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Abstract

This study investigates how infants recognize agents and their goal-directed actions. Infants habituated to a hand reaching for a toy react more when the hand reaches for a new toy at the old location than for the old toy at a new location (Woodward, 1998). By 5 or 6 months, infants understand this action as goal-directed, but the data leave open whether their goal attribution is specific to human reaching, or signals a more general grasp of goal-directed action. To test this, we implemented a minimal, animated version of the paradigm. Infants were habituated to a square moving towards one of two circles. When the circles' locations were switched, infants reacted more to movement towards a new goal than a new location – but only if the square moved in a non-rigid, rhythmic motion (Michotte, 1963), not if it moved rigidly. Adults described the non-rigid motion as more animate and more goal-directed. The infant data suggest that they already interpret these 2-dimensional events in a similar manner. Overall, goal attribution extends to simple schematic motions, but not all self-motions. These results contribute to growing knowledge about the origins of social cognition.

Keywords: Cognitive development; human experimentation.

Introduction

Much recent work has focused on the perceptual basis and developmental origins of our understanding of the social/psychological world. Two central questions here are how we identify social/psychological agents, typically animates, and how we make sense of these agents' actions. The actions of inert objects are organized by physical law, but animates' actions are often goal-directed: We tend to treat two actions as similar if they have the same goal, even if they are not close in terms of their physical parameters.

To investigate how agents and their actions are perceived it is particularly useful to study infants, because they lack much experience of the social world and its conventions. Adults' understanding of goal-directedness owes a lot to familiarity with particular actions, typical reasons for engaging in them, and their goals. Infants' abilities, however, are likely to reflect, in part at least, perceptual cues and possibly innate structural reasoning principles.

Traditionally, infants' grasp of agents and their actions was studied in the context of how they act and interact socially, with their understanding seen as derived from such experiences (e.g., Tomasello, 1999). Young infants' social interactions do not show many signs of understanding that others have goals and intentions until the end of the first year when triadic interactions become much more widespread (e.g., Carpenter et al., 1998). Even then, however, the interaction data are not clear on whether infants react to others' goals and intentions or merely to their overt actions (Moore & Corkum, 1994). On the other hand, infants could have much earlier understanding, with limited action/interaction skills preventing them from expressing it. Recently, therefore, researchers have begun to study infants as observers of, rather than participants in, goal-directed action and interaction, to unconfound ability to engage with the social world from understanding of it.

A number of such studies suggest quite sophisticated social/psychological understanding by the end of the first year. Gergely and colleagues (Gergely, Nadasdy, Csibra & Biro, 1995; Csibra, Gergely, Biro, Koos & Brockbank, 1998) showed that 9- but not 6-months-olds recognize goal-directed actions even when animated shapes rather than humans are involved. Infants were habituated to a circle that jumped over an obstacle to reach another circle. Upon removal of the obstacle infants dishabituated more when the circle took the familiar, but now unnecessary, curved path to the target than when it used a novel, but direct straight path. This suggests that infants saw the movement as goal-directed and evaluated whether it was efficient in this environment.

Kuhlmeier, Wynn and Bloom (2003) showed that 12- but not 5-months-olds can even extrapolate from goal-directed action in one physical context to another context with a different goal. They habituated infants to an animation in which a ball climbed up a hill, either helped or hindered by another shape that pushed it up or down. Upon test, infants preferred to look at the ball sidling up to the stationary helper than the hinderer, even without the hill present By the end of the first year infants thus seem capable of quite elaborate reasoning about goal-directed actions.

Evidence from half-year-old infants pertains to simpler forms of goal-directed action. In Woodward's (1998, 1999) now classic paradigm infants are habituated to a hand reaching for one of two toys. When the location of the toys is eventually switched, infants as young as 5 to 6 months dishabituate more if the hand reaches for a new toy at the old location than for the old toy at the new location, i.e., they treat an action physically identical to the habituation event, but different in its goal as more novel than an action that is physically less similar, but has the same goal. Infants do not react in this way if a mechanical claw rather than hand reaches for the objects or if the back of the hand just touches the objects. Thus, these very young infants may see reaching as goal-directed, but their understanding could be limited to familiar, human action, for which they may even have dedicated neural mechanisms (Gallese, 1996).

