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The early origins of goal attribution in infancy

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Abstract

We contrast two positions concerning the initial domain of actions that infants interpret as goal-directed. The 'narrow scope' view holds that goal-attribution in 6- and 9-month-olds is restricted to highly familiar actions (such as grasping) (Woodward, Sommerville, & Guajardo, 2001). The cue-based approach of the infant's 'teleological stance' (Gergely & Csibra, 2003), however, predicts that if the cues of *equifinal variation of action* and a *salient action effect* are present, young infants can attribute goals to a 'wide scope' of entities including unfamiliar human actions and actions of novel objects lacking human features. It is argued that previous failures to show goal-attribution to unfamiliar actions were due to the absence of these cues. We report a modified replication of Woodward (1999) showing that when a salient action-effect is presented, even young infants can attribute a goal to an unfamiliar manual action. This study together with other recent experiments reviewed support the 'wide scope' approach indicating that if the cues of goal-directedness are present even 6-month-olds attribute goals to unfamiliar actions.

1. Introduction

As adults, we consider an action goal-directed when we judge that it is performed in order to bring about a change of state in the world, i.e., when we see the action as a means to an end. This paper will examine the conditions under which the ability to make such a judgment first occurs in infancy. The early development of representing actions as goal-directed has been studied from two different angles: researchers either investigated (a) the emergence of the capacity to *produce* intentional goal-directed actions, or (b) the development of *recognizing*, *interpreting*, and *predicting*

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goal-directed actions of others. Historically, studying the first aspect started significantly earlier with the influential investigations of Piaget (e.g., Piaget, 1952; Uzgiris & Hunt, 1975; Willatts, 1999). In contrast, theoretical models (Baron-Cohen, 1994; Csibra & Gergely, 1998; Gergely & Csibra, 1997; Leslie, 1994, 1995; Premack, 1990; Premack & Premack, 1995; Tomasello, 1999) and new experimental paradigms (Carpenter, Nagell, & Tomasello, 1998; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Csibra, Bíró, Koós, & Gergely, 2003; Gergely, Nádasdy, Csibra, & Bíró, 1995; Gergely, Bekkering, & Király, 2002; Meltzoff, 1988, 1995a, 1995b; Woodward, 1998, 1999; Woodward & Sommerville, 2000) to study the emergence of interpreting and predicting goal-directed actions of others have been introduced only during the last 15 years or so.

By now converging evidence coming from both lines of research indicates that by 6–9 months of age, *infants can represent and interpret actions as goal-directed*. It has been shown that young infants can (a) segment and differentially represent actions and their goals, (b) understand that different actions can function as means towards the same goal, (c) comprehend that when relevant aspects of the environment change, agents can adjust their actions adaptively to achieve the same goal efficiently in the new situation, (d) evaluate the relative efficiency of alternative means available in a given situation and expect the agent to perform the one that seems most efficient to realize the goal, and (e) differentiate actions that are goal-directed from actions that are not (for reviews, see Gergely, 2002; Tomasello, 1999).

To account for this early ability to understand goal-directedness, several theories proposed innately based, abstract, and domain-specific representational systems specialized for identifying intentional agents and/or for representing and interpreting actions as goal-directed (e.g., Baron-Cohen, 1994; Csibra & Gergely, 1998; Gergely & Csibra, 1997, 2003; Johnson, Slaughter, & Carey, 1998; Leslie, 1994, 1995; Premack, 1990; Premack & Premack, 1995). While these models differ in several significant respects, they all assume an initially *wide scope* of entities (including unfamiliar actions of humans or unfamiliar agents with no human features) that infants can recognize as goal-directed from very early on. This generality in scope is due to the fact that these theories all postulate or imply sensitivity to *abstract behavioural cues* (such as self-propulsion, direction of movement or eye gaze, contingent reactivity, equifinal variation of actions, cues for evaluating the relative efficiency of alternative goal-approaches, etc.) that indicate agency, intentionality, or goal-directedness, irrespective of previous experience with the types of agents or actions that exhibit these cues.

Recently, Amanda Woodward (Woodward, 1998, 1999; Woodward et al., 2001) has challenged this central assumption based on her innovative studies applying a novel type of habituation procedure (Woodward, 1998, 1999; Woodward et al., 2001). In her first study (Woodward, 1998), she habituated 6- and 9-month-olds to a hand repeatedly reaching into a stage and grasping one of two objects (either a bear or a ball) placed on separate platforms on the left and the right side. (The hand grasping the target object then remained stationary as long as the infant fixated the display.) After habituation, a screen was lowered and the respective positions of the objects were changed outside of the infant's view. During the test phase the infants saw the hand reaching for and grasping either the same object as before, which, however, was now in a new position ('old object/new path' event), or the new object at the old position ('new object/old path' event). Infants in both age groups looked longer at the 'new object/old path' than at the 'old object/new path' display indicating that grasping the old object was attributed as the goal of the hand's action. Woodward argued, however, that this early understanding of goal-directedness is not general in scope, but is restricted to highly familiar actions such as grasping that even 6-month-olds have had sufficient previous experience with.

To demonstrate this, Woodward applied the same paradigm to a number of unfamiliar manual actions (such as touching the object by lowering the back of the hand on it, or touching the object with an extended index finger) as well as to actions of novel objects with no human features (e.g., grasping the object with an unfamiliar inanimate claw; Woodward, 1999; Woodward et al., 2001). In contrast to the familiar grasping action, she found no evidence for goal attribution for either of the unfamiliar actions tested in 6- and 9-month-olds. Thus, Woodward et al. (2001) concluded:

> In summary, our findings indicate that the early development of *intentional understanding* is not a process of paring down initially overgeneral notions, but instead of building up initially undergeneral ones. Infants begin by *understanding actions as goal-directed*, and, with time, the range of actions they understand this way increases. Just as infants' notions of actors seem to focus on people in particular, rather than the broad class of anything that moves on its own, so infants' notions of goal-directed action seem to focus on particular actions. (p. 162)

2. The teleological stance and the cues for goal-directedness it specifies

Below we shall consider Woodward's results from the point of view of the theory of the infant's *teleological stance* (Csibra & Gergely, 1998; Gergely & Csibra, 1997, 2003). This theory predicts that the initial domain of actions infants can interpret as goal-directed has a *wide scope* that includes unfamiliar human actions as well as actions of novel agents with no human features, as long as they exhibit the cues of goal-directedness that are specified by the basic assumptions of the teleological action interpretative system.

