Brief article

Infants attribute goals even to biomechanically impossible actions

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Abstract

Human infants readily interpret the actions of others in terms of goals, but the origins of this important cognitive skill are keenly debated. We tested whether infants recognize others’ actions as goal-directed on the basis of their experience with carrying out and observing goal-directed actions, or whether their perception of a goal-directed action is based on the recognition of a specific event structure. Counterintuitively, but consistent with our prediction, we observed that infants appear to extend goal attribution even to biomechanically impossible actions so long as they are physically efficient, indicating that the notion of ‘goal’ is unlikely to be derived directly from infants’ experience.

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1. Introduction

As adults, we readily perceive the actions of other humans in terms of their goals and intentions (Csibra & Gergely, 2007). This basic aspect of action perception allows us to interpret the behaviours of others in ways that would otherwise be
impossible (Baldwin & Baird, 2001), and it is now generally agreed that, at least by the middle of the first year of life, infants too construe the actions of others in this goal-directed way (Csibra, 2008; Gergely, 2002; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Tomasello, 1999; Woodward, 1998).

A debate over how this understanding arises during ontogeny centres on the extent to which experience with a particular action is necessary in order to be able to interpret it as goal-directed. One view of action understanding holds that actions are understood when the observer directly matches, or mirrors, the observed action onto their own motor system (Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001). If this kind of motor simulation of what is observed permits action understanding, it follows that only actions that observers can themselves perform will be able to be simulated (Buccino et al., 2004) and hence acquire meaning (Rizzolatti et al., 2001). In a similar vein, Woodward and colleagues have proposed that through experience with particular actions, both their own and those that they observe, infants gradually come to construe actions in terms of attaining goals (Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001). According to these views, action understanding emerges in parallel with the infants’ own ability to produce means-end action sequences and with their opportunities to observe others performing similar actions (Sommerville & Woodward, 2005). Although intentional grasping, the action portrayed in the Woodward paradigm, is an action that infants do not begin themselves until 4–6 months of age (Piaget, 1953), if 3-month-olds are given experience with grasping (by means of Velcro gloves), they then subsequently also interpret an observed grasping action as goal-directed (Sommerville, Woodward, & Needham, 2005). This result suggests that experience with a particular action facilitates the construal of an event in terms of goals.

An alternative explanation for the development of understanding goal-directed actions holds that infants possess cognitive mechanisms that can recognize goal-directed actions irrespective of their familiarity. Specifically, an action may be interpreted as goal-directed whenever it is judged to be an efficient means to achieve its end (Gergely & Csibra, 2003). In a series of studies, Gergely, Csibra, and colleagues have demonstrated that infants attribute goals to actions only when they appear efficient in the context in which they are occurring. The general paradigm involves habituating infants to a ball jumping over an obstacle and coming to rest adjacent to another ball (Csibra, Gergely, Biro, Koós, & Brockbank, 1999; Gergely, Nadasdy, Csibra, & Biro, 1995). They are then presented with a scene where there is no obstacle and see the ball either taking the same route as it did in habituation (indirect path), or taking a new, straight path towards the other ball (direct path). Infants look longer towards the indirect test event, even though this is perceptually more similar to what they saw during habituation. Crucially, when the habituation event portrays a behaviour that does not constitute an efficient action towards an end state (the ball jumping when there is no barrier), infants show no preference when presented with the same two test events, suggesting that they have not construed the jumping behaviour as a goal-directed action in that situation.

These two views make markedly different predictions regarding the type of actions infants will successfully attribute goals to. According to the experience-based view,
only familiar actions will be interpreted as goal directed, since the understanding of goals is built up from infants’ experience of actions. In contrast, the opposing view asserts that infants possess a system enabling them to encode the event structure of goal-directed actions, but this is not dependent on prior learning about the details of human action. Hence, infants could recognize goal-directed actions even in unfamiliar behaviours of humans as long as they represent an efficient goal attainment. Accordingly, a human action that is biomechanically impossible, hence unfamiliar, but represents an efficient goal approach could only be perceived as goal-directed under the latter account. This hypothesis is based on the assumption that knowledge of the biological constraints on the human body and human action is gradually acquired during infancy, and may not be firmly established in infants in the middle of the first year of life (Reid, Belsky, & Johnson, 2005; Slaughter, Heron, & Sim, 2002).

