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Extrapolation and direct matching mediate anticipation in infancy

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ABSTRACT

Why are infants able to anticipate occlusion events and other people's actions but not the movement of self-propelled objects? This study investigated infant and adult anticipatory gaze shifts during observation of self-propelled objects and human goal-directed actions. Six-month-old infants anticipated self-propelled balls but not human actions. This demonstrates that different processes mediate the ability to anticipate human actions (direct matching) versus self-propelled objects (extrapolation).

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1. Introduction

Anticipatory eye movements reflect our expectations about the world around us. These expectations may concern observed physical events as well as the actions of others. Whether anticipating the next move of our tennis partner or the path of an approaching ball, the ability to generate these predictions is an important part of our everyday lives.

Adults as well as infants use anticipatory eye movements while observing other people's actions, just as when they perform the actions themselves (Flanagan & Johansson, 2003; Land, Mennie, & Rusted, 1999; Rosander, & von Hofsten, 2011). Falck-Ytter, Gredebäck, and von Hofsten (2006) observed adults, 12-month-olds, and 6-month-olds who watched a series of videos in which an actor picked up toys and put them in a bucket (termed a 'human agent' condition). Adults and 12-month-olds, but not 6-months-olds, looked to the goal of the action anticipatorily. The authors noted that 6-month-old infants have not yet started putting objects into containers, which explained their inability to anticipate the goal of the human action. At the same time, 6-month-old infants look ahead of the action to the mouth of an actor eating a banana (Kochukhova & Gredebäck, 2010). Gredebäck and Melinder (2010) further showed that the latency time for fixating on the goal (i.e. the mouth) during feeding actions is dependent on the experience of being fed. In that context, almost 200 days of experience was required for anticipation to develop. Further, Gredebäck and Kochukhova (2010) found that older infants who had experience in performing a manual task (in that case, solving a puzzle) showed faster anticipatory eye-movements to the goal while observing the task, indicating a connection between the infants' own motor experience and their ability to predict the action goals of others. Thus, when it comes to human actions, the ability to anticipate future events seems to be dependent on ample experience with the observed action (Cannon, Woodward, Gredebäck, von Hofsten, & Turek 2012; Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011; Kochukhova & Gredebäck, 2010).

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The apparent link between motor experience and action anticipation has been interpreted as supporting the direct-matching hypothesis, which states that we understand the action of another person by mapping the observed action onto our own motor representation of that action (Flanagan & Johansson, 2003; Hari et al., 1998; Rizzolatti, Fogassi, & Gallese, 2001; Rizzolatti & Craighero, 2004). Recently Elsner, D'Ausillio, Gredebäck, Falck-Ytter, & Fadiga (2013) showed that there is indeed a causal connection between anticipatory eye movements and motor cortex activity. Specifically, each subject observed reaching actions while the motor cortex corresponding to the hand or the leg area was stimulated with transcranial magnetic stimulation (TMS). Stimulation over the hand area, but not stimulation over the leg area, negatively affected goal-directed gaze latency times. There is evidence that infants, too, employ their motor system during action observation (Nyström, Ljungammar, Rosander, & von Hofsten 2011; Nyström, 2008; Southgate, Johnson, Karoui, & Cibra, 2010; van Elk, van Schie, Vesper, & Bekkering, 2008). Together, these findings suggest that while observing human actions, both infants and adults make anticipatory gaze shifts to the goal or to the endpoint of the action and that in infants, this ability is connected to the infants' own motor experience with the action. (For alternative interpretations that emphasize more cognitive aspects of action anticipation, please see Csibra, 2008; Southgate & Begus, 2013.)

