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CHAPTER 17

The role of behavioral cues in understanding goal-directed actions in infancy

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Abstract: Infants show very early sensitivity to a variety of behavioral cues (such as self-propulsion, equifinal movement, free variability, and situational adjustment of behavior) that can be exploited when identifying, predicting, and interpreting goal-directed actions of intentional agents. We compare and contrast recent alternative models concerning the role that different types of behavioral cues play in human infants' early understanding of animacy, agency, and intentional action. We present new experimental evidence from violation of expectation studies to evaluate these alternative models on the nature of early development of understanding goal-directedness by human infants. Our results support the view that, while infants initially do not restrict goal attribution to behaviors of agents exhibiting self-propelled motion, they quickly develop such expectations.

Keywords: infancy; goal attribution; agency; animacy; action interpretation; intentionality

Introduction

Understanding actions in terms of the goals they are designed to achieve is a fundamental human faculty that emerges early in development (Biro and Hommel, 2007; Csibra and Gergely, 2007). How do infants decide whether a certain behavior is an ''action'' worthy of goal attribution? What classes of entities invoke infants' interpretation of the behavior of the entity in terms of goals? The central interest of this paper is the nature of the process involved in the identification of the entities that pursue goals. Categorization of entities is generally thought to be based on certain types of cues or features available through perception. Three types of observable cues have been hypothesized to form the basis of identifying the scope of goal attribution in infants (Table 1).

''Featural and/or biomechanical cues'' that correspond to the appearance and biomechanical movement properties of humans constitute the first type of cue. It has been proposed that specific cues, like human features such as eyes, a face, hands or body (e.g., Woodward, 1998; Legerstee et al., 2000), or biomechanical bodily movements such as facial expressions or manual acts (Meltzoff and Moore, 1997), can identify the class of entities whose behavior could be interpreted in psychological terms. The category that these cues are assumed to indicate is HUMAN.

The second type of cues are the ''Self-propulsion movement cues,'' which involve behavioral changes in the entity that occur without external

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Table 1. Three types of cues for identifying entities and behaviors that are to be interpreted as goal-directed

Types	Featural cues	Self-propelled movements	Context-sensitive behavioral changes
Cues	• Human surface features (such as eyes, face, hand, body) • Biomechanical movements (such as facial expressions, manual acts)	• Self-generated movement (starting to move by itself, changing speed or direction abruptly, non-rigid transformation) • Independent • Irregular • Unpredictable motion patterns	• Equifinal • Consistently adjusted • Efficient • Predictable motion patterns
Categorization/interpretation	HUMAN	AGENT	GOAL-DIRECTED ACTION

impact. Observing an entity starting to move by itself, abruptly changing its speed and direction, undergoing non-rigid transformation, or generally being capable of independent, irregular, unpredictable movements are all indication of self-propulsion and have been suggested to form the basis for identifying entities in the domain of naïve psychology (e.g., Premack, 1990; Mandler, 1992; Leslie, 1994; Gergely et al., 1995; Tremoulet and Feldman, 2000). The presence of these cues is hypothesized to trigger the categorization of an entity as AGENT.

While the first two cues identify *entities* that are normally engaged in goal-directed actions, the third type of cue single out *behaviors* that are likely to indicate goal-directed actions. These cues can be called "Context-sensitive behavioral changes." This type of cues are characterized by equifinality of the behavior (Heider, 1958), consistent adjustment to changes of the environment (Mandler, 1992; Csibra et al., 1999; Gergely and Csibra, 2003), and performing optimal and efficient actions toward certain states. These cues are assumed to indicate GOAL-DIRECTEDNESS. (See Table 1 for a list of characteristics of the three types of cues.)

The main theoretical questions of this paper are concerned with the relationship between the categorization of an entity and the interpretation of its behavior as goal-directed action. Does the categorization of an entity with one type of cue automatically and necessarily imply the attribution of further properties? For example, if infants have categorized an entity as HUMAN and/or AGENT, do they automatically interpret its actions as GOAL-DIRECTED? Or if infants have identified an action of an entity as GOAL-DIRECTED, would that imply that they consider the entity as an AGENT or HUMAN? What is the underlying mechanism of these possible inferential links? Are they based on pre-wired connections, learnt by registering statistical associations between the observable cues, or are they mediated by automatic simulation processes? Several theoretical accounts have been proposed concerning the relationship between the categorization of an entity and the interpretation of its actions as goal-directed. We will briefly review these theoretical approaches and then outline our position on these issues.

Theoretical accounts on the relationship between HUMAN and AGENT categories and GOAL-DIRECTED ACTION interpretation

"Human first" — cue-based approach

This approach claims that only those entities that can be categorized as HUMAN by featural and/or biomechanical cues belong to the domain of naïve psychology. If the observed entity does not display these cues, infants will not categorize it as human and will not proceed with attributing goals to its actions. Thus, the cue-based categorization of an entity as HUMAN is proposed to be a precondition for interpreting the behavior of the entity as GOAL-DIRECTED. Meltzoff and Moore (1997) proposed that the mechanism to infer further properties of human actions is based on innate simulation processes that are present at birth. These processes allow infants to automatically map observed actions to their own experience and then to project goals and intentions to others based on the relationship between their own acts and underlying mental states. Woodward (1998, 1999) also claimed the primacy of cue-based categorization of entities as HUMAN on the basis of featural cues in evaluating actions as GOAL-DIRECTED. However, she argued that infants learn *gradually* which human actions can be considered as goal-directed through experience with their own actions.

"Agent first" — cue-based approach

The second group of theoretical approaches assumes that the cue-based pre-categorization of the observed entity as an AGENT — on the basis of "Self-propulsion movement cues" — is a precondition for considering the action of the entity as GOAL-DIRECTED. Agents form a broader category than people and are not tied to any specific appearance. Agents are generally defined as a class of objects that have the capacity to be the causal source of events. Agency and its relation to other ontological properties have, however, been conceptualized in different ways in various theoretical accounts. For example, in Leslie's modular theory of agency (Leslie, 1994) self-propulsion defines the first subsystem, in which objects are categorized as mechanical agents with internal and renewable source of energy. The second component of this system — which receives its input form the first subsystem — deals with the actional properties of agents, such as attaining goals and reacting to the environment. Thus, "Context-sensitive cues" such as the repeated equifinal outcome of the agent's action is a useful behavioral cue at this level as it can be teleologically interpreted as the goal state. In contrast, other theories have proposed that the detection of self-propelled movement (Premack, 1990; Baron-Cohen, 1994) or contingent reactivity (Johnson et al., 1998) automatically triggers the interpretation of an entity as an intentional agent. Once an entity has been categorized as an intentional agent, infants can use further "Context-sensitive behavioral cues" to attribute various psychological properties such as goals, perception, or attention to the entity. All of these theories assume that the link from the category AGENT to GOAL-DIRECTED ACTION interpretation is "pre-wired."