The theory of the teleological stance is based on the results of a series of habituation studies (Csibra et al., 1999, 2003; Gergely et al., 1995) that—using a different paradigm than that of Woodward's experiments—demonstrated goal attribution in 9- and 12-month-olds. All the experiments used computer-animated events involving abstract 2D figures (circles and rectangles) with no human features that behaved in ways that adults describe as goal-directed intentional actions (cf. Heider & Simmel, 1944). For example, Gergely et al. (1995) habituated infants to a small circle approaching a large circle (goal) by jumping over (means act) an obstacle separating them (situational constraint). During the test phase the situational constraints were changed by removing the obstacle. Infants then saw two test displays: the same jumping goal-approach as before, or a perceptually novel straight-line goal-approach. Subjects looked longer at the old jumping action (suggesting that they found it unexpected as it appeared to be an inefficient means to the goal in the absence of the obstacle), while showing no dishabituation to the straight-line goal-approach (indicating that this action, though novel, matched their expectations as it was seen as the most efficient means to the goal in the new situation).

These studies indicate that at least by 9 months infants can (a) attribute goals to observed actions; (b) do so even if the agents are unfamiliar abstract entities that lack human features; (c) evaluate the relative efficiency of the goal-approach in relation to the situational constraints on actions; and (d) if the relevant environmental constraints change, they expect the agent to *modify* or *change* its means action adaptively to achieve efficient goal-attainment in the new situation (Csibra et al., 1999, 2003; Gergely et al., 1995).

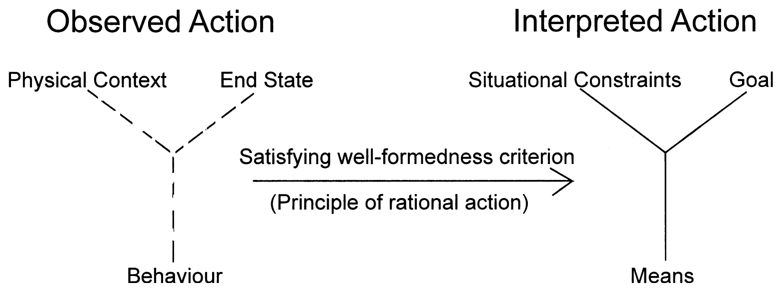

Fig. 1. Teleological representation of goal-directed actions according to Csibra et al. (2003).

To account for these findings, Csibra and Gergely proposed that infants are equipped with an abstract and domain-specific action interpretational system, the teleological stance, that is specialized for representing and predicting goal-directed actions (Csibra & Gergely, 1998; Gergely & Csibra, 1997, 2003). Briefly, the teleological stance is a representational system (Fig. 1) that relates three kinds of elements in a specific type of (teleological) explanatory structure: (a) the observed behaviour (Action), (b) the consequent change of state in the world (Goal), and (c) the relevant aspects of the situation that constrain actions leading to the goal (Situational Constraints).

An essential component of the teleological stance is the 'principle of rational action' (Csibra & Gergely, 1998; Dennett, 1987; Gergely & Csibra, 1997, 2003) that drives inferences about goal-directed actions and provides criteria of well-formedness for teleological action interpretations. The rationality principle represents two basic assumptions about the essential nature of actions: (a) that the basic function of actions is to bring about some particular *change of state in the world,* and (b) that agents will perform *the most efficient (rational) means available to them* within the constraints of the situation.

Note that these assumptions imply *two types of perceptual cues* indicating goal-directedness whose presence can guide infants to attribute goals to a wide scope of actions. The first cue specifies that the outcome of the action should involve a (salient) *change of state in the environment*. This cue can be derived from the first assumption of the rationality principle that the essential function of actions is to bring about a change of state in the world. The second cue specifies that the actor should be capable of *equifinal variation of actions*. This cue is implied by the further assumption of the rationality principle stating that agents pursue their goals through the most efficient means available to them in the situation. This leads to the expectation that if the environmental conditions change, an agent 'ought to' be able to adaptively modify or change its action to achieve the same goal in the most efficient manner in the new situation. Therefore, evidence that an actor is engaging in (or known from previous experience to be capable of) equifinal variation of action is a powerful cue suggesting goal-directedness.

3. The role of cues of goal-directedness and previous knowledge of agency properties

Below we shall propose an alternative interpretation in terms of our cue-based approach for Woodward's findings by calling attention to a peculiar feature of her habituation studies. We hypothesize that this feature in itself may be sufficient to explain why her results show early goal-attribution only for the familiar grasping action, and not for the other, unfamiliar actions she tested. In particular, note that in all of Woodward's habituation displays *both of the central cues suggesting goal-directedness* that we have derived from the assumptions of the teleological stance *were missing*. The first cue specifies that the outcome of the action should involve a salient change of state in the object acted upon. However, in Woodward's habituation events the end states of the object-directed actions consisted of the establishment (and then static maintenance) of physical contact between the actor and the target object (e.g., the back of hand falling on and then remaining in static contact with the object, a hand, or an inanimate claw grasping the object and then maintaining that static configuration, or a pointed index finger touching the object and then staying in touch with it). Significantly, contacting the target object in neither case led to any salient change of state in the object! The second cue involves the presence of equifinal variation of action. However, Woodward's habituation actions always repeated an invariant target approach without any modification of the actor's behaviour.