Another line of evidence that supports the direct matching hypothesis is that infants and adults fail to anticipate self-propelled objects that move toward goals. In the study by Falck-Ytter et al. (2006) mentioned above, a control condition included animated events that mimicked the movement path of the objects being manipulated by the actor in the human agent condition. In this animated condition, neither adults nor 12-month-olds looked at the goal significantly ahead of the moving object. The authors concluded that twelve-month-old infants and adults do not see self-propelled objects as goal-directed and that anticipatory goal-directed eye movements seem to require an interaction between an agent and an object for direct-matching to occur. Results from other studies involving self-propelled goal-directed objects also support this conclusion (Eshius, Coventry, & Vulchanova, 2009; Kochukhova & Gredebäck, 2010). In these studies, both adults and infants fixated on the goal of self-propelled objects later (showing longer latencies) than on the goal of human actions.

In summary, both infants and adults anticipate the goals of actions performed by humans but not the end-point of a self-propelled objects motion. These results fit nicely with the direct-matching hypothesis. However, the results are rather puzzling in light of another body of work. In fact, object representation studies demonstrate that both infants and adults are able to anticipate the motion of self-propelled objects. When observing an object that is moving back and forth on a screen in a linear manner, infants track the moving object in an anticipatory manner from 3 months of age on. This means that the gaze is not lagging behind the object of interest but is directed toward it during the changes of motion (von Hofsten & Rosander, 1996, 1997). This ability to anticipate the object's motion is based on assumptions of how the object will move in the future. When an object moves behind an occluder, smooth tracking is interrupted; to pursue tracking, a saccade is performed that shifts the gaze to the reappearance side of the occluder (Bertenthal, Gredebäck, & Boyer, 2013; von Hofsten, Kochukhova, & Rosander, 2007). Several studies have shown that from four months of age, infants anticipate that an object that moves behind an occluder will reappear on the other side (Gredebäck & von Hofsten, 2007; Rosander and von Hofsten, 2004; von Hofsten et al., 2007). Infants represent the object when it is not visible and anticipate where and when the object will reappear, even when the occlusion duration is several seconds long, and, from 6-months of age, even when the path of the object motion is circular rather than straight (Gredebäck, von Hofsten, & Boudreau, 2002; Gredebäck & von Hofsten, 2004).

Kochukhova and Gredebäck (2007) investigated whether 6-month-old infants use previous experience or extrapolation when viewing a ball rolling behind a circular occluder. When the object appeared on a trajectory positioned 90° to the original path, infants failed to make an accurate prediction; instead, they looked to the other side of the occluder as if the object would continue the original path. After a very few trials, the infants learned the "new" location and looked to the correct place. These results indicate that infants initially use extrapolation of the object's previous motion path to predict the future path of the object. Several studies support this conclusion (Spelke & von Hofsten, 2001; von Hofsten, Feng, & Spelke 2000; von Hofsten et al., 2007); see also Gredebäck and von Hofsten (2007) for a review. Taken together, these studies show that from a very young age, infants can represent objects during occlusion and anticipate the future path of an object based on its previous motion.

These data raise the question: Why can infants anticipate the reappearance of temporarily occluded objects and the goal of manual actions but fail to anticipate the future path or goal of self-propelled objects? The current study investigates the surprising discrepancies between findings from the action anticipation literature versus the object representation literature. Notably, there are some differences between action anticipation and object representation studies that might account for the fact that infants anticipate some events (i.e. human goal-directed actions and balls moving behind screens), but not others (i.e. self-propelled objects).

One clear difference is the *presence or absence of social context*. In action anticipation studies that involve human actions and self-propelled objects, a human actor is present, even when that actor is not moving and the objects are moving on their own (Eshius et al., 2009; Falck-Ytter et al., 2006; Kochukhova & Gredebäck, 2010). In contrast, object representation studies typically do not involve a human actor. In such studies, the ball is usually moving over a uniform background without contextual and social cues (von Hofsten et al., 2007).

A second difference relates to *the path of the moving object/hand*. In object representations studies, objects typically move in linear paths that can easily be extrapolated. In action prediction studies, objects typically move in curved paths, which are not as easy to predict with physical laws. A third difference between action anticipation and object representation studies involves the *presence or absence of an occluder* that visually blocks parts of the movement trajectory. In object representation studies, an occluder temporarily blocks the visibility of the moving object (von Hofsten et al., 2007) whereas

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