"No primacy" — principle-based approach

We propose — as a third, alternative approach — that the interpretation of an action as GOAL-DIRECTED is initially independent from both HUMAN and AGENT categories (see also Csibra et al., 1999). In other words, an entity does not need to have been identified as HUMAN or AGENT in order to allow infants to evaluate its action in terms of goals. Furthermore, this approach claims that the basis of goal attribution is not cue-based but principle-based: the selection of entities belonging to a given domain is not dependent on specific perceptual cues but on the successful application of the central principle that is used to reason about the behavior of entities in that domain (cf. Carey and Spelke, 1994 for a contrast of cue-based vs. principle-based models). We have suggested (e.g., Csibra and Gergely, 1998) that a goal-directed entity can be identified by the successful application of a psychological interpretational system that represents the observed behavior of entities in teleological terms. This interpretational system is assumed to establish a specific explanatory relation among three representational elements: the actions, the goal state, and the constraints of physical reality. However, this representational structure forms a teleological representation only if it satisfies the "principle of rational action," which states that an action can be explained by a goal state if it appears as the most efficient action toward the goal state that is available within the constraints of reality. Therefore, we propose that certain "Context-sensitive behavioral cues" can inform about GOAL-DIRECTEDNESS inasmuch as they can be derived from the principle of rational action itself (see Csibra et al., 1999, 2003; Király et al., 2003). Finally, we believe that categorizing an entity as HUMAN or AGENT and interpreting its action as GOAL-DIRECTED are initially independent from each other, and infants create links between these concepts by gradual learning of the statistical correlations between the observable cues that indicate the three properties.

Our aim in this paper is to contrast these theoretical approaches. First we will review some empirical studies that have investigated the role of the three types of cues in categorizing and reasoning about entities, paying particular attention to what these studies revealed about the inferential link between them. Following this we will report two experiments that tested our hypotheses on the possible links between AGENCY categorization and GOAL-DIRECTED action interpretation.

Research on the inferential link between the categorization of HUMAN or AGENT and GOAL-DIRECTED action interpretation

There is no doubt that from early on infants show sensitivity to the three types of cues described above (see Table 1). Several studies have found that infants pay special attention to human featural cues such as faces, eyes, eye direction, facial expressions (e.g., Farroni et al., 2002, 2005), etc. Three-month-olds have been found to be sensitive to human biomechanical motion: they can differentiate between point-light displays of a human walk and random movement patterns (e.g., Bertenthal, 1993). Similar sensitivity was also shown to Self-propulsion and Context-sensitive behavioral cues. Five-month-olds can distinguish between movements that are self-propelled and movements that are caused by another object (Kaufman, 1997), and can discriminate between non-rigid and rigid transformations of objects (Gibson et al., 1978). Nine-month-old infants' sensitivity to the temporal and spatial characteristics of "causation at a distance" has also been demonstrated (Schlottman and Surian, 1999). As early as 2–3 months of age, infants also show sensitivity to the contingency between observed events and their own movements, or between the movements of two entities (Watson, 1979; Rovee-Collier and Sullivan, 1980; Rochat et al., 1997). What type of inferences can infants make about entities on the basis of these cues?

From HUMAN to AGENT

Some studies provide evidence for infants' ability to infer that an entity that had been categorized as human is capable of self-propelled movement or to show other characteristics of agents. For example, from 7 months of age, infants are surprised if an inanimate object starts to move without external force but not when people move by themselves (Golinkoff et al., 1984; Poulin-Dubois and Shultz, 1990; Spelke et al., 1995; Poulin-Dubois et al., 1996). Infants have also been shown to vary their own behavior (vocalization vs. engaging in manual search) in a "hide and seek" game depending on whether the entity is a human or an inanimate object (Legerstee, 1994). Pauen and Trauble (under review) demonstrated that when 7-month-olds observe a ball and an animal-like furry creature moving together in an ambiguous causal structure, they expect the animal to be able to move by itself and not the ball. Note that these findings cannot tell us whether the link from HUMAN to AGENCY is learnt or pre-wired.

From AGENT to AGENT/HUMAN

Another group of studies has used self-propulsion as the independent variable and tested if infants can use this cue to make further inferences about other agentive properties of the entity. Kaufman (1997) showed that 5-month-olds inferred that self-moving objects can reverse their trajectories while inert objects cannot. Luo and Baillargeon (2000) demonstrated that 6-month-old infants expect inert objects to be displaced when hit while self-propelled objects can "resist." Kotovsky and Baillargeon (2000) found that 7.5-month-old infants know that, in the case of an inert object, a contact with another object is necessary to make the object move. Note that in the above studies both self-propelled and inert objects had identical non-human features, hence infants' inferences were solely based on observable behavioral cues. Saxe et al. (2005) found that only if an object previously showed no evidence of self-propulsion do 10- and 12-month-old infants infer a hidden cause when they see the object move. (In this study, however, available featural cues might have also influenced this inference because the self-propelled object was a furry puppet with a face). These findings suggest that infants do not simply perceptually distinguish self-moving from inert objects but also categorize them as ''mechanical agents'' (Leslie, 1994). When infants witness an entity displaying one type of behavioral cue for agency (e.g., self-propulsion), they also expect the entity to exhibit other behavioral features that are typical of mechanical agents. Finally, there is a further study that might have provided evidence for the ''AGENT to HUMAN'' type of inference. Molina et al. (2004) demonstrated that 6-month-old infants inferred the identity of a hidden entity (person vs. ball) on the basis of the type of action (speaking vs. shaking) another person performed to set the objects in motion. Thus, infants inferred that if an entity could move without external physical contact then it is a human.

From HUMAN to GOAL-DIRECTED ACTION

Several studies investigated the role of human featural cues in infants' ability to attribute goals. Meltzoff (1995), for example, showed that 18-month-old infants can successfully infer the goal and reenact a human model's intended act — but not that of a mechanical device — by observing the model's failed attempts to achieve the goal. However, Johnson et al. (2001) found that the model does not need to be a real person: 15-month-olds can imitate the intended action of a non-human agent as long as it has a face and exhibits behavioral agency cues such as self-propulsion and contingent reactivity.

Much recent research on goal attribution applied Amanda Woodward's influential paradigm to investigate infants' emerging ability to interpret action in terms of goals. In Woodward's original visual habituation experiment (1998), 6- and 9-month-old infants were presented with an action in which a hand repeatedly reached toward and grasped one of two toys sitting on a stage. After the infants were habituated to this event, the experimenter swapped the two toys behind a screen. In the test phase, the hand either grasped the same toy as before, which, however, was at a new location, or the other toy at the same location. Looking times for these two events were markedly different: both 6- and 9-month-old infants looked longer if the hand grasped the new toy at the old location than if it grasped the old toy at the new location. This result indicates that infants associated the grasping hand with the grasped object rather than with its location, i.e, they expected the hand to reach toward the same toy. In another version of this study, inanimate novel objects (such as a rod, a mechanical claw, or a flat occluder) replaced the human hand, and in subsequent studies (Woodward, 1999; Woodward et al., 2001) unfamiliar hand actions (the back of the experimenter's hand dropped on the target toy, or a gloved hand grasped the target toy) were used to approach the target toy. Woodward found that in these conditions 6- and 9-month-old infants looked equally long at the two test events (or longer in the old toy/new location event), suggesting that the infants did not selectively encode the goal object in the case of inanimate actors or unfamiliar hand actions.

These findings have been interpreted to show that young infants restrict goal-directed interpretation to human actions and, in fact, only to actions that are already familiar to them, such as grasping. However, Király et al. (2003) and Jovanovic et al. (under review) demonstrated that if the unfamiliar ''dropping the back of the hand'' action was accompanied with a salient action effect (the hand transferred the toy to another location) infants as young as 6 months were able to encode the goal of the action. Similarly, Biro and Leslie (2007) (Experiment 1) found the same positive result when ''equifinal variations'' were added as a behavioral cue to another unfamiliar action (a poking hand). These latter studies therefore suggest that the familiarity of the action is not a precondition for goal attribution, it is rather the availability of behavioral cues that determines whether infants are able to interpret an action as goal-directed. In the case of human actions, however, it is problematic to determine the exact role of different behavioral cues (i.e., Self-propulsion cues vs. Context-sensitive cues). Infants have ample experience with their own or others' observed hand actions which could allow them to associate various behavioral cues (such as self-propulsion, variability, adjustments, mechanical effects) with hands and rely on these associations when evaluating the goal-directedness of a hand action even when these cues are not present (for a similar argument concerning the basis of goal attribution in the case of the familiar grasping action, see Király et al., 2003; Biro and Leslie, 2007).

