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).

Keywords: infant; eye tracking; social cognition; anticipation; extrapolation; action; prediction

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, & 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 & 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 & 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 (Falck-Ytter et al., 2006;

Kochukhova & Gredebäck, 2010; Kanakogi & Itakura, 2011; Cannon, Woodward, Gredebäck, von Hofsten, & Turek 2012).

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 et al., 2001; Rizzolatti & Crahiero, 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, 2008; van Elk, Schie, Vesper, & Bekkering, 2008; Southgate, Johnson, El Karoui, & Cibra, 2010; Nyström, Ljungammar, Rosander, & von Hofsten 2011). 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 and Southgate & Behus, 2013).

Another line of evidence that supports the direct matching hypothesis is that infants and adults fail to anticipate self-propelled objects that move towards 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 towards 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 (von Hofsten, Kochukhova, & Rosander, 2007; Bertenthal, Gredebäck, & Boyer, 2013). 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 (Rosander & von Hofsten, 