Considering first the lack of the cue of salient change in the target object, we should note that simple physical contact with an object is ecologically rather unrepresentative of the type of naturally occurring goal states that goal-directed actions tend to bring about in the infant's physical environment. On the contrary, such actions (e.g., grasping) typically result in some visible change of state in their goal object (such lifting it or transporting it to a new location) that forms the actual goal of the action. Furthermore, to attribute a goal to an action, infants must be able to parse the behaviour to set up differentiated and separate representations for the means act and the goal. For young infants, however, to be able to segment a continuous behaviour in such a way it may be necessary to perceive a salient change of state in the goal object that is perceptually clearly separable from the action itself. Therefore, we hypothesize that the lack of a perceptually salient change of state in the target object may have contributed significantly to the failure of Woodward's 6- and 9-month-old subjects to understand the goal-directedness of unfamiliar actions.

Another theoretical approach emphasizing the role of a salient change of state in action perception and production is the Common Coding approach (Prinz, 1990, 1997), recently complemented by the Theory of Event Coding (Hommel, Müsseler, Aschersleben, & Prinz, 2001). This approach considers action goals to be anticipated, distal action effects that are the key elements of action representations. A salient change of state in the goal object is one possible realization of a distal action effect. There is ample evidence from studies with adults that action goals are coded in terms of anticipated action effects that play an important role both in action acquisition and control. Recent studies demonstrate that the action effect principle applies to infants' action perception and production as well (e.g., Elsner & Aschersleben, 2003; Hauf, Elsner, & Aschersleben, in press; Jovanovic et al., 2003). Thus, support for the general argument that for infants the outcome of an action should involve a salient change of state in the object acted upon comes from various theoretical and empirical lines of research.

However, while the cue of salient change of state may indeed provide important information about goal-directedness under certain conditions, it is, in and of itself, neither necessary nor sufficient to trigger goal attribution. First, note that for the familiar grasping action Woodward (1998) did find evidence for goal attribution in both 6- and 9-month-olds even though the habituation action did not bring about a salient change of state in the object grasped. Second, in a recent study, Jovanovic et al. (2003) carried out a modified version of Woodward's 'claw' experiment in which they introduced a salient change of state in the grasped object (after grasping it, the claw transported the object to a new location). In spite of this, the 6-month-olds still failed to show evidence of goal attribution to the claw's action.

This brings us to consider the potentially crucial role of the other cue for goal-directedness, that of *equifinal variation of action.* We argued that adaptive equifinal modification of action in response to relevant environmental changes is a defining property of goal-directedness, given the assumptions of the teleological stance. This implies that *the ability to autonomously vary one's behaviour* is a necessary precondition for an actor to be categorized as an agent capable of pursuing goals. Therefore, we can hypothesize that lacking either direct perceptual evidence or knowledge based on such prior evidence indicating that the actor is an autonomous agent capable of equifinal modification of its actions, infants will *not* interpret the outcome of its behaviour as its goal, *even if* that outcome involves a salient change of state.[1] This may then account for the lack of goal attribution to the unfamiliar claw's grasping behaviour in young infants both in the original Woodward study (with no salient change of state in the object) and in Jovanovic et al.'s modified replication (where a salient change was introduced), as in both studies the novel object repeatedly presented the same invariant target-oriented behaviour during habituation without exhibiting any modification of the action.[2]

But how can we account in terms of our cue-based approach for Woodward's (1998) success in showing goal attribution for the familiar grasping action in both 6- and 9-month-olds, even though, just as in her other studies, the habituation displays lacked both cues of goal-directedness? We agree with Woodward that manual object-grasping is special in that even by 6 months of age infants have had a significant amount of (both perceptual and motor) experience with it. However, what 6-month-olds are familiar with is *not* the peculiar type of grasping event performed during Woodward's habituation events that repeatedly presented the same unmodified target approach that always terminated when the object was grasped. In contrast, natural grasping events familiar to infants often exhibit equifinal modification of action as a function of environmental changes when lifting, transporting, shaking, etc. of variable goal objects grasped in different situations. Furthermore, such natural object grasping events typically involve some subsequent change of state in the grasped object (such as its *transport* to a different location by the hand). In such familiar grasping events physical contact with the goal object forms only the initial part of the full goal-directed action, which is only a *causal enabling condition* (in fact, a *sub-goal*) necessary for the realization of the *actual goal* that involves a change of state in the object grasped. Therefore, we hypothesize that during the infant's previous experience with the typical changes of states brought about by manual grasping (such as object transport), these salient effects have become associated with the grasping action as its likely goals. We suggest that this activated memory representation of expectable salient effects mandates goal attribution to the grasping action (providing its content) *even when* direct perceptual evidence of a salient change of state in the target object is not presented.

[1] Consider observing a dripping faucet where as a consequence of the repeated and invariant behaviour of the water drops the sink becomes visibly filled with water. It is most unlikely that one would interpret this outcome as being the goal of the water drops. In fact, we suggest that, due to lack of evidence of behavioural variation, even 6-month-olds with no familiarity with dripping faucets would refrain from such a goal-directed interpretation of this event.

[2] Note, furthermore, that the mechanical claw (or, in fact, any of the other actors tested in Woodward's studies) did not exhibit self-propulsion either (another potential cue of agency suggesting the capacity for autonomous variation of behaviour, see Leslie, 1994; Premack, 1990) as it always moved into the stage from occlusion.