From AGENT to GOAL-DIRECTED ACTION

Several studies looked at the role of behavioral cues in goal attribution in the absence of human features. One group of these studies introduced behavioral cues to the inanimate actors in Woodward's paradigm. Luo and Baillargeon (2005) demonstrated that 5.5-month-old infants could interpret the action of a self-propelled box as goal-directed. A study by Shimizu and Johnson (2004) also found that infants can consider inanimate actions as goal-directed. However, in their study the infants could encode the goal of a novel, faceless, oval-shaped object only if, besides self-propulsion, it also exhibited contingent reactivity and a rotating movement along its axis. This axial turn gave the impression (at least for adults) that the object was making a ''choice'' by turning away from the non-target toy, i.e., it indicated that it can adjust its behavior for goal attainment. Biro and Leslie (2007) suggested that there is a developmental trend between 6 and 12 months in the extent to which infants rely on behavioral cues for attributing goals to actions of inanimate objects in the Woodward paradigm. They showed that the older age groups can rely on the simultaneous presence of two cues — self-propulsion and a salient action effect — to consider the action of a wooden rod as goal-directed. For the youngest infants, however, these two cues were not sufficient. Only when equifinal variations of the action in goal attainment were also provided did this group of infants attribute a goal.

In another group of studies 6-, 9-, and 12-month-old infants were shown animations of geometric figures. Gergely et al. (1995) (and Csibra et al., 1999) conducted a visual habituation study in which infants observed a small circle repeatedly approach and make contact with a large circle by ''jumping over'' a rectangular figure separating them in the habituation phase. Adults typically interpret this behavior as a goal-directed action, where the goal state is reaching or contacting the large circle. In the test trials the rectangular figure (the ''obstacle'') was removed. Infants saw either a novel action (the small circle approached the large circle in a straight line) that was the most efficient action toward the goal in the changed circumstances, or the already familiar jumping action which, however, was no longer the most efficient action to achieve the same goal state. Nine- and twelve-month-old infants showed less recovery of attention to the novel straight-line action, which indicates that they interpreted the action in the habituation event as goal-directed and predicted the most efficient action to achieve the inferred goal in the changed situation.

The actor exhibited several behavioral cues in these studies: self-propulsion (it started to move by itself and it changed direction), contingent reactivity and nonrigid surface movements (the two circles ''contracted'' and ''expanded'' in a contingent ''turn-taking manner''), equifinal variations in goal attainment (the positions of circles on the left vs. right side of the screen were varied), and situational adjustment of behavior in goal approach (the circle changed its path to jump over the obstacle). In the control condition of this study, infants saw the same event as in the habituation phase except that the rectangular figure (the ''obstacle'' in the experimental condition) was placed *behind* the small circle and so it did not block the small circle's direct approach route to get to the target circle (i.e., the block was not an ''obstacle'' anymore). In spite of this, the small circle performed the same jumping behavior (this time, however, jumping over nothing) as in the experimental condition to get to the target circle and so its target approach could not be interpreted as the most efficient action available to achieve its goal. Infants in this condition did not look differently in the two test events, i.e., they did not have any expectations about the small circle's future action.

Note that in the control condition the same behavioral cues were present — including those that indicated agency — as in the experimental condition, however, these cues themselves did not allow infants to interpret the action in terms of goals in the control condition.

Kamewari et al. (2005) also used the Gergely paradigm with 6.5-month-old infants in three different conditions involving real actors: a person, a humanoid robot, or a moving box. They found that infants attributed goal in the first two conditions, but not in the third. Csibra (submitted), however, hypothesized that even though the unfamiliar box has shown self-propulsion, this — in itself — may not have been a sufficient cue for young infants to attribute the final outcome state as the goal of the box's action, as the box had not exhibited any form of behavioral variability across trials in its manner of target approach. He, therefore, replicated the self-propelled box condition but added equifinal variations in goal approach (making the box go around sometimes on the right side while sometimes on the left side of the obstacle to get to the goal object) and found that under these conditions even 6-month-olds interpreted the action of an inanimate and unfamiliar object as goal-directed.

Summary

Two conclusions can be drawn from the research reviewed above. First, the categorization of HUMAN on the basis of featural cues does not seem to be an obligatory precondition for identifying the entity as an AGENT or for considering an entity's action as GOAL-DIRECTED. This has been shown by studies that demonstrated that infants are willing to interpret actions of entities in terms of goals or other agentive or psychological properties that display no human features. Second, there is converging evidence that the categorization of an entity as an AGENT is not sufficient for interpreting the entity's action GOAL-DIRECTED. Thus, the hypothesis that agency cues would directly trigger intentional action interpretation is not supported by the empirical evidence either. The studies we reviewed above, however, cannot tell if categorizing an entity as an AGENT is necessary for giving GOAL-DIRECTED interpretation to its behavior. Although many "Self-propulsion movement cues" and "Context-sensitive behavioral cues" have been used either in solo or in combination with others in these studies, no clear picture has emerged regarding the respective roles of particular behavioral cues in identifying goal-directedness. (This is mainly because the aim of these studies was not to systematically tease these cues apart, but to show that infants can make use of behavioral cues without featural cues in identifying goal-directed actions.) Thus, the "Agent first" (cue-based) and the "No primacy" (principle-based) theoretical approaches have not yet been contrasted with regard to the question whether or not infants must first embrace a prior ontological commitment that the entity in question is an agent for applying a goal-directed interpretation to its behavior. In the next section we will address this question by taking a closer look at the nature of the possible link between the categorization of an entity as an AGENT and interpreting an entity's behavior as GOAL-DIRECTED.

Three possible functional relations between AGENCY and GOAL-DIRECTEDNESS

Both the "Self-propulsion movement cues" that indicate an AGENT and the "Context-sensitive cues" that indicate GOAL-DIRECTEDNESS have been hypothesized to form the basis of perception of animacy in adults as well as in infants (see Scholl and Tremoulet, 2000, for a review). It seems, however, that these two types of behavioral cues sometimes contradict each other and so it would not be easy to build an animacy detector that could rely on both aspects of animacy simultaneously. Let us illustrate this computational problem by a study of Rochat et al. (1997). In that study infants were presented with two discs on a computer screen which were engaged in a "chase" event: one of them, the "chasee" changed its direction and speed unpredictably, while the other, the "chaser" followed it persistently, at a constant speed in a "heat-seeking" fashion. Young infants were able to discriminate this event from another one in which the two disks were performing the same individual movements but this time unrelated to each other's behavior. This suggests that they were sensitive to the presence of the cues embedded in the disks' behavior. One can, however, raise the question: which of the two objects did they consider animate? From the point of view of a "Self-propulsion cues" analysis, the chasee would be categorized as animate because it demonstrated self-generated, independent behavior, while the chaser could be considered as an inanimate object, a perfectly predictable, physical heat-seeking device. However, if infants were looking for "Context sensitive cues" to find an animate entity, the chaser would be considered animate because it adjusted its path consistently to the chasee's path in accord with the goal of catching it up. This example illustrates that coordinating these two aspects of animacy would pose a considerable computational problem for an automatic animacy-detector system.