Other work (Schlottmann & Surian, 1999; Schlottmann, Surian & Ray, under review; Schlottmann, Ray & Surian, 2002) found that 6-months-olds react more to the reversal of a reaction event -- in which a square appears to run away from another square chasing it -- than they react to reversal of the same motions separated by a brief pause. The reaction event appears as goal-directed action and reaction to adults and young children, but the delayed motions appear unrelated. (Kanizsa & Vicario, 1968; Schlottmann, Allen, Linderoth & Hesketh, 2002). Accordingly, reversal alters spatio-temporal structure in both events, but affects the causal agents only in the reaction. Increased attention to a reversed reaction thus suggests that infants are sensitive to its causal structure. We do not know definitely whether 6-months-olds, like older observers, also see the event as goal-directed because they could initially have a more general, unspecific notion of causality ('A does something to B') that does not clearly distinguish social from physical causality, but 12-months-olds see somewhat more complex action-and-reactions as goal-directed (Csibra, Biro, Koos & Gergely, 2003).

The apparent discrepancy between the ages at which infants succeed in these studies thus can be resolved in two ways: First, computational complexity could account for why only older infants reason about rational goal completion (Gergely et al., 1995, Csibra et al., 1998, 2003) or the implications of one action for the next (Kuhlmeier et al., 2003). In line with this, Kamewari, Kato, Kanda, Ishiguro & Hiraki (2005) showed that 6 months-olds attributed goals in the Gergely et al. (1995) paradigm when more agency cues were provided -- a human or robot performed the motions and the 3-dimensional display may also have helped. Alternatively, as outlined above, the data with younger infants have interpretations that do not imply a general understanding of goals.

The interpretations of these studies also differ in their implications for the origins of infants' ability to reason about goals. On the one hand, structural reasoning principles and perceptual agency cues may be available to infants independent of experience with actual social agents in the real world (e.g., Csibra et al, 1998; Premack, 1990), providing infants with mechanisms for learning about unfamiliar agents and actions. This view makes it easy to understand that infants (and older observers) readily attribute goals and other aspects of social agency to non-human objects and shapes. On the other hand, infants may learn from experience with the goal-directed actions of actual social agents (e.g., Meltzoff, 1995; Tomasello, 1999). The latter is more in line with traditional views, and with Woodward's (1998) findings that younger infants attribute goals to familiar actions and human agents only. To resolve this issue, more evidence is needed on the scope of goal-based reasoning when it first appears in infants.

Accordingly, we considered 6-months-olds' sensitivity to goal-directed action in Woodward's task when all references to reaching and humans are eliminated. At the simplest level, in this paradigm one object moves on a straight line towards another. This is the habituation stimulus in our study, which involved 2-dimensional shapes rather than hands and toys (Figure 1). If infants still react more to a new goal than a new location with such schematic motions, it suggests that even very young infants have some general ability to interpret action in terms of its goals.

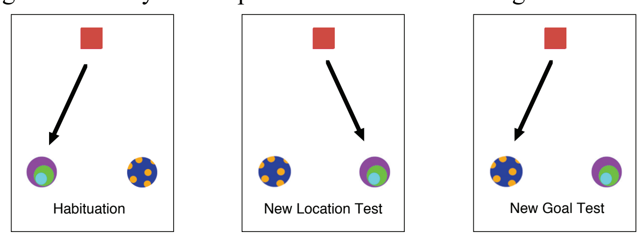

Figure 1: Schematic of the motions shown during a habituation, new location and new goal test trial.

Woodward's paradigm also provides a unique opportunity to study how infants identify the agents that can engage in goal-directed action. Many have argued that agents are perceptually distinguished from inert physical objects in that only agents can self-initiate motion and react at a distance (Leslie, 1994; Mandler, 1992; Premack, 1990). Of course, there are many other cues to agency, e.g., morphological cues, such as having a face and body orientation (Johnson, 2000) or the bio-mechanical manner of animate motion (Bertenthal, 1993). While infants are sensitive to these cues, evidence that they use them to identify agents is scarce. For instance, several of the studies previously described involved self-initiated motion, but when tested this turned out not to be crucial for the interpretation (Csibra et al., 1998; Schlottmann et al., under review). However, these studies involved complex motion configurations that might be sufficient in themselves for goal attribution. This would make the paradigms insensitive to the role of other agency cues. The simple event used here, in contrast, may provide a better test case because further agency cues may be necessary before a straight-line motion appears goal-directed.