In sum: we hypothesize that by 6 months of age infants have established from previous experience a representation of a manual action scheme for object transport. In our view, the grasping action in Woodward's habituation events repeatedly activated the first component of the memory representation of the manual object transport scheme which then primed its second component resulting in an *active anticipation of a subsequent transfer of the object by the hand to some new location.* However, this expectation was not fulfilled by the habituation events that terminated when contacting the object. We suggest that it is this expectation (to see the hand with the same object appear at some new location) that is finally fulfilled by the sight of the end state of the 'new path/old object' test event in which the hand eventually does appear with the object originally grasped at a new location. This explains why infants look at the 'old object/new path' test event significantly less than they do at the 'old path/new object' test display.[3]

Finally, let us see how our cue-based approach can accommodate Woodward's (1999) negative findings in the case of the unfamiliar 'back-of-hand' action. Woodward interpreted the failure of 6- and 9-month-olds to demonstrate goal attribution as being due to their *unfamiliarity* with this type of manual action. We agree with Woodward to the degree that due to their lack of previous experience with 'back-of-hand' actions young infants could not have established a memory representation for it as a familiar goal-directed action associated with typical change of states in its goal objects. While in the case of the familiar grasping action the infant had access to such memory representations of typical effects to support goal attribution, in the case of the unfamiliar 'back-of-hand' action no such representation was available. As a result, Woodward's young subjects indeed have not attributed a goal to the 'back-of-hand' action. However, it should be emphasized that, given the nature of her habituation stimuli, the infants could not have succeeded in identifying a goal for the action, even if otherwise they possessed the ability to attribute goals to even unfamiliar actions, under the right cuing conditions.

Therefore, we hypothesize that by modifying Woodward's 'back-of-hand' study through including a salient change of state in the target object (e.g., its displacement by the 'back-of-hand' action), we could provide the necessary perceptual cue that could serve as the basis for goal attribution in spite of the unfamiliarity of the manual action. One could ask, however: why do we believe that adding such a cue would work in the case of the unfamiliar manual action, when it did not work when applied to the action of the unfamiliar novel object, the mechanical claw (Jovanovic et al., 2003)?

We believe that the relevant difference between these two types of unfamiliar actions lies in the fact that even young infants have extended previous experience with *hands* performing equifinal variation of actions in a variety of situations, while they have no comparable experience with the unfamiliar claw. As a result, hands but not claws are likely to have become categorized by the infants as *agents capable of pursuing goals*. Therefore, we predict that relying on this categorical knowledge of hands as agents, young infants may be able to interpret the unfamiliar 'back-of-hand' action as goal-directed, even if the observed action does not provide direct perceptual evidence of the capacity for equifinal variation of behaviour. Of course, to do so infants will need

[3] This interpretation is also in line with a recent replication of Woodward's (1998) grasping study by Jovanovic et al. (2003) that demonstrated goal-directed interpretation of object grasping in 6-month-olds also when in both habituation and test events the grasping of the object was followed by its visible displacement to a new location by the grasping hand.

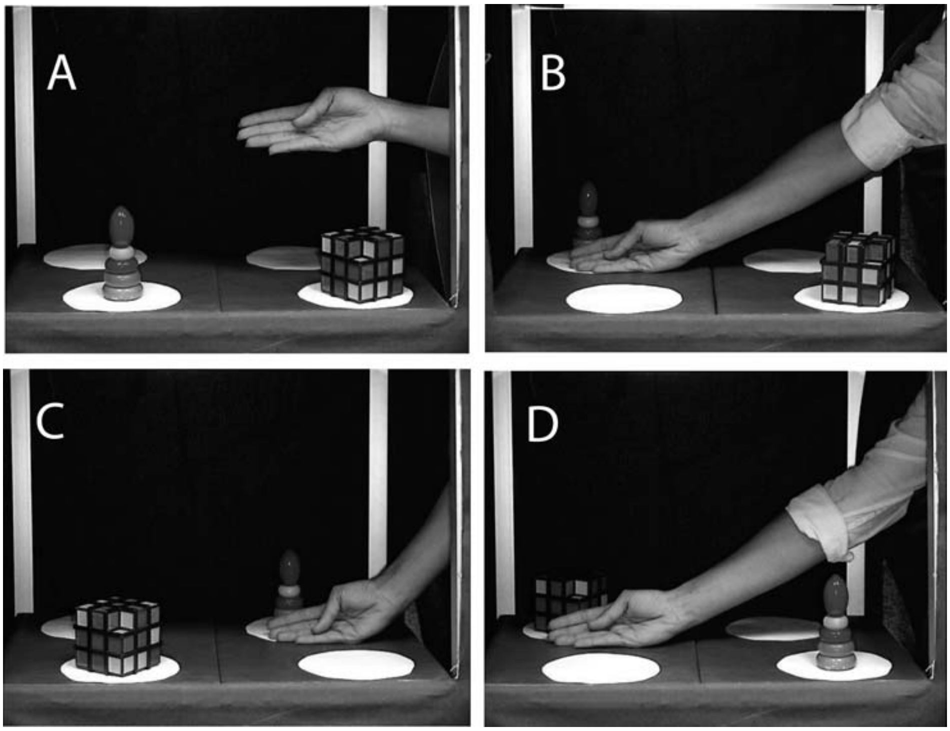

Fig. 2. Examples of events presented during habituation and during test trials: (A) Beginning of the 'back-of-hand' event during habituation. (B) End of the of the 'back-of-hand' event during habituation. (C) 'New path/old object' test event. (D) 'Old path/new object' test event.

direct perceptual evidence of a salient change of state in the target object that would enable them to identify the content of the goal to be attributed to the unfamiliar manual action. To test this hypothesis we designed a modified version of Woodward's (1999) 'back-of-hand' study. The only change we introduced was that the 'back-of-hand' action during habituation (as well as during the test phase) brought about a salient visible change of state in the target object (following contact it pushed the object from location A to location B on the stage, see Fig. 2).