The current study tested this prediction by presenting 6- to 8-month-old infants with a variation of the Gergely et al. paradigm, which contrasted a biomechanically impossible yet relatively more efficient action with a biomechanically possible yet relatively less efficient action. The efficiency principle of goal attribution requires that agents expend the least possible amount of energy within their motor constraints to achieve a certain end. Since energy consumption is not directly perceivable, the application of this principle boils down to evaluation of various simple spatio-temporal motion parameters, like the length of the path (e.g., Gergely et al., 1995), or the time spent on the action. In the present study, we operationalized the principle in terms of the number of action steps the agent performs for achieving its goal. Ceteris paribus, the less number of steps it takes to achieve a goal, the more efficient is an action. In reality, this heuristic provides valid evaluation of efficiency, hence valid goal attribution, only if the actions that are compared are biomechanically possible. For infants, who may not yet have accumulated enough knowledge about the biological constraints on human actions, the reliance on such a heuristic may mislead them by creating an illusion of efficiency for an impossible action.

Infants were randomly assigned to an experimental and a control group, which differed only in the familiarization event they observed. Infants in the experimental group repeatedly saw a videotaped scene in which a human arm moved an obstructing box out of the way and then reached out and retrieved an object (Fig. 1a). Infants in the control condition saw a similar familiarization event but in this case the moving of the box was unnecessary considering its location relative to the to-be-retrieved object (Fig. 1b). The main aim of our control condition was to ensure that infants did not simply have a perceptual preference for one test event over the other. The added benefit of familiarizing infants with a non-efficient action was, like in other studies employing a similar paradigm, to show that when infants are unable to link the action to the goal, they do not have any expectations concerning how the agent should behave in a changed environment. Following familiarization, both groups

1 The role of the efficiency principle is the same in goal attribution as the role of the principle of rationality in mental state attribution (Gergely & Csibra, 2003), but is applied to states of the world rather than to mental state contents.
saw identical test trials, counterbalanced for order of presentation. In both test events, a second box obstructed a straight reach to the object. In one test event (Possible Less Efficient) infants saw the arm push the second box out of its obstructing position and then reach to retrieve the object (Fig. 1c), whereas in the other test event (Impossible More Efficient), infants saw the arm snake around the second box in a biomechanically impossible fashion and retrieve the object (Fig. 1d). In other words, the possible action reached the goal state in more steps (less efficiently) than did the biomechanically impossible one.

If infants come to interpret actions as goal-directed only after becoming familiar with them, then they should not interpret the impossible test event as a goal-directed action and should find this action unexpected. On the other hand, if infants are biased to detect efficiency, then those in the experimental group should interpret the familiarization event as a goal-directed action because it was efficient: the box needed to be moved in order to obtain the ball. Having construed the action in terms of a goal, when presented with the new test stimuli, infants should continue to expect the arm to behave in an efficient goal-directed manner towards this goal. In accord with this expectation, infants should recover more attention when presented with the action that is a relatively less efficient means to achieving the goal: the action in
which the arm moves the second box out of the way. Infants in the control condition, on the other hand, should be unable to predict what the agent will do under different circumstances and so should not find either test event more unexpected than the other.