Nevertheless, since as our adult intuition suggests that both "Self-propulsion" and "Context-sensitive behavior" cues may indicate objects that we treat equally as members of the unitary category of "animate" objects, it is plausible to assume the existence of some *functional* relation between them. This hypothesis can take different forms according to the nature and relative strength attributed to this functional link.

1. The "*Mandatory link*" *hypothesis*: Agent categorization *is required* for goal-directed interpretation of actions. According to this view, goals are attributed to objects *only if* the cues of "self-propulsion" are explicitly present.
2. The "*Exclusive link*" *hypothesis*: Categorization of an entity as non-agent *precludes* goal-directed interpretation of its actions. In this view, goals would not be attributed to objects that are explicitly perceived as being "non-self-propelled."
3. The "*Probabilistic link*" *hypothesis*: Agent categorization *biases* toward goal-directed action interpretation. This view holds that goals will be more likely to be attributed to objects that are perceived "self-propelled."

The "Mandatory link" hypothesis

The first version of this hypothesis, which assumes a mandatory relation between AGENCY and GOAL-DIRECTEDNESS, has already been tested (Csibra et al., 1999, Experiment 2). In this experiment, we sought to determine whether the presence of cues of "self-propulsion" is a necessary precondition for goal attribution in infants. To do so, we created a computer-animation that did not contain *any* information about the source of the motion of the object but still displayed signs of "goal-directedness" in terms of optimal adjustment of its behavior to the relevant changing aspects of the situation across trials. The object repeatedly "flew in" from outside of the screen (the source of the origin of its movement being thus always occluded from view). It always followed an inert, parabolic trajectory — as if driven only by gravitational forces — flying just over a rectangular "obstacle" in the middle of the screen and ending up at the same final spatial position making contact with a stationary target object, which was positioned at the other side of the screen. However, across trials the relative height of the trajectory of the flying object changed to optimally match the varying height of the "obstacle" in the middle, thus managing to fly just over it. This way, the variable behavior of the flying object could be considered to exemplify an efficient action to achieve the same final target position across trials under variable situational constraints. This aspect of the events may have provided sufficient basis for attributing the identical spatial end position reached across trials as the goal of the action.

Whether or not infants made this goal attribution was tested by the same logic that we used in our previous study (Gergely et al., 1995). During the test phase, we removed the obstacle and presented two alternative events to the infants: either the "Old Action" test event, which consisted of the same — already familiar — medium-high parabolic flight trajectory leading to the same end state as had been observed during habituation trials, or the "New Action" test event, which consisted of a novel straight line horizontal approach route to the target position that had become available only now that the "obstacle" has been removed. If infants attribute the final position as the goal of the object's actions, they should see the straight-line approach as being the most efficient action toward that goal in the new situation, hence being compatible with their previous goal-directed interpretation. In contrast, given the removal of the "obstacle" and the subsequent availability of a more efficient alternative new pathway to the goal, the sight of the "Old Action" test event should be considered unjustified and incompatible with the previously attributed goal.

Looking patterns of both 9- and 12-month-olds suggested that this was, indeed, the case. Both age groups looked significantly longer at the familiar "Old Action" event, and an appropriate control condition demonstrated that this could not have been due to an inherent preference toward watching the "Old Action" event over the "New Action" event. These results suggest that positive perceptual evidence indicating that an object's movement is self-propelled is not a necessary precondition for attributing a goal to its behavior. Rather, it seems that infants can recognize the "pure reason" (Csibra et al., 1999) manifested in the observable pattern of justifiable variability of the object's actions in relation to the changing constraints of the situation, which, in itself, may provide sufficient information for goal attribution.

One could object, however, that although the object's observable behavior in these events did not display any direct sign of self-propulsion, it did not exhibit positive evidence to the contrary either: the object's behavior after all *could* have been actually self-propelled for all we know. On this ground, one could still argue that there is a mandatory connection between self-propulsion and goal-directedness if self-propulsion were considered the default interpretation for moving objects whose source of motion cannot be identified. This assumption would make the cues for self-propulsion less valuable because they would just trigger the same interpretation of the event that would be applied to it anyway (unless positive evidence to the contrary is available). In fact, this assumption would change the hypothesis that "self-propelled objects pursue goals" into another hypothesis to the effect that "non-self-propelled objects do not pursue goals." This new form of the hypothesis, which we labeled above as the "Exclusive link hypothesis," leads to the prediction that although the absence of evidence for self-propulsion does not prevent goal-attribution, the presence of positive evidence for *non*-self-propulsion should prevent it. This prediction was tested in Experiment 1.

Experiment 1: the "Exclusive link" hypothesis

Infants were presented with habituation events similar to the previous study (Csibra et al., 1999) with the exception that we provided direct evidence for the object being non-self-propelled. The object again approached its final target position through an inert parabolic pathway whose height was optimally adjusted to match the relative height of the obstacle in the middle that varied its size across habituation events. However, in this condition the object was always visibly launched to its flight trajectory by the direct impact of another moving object hitting it in a Michottean fashion. After habituation, the obstacle was again removed and infants were presented with two alternative test-events: the old "jumping" action vs. the new straight-line approach to target. The moving object was in both cases directly launched by the visible impact of another moving object hitting it. The "non-self-propelled objects do not pursue goals" hypothesis predicts that since the presence of direct evidence for non-self-propulsion must have prevented goal attribution during the habituation events, infants would look equally long at the two test events.

Methods

Participants. Forty-two 12-month-old infants participated in this experiment (27 males and 15 females, mean age: 372.74 days, SD: 12.89 days, range: 352–406 days). An additional 10 infants were also tested but were excluded from the data analysis due to fussiness (7) or short looking time in the test event (3). All of the subjects were healthy, full-term infants who were recruited through advertisements in local magazines.

Stimuli. The stimuli were computer-animated visual events. In the habituation event (see Fig. 1A) first a small red circle on the left side of the screen and a large blue circle on the right side of the screen

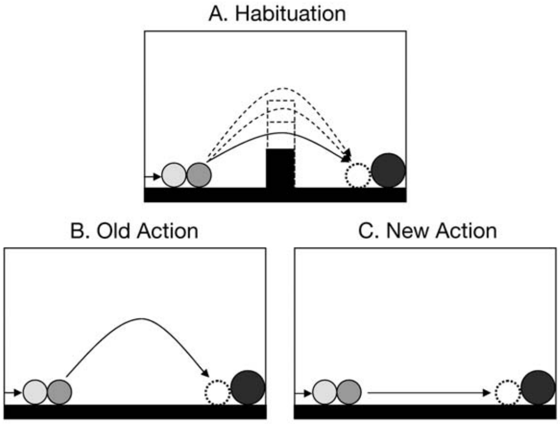

Fig. 1. Habituation event (A), Old Action test event (B), and New Action test event (C) of Experiment 1. Note that in all events the small circle's movement across the screen appeared as if it were launched by the impact of the other one.

appeared with a black rectangular column positioned in between them. The height of the column was randomly varied over trials, being either small, medium, or large. The event started when a third yellow circle entered the screen horizontally from the left side and contacted the small red circle. Upon contact the yellow circle stopped and the small red circle immediately started to move. The small red circle's movement appeared as if it were launched by the impact of the yellow one. It followed a parabolic pathway as if "flying over" the rectangular figure in the middle (the "obstacle"), and then it landed and stopped at the position adjacent to the large blue circle. The rectangular column appeared to form an "obstacle" separating the large circle and the small circle. The height of the small red circle's parabolic pathway was always adjusted to optimally match the variable height of the "obstacle" in such a way that it always just managed to pass over it without colliding with it.