In the present study, the motion of the red shape is always self-initiated. Apart from this, the event provides no cues to its interpretation other than that is repeated and selective, i.e., during habituation the shape always moves towards one and not the other target. In a second condition, however, we provided additional information: In particular, the shape did not move rigidly towards the goal, but turned to face in the direction of motion, then moved in a non-rigid, rhythmic manner that appears animate to adults (see Figure 2; Michotte, 1963, Schlottmann & Ray, 2004) and young children (Schlottmann et al., 2002). The present study thus begins to investigate how much information about agency infants need to attribute a goal. Is self-initiated motion sufficient or do infants need additional cues, for instance, that the agent moves in an animate fashion?

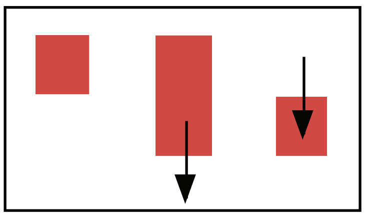

Figure 2: Schematic caterpillar motion

Method

Infants were habituated to rigid or non-rigid motion towards one of two circles, then circle location was switched, and infants were tested on both new location/old goal and old location/new goal motion. We also elicited verbal descriptions of both rigid and non-rigid motion from adults.

Subjects

The final infant sample consisted of 24 girls and 25 boys, ranging from 185 days to 215 days with a mean age of 200 days. Thirty-two further infants did not habituate, and 20 were excluded for non-compliance. The adult sample consisted of 40 females and 6 males, mostly undergraduate students in their early twenties.

Materials

Each event involved two colorful circles (100 pixels diameter) at the bottom left and right of the screen with a red square (70 x 70 pixels) centered at the top (Figure 1). After 30 stationary frames, it moved diagonally towards one circle, stopping after 72 frames with 13 pixels overlap between shapes and remaining in this position for 88 frames. The square moved either rigidly, without change in orientation, at a rate of about 6 pixels/frame. Or it turned over 6 frames to face the circle, then moved non-rigidly: The square first expanded over 10 frames at about 13.4 pixels/frame with the rear edge stationary, then it contracted over 10 frames with the front edge stationary until the original shape was recovered. It repeated these steps twice more, then returned to horizontal orientation.

The events were generated in MacromediaDirector. One 190 frame cycle took about 5.6 seconds, repeated for up to 10 times, with a 750 ms interval during which the screen turned grey. Each event existed in 4 versions: Left motion towards the purple circle, left motion towards the blue circle, right motion towards purple, and right motion towards blue. Two additional stimuli showed only the initial position of the shapes, with purple either on the left or right. These stationary stimuli, lasting up to 1500 frames, were used to familiarize infants with the switch in circle location.

Design and Procedure

Infants were habituated to either rigid or non-rigid motion, with the initial direction of motion and location of the circles approximately counterbalanced within groups. They were then shown the switched circle display and finally tested on 3 pairs of test trials, with the order of test trials counterbalanced. The overall design was a 2 (new goal or new location test) x 2 (rigid or non-rigid motion) x 2 (habituation motion to left or right) x 2 (habituation motion towards blue or purple circle) x 2 (new location test first or new goal test first) 5-factor mixed model factorial design, with type of test trial as the within-subjects factor.

Infants sat in a semi-dark room, on their caretaker's lap about 90 cm away from a LaCie monitor (21 inches diagonally view). Other equipment was hidden. Caretakers had no knowledge of purpose/design of the study and were told not to interfere with the infant. A camera above the monitor was centered on the infant's face; the experimenter observed the infant on video. A Macintosh G5 was used to control the display and record looking times.

Trials began with sounds and a flashing screen to attract attention to it. When the baby looked, the experimenter hit a key to start the movie and record onset of a look. When the baby looked away, the experimenter hit another key. If the baby looked away prior to the square reaching its target the trial was abandoned, otherwise it ended if the baby looked away for 2 s consecutively, or after 10 complete cycles. Habituation continued until mean looking time on 3 consecutive trials fell below half of the mean on the first 3 trials; the minimum number of trials was 6, the maximum 12. Another observer without knowledge of purpose/design of the study checked videos for a random third of the babies. The correlation of looking times measured on- and offline was r = .94, so reliability was high.

Adults were tested in groups, on one trial with non-rigid and one with rigid motion, presented in counterbalanced order (adults only saw left motion towards purple, repeated 15 times each). For each stimulus, observers briefly described in writing “what the red is doing”. Then they saw the switched objects display and predicted whether on the next trial red would move to the left or right; they were also asked to justify answers. All answers were coded for mention of animate agents, and for descriptions of clearly intentional or unintentional movement; disagreements between the two coders were resolved by discussion.