2. Methods

2.1. Participants

Twenty-eight 6- to 8-month-old infants participated in the study (14 females, 14 males, mean age 6.9 months, range 6.0–7.8 months). They were assigned randomly to the experimental (mean age 6.7 months) and control (mean age 7.0 months) groups. A further 36 infants were excluded due to fussiness (8), too short looking times (18), failing to meet our familiarization criterion (4), and experimental error (6). In order to ensure that infants’ looking times reflected their processing of the goal attainment of the hand’s actions in the video clips, we excluded all infants from further analysis whose short looking time in either test trial would not have allowed them to see the hand grasping the target object. Our lengthy minimum looking time criterion (corresponding to the time needed to see that the hand reached the goal object) resulted in a large number of babies being excluded from analysis.2 Furthermore, we excluded any babies who looked for the maximum duration (90 s) on any of the last three familiarization trials. Of the infants who were excluded but who completed the study (27), 16 were from the experimental group and 11 were from the control group, a difference which is not statistically significant in a $\chi^2$ test. Exclusion based on our looking time criterion ($n = 18$) resulted in 10 infants being excluded for not looking long enough on the possible but less efficient test trial, 6 for not looking long enough on the impossible but more efficient test trial, and 2 for looking for too short a duration on both test trials. Most infants excluded on this basis exhibited the short looks on the second test trial (12) rather than the first test trial (4).

2.2. Stimuli and procedure

Digitally edited video recordings of a hand grasping a small ball served as stimuli. The familiarization event for the experimental group depicted a human arm moving an obstructing box out of the way and reaching out and retrieving the ball. Infants in the control condition saw a similar familiarization event but in this case the moving of the box was unnecessary considering its location relative to the ball. In the test events a second box obstructed the arm’s straight route towards the ball. In the Possible Less Efficient test event the hand pushed this box away, while in the Impossible

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2 This high attrition rate is not unprecedented in similar studies that also required a minimum looking time in the test events after habituation or long familiarization (see e.g., Csibra et al., 1999; Gergely et al., 1995).
More Efficient test event the arm snaked around it to reach the ball. This latter effect was achieved by a digital distortion software (Adobe After Effects). All four events lasted for 10 s (including a one-second blank screen), and were presented in a loop as long as the infants watched them.

Infants were seated on the caregiver’s lap at a distance of approximately 100 cm from a 50 × 67 cm plasma screen in a darkened room. A cartoon preceded the onset of each trial, which served to attract the infants’ attention towards the screen. A bell behind the screen was occasionally rung to get the infant’s attention if they became distracted. The infants’ behaviour was monitored and recorded by a remote-control infrared video camera. When the infant was looking at the screen, the experimenter started the presentation of the familiarization stimulus, which was repeated in a loop continuously until the infant looked away from the screen for 2 s or until 90 s elapsed. At this point, the computer calculated the total looking time for that event. When the infant looked back at the screen, the next trial was started. Infants were presented with six familiarization trials. Following familiarization, infants saw the two test trials (counterbalanced for order of presentation), which again, were repeated until the infant looked away for 2 s. The caregivers were instructed to close their eyes during the presentation of the test events. A lullaby tune played continuously throughout the experiment from speakers located behind the plasma screen. The stimuli were controlled, and the looking times were measured, by a custom-built computer program. The video stimuli were mixed to the recording of the infants’ behaviour for off-line coding.

2.3. Data analysis

Looking times were measured on-line by a research assistant who was unaware of the experimental hypotheses. Looking times during the test trials of nine of the 28 infants were re-coded off-line by a secondary coder to check reliability. The two measurements correlated at a high level (\( r = .987 \)) with the average absolute difference between online and offline coding being 450 ms. The data analyses were based on the on-line measurements.