During the test events, the "obstacle" was no longer present and so the small circle's path to the target circle was unobstructed. In the Old Action test event (Fig. 1B) the behaviors of the red and yellow circles were identical to those in the habituation event, i.e., the small red circle was set in motion by the moving yellow circle and then "flew" to the position adjacent to the large blue circle along a parabolic trajectory that corresponded to the average (medium) height of its trajectory during the habituation events. In the New Action test event (Fig. 1C), however, the small red circle approached the same end-point through a novel pathway taking the shortest straight-line route that has now become available.

Apparatus. The infants sat in their parent's lap in a darkened experimental room looking at an 18×24 cm monitor placed at eye level from a distance of 1.2–1.4 m. A video camera focusing on the baby's face was mounted above the monitor peeping through the opening of a black curtain, which allowed the experimenter to monitor the infant's eye fixations. The experimenter controlled the stimulus presentation and registered the looking times by operating a keyboard of a computer.

Procedure. At the beginning of each trial, the experimenter drew the infant's attention to the display by presenting colored flashes on the monitor. When the baby looked at the screen, the experimenter pressed a key that started the presentation of the stimulus event, which was then repeated continuously until the infant looked away for more than 2 s. When the infant looked away, the experimenter released the key on the keyboard, and if she did not press it again within 2 s indicating that the infant looked back again, the computer program stopped the stimulus display and registered the looking time for the trial. When the infant looked at the screen again, the next trial was started. A trial had to last at least 2 s to be treated as valid, i.e., if the infant looked at the event for less than 2 s, the trial was ignored. The computer program calculated the average fixation time for the first three habituation trials and compared this value on-line with the running average of the last three fixation times. We used a habituation criterion that required that the average fixation time for the last three trials be less than half of the average looking times for the first three habituation trials. Thus, the minimal number of habituation trials was six.

After the habituation criterion was reached, a 30 s long break was introduced during which the parent, who was sitting on a swivel chair, was asked to turn with her baby away from the monitor. When they turned back and the test trials

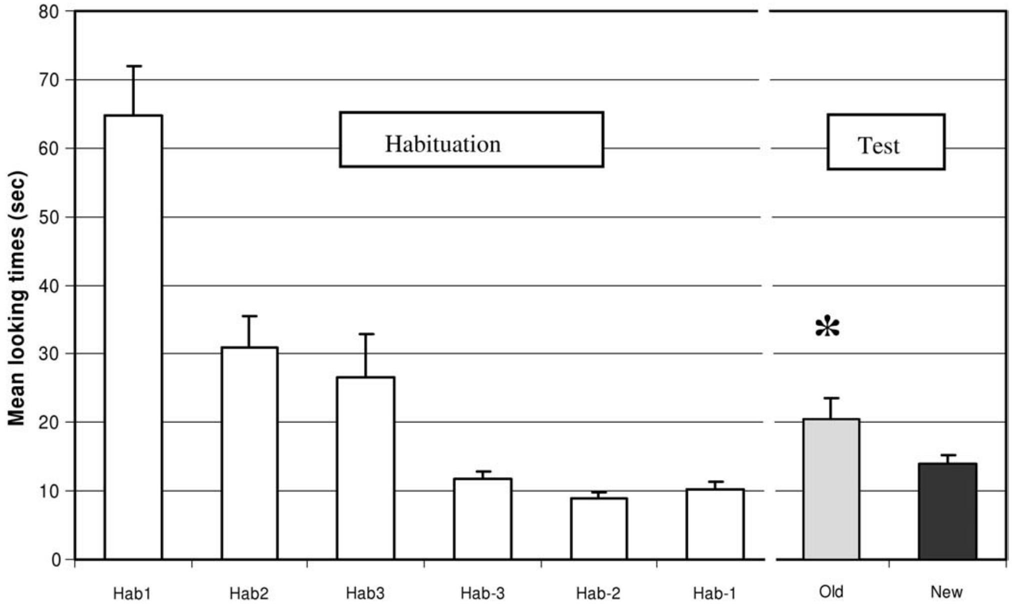

Fig. 2. Mean looking times and standard errors in the first and last three habituation trials, and in the two test events in Experiment 1 (*$p<0.05$).

started, we instructed the parents to close their eyes so that they could not inadvertently bias their child's reaction to the test displays. The test trials were delivered in the same way as the habituation trials. Each infant watched two test trials: an Old Action and a New Action event. For half of the infants the first test trial was an Old Action display followed by a New Action event, while the other half received the same stimuli in the opposite order. The experimenter was blind to the order in which the two test stimuli were presented. In order to ensure that the dishabituation scores reflected the infants' reaction to the nature of the stimulus event, we had to make sure that they had a chance to identify which kind of event was presented to them. Therefore, since the difference between the two test events could not have been detected earlier than 2.5 s within the trial, we excluded from the analysis all the infants who watched either of the test trials for less than 2.5 s and so had no opportunity to observe the full-event structure.

Results

The average number of completed habituation trials was 6.48. The mean looking times during the test phase were analyzed by ANOVAs using event type (old vs. new) as a within-subject factor, and order (old first vs. new first) as a between-subject factor. The analysis revealed a main effect of event type ($F(1,40) = 4.61$, $p<0.05$), indicating that the infants looked at the Old Action test event significantly longer than at the New Action test event. No effects of order were found. The mean looking times for habituation and test events are depicted in Fig. 2.

Discussion

In Experiment 1 we tested whether the perception of an object's movement as non-self-propelled would prevent 12-month-olds from attributing a goal to its behavior. Our findings demonstrate that this was not the case. The only informational basis for goal-attribution in this study was provided by the consistent pattern of adjustments observable in the height of the trajectory of the different goal-approaches performed by the object across trials that always optimally matched the variation in the height of the "obstacle" that separated the object from its target. These adjustments were justifiable in so far as they ensured efficient goal approach across the variable situational conditions. Thus, justifiable adjustment of goal approach in itself proved to be a sufficient cue for goal attribution. In sum, we can conclude that "self-propulsion" is not a necessary prerequisite for goal attribution and its absence does not necessarily inhibit the interpretation of behaviors in terms of goals.

Does this conclusion imply that infants do *not* rely on cues of "self-propulsion" at all when assessing which objects may pursue goals and which may not? Not necessarily. Our evidence demonstrates only that there is no *exclusive link* relating AGENCY to GOAL-DIRECTEDNESS, but it still leaves open the possibility that there is a *probabilistic* relation between them. Perhaps behaviors of self-propelled objects are *more likely* to be interpreted in terms of goals than behaviors of non-self-propelled objects, especially in otherwise ambiguous events which lack any other behavioral cues (such as consistent adjustments) that would positively indicate goal-directedness.

Experiment 2: the "Probabilistic link" hypothesis

One way to investigate whether infants are more likely to attribute goals to self-propelled objects than to externally driven objects is to present such objects engaging in a behavior that is otherwise ambiguous as to whether it is goal-directed or not. In our next study, therefore, we presented such ambiguous object behavior during habituation events. A moving object repeatedly approached a stationary target object at the other side of the screen via the simplest, shortest, straight horizontal pathway leading to it. Note that although this behavior is consistent with the goal of reaching the target and although it qualifies as the most efficient goal-approach available in the given situation, the object's target approach presents no Context-sensitive behavioral cues (such as justifiable adjustment of movement) that would independently indicate whether it is goal-directed or not. Note also that this behavior is equally consistent with a physical causal interpretation that would assume that some kind of external force had been imputed to this object making it roll on a straight-line path until it bumped into the other object in its way.