Results

Habituation

Looking times during habituation (Figure 2) decreased from 38.4 s on the first trial to 7.7 s on the last habituation trial for infants habituated to rigid motion (N = 22), and from

39.4 to 9.1 s for those habituated to non-rigid motion (N = 27). The only significant effect in the 5-factor ANOVA on looking times during the first 3 and last 3 habituation trials was a significant decrease across trials, F(2.734, 90.229 [Greenhouse Geisser]) = 53.419, MSE = 252.078 p < .001.

The groups did not differ in the number of habituation trials, 6.7 for rigid and 6.9 for non-rigid motion. However, the 4-way interaction was significant, F(1,33) = 6.276, MSE = 1.149, p = .017, with 3 contributing 2-way interactions. This was due to one of the 16 counterbalancing groups in which the number of habituation trials was 9, when it lay between 6 and 7 for the other 15 groups.

Looking times when the circles were initially switched, 16.9 in the rigid motion group and 12.5 s in the non-rigid groups, also did not differ significantly. There was a 3-way interaction: Infants that would see new location test trials first looked longest, 27.51 s, at the switched objects, but only if habituated to rigid motion towards a blue circle, while those habituated to non-rigid motion towards blue looked shortest, 8.85 s. In the other 6 counterbalancing groups infants looked at the switched objects for between 11 and 17 s. With these minor exceptions, however, the groups appeared largely equivalent during habituation.

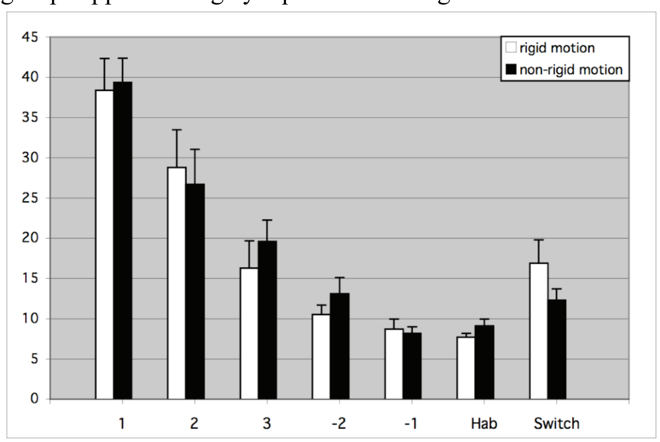

Figure 3: Mean looking times in seconds (and standard errors) for the first and last 3 habituation trials and for the stationary display of the switched shapes.

Test Trials

Looking times on the test trials are in Figure 4. Infants in the rigid motion group looked about equally long on both types of test trial, 32.77 and 30.57 s. Infants in the non-rigid motion group, however, looked longer when the shape moved towards the new goal, 45.67 s, than when it moved towards the old goal at a new location, 39.03 s. This pattern of looking led to a Trial x Type of Motion interaction, F(1,33) = 4.651, MSE = 551.94, p = .038, confirmed non-parametrically, Mann-Whitney U = 172, p = .012.

Follow-up tests found that infants in the non-rigid group looked longer at new goal trials, F(1, 19) = 4.496, MSE = 153.715, p = .047, but infants in the rigid group did not differ significantly, F < 1. The same pattern appeared non-parametrically, with z (Wilcoxon) = -2.354, p = .019 for non-rigid motion and z < 1 for rigid motion. The data therefore suggest that 6-months-olds reacted to an unexpected change in goal, but only when the shape moved in a non-rigid, apparently animate manner.

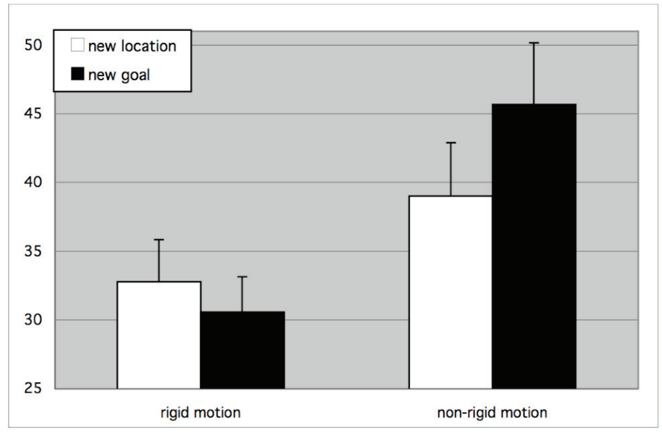

Figure 4: Mean looking times in seconds (and standard errors), summed over 3 new location and 3 new goal test trials.