3. Results

The pattern of looking during familiarization did not differ significantly between the experimental and control group. The attention decrease from the first familiarization trial to the last familiarization trial was roughly 30 seconds for infants in both groups. Furthermore, in both groups, the mean duration of looking time during the last two familiarization trials (Experimental mean = 11.8 s, SD = 5.65 s, Control mean = 17.1 s, SD = 9.16 s) was less than half that of the first two familiarization trials (Experimental mean = 40.4 s, SD = 32.6 s, Control mean = 37.5 s, SD = 21.4 s), indicating that our fixed-trial familiarization procedure designed to reduce infant fatigue and boredom resulted in the same outcome as the standard infant-controlled habituation criterion. Statistical tests confirmed that there was
no significant difference between groups in looking times on either the first or the last two familiarization trials (1st and 2nd familiarization trial, \( p = .65 \) and \( .37 \), respectively, and 5th and 6th familiarization trial, \( p = .30 \) and \( .16 \), respectively.

An analysis of variance was conducted to test the effects of condition (experimental vs. control), order (impossible test trial first vs. possible test trial first) and trial type (Impossible More Efficient vs. Possible Less Efficient) on looking times at the two test events. This analysis revealed only a significant interaction between test trial type and group \([F(1,24) = 7.95, P = .009]\) and so the data were collapsed over order for further analyses. Paired-sample \( t\)-tests revealed significantly longer looking at the possible test event (mean = 22.48 s, \( SD = 11.73 \) s) than the impossible test event (mean = 13.64 s, \( SD = 7.62 \) s) for the experimental group \([t(13) = 2.47, P = .028]\) suggesting that infants found the less efficient but biomechanically possible route unexpected. This conclusion was confirmed in a non-parametric Wilcoxon-test \([Z = 2.17, P = .030]\). No significant differences in looking at the test events were found for the control group \([t(13) = 1.30, p = .215, Z = .659, p = .510]\), who looked approximately equally to the possible (mean = 14.91 s, \( SD = 5.31 \) s) and impossible (mean = 17.79 s, \( SD = 11.01 \) s) actions (Fig. 2).

The relatively wide age range of the participants in the current study (6–8 months) would leave open the possibility that there may be differences in infant’s responses as a function of age. In order to address a potential age effect, we included age group (younger and older, split according to the median age) as an additional factor in a further ANOVA, omitting order as a factor (as there were not equal numbers who had received each order within each age group as defined by the median age). This

![Fig. 2. Looking times to the test events. Infants in the experimental group looked longer at the Possible but Less Efficient action than the Impossible but More Efficient action, while no such effect was found in the control group. Error bars represent standard error.](image-url)
ANOVA revealed again a condition (Experimental vs. Control) × Trial Type (impossible vs. possible) interaction \[F(1,24) = 7.44, p = .012\], but no interactions with age, suggesting that infants in the whole age range responded similarly.

4. Discussion

These results strongly indicate that experience with the details of a particular action (Woodward et al., 2001) or direct matching between an observed action and the observers own motor system (Rizzolatti et al., 2001), are not prerequisites for interpreting the structure of an action in terms of goals. Because the biomechanically impossible action was, by definition, unfamiliar (and motorically ‘unmatchable’), it is unlikely that infants were drawing on experience of the details of the action in order to accept it as goal-directed. Nevertheless, despite being entirely unfamiliar, infants apparently did extend their attributions of goal-directedness formed during familiarization, to the biomechanically impossible test event. They expected the arm to continue to behave in an efficient way, and when it did not, they responded with increased attention. It is unlikely that infants were merely responding to a perceptually more complex or interesting action when they looked longer at the biomechanically possible action. Such an effect should also be evident in the control group, who saw exactly the same test events as the infants in the experimental group. The absence of a looking time difference during the test events in the control group suggests that they could not make sense of the inefficient familiarization event they had observed, did not relate that action to its end state (its ‘goal’), and did not develop an expectation about the action the hand would perform in an altered environment. Although there were elements of the biomechanically impossible event that were still possible to mirror (i.e., the grasping of the target object), had infants paid attention only to the hand it is still unlikely that they would have predicted its efficient action via simulation because young infants are unable to perform double-detour reaching actions themselves (Diamond, 1990).