One can test whether infants interpret this ambiguous behavior in a teleological or causal manner by presenting them with a situation in which a new object (an obstacle) is placed between the horizontally moving and the stationary target object. If infants attributed the goal of reaching the target to the moving object's behavior during the preceding habituation events, in the test event they should expect the ball to adjust its behavior by jumping over the obstacle to reach its goal object via such a new (and justified) detour action. If, however, they interpreted the habituation event in purely causal physical terms, they should expect the ball to repeat its previous straight-line movement during the test event and to bump into the obstacle as a result. We also included a third, control test in which the ball did perform a jumping action while approaching the target ("hopping") without, however, any obstacle blocking its approach toward the target. This "hopping" event would not be justified by either the causal or the teleological interpretation of the object's previous behavior.

Two groups of 12-month-olds were presented with such events, which, however, were embedded in different movement initiating contexts. One group saw that the — originally stationary — object started its movement as soon as it was contacted by another object rolling into it from the side ("Direct Launching") resulting in the impression that it was externally propelled. The other group saw the same initial object contact event with the only difference that a half-a-second pause was introduced between the launcher making contact with the ball and the initiation of the latter's movement ("Delayed Launching"). This delay resulted in the impression that the ball's movement was an internally caused self-propelled behavior.

Now, we have two hypotheses on the table that would predict different response patterns for the test events in this study. According to the first hypothesis, it is the perceived type of the source of motion (self-propelled: "Delayed Launching" vs. externally caused: "Direct Launching") that would determine what kind of interpretation the infant assigns to the object's behavior. On the one hand, this hypothesis predicts that during habituation the sight of a self-propelled object (in the ''Delayed Launching'' group) taking the most efficient straight-line path available to reach the target object would invoke a teleological interpretation that would assign ''contacting the target object'' as the goal of the self-propelled object's action. For the test events in which an obstacle appears in the middle of the screen the hypothesized goal assignment would predict longer looking times for the ''bumping into the obstacle'' event (in which no behavioral adjustment that would have been necessary to achieve the goal occurred) and shorter looking times for the ''jumping over the obstacle'' action (in which the ball adjusted its behavior to the new situation and achieved its goal of contacting the target circle). On the other hand, this hypothesis predicts that the sight of an externally propelled object (in the ''Direct Launching'' group) during habituation would invoke a causal interpretation of the event that would produce the opposite pattern of looking times. Additionally, both groups should show violation of expectation (therefore, should look longer) when seeing the object ''hopping'' without the presence of an obstacle.

In contrast, according to the alternative hypothesis (which is certainly in line with our previous results), the perceived source of motion (self-propelled vs. externally caused) should not have an influence on the interpretation that infants give to the object's behavior. This view then predicts that both groups should show the same looking pattern in the test events.

Methods

Participants. Eighty-three 12-month-old infants participated in this experiment (38 males and 45 females, mean age: 368.49 days, SD: 7.51 days, range: 352–388 days). An additional 13 infants were also tested but were excluded from the data analysis due to fussiness (9) or failing to reach habituation criteria within 15 trials (4). Half of the participants were assigned to the Direct Launching group, while the other half took part in the Delayed Launching group. All of the subjects were healthy, full-term infants who were recruited through advertisements in local magazines.

Stimuli. The stimuli were computer-animated visual events. In the habituation event (see Fig. 3A) first a large blue circle and a small red circle appeared on right and left side of the screen, respectively. The habituation event started when a third small yellow circle entered the screen from the left side and contacted the small stationary red circle. In the Direct Launching group, the yellow circle stopped upon contact and the small red circle immediately started to move toward the right side of the screen on a horizontal path with a constant speed until it reached and made contact with the large blue circle at the other side of the screen. The Direct Launching event resulted in the visual impression as if the small red circle's movement were externally induced by the force impact exerted through the colliding yellow circle. In the Delayed Launching group the habituation event was identical to the one in the Direct Launching group except that the small red circle started to move only 0.5 s after the yellow circle contacted it. The small red circle's movement appeared as if it were self-propelled, internally caused behavior.

In all test events (Fig. 3B–D), the large blue circle and the small red circle appeared in the same starting positions as during habituation events (on the right and left side of the screen, respectively). In the ''Jumping'' and ''Bumping'' test events a black rectangular column also appeared between the two circles. All the test events started when the third small yellow circle entered the screen from the left side and contacted the small red circle the same way as it did in the habituation events. In the Direct Launching group, the yellow circle stopped upon contact and the small red circle immediately started to move. In the ''Jumping'' test event (Fig. 3B), the red circle took a parabolic pathway and ''jumped over'' the rectangular column landing at the position adjacent to the large blue circle making contact with it. In the ''Bumping'' test event (Fig. 3C), the red circle followed a horizontal path and ''bumped into'' the obstacle stopping at the position adjacent to the rectangular column. The red circle in the ''Hopping'' test event (Fig. 3D) followed the very same parabolic pathway as did

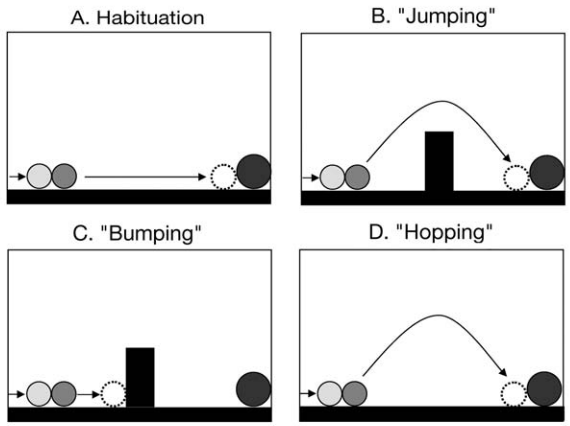

Fig. 3. Habituation event (A), Jumping test event (B), Bumping test event (C), and Hopping test event (D) of Experiment 2. Note that in the Direct Launching group the circle started to move immediately after the other one, coming from outside the screen, contacted it, while in the Delayed Launching group it started to move with a delay of 0.5 s.

the red circle in the "Jumping" test event. However, given the absence of the rectangular column in this test event, there was no "obstacle" to "jump over" and so the red circle's "hopping action" took place over an empty area and appeared unmotivated. The test events in the Delayed Launching group were identical to those in the Direct Launching group except that the small red circle started to move only 0.5 s after the yellow circle contacted it.

Apparatus. The experimental apparatus was identical to the one used in Experiment 1.

Procedure. The procedure was the same as in Experiment 1 with the following difference. Each infant watched three test trials: a Jumping, a Bumping, and a Hopping test event. The order of the test events was counterbalanced which resulted in six order groups.

Results

The average number of completed habituation trials was 7.39. There was no difference in the average number of habituation trials or in the average length of looking during the habituation trials between the Delayed and Direct Launching groups. The looking times during the test phase were first analyzed by a three-way ANOVA in which the event type (Jumping, Bumping, Hopping) was the within-subject factor and the condition (Direct vs. Delayed Launching) and order of the test events were the between-subject factors. This analysis yielded an interaction effect between event type and condition ($F(2,142) = 3.60$, $p < 0.05$), and between even type and order ($F(2,142) = 2.76$, $p < 0.05$). Two-way (event type X order) ANOVAs for each condition were carried out next. In the Direct Launching condition no main effects or interaction was found significant. In the Delayed Launching condition an event type main effect was found ($F(2,72) = 6.50$, $p < 0.05$). Pairwise comparisons revealed that infants looked significantly longer in the Hopping test event than in the Jumping ($p < 0.02$) or the Bumping test events ($p < 0.007$). Looking times in the Jumping and Bumping test events, however, did not differ significantly. In addition, an interaction effect was also found between the event type and order factors in the Delayed Launching condition ($F(2,72) = 2.42$, $p < 0.05$). This interaction was explored with an ANOVA and pairwise comparisons showed that infants in two order groups looked significantly longer in the Hopping test event than in the other two test events, while in the other order groups no difference was found in the looking times between the test trials. The mean looking times for habituation and test events are depicted in Fig. 4.