In addition, the overall 5-factor ANOVA found a 4-way interaction between Type of Motion and the 3 counterbalancing factors, F(1,33) = 6.228, MSE = 2502.49, p = .018. The Type of Motion x Direction of Habituation Motion interaction, F(1,33) = 5.696, MSE = 2398.61, p = .02, and both main effects were significant as well, F(1,33) = 7.458, MSE = 2996.67, p = .01, and F(1,33) = 11.285, MSE = 4534.48, p = .002. Across both types of test trial, infants looked particularly long if habituated to non-rigid motion to the left. The 4-way interaction reflects that within this group, infants habituated to movement towards the blue circle looked longer when new goal preceded new location trials, but infants habituated to movement towards purple looked longer if new location trials came first.

Importantly, none of these effects interacted with the Trials factor. No qualification is therefore required of our main finding that infants treated the motion as goal-directed only if the agent appeared to move in a non-rigid, animate fashion. In fact, infants looked longer at new goal trials in 7 of 8 counterbalancing groups involving non-rigid, animate motion, but only in 2 of 8 groups involving rigid motion.

Adult Descriptions

The non-rigid stimulus elicited more animate descriptions (e.g., “crawled like a worm”, 48%) than the rigid stimulus (9%), p < .001 (sign test). It also elicited more intentional (e.g.,“uses effort to move to the bottom left”, 30%) and less unintentional (0%) descriptions than the rigid stimulus (19% intentional, 13% unintentional; e.g., “the red box floats down), p = .039. Thus, adult intuition about the meaning of the events is consistent with infant looking patterns. That the effects remain weak in spontaneous verbal report was to be expected (Schlottmann et al, 2005).

Adults expressed no clear expectations of what should happen when the circles were switched. Only 46% predicted that the non-rigid shape should continue to move towards the same goal; 41% did so for the rigid shape.

These predictions did not differ from each other or chance. In contrast to infants, adults may consider not only goals for which they have perceptual evidence, but they may go beyond to consider possible goal changes – or, in this case, how the display was programmed. Justifications for the predictions also did not differ between conditions; they often simply restated that red would continue to move towards the same side/circle.

Nevertheless, of those predicting movement towards the old goal, 43% mentioned the shape's or programmer's goal, when only 8% did so if they had predicted motion in the same direction. A further 17% of these said that red's motion was independent of the circles and/or that red couldn't detect the location switch; no-one predicting motion towards the old goal argued in this way. This difference in how predictions were justified was significant, Mann-Whitney U = 183 for non-rigid, 129 for rigid motion, both $p < .01$. Thus statements reflect that same-object-motion is likely to be intentional, while same-direction-motion is not.

All in all, therefore, adults' verbalizations indicate both that non-rigid motion appears more animate and goal directed to them, and understanding that continued movement towards an object that changes location is likely to be motivated by an unchanging goal. Such interpretations agree with the findings from infants.

Discussion

In this study, 6-month old infants appeared to attribute a goal to the motion of a square shape when it moved in a non-rigid, rhythmic manner, but not if it moved rigidly.

These results suggest that infants of this age seem to have a notion of goal-directed action that extends beyond simple familiar actions: They can apply this notion even to the movements of unfamiliar 2-dimensional shapes. Infants' grasp of goal directed reaching (Woodward, 1998, 1999) thus does not seem initially restricted to particular familiar actions of clearly human agents.

Nevertheless, infants do not see all repeated self-initiated motion towards one of two targets as goal directed: Here, infants did so only if the shape moved itself in a non-rigid, rhythmic manner seen as animate by older observers. Our data suggest that 6-months-olds may already see this motion in a similar way.

Previous work by Bertenthal (1993) showed even 3-months-olds are sensitive to bio-mechanical motion patterns in point-light displays and that infants distinguish them from jumbled displays with identical local motion. Such sensitivity alone does not, however, imply that infants use bio-mechanical motion as a cue to agency or animacy. In the present study, in contrast, the evidence is stronger, because a schematic form of bio-mechanical motion helped trigger early goal-based reasoning. This link suggests that infants take this style of motion as a cue to agency/animacy.