The result reported here adds strength to an emerging body of findings also suggesting that familiarity and experience with action details are not the primary variables that determine attributions of goal-directedness. For example, both Kamewari et al. (2005) and Sodian, Schoepner, & Metz (2004) have shown that infants do attribute goals to humans performing actions that the infant cannot yet perform (walking by 6-month-olds and jumping by 12-month-olds, respectively). Furthermore, while Woodward (1998, 1999) has shown that infants do not attribute goals to an unfamiliar back-of-hand action or a grasping mechanical claw, more recent studies have shown that infants as young as 6 months will attribute goals in both of these conditions if they are given further cues to goal-directedness, such as equifinal variation of action (slight variations in actions during habituation) and a salient change of state in the object that is acted upon (Biró & Leslie, 2007; Jovanovich et al., submitted for publication; Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003).
An important difference between the current study and the paradigm on which it was based (Gergely et al., 1995) is that the two test events presented to infants here, biomechanical possibility aside, could both be seen as reasonable ways to achieve the goal. The difference between the two events lies in their relative efficiency. What led infants in our study to judge the biomechanically impossible event as more efficient? While it is most unlikely that infants would have predicted the particular impossible action portrayed, they may have expected that the arm would behave in a way that is at least as efficient as what they witnessed during the familiarization. A number of different factors may influence judgements of efficiency, and considering infants of this age abilities to individuate and enumerate actions (Wynn, 1996), one plausible factor may be the number of sub-components of the perceived action (see also Baldwin, Baird, Saylor, & Clark, 2001). The familiarization event consisted of a two-step action to goal achievement as did the impossible test event, whereas the possible test event consisted of a three-step action to goal achievement. Therefore, it is possible that infants’ expectations of continued efficiency were better fulfilled in the impossible test event than the possible test event. Due to the non-efficient familiarization action, infants in the control condition did not form any expectations about how the arm will behave during the test event, and so the number of sub-components were not relevant to them.

Although infants have been known to be sensitive to certain aspects of biological motion (e.g., Bertenthal, 1993), little is known about the young infants’ knowledge of biological constraints on human action. Our findings suggest that even if infants of this age may possess some rudimentary familiarity with the capabilities of a human arm, it is too weak to override the expectation of physical efficiency required for goal attribution. This suggests that the tendency to encode overall structure in sequences of human action in terms of goals is strong in young infants. We propose that this general event structure provides a framework for subsequent learning about the constraints on human action. Once these biases have been deployed to identify instances of goal-directed action, infants can then begin to build up a knowledge base of what actions are possible. Insofar as infants will never view, nor themselves perform, actions that are biomechanically impossible, they may use this negative evidence to eventually learn about what actions are also not possible. (Note that in the case of non-human agents, such as animals, only the expectation of efficiency allows such a learning of biological constraints from negative evidence.) There is evidence that some 8-month-old infants who themselves have finely tuned motor skills are better able to detect biomechanically impossible actions than infants who do not have such finely tuned motor abilities (Reid et al., 2005), suggesting that infants own abilities to perform actions may facilitate learning about biological possibility, in a way that it apparently also facilitates their learning about the consequences of novel actions (Sommerville et al., 2005). Presumably, at a later age when infants’ knowledge of the biomechanical constraints on human actions is stronger, they will no longer accept an impossible action as being an efficient means of achieving a goal. For example, 5-month-olds understand that humans are solid and cannot violate the laws of solidity (Moore, 2002; Saxe, Tzelnic, & Carey, 2006) and so we should expect that they would not find an action which does so efficient.
In accord with the view that infants interpret events as goal-directed based on a system that detects efficient actions, infants in the current study extended attributions of goal-directedness to an unfamiliar action of a human arm. This finding suggests that the extraction of goal-directedness on the basis of the efficiency principle may precede, and guide learning about, the biological constraints of human action. The further question of whether this precedence of goals in the interpretation of human actions is acquired quickly in early infancy, or whether it is based on an inborn principle or bias, remains a question for future research.

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