Discussion

These results confirmed neither of the two hypotheses entirely. Nevertheless, these looking patterns allow us to draw three interesting conclusions. First, the different looking patterns of the two groups (Direct vs. Delayed Launching) suggest that the infants *did* utilize the information about the type of source of motion to interpret the object's behaviors. This result, we believe, clearly demonstrates that 12-month-old infants not only register whether an object is self-propelled or not but also interpret its behavior differently.

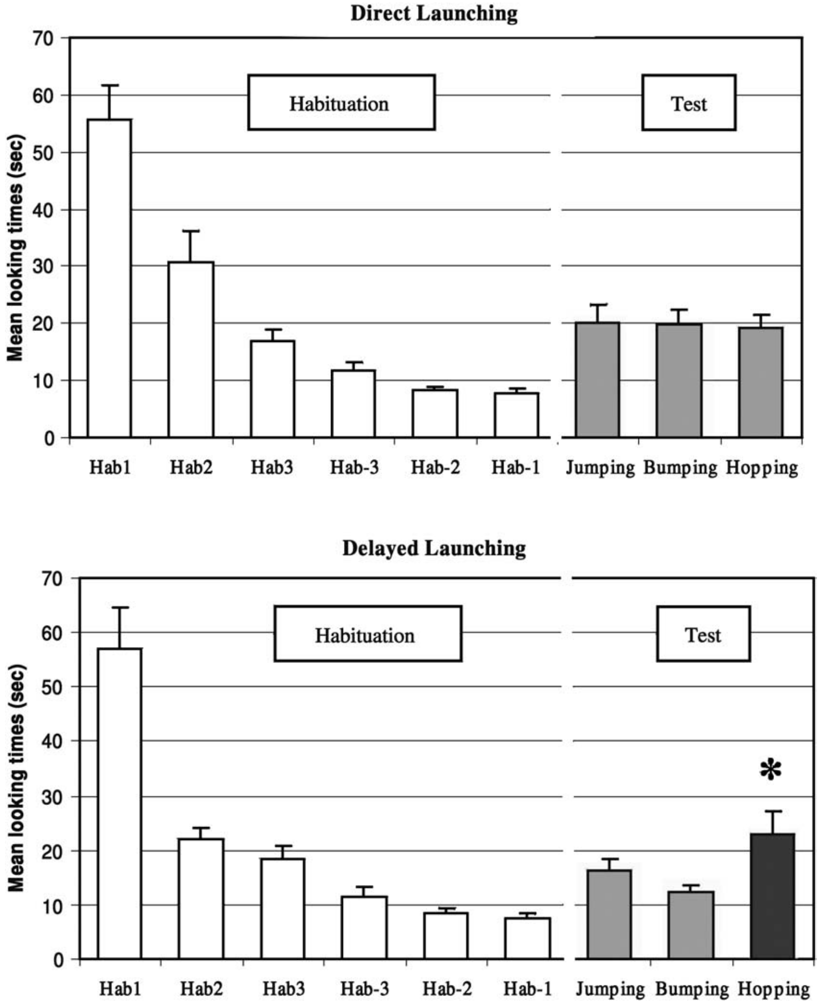

Fig. 4. Mean looking times and standard errors of Experiment 2 in the first and last three habituation trials, and in the three test events by the two groups (Direct and Delayed Launching) (*$p < 0.05$).

Second, the most surprising aspect of the findings is the lack of difference in looking times in the "Direct Launching" group. The tacit assumption behind the intuitions about self-propulsion that many researchers seem to share is that infants are only willing to apply a non-physical (i.e., "intentional") interpretation to observed behavior as a kind of "last resort," i.e., only when their causal physical understanding fails to explain the behavior in question. This implies a kind of primacy of physical interpretations, and would suggest that infants should have no difficulty in inferring that an externally launched object will not change its path just because it is blocked by an obstacle. Our infants did *not* make this inference, however. Instead, they seemed to have developed no specific expectations about the subsequent behavior of an externally propelled object. There might be several explanations for this result, but the fact that the other ("Delayed Launching") group *did* differentiate among the test events suggests that causal physical reasoning does not enjoy the kind of primacy in the mind of young infants that is commonly assumed.

Third, the looking times in the "Delayed Launching" group also showed an unexpected pattern. The infants seem to have considered the unjustified hopping action inconsistent with the habituation events, but they accepted the two alternative outcomes (Jumping and Bumping) in the presence of the obstacle equally. While, clearly, we did not predict this result, in retrospect it seems to fit our teleological model in an interesting (though admittedly post-hoc) way. Remember that, lacking cues of behavioral variation that could guide goal assignment, the habituation event in the study was necessarily ambiguous, even if one is inclined to interpret it as a goal-directed action. In fact, the goal of the straight-moving action could equally be either (1) to approach and contact the target object (as we originally hypothesized), or (2) to *move away* from the ''intruding'' yellow object that first came up close, then established and maintained physical contact with the red object, which the latter eventually ''tried to escape from'' by moving away toward the other side. (Note that the intentional ascriptions provided here as ''reasons'' are purely for illustrative purposes and are clearly not necessary for the infant to make in order to attribute the well-formed goal of ''moving away from the yellow object'' to teleologically explain its observed behavior.) Note that the actions depicted by the two test events that elicited shorter looking times are consistent with these two alternative goals, respectively. Therefore, this looking pattern may reflect genuine goal attribution, but the attribution of two different goals.

It should be pointed out that the hypothesized ambiguity of goal-attribution might be manifested in these looking patterns in two different ways. On the one hand, it is possible that the infants could not decide during habituation which goal to attribute, but they were happy to accept either of them during the test phase. On the other hand, it is also possible that, while observing the habituation events, some infants came to the conclusion that the goal of the red object's action was ''to go to the blue object'' on the right, while other infants reasoned that its goal was rather ''to move away'' from the close proximity that the little yellow ball coming from the left has just established with it, and the average looking times, in fact, reflected the differential reactions of these two sub-groups.

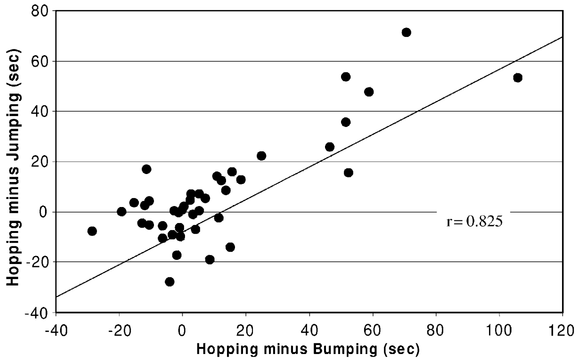

Fig. 5. The association between the difference in looking times between Hopping and Jumping (vertical axis) and Hopping and Bumping (horizontal axis) test events in the Delayed Launching condition for each participant.

There is a way to empirically contrast these two alternatives and to derive differential predictions from them about the clustering of the looking time data for two of the test events. While the first option predicts a positive correlation between the looking times elicited by the ''Jumping'' and the ''Bumping'' action test events, the second one predicts a negative correlation for the same two test events: the infants who attributed one specific goal should be surprised to see a behavior consistent with the other, and vice versa. We calculated the difference in looking times between these actions and the ''Hopping'' test event for each infant and correlated these measures with each other (see Fig. 5). The result ($r = 0.825$, $p < 0.0001$) showed a very strong positive correlation, suggesting that the infants did *not* commit themselves to one goal during habituation.