4. Method

4.1. Participants

Forty-eight full-term infants participated in the study. They were recruited through advertisements in local newspapers. Three age groups were tested: 6-month-olds (mean age in months and days = 6–15 ranging from 5–3 to 7–6); 8-month-olds (mean age = 8–12 ranging from 7–21 to 9–0); and 10-month-olds (mean age = 9–24 ranging from 9–6 to 10–24). Each group consisted of 16 infants. An additional 18 babies were tested but were excluded from the study either due to experimenter or technical errors (11) or due to failure to complete all the trials (7).

4.2. Procedure

The procedure was identical to that used by Woodward (1999) with the sole difference that the 'back-of-hand' action did not end when contacting the target object, but smoothly continued its movement pushing the object to a new location. This introduced a clearly visible change of state (change of location) in the object acted upon. Infants were seated in their mother's lap facing a stage (from a distance of approx. 1 m). Two colourful shiny wooden toy objects, a Rubic-cube-like rectangular object and a Hanoi Tower-like object were placed at the left and the right side of the stage. The two toys differed saliently only in one visual feature, namely their clearly distinguishable shapes. Their other visible features were very similar: they were of the same height, both had a colorful pattern, and an equally smooth and shiny looking surface. Parents were instructed not to interact with their infant during the experiment. Both objects were placed on a white circle on a dark blue tray at the two sides of the stage. On both sides there were two pairs of white circles on the tray: one in the front (the starting position of the objects) and one slightly further back and to the side (the end position of the objects after their displacement) (Fig. 2, panels A and B). At the two sides of the stage dark-blue curtains were hanging. Infants were videotaped during the sessions using a camera hidden above the stage at the center facing the baby. Between trials a blue screen was slid in from one side so that it fully occluded the objects from the infant's view.

4.3. Habituation phase

Each trial started with the removal of the screen making the objects on the stage visible. The actor (hidden from view standing behind the curtain at the right side of the stage) waited for the observer behind the camera to signal that the infant was looking at the stage. When the infant attended, the actor's arm entered the stage from the right as in Woodward's study (1999) (only the actor's arm was visible throughout the session). She lowered her hand in such a way that her back of hand made contact with the target object, and then—continuing to move her hand in a smooth uninterrupted fashion—pushed the object to its new location marked by the second white circle (Fig. 2, panels A and B). After the object reached its new location, the actor's arm remained in static contact with it until the infant looked away for more than 2 s. After each trial the screen was pulled in and the stage was rearranged outside of the infant's view.

A trained coder measured the infant's looking time on-line, watching the infant's gaze direction on a monitor in another room. When the baby turned towards the stage, the observer depressed a key on the computer and released it only when the infant looked away. The computer registered the infant's looking times automatically. The program averaged the fixation times for the first three habituation trials and compared this value on-line with the average of the last three fixation times. The habituation criterion used required that the average looking time for the last three trials be less than half of that of the first three habituation trials. Thus the minimal number of habituation trials was 6. The maximum number of habituation trials was set to 14. A trial was treated as valid only if the infant fixated the event for at least 2 s, which ensured seeing the full event structure. If the subject looked at the event for less than 2 s, the trial was repeated. A trial was ended when the infant looked away for 2 s. In the habituation phase the events were counterbalanced across subjects for target position (left vs. right) as well as for target type (cube vs. tower).

4.4. Test phase

Following habituation the screen was slid in again to hide the stage and the respective positions of the two objects were reversed. Then the screen was removed and the infants were allowed to look at the two stationary objects in their new positions for 15 s. After this familiarization phase each baby saw the two types of test trials whose order of presentation was counterbalanced across subjects. The two test displays were presented three times for each subject who thus saw six test stimuli overall. In the 'new path/old object' test event the 'back of hand' action was directed at the same 'old' target object as during habituation, which, however, now appeared in the new location. In contrast, in the 'old path/new object' test event the direction of the actor's arm movement remained the same as during habituation, but now it contacted and displaced *the other ('new') object* (Fig. 2, panels C and D).

For statistical analysis we measured the infants' looking times starting from the end of the displacement of the object (at which point the hand became stationary). For this, a trained coder (blind to the experimental condition of the events) re-coded all sessions off-line from the video-records of the infants' looking behaviour. She received a signal to start measurement (by depressing a key on the computer keyboard) from another trained coder who was watching the video-records of the habituation and test events.

4.5. Reliability coding

In order to check the reliability of the off-line coding, a second coder, who was also unaware of the experimental conditions, re-coded the infant's looking times off-line from the videotape of the events. For any given test trial agreement was accepted when the difference between the looking times measured by the two independent coders did not exceed .5 s. If the difference was higher than .5 s, the coders repeated coding the event independently, until they managed to arrive at an agreement. In the analysis only those looking times were used that the two coders finally reached an agreement about. There was initial disagreement only for 4% (24 trials) of all the trials.

5. Results

The average number of completed habituation trials was 11 in the group of 6-month-olds ($SD = 3.0$), 10 for the 8-month-olds ($SD = 2.5$), and 8 for the 10-month-olds ($SD = 3.0$). The mean duration of looking at the last three habituation trials are displayed in Table 1.

