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## The role of the efficiency of novel actions in infants' goal anticipation

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### ABSTRACT

In two experiments, we recorded infants' eye movements to test whether the efficiency of the action influences infants' ability to anticipate the outcome of an ongoing action performed by abstract figures. In Experiment 1, we found that predictive eye movements were elicited by both nonefficient and efficient actions, but anticipation of the outcome occurred much earlier in the efficient action condition. Experiment 2 was designed to test the effect of saliency of the goal and the possibility that automatic extrapolation of the movement was partly responsible for the predictive gaze shifts in Experiment 1. We found that when automatic extrapolation was prevented and the goal was not salient, infants showed predictive gaze shifts only in the efficient action condition. Taken together, our findings support the importance of teleological inferences in anticipating the goals of ongoing actions.

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### Introduction

The ability to anticipate the outcome of others' ongoing actions allows us not only to attribute goals to observed actions but also to prepare ourselves to interact with or, if necessary, to counteract others before their actions are completed. Therefore, this capacity is undoubtedly useful, and its early emergence is crucial for survival as well as for social learning (Csibra & Gergely, 2007; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Although several different mechanisms have been proposed to be responsible for the development of the ability to identify the likely outcome and goal of an action

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(Gergely & Csibra, 2003; Hommel, Musseler, Aschersleben, & Prinz, 2001; Rizzolatti, Fogassi, & Gallese, 2001), there is no consensus about their relative importance.

According to one of the theories on action interpretation, we use a teleological framework to attribute goals (Gergely & Csibra, 2003). Thus, when we observe an action, we seek to establish a relationship among three relevant aspects of current reality: the action, the outcome, and the physical constraints of the situation. The teleological stance theory argues that an observed action will be interpreted as goal-directed only if the action can be considered as the most efficient means to achieve the outcome under the current situational constraints. It is claimed that the application of this abstract interpretational schema requires neither extensive experience with actions nor the ability to perform them and that, therefore, it can be applied to interpret actions of a wide range of entities. Several studies have used the “violation of expectation paradigm” to test the application of the teleological framework during infancy. The looking time patterns found in these studies suggest that infants from around 6 to 9 months of age are able to rely on the efficiency<sup>1</sup> of both human and novel nonhuman (robotic or self-propelled objects) actions to interpret the actions as goal-directed (Biro, Csibra, & Gergely, 2007; Biro, Verschoor, & Coenen 2011; Csibra, Gergely, Biro, Koós, & Brockbank, 1999; Csibra, 2008; Csibra et al., 2003; Gergely, Nádasdy, Csibra, & Biro, 1995; Hernik & Southgate, 2012; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Sodian, Schoepner, & Metz, 2004; Southgate, Johnson, & Csibra, 2008; Verschoor & Biro, 2012; Woodward & Sommerville, 2000).

Furthermore, the teleological stance theory claims that the teleological interpretational system also allows the generation of predictive inferences, including goal prediction. Thus, when we observe an ongoing incomplete action, we can rely on the assumption of efficiency to infer an outcome that can be justified under the given situational constraints. This hypothesized outcome can then be attributed as the goal of the action. Some studies suggest that from around 12 months of age, infants can make inferences about the unseen goals of incomplete actions. For example, during the observation of “chasing” events of abstract geometric figures or balls (Csibra et al., 2003; Southgate & Csibra, 2009; Wagner & Carey, 2005), infants were able to interpret the observed action as chasing and infer the outcome that the chaser would catch up. However, the infants were able to do so only if the observed ongoing action could be considered as an efficient means toward the hypothesized outcome given the situational constraints.

Because the findings in all of these studies are based on duration of looking time measures, they might be open to alternative interpretations. Indeed, it has been argued that these measures do not necessarily reflect true predictions about the outcome; they could instead indicate retrospective inferences. Infants could, in principle, have evaluated the efficiency of the action when they were presented with the outcome during the test events rather than while they were watching the incomplete actions during the habituation/familiarization phase (Gredebäck & Melinder, 2010; Southgate, Johnson, Karoui, & Csibra, 2010).

Another (more direct) measure that has recently been used to investigate adults' and infants' ability to anticipate the outcome of observed ongoing actions is predictive eye gaze (Cannon & Woodward, 2012; Eshuis, Coventry, & Vulchanova, 2009; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Flanagan & Johansson, 2003; Gredebäck & Kochukhova, 2010; Gredebäck & Melinder, 2010; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Kanakogi & Itakura, 2011; Kochukhova & Gredebäck, 2010; Paulus et al., 2011). Falck-Ytter and colleagues (2006), for example, demonstrated that 12-month-olds, but not 6-month-olds, show predictive eye movements when they observe a human hand transferring balls to a basket; that is, they shift their gaze to the basket before the hand arrives and drops the ball into the basket. However, predictive eye movements were not found in this study when the balls moved to the basket by themselves without help from the hand. In this case, infants followed the movement, but their gaze did not arrive at the basket ahead of the moving balls. The authors argued that these findings suggest that predictive looking, and therefore goal anticipation of ongoing actions, is restricted to human actions and that infants need to be able to perform the actions themselves to anticipate the goals of similar actions by others. This argument supports the direct

<sup>1</sup> In these studies, the evaluation of efficiency was based on various perceptual cues such as taking the shortest pathway, exerting the least effort, and taking only causally necessary steps. Therefore, it has been suggested that the efficiency of the action is applied as an abstract principle for representing actions during infancy (e.g., Csibra, Biro, Koós, & Gergely, 2003).

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