Conclusions

We have described three types of observable cues assumed to be utilized by infants in determining the scope of goal attribution to various behaviors, and investigated the potential inferential links between the concepts indicated by these cues. In particular, three possible functional links between AGENCY and GOAL-DIRECTEDNESS were hypothesized, differing from each other in the relative strength they attribute to this link. The ''Mandatory link'' hypothesis claimed that categorization as an agent is *required* for the identification of a goal-directed entity. The second, "Exclusive link" hypothesis stated that categorization of an entity as non-agent *precludes* the identification of a goal-directed entity. Finally, the third, "Probabilistic link" hypothesis assumed that agent categorization *biases* toward the identification of a goal-directed entity.

To test these hypotheses we have reported experiments in which we varied the availability of behavioral cues for self-propulsion that are hypothesized to perceptually identify an AGENT, and Context-sensitive cues, which are assumed to indicate a GOAL-DIRECTED entity. We found no support for the first two hypotheses. Twelve-month-old infants were able to interpret an observed action of an entity as goal-directed and predict its most efficient action in a changed situation even when the cue of self-propulsion was not present (Csibra et al., 1999) or when the entity was explicitly shown as non-self-propelled (Experiment 1). These findings indicate that infants do not need to perceive cues of self-propulsion to interpret behaviors as goal-directed actions. In other words, the categorization as AGENT is not a necessary prerequisite for identification of a GOAL-DIRECTED entity. In addition, perceiving that an entity is *not* self-propelled does not prevent infants from attributing a goal to its action. In other words, the categorization as non-agent does not preclude the identification as a goal-directed entity. The third, "Probabilistic link" hypothesis was, however, partly supported by our findings. In Experiment 2, we found that in an ambiguous situation (in which Context-sensitive cues are not available) perceiving self-propulsion does not by itself allow attributing specific goals, but makes it more likely that 12-month-olds will interpret the ambiguous action as goal-directed. Thus, the categorization of an entity as an AGENT can bias the interpretation of its behavior as GOAL-DIRECTED.

What are the implications of these findings for the theoretical approaches that have been proposed concerning the identification of the scope of naïve psychological reasoning? Regarding the question of the direction of possible inherent inferential links, both our current findings and those that we have reviewed suggest that none of these categories enjoy primacy over the others. In particular, we have demonstrated that prior commitment to conceiving an entity as an agent is neither sufficient nor necessary for applying goal-directed interpretation to the entity's behaviors. Therefore, the "Agent-first" and the "Human-first" views are not confirmed by evidence while the "No-primacy" account is corroborated.

Another related question on which theoretical approaches are divided is whether the nature of the selection process involved in the identification of the entities and events that belong to the domain of naïve psychology is *cue-based* or *principle-based*. We argued that the selection of events to be interpreted as GOAL-DIRECTED is not based on specific human featural or behavioral cues such as self-propulsion or context-sensitive behavioral changes, but on the successful application of the rationality principle. Our present findings confirm this position. Note that although Context-sensitive cues such as contingent behavioral adjustments have been suggested to trigger goal attribution, our previous studies (Gergely et al., 1995; Csibra et al., 1999) demonstrated that the presence of this cue in itself is not sufficient for the interpretation of an event as goal-directed. For example, in the experiment that provided evidence against the "Mandatory link" hypothesis (Csibra et al., 1999) behavioral adjustment was present in both the experimental and the control conditions: the height of the jumping action was contingently adjusted to the height of the rectangular figure. In the control condition, however, the rectangular figure did not form an obstacle between the two circles but was "hanging in the air," leaving the more efficient straight-line approach available. Thus, the jumping action — even though it was contingently varying with the situational changes — was not efficient and could not satisfy the principle of rational action. In the test phase of the control condition, infants did not display expectations about the circle's action in the changed situation, which suggests that they did not interpret its action as goal-directed during habituation. Context-sensitive cues therefore do not elicit goal attribution by themselves, although they can be considered as principle-driven cues that can trigger the *search* for a teleological interpretation. We thus propose that the same principle — namely the principle of rational action — is applied both for identifying entities that are potentially engaged in goal-directed behavior and for reasoning about their behavior. A similar principle-based single-knowledge system was proposed and argued for in the domain of physical objects (e.g., Carey and Spelke, 1994).

Experiment 2 suggested that the infants assume a probabilistic link between AGENT categorization and the identification of a GOAL-DIRECTED action. It is an empirical question whether this probabilistic relation is pre-wired (and acts as a "prior" providing statistical biases and constraints on Bayesian inferences), or learnt by discovering statistical associations between the corresponding cues in the world. By 12 months of age infants are likely to have accumulated sufficient amount of relevant evidence in the domain of action perception that could provide them ample informational basis from which to extract and represent such statistical associations. Such associations may be employed in probabilistic inferences, or can generate biases and constraints, to direct infants' teleological interpretations especially under conditions of underdetermination or ambiguity of the input.

Some findings by Biro and Leslie (2004) and Sommerville et al. (2005) can be viewed as supporting the assumption that gradual associative learning between observable behavioral and featural cues does take place during the first year. Both studies used similar designs: they introduced a "pre-training session" in which infants had the opportunity to learn to associate behavioral cues indicating goal-directedness with featural cues, and to rely on these associations to attribute a specific goal in the subsequent testing session when only the featural but not the behavioral cues were present.

The discovery of the strong correlation between cues of HUMAN features, cues of AGENCY, and cues of GOAL-DIRECTEDNESS in the world leads to the conjecture that the principles that guide psychological reasoning about goals need to be invoked mostly in the case of human intentional actions. Thus, relying, for example, on human/animate appearance to anticipate goal-directed intentional action from an entity is a useful strategy because most of the time it is justified and economical. Recognizing featural cues as opposed to behavioral cues does not require the observation of an entity over time. Featural cues can be processed fast and thus allow us to make quick predictions of the possible actions of an entity, and be prepared for an appropriate response.

On the one hand, while featural cues can function as predictive cues, they can also lead to incorrect conclusions about the domain that an entity belongs to. Imagine that you are in a forest and notice something hanging on a tree in front of you. It does not move and looks like a small piece of a tree branch like many others that you have passed during your walk. Suddenly this piece of wood falls, hurries behind the tree, and disappears in a hole in the tree trunk. You conclude that this was not a piece of wood after all but some kind of animal that got scared and wanted to hide from you. This example also illustrates that if behavioral cues exhibited by the entity are in conflict with our initial categorization based on featural cues, we change the categorization of the entity without hesitation to match to the behavioral cues, and predict the behavior of the entity on the basis of this new category. Moreover, such an experience has an impact on our future categorization of entities that have similar featural cues: these featural cues will now be associated with a new category.

On the other hand, cues of self-propulsion can also generate statistically based expectations that the entity will engage in goal-directed actions. However, we have no difficulty in refraining from reasoning in psychological terms about falling leaves, dropping faucets, or objects blown by the wind.

In conclusion, we propose that the domain of goal attribution is initially defined only by the applicability of its core principle (the principle of rational action, see Gergely and Csibra, 2003), and its ontology is not restricted to featurally or behaviorally defined entities such as persons or agents. During development, however, this purely defined domain becomes "contaminated" by the learnt associations between goal-directedness, human appearance and self-propelledness, allowing children to take the "teleological stance" toward people and other agents.

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