The means of the total amount of looking times were calculated for the three 'new path/old object' and the three 'old path/new object' test trials, respectively (Fig. 3). Because preliminary analyses showed no effect of object position, object type, or order of presentation of test event types, these factors were eliminated from subsequent analysis. The means of the total amount of looking times for the test events were analysed by a 2×3 ANOVA using event type (new path vs. new object) as a within-subject factor and age (6-, 8- or 10-month-olds) as a between-subject factor. This analysis revealed a significant main effect for test event types: $F(1,45) = 9.74$, $p < .005$, and a marginal main effect of age: $F(2,45) = 2.90$, $p = .065$, with no significant interaction between these factors ($F(2,45) = 1.252$, $p = .296$). The results indicate that overall infants

Table 1
The mean duration of looking at the first test trials and at the last three habituation trials in the three age groups

	The mean of the last three habituation trials (*SD*)	First test trials (*SD*)	
		New object/old path	Old object/new path
Six-month-olds	2.73 (1.52)	5.75 (7.89)	4.31 (1.98)
Eight-month-olds	2.21 (1.3)	3.95 (2.06)	2.33 (1.01)
10-month-olds	2.51 (1.23)	5.22 (1.95)	2.80 (2.41)

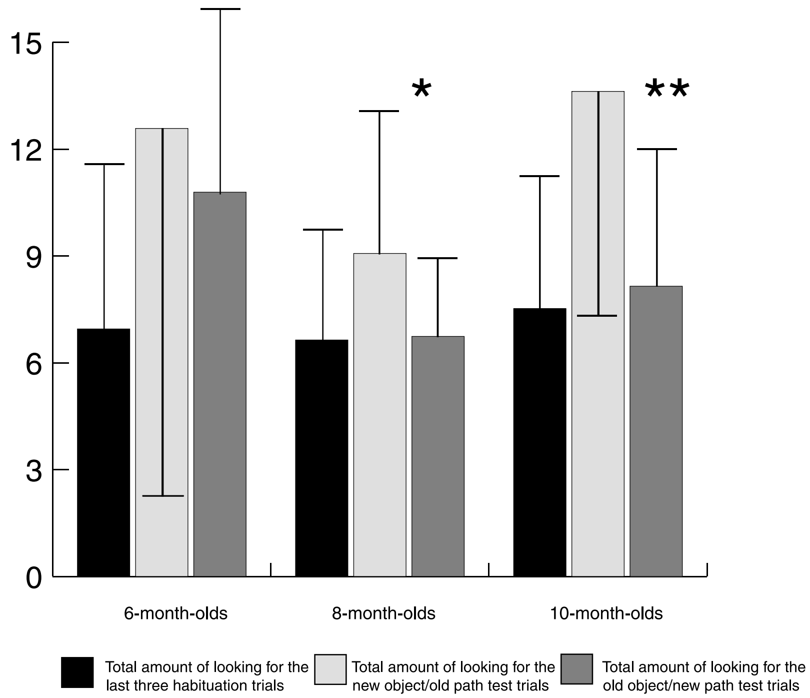

Fig. 3. Means of the total amount of looking times in the three age groups. (error bars indicate standard errors).

across all age groups tended to look significantly more at the '*old path/new object*' test event. Even though there was no significant interaction between age and event type, we nevertheless thought it would be informative to examine the effect of test event type separately for the different age groups. Therefore, we carried out separate pair-wise comparisons for the three age-groups testing for the difference between the means of the total amount of looking for the two types of test events. Infants in the 8- and 10-month-old groups looked significantly longer at the 'old path/new object' test events ($t(15) = 3.23$, $p < .01$ for 8-month-olds, and $t(15) = 3.78$, $p < .005$ for the 10-month-olds), but we found no significant difference in the group of 6-month-olds ($t(15) = .70$, *ns*). The same results were obtained when comparing the first two test events presented: $t(15) = 2.46$, $p < .05$ for the 8-month-olds, and $t(15) = 3.32$, $p < .005$ for the 10-month-olds, and $t(15) = .68$, *ns* for the 6-month-olds.

The analysis of recovery from habituation also confirms these results. We compared the mean of the total amount of looking for the last three habituation trials and the mean of the total looking for the three test trials for both the 'old path/new object' or the 'new path/old object' test events in the three age groups separately. We found that while the 8- and 10-month-old groups showed no significant recovery for the 'new path/old object' test trials ($t(15) = .104$, *ns* for 8-month-olds; $t(15) = .57$, *ns* for 10-month-olds), both of these age groups dishabituated to the 'old path/new object' test trials ($t(15) = 1.9$, $p = .078$ for 8-month-olds; $t(15) = 3.49$, $p < .005$ for 10-month-olds). In contrast, 6-month-olds showed significant dishabituation to *both* kinds of test events: $t(15) = 2.15$, $p < .05$ for the 'old path/new object' test event; $t(15) = 2.57$, $p < .05$ for the 'new path/old object' test display. This indicates that the 6-month-olds have detected the changes between the habituation and the test events, therefore the absence of differential looking in this age group cannot be attributed to a lack of attending to the stimuli.

The comparison of the mean duration of looking at the last three habituation trials and the looking times for the first test trials also showed the same pattern: both for the 8- and 10-month-olds there was significant recovery only for the first 'old path/new object' test event ($t(15) = 2.517$, $p < .05$ for 8-month-olds; $t(15) = 4.705$, $p < .001$ for 10-month-olds), while there was no dishabituation for the first 'new path/old object' test event, ($t(15) = .432$, *ns* for 8-month-olds; $t(15) = .438$, *ns* for 10-month-olds). Six-month-olds again showed recovery for both types of first test-events ($t(15) = 1.763$ $p = .098$ for the 'old path/new object' and $t(15) = 3,877$ $p < .001$ for the 'new path/old object' test event).

Non-parametric comparisons using the sign-test confirmed the above findings. In 6-month-olds, nine infants looked longer at the 'new path/old object' test events, while seven at the 'old path/new object' test events ($p > .1$). In 8-month-olds, four infants fixated longer to the 'new path/old object' test events, while 12 looked longer at the 'old path/new object' test events ($p = .07$). In the 10-month-old group, only two infants looked longer at the 'new path/old object' test events, in contrast to 14 infants with longer looking times to the 'old path/new object' test events ($p = .004$).

