4 to 6), the animal depicted in a picture depended on the picture's orientation (Experiments 5 and 6), and the actor was physically present with the toddlers (Experiment 8) vs. in a video on a screen (Experiments 1 and 3–7). Moreover, toddlers' failures cannot be attributed to the exceptional difficulty of our displays, because children, who were presented with these displays under the same conditions of video conferencing performed successfully, at the same ages, and using the same methods, as in classic studies of children's developing capacities for perspective-taking (Birch & Bloom, 2004; Flavell et al., 1981; Masangkay et al., 1974).

16.1. Evidence for a signature limit to mental state reasoning

Our findings stand in contrast both to the evidence for an implicit, early-emerging understanding of others' beliefs about objects' locations (e.g., Onishi & Baillargeon, 2005; Southgate et al., 2007) and identities (e.g., Buttelmann et al., 2015; Buttelmann & Kovács, 2019) and with proposals that infants are altercentric (Southgate, 2020). Recent research suggests that early capacities to represent others' false beliefs are fragile and unreliable (Fizke et al., 2017; Holland & Phillips, 2020; Kampis et al., 2021; Low et al., 2014; Low & Watts, 2013; Oktay-Gür et al., 2018; Phillips et al., 2020; Poulin-Dubois et al., 2018; B. Wang et al., 2015). In addition, most tasks from past research in the false belief literature can be solved by tracking whether an agent has seen an object change locations or another agent demonstrating the object's true function; that is, perceptual access to the location change or the object function differs between participants and the agent.

By contrast, in all the present experiments with toddlers except Experiment 2 (in which toddlers performed non-egocentrically), toddlers were presented with a situation in which they and another agent had equal perceptual *access* to the pictures that the agent acted on, but their perceptual *experiences* of those pictures differed because of differences in the orientations of the actor and the child. Taken together, the present findings support claims for the existence of a signature limit to early mental state reasoning that applies not only to adults and young children but also to toddlers (Apperly & Butterfill, 2009; Butterfill & Apperly, 2013; Spelke, 2022). These findings also are consistent with the claim that separate systems of core knowledge guide reasoning about people's actions and their shareable experiences (Spelke, 2022). At least in the context in which we tested toddlers, toddlers appear to be insensitive to an actor's visual experiences of objects when those experiences differ from their own.

16.2. Open questions

The toddlers' failure to appreciate this feature of action understanding raises key questions for future research. One question concerns the generality of this limit across species: Do young or adult non-human animals show the same limit to their mental state reasoning as do toddlers, or does their reasoning transcend that limit, as it does in verbal tasks for older children? Because many species of non-human animals attend more to upright than to inverted faces (Guo et al., 2003; Rosa-Salva et al., 2010; Tomonaga, 1994) and their recognition of faces is impaired by inversion (Kendrick et al., 1996; Parr et al., 1998; Racca et al., 2010; M.-Y. Wang & Takeuchi, 2017), the present experiments introduce methods that can serve to probe the nature and evolutionary origins of this aspect of mental state reasoning.

A second question concerns the generality of the limit to toddlers' mental state understanding across contexts. Insight into this question may come from considering the circumstances in which older children and adults reason about others' experiences. When older children and adults are engaged in social interactions with others, they can overcome differences between theirs and others' experiences through communication. Language is a primary means by which people express and share their diverse experiences of objects and events with their social partners (Bartsch & Wellman, 1995; Clark, 1996; Grice, 1969). For example, when one adult is facing another adult and they are trying to coordinate, one might clarify to the other that one's left is the other's right, or that text that appears upright to one on a table is instead inverted to the other.

There are two ways in which the present experiments differed from this example of how people can overcome differences in their experiences. First, in all the present experiments, toddlers viewed an actor in a non-social context: The actor never engaged with the child, the child's caregiver, or any other agent. Because even young infants respond to others' behaviors that convey their states of attention and emotion, it is possible that toddlers will be more sensitive to others experiences of objects if they presented with an actor in a social context. Future research could explore whether toddlers would demonstrate increased sensitivity to others' distinctive experiences in contexts in which those experiences are socially relevant (see Woo and Spelke, 2023; Woo, Tan, Yuen, & Hamlin, 2023).

Second, in the present experiments, as in most past research on early goal attribution (e.g., Woodward, 1998; Woodward & Guajardo, 2002), the actor did not speak when acting on objects. There was therefore limited information available to the toddlers concerning the actor's experiences of the objects. It is possible that toddlers can appreciate that different people have different experiences of the same objects, but they rely on language or other means of communication with others to determine what the others' experiences are. Because different people's experiences of objects often coincide, the assumption that others' experiences align with one's own may be rational in circumstances where one lacks language, or other means, to determine when experiences diverge. Consistent with this possibility, a large body of research has linked advances in children's mental state reasoning to advances in their mastery of language (Milligan, Astington, & Dack, 2007).

In sum, more research is necessary to chart the development of children's implicit and explicit understanding of others' distinctive experiences of objects. We look forward to research that probes the nature and sources of this limit to toddlers' mental state reasoning, as well as research exploring when and how the limit is overcome.

CRediT authorship contribution statement

Brandon M. Woo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Gabriel H. Chisholm:** Data curation, Methodology. **Elizabeth S. Spelke:** Conceptualization, Supervision, Writing – review & editing, Funding acquisition.

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Appendix A. Supplementary data

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