We do not know yet, of course, whether animate motion is sufficient to trigger reasoning about goals in this context. Our stimulus involved further cues, in particular, the object self-started its motion and oriented itself towards the target before moving towards it. We also do not know yet which aspect of the present motion pattern was effective. Infants might react to the motion's rhythm or its non-rigidity alone, or like older observers, they might see only particular non-rigid and rhythmic patterns as animate (Schlottmann & Ray, 2004). Work is currently underway to investigate this.

In contrast to animate motion, merely self-initiated motion did not trigger goal-based reasoning. This finding agrees with Shimizu and Johnson (2004), who used the Woodward paradigm to show that 12 months-olds saw the self-initiated motion of a 3-dimensional featureless oval object as goal-directed, but only after they had seen it turn to the experimenter, who conversed with it, and it responded by beeping. So the object interacted contingently at a distance with the experimenter and the experimenter endorsed its status by interacting with it. Without this, infants did not see the object as goal-directed, even if it beeped and moved itself in the same manner. Shimizu and Johnson's results fit with ours, but the study left open whether infants attribute goals to non-humans from early on or whether they learn this gradually by the end of the first year. It also left open whether the operative cues were perceptual in nature or depended on observation of the object in social interaction.

That self-initiated motion may play a smaller role in agent identification than initially proposed (e.g., Leslie, 1994; Mandler, 1992; Premack, 1990) also appeared in Csibra et al. (1998) and Schlottmann et al. (2005), reviewed earlier. Both studies found that self-initiated motion was neither sufficient for 9-months-olds' goal attribution in their control events, nor was it necessary in their experimental events. Finally, in Kamewari et al.'s (2005) study, 6-months-olds looked longer at a familiar curved motion, made irrational by removal of a previous obstacle, than an unfamiliar, but more rational straight motion if performed by a human or robot, but not by a block. In this case, self-initiated motion, even with additional evidence that the action was rational, was insufficient to trigger goal-based reasoning.

The only exception to this pattern is work by Luo and Baillargeon (2005). They found that 5-months-olds attributed a goal to a self-moving 3-dimensional block in the Woodward paradigm after seeing it repeatedly move back and forth across the stage. Infants did not attribute a goal to such a block, if familiarization trials (in a fixed trial rather than infant-led procedure) involved only one target, so that the block's movement towards it did not imply a preference of this target over the other. Thus observation of selective behavior also seems crucial for infant goal-attribution. Nor did infants attribute a goal if the block had a handle extending past the stage, so that it was not clear whether the block moved itself or not. This factor may have prevented infants from attributing a goal to the mechanical claw in Woodward's (1998) own studies.

Luo & Baillargeon's (2005) results may differ from all the other studies reviewed earlier because information about self-motion was far more salient in their study. In particular, in initial trials without targets the block moved back and forth across the screen on average more than 12 times, with second-long pauses between the motion phases. In the other studies, in contrast, the object simply moved itself towards the target without prior history of self-motion. Such simple self-initiated motion without further amplification does not appear sufficient for goal attribution. It remains to be seen what the effective component of Luo and Baillargeon's (2005) stimulus is: How extensive a history of self-motion is needed, whether this would or would not need to involve changes in direction or merely stop-go motion, or whether what matters is that infants attend to self-initiated motion over a sufficiently long period of time without distraction by the potential goal and motion towards it.

Be this as it may, the most important new finding in the present study was that even without a history of self-motion, and even in computer-animated, 2-dimensional events, 6-months-olds attributed a goal to a rectangular shape, as long as it moved itself in a non-rigid, rhythmic manner that older observers see as animate. Infants did not attribute a goal to the object moving itself in the rigid manner of an inert object. By 6 months, infants may thus perceive this non-rigid style of motion as a cue to agency/animacy.

Previous work on how infants might identify agents was hampered by lack of tasks that could show more than sensitivity to various cues. This problem can be overcome by testing their role in the Woodward (1998, 1999) paradigm: If a hypothesized agency cue can successfully trigger goal-attribution, this demonstrates its link to an early system for social/psychological reasoning. The present results agree with other recent data in their support of the view that infants have early access to domain-specific, abstract reasoning systems. Clearly a variety of perceptual cues or cue combinations, usually correlated with, but not necessarily tied to humans can trigger psychological/social reasoning. Future research is needed to measure cue strength and delineate effective cue combinations not just by example, but in principle.

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