6. Discussion

Our positive results for the 8- and 10-month-olds provide evidence for our hypothesis concerning the importance of a salient visible change of state in the object acted upon as a perceptual cue supporting early goal-attribution. (We shall discuss the possible explanations for our failure to show the same effect in 6-month-olds later.) This finding contrasts with Woodward's (1999) results showing no goal attribution in 6- and 9-month-olds when testing the same 'back-of-hand' action. In her study, however, the cue of salient change of state in the goal object was not present as the 'back-of-hand' action always terminated in static contact with the target object. It seems, therefore, that by introducing a salient visible effect (a change of location in the object brought about by the 'back-of-hand' action) we have made it possible for our 8- and 10-month-old subjects to parse the action into two components and to set up differentiated representations for the effect and the action that brought it about. The cue of salient change in the object also provided the necessary perceptual basis for identifying the content of the goal that infants could then attribute to the unfamiliar 'back-of-hand' action. This is shown by the longer looking times found for the 'old path/new object' test event that indicates a violation of the expectation that the goal of the 'back-of-hand' action was that of displacing the *old* object, as experienced during habituation.

These results also support our further hypothesis that young infants are not restricted to attribute goals to only highly familiar actions (such as grasping). Woodward (1999) explained her subjects' failure to demonstrate goal attribution to the unfamiliar 'back-of-hand' action as being due to their lack of previous experience with this unusual action. Our positive results suggest, however, that the lack of evidence for goal attribution in her sample was more likely to be due to the absence of a salient change of state in the object acted upon, than to the lack of familiarity with the action tested.

In the case of 6-month-olds however, we found no difference in looking between the two test events. One possible conclusion, of course, could be that 6-month-olds are simply not yet able to interpret unfamiliar actions as goal-directed. An alternative explanation is suggested, however, by recent work on object individuation and identification (e.g., Kaldy & Leslie, 2003; Leslie, Xu, Tremoulet, & Scholl, 1998; Xu & Carey, 1996) indicating that the ability to identify an object as the same individual object following an occlusion on the basis of a single visual feature is not present before 8–9 months of age. This raises the possibility that the particular objects used in our study were simply not discriminable enough in terms of features for our 6-month-olds to identify the goal object during test following its occluded displacement. The potential features that could be used to discriminate the goal-object were location, shape, size, color-pattern, and visible texture. However, our objects (Fig. 2) were actually very similar in their size, color, and texture, and were clearly discriminable only in terms of their *shape* and *location*. Now if 6-month-old's are indeed unable yet to rely on a single visual feature for establishing object identity, then they may have been incapable of discriminating which of the two test objects is identical to the goal object of the habituation phase, as both test objects could have changed either its location, or its shape. The fact that we found significant but equal amount of dishabituation for both test displays is, in fact, in line with the above interpretation suggesting that our 6-month-olds detected an equal amount of feature change in the two test displays. This raises the possibility that if the goal object in our 'back-of-hand' study had been differentiable by *a combination of features*, maybe even our 6-month-olds would have been able to identify the goal object during the test trials following its previous invisible displacement. (As indeed it must have been the case for the objects used in Woodward's (1998) grasping study showing positive evidence of goal attribution in 6-month-olds.) Recently, Jovanovic et al. (2003) carried out such a different version of the present study using similar objects that were, however, discriminable in terms of *three* visible features (shape, color-pattern, and texture) rather than *one*. They report significantly longer looking at the 'old path/new object' test display even in their 6-month-old group when using more discriminable stimuli than the ones used in our study. This result is in line with the above interpretation explaining our negative finding in terms of the low discriminability of our stimuli, while providing positive evidence that 6-month-olds are capable of attributing goal to even unfamiliar manual events if the cue of a salient change of state in the goal object is present.

There is, however, an alternative explanation for the above positive findings that, if viable, could account for the results without assuming goal attribution.[4] Note that in both our and Jovanovic et al.'s study only one of the objects went through the salient perceptual change of

[4] We are grateful to Amanda Woodward for calling our attention to this alternative explanation.

moving from location A to B; and this object was the same one in the habituation and in the 'new path/old object' test display. Therefore, infants could have looked longer at the 'old path/new object' test event, because they were surprised to see the *other* ('new') object move rather than the 'old' object that was the only one moving during habituation.[5]

However, the results of Jovanovic et al.'s modified 'claw' study discussed earlier seem to rule out this alternative explanation. In that study the grasping claw displaced the target object in the same way as did the 'back-of-hand' action in both our and Jovanovic et al.'s study. But introducing the same salient change in the target object did *not* result in longer looking at the 'old path/new object' test event in the modified 'claw' study, while it did so in both of the modified 'back-of-hand' studies suggesting goal attribution in the latter but not in the former case. The differential results of the modified 'claw' *versus* the modified 'back-of-hand' studies are also informative in relation to the general question of the degree of specificity versus generality of the initial scope of understanding goal-directedness in infancy. At first sight, the failure to find goal attribution in Jovanovic et al.'s modified 'claw' study may seem to support (a version of) Woodward's 'narrow scope' position suggesting that young infants are initially restricted to attribute goals to agents that have human features and so are familiar (such as a human hand), but they fail to attribute goals to the actions performed by unfamiliar agents with no human features (such as a mechanical claw).

However, as argued earlier, the negative result of the modified 'claw' study is explicable in terms of our cue-based theory as well. We proposed that if the actor is unfamiliar and lacks human features, infants need positive perceptual evidence indicating that it is capable of equifinal modification of behaviour in order to attribute a goal to its actions. Since the invariant actions of the claw during habituation provided no such evidence, infants failed to interpret the behaviour as goal-directed.

In fact, seeing an unfamiliar object repeatedly perform the same behaviour with no modification during habituation, infants may end up categorizing it as a non-agent who performs only one type of behaviour. Infants would then expect the object to repeat its earlier behaviour during the test phase as well. There are two pieces of evidence supporting this possibility. First, in one condition of a recent habituation study (Csibra, Gergely, & Brockbank, 1998; Gergely, 2003), during habituation an unfamiliar 2D abstract figure repeatedly approached a target object always following the same path in an unmodified manner. It did so in spite of the fact that there was an alternative approach route available that it could have followed, but did not, and that—as the other condition of the experiment demonstrated—appeared to infants to be a more efficient target approach. During the test phase, the situational constraints were changed in such a way that a new and again more efficient alternative route to the target became available (while the previously unused alternative pathway was blocked). The 12-month-old subjects looked longer when the object—changing its previously invariant behaviour—now took the (more efficient) new alternative route than when it repeated its earlier behaviour.

[5] Incidentally, this kind of methodological confound seems to be inherent in all of the goal attribution studies applying the paradigm developed by Woodward. It is possible, for example, that in the Woodward (1998) grasping study infants associated the grasping hand's visual configuration with the features of the 'old' target object grasped and they expected to see the same associated configuration of features to reoccur in the test phase as well. This expectation was violated, however, by seeing the hand grasping the new object during the test trials resulting in longer looking times. Again, no goal attribution needs to be invoked to account for the findings given the viability of this alternative interpretation.

Second, while Jovanovic et al.'s modified 'claw' study found no difference in looking between the 'new path/old object' versus the 'old path/new object' test displays when contrasting the total amount of looking in the three test trials for the two events, a more detailed analysis that also included trial order as a factor revealed a significant main effect of trial order. As post hoc comparisons indicated, this effect was entirely due to a significant difference between the first 'new path/old object' test trial, which showed unusually high looking times, as compared to the second and third 'new path/old object' trials. This suggests that apart from not showing goal attribution, infants actually developed an expectation that the unfamiliar claw will continue its invariant habituation behaviour during the test phase as well: an expectation that was violated by the first 'new path/old object test' event.

Finally, there are three new studies with 6-month-olds that support the assumption of our cue-based theory that if there is perceptual evidence of equifinal variability of action during habituation, infants will attribute goal to the actor's action *even if* the actor is unfamiliar and lacks human features. First, Bíró and Glanville (2003) reported a variation of Woodward's paradigm where during habituation *both* of the cues of goal-directedness that we have derived from the assumptions of the teleological stance were present: (1) the actor (either a human hand with an extended finger, or a novel inanimate object: a paper tube) was repeatedly poking the target object in a way that exhibited equifinal variation of action (the actor was poking the object from varying angles and at slightly different spots), and (2) the target object went through a salient change swaying in different directions under the impact of the poking actions. Under these cuing conditions, Bíró and Glanville (2003) found evidence for goal attribution for both types of agents in 12-, 9-, and 6-month-olds: even the youngest infants tended to look longer at the 'old path/new object' test event than at the 'new path/old object' test display.

Second, Luo and Baillargeon (2002) reported a study with 5.5-month-olds using the Woodward paradigm again. Their actor was an unfamiliar box with no human features that approached and contacted one of two objects repeatedly during habituation. The box exhibited self-initiated and irregular movement reaching its target through variable equifinal pathways during familiarization. Luo and Baillargeon found longer looking times for the 'old path/new object' test event indicating goal attribution to the unfamiliar object that, nevertheless, exhibited the above agency cues.

Third, consider Gergely et al.'s (1995) 'jumping-over-the-obstacle' study described earlier that demonstrated goal attribution in 12-month-olds to unfamiliar computer-animated abstract figures exhibiting equifinal variation of action. Csibra et al. (1999) replicated this result with 9-month-olds, but failed to find the effect in 6-month-olds. However, the latter negative finding may have been due to the 6-month-olds' difficulty to interpret the 2D figures as solid physical objects moving in 3D space as the stimulus events lacked salient depth cues (such as partial occlusion of the agent or the goal object). A 3D interpretation of the event seems necessary, however, for considering the circle's behaviour as goal-directed, since the presence of the rectangle can justify the circle's jumping action as an efficient goal-approach only if it is interpreted as a solid 3D 'obstacle' separating the actor from the goal object. This interpretation of Csibra et al.'s negative result with 6-month-olds has recently received independent support from a modified replication of the Gergely et al. study by Kamewari, Hiraki, Kato, Kanda, and Ishiguro (in preparation) using 6.5-month-old subjects. These authors used videotaped habituation events in which either a real person or an unfamiliar robot moving on four wheels approached its goal by making a detour around an obstacle separating them. Unlike in the Csibra et al. (1999) study, Kamewari et al.'s stimuli provided sufficiently salient depth cues to allow even 6-month-olds to interpret the 2D figures as solid 3D objects as the moving actor was partially occluded from them by the barrier during the detour action. Under these conditions 6.5-month-olds did show evidence of goal attribution both when the actor was human or when it was an unfamiliar robot.

We can conclude that the fact that in all of these studies even 6-month-olds showed goal attribution when interpreting the actions of *unfamiliar objects* (such as a robot) *or objects lacking human features* (a paper tube, or a box) *as long as they exhibited equifinal variation of action* supports the hypothesis that the initial domain of goal attribution has a general and 'wide scope.' Thus, as predicted by the teleological stance (Csibra & Gergely, 1998; Gergely & Csibra, 1997, 2003), if the abstract cues of goal-directedness are present, even very young infants are able to attribute goals to the actions of a wide range of entities even if these are unfamiliar objects lacking human features.

7. Conclusion

In conclusion: The present study together with a set of recent experiments reviewed provide converging evidence that infants as young as 6 months of age can interpret actions as goal-directed as long as they exhibit abstract perceptual cues suggesting goal-directedness such as equifinal variation of action or salient change of state brought about in the goal object. The fact that when the cues of goal-directedness are present goal attribution can be demonstrated as early as 6 months of age for unfamiliar human actions as well as for actions performed by novel objects lacking human features suggests that understanding goal-directedness does not develop in a piecemeal fashion as a function of learning about particular actions as they become familiar to the infant, but is due to a more general representational understanding of the concept of goal that indicates the very early presence of a teleological action interpretational system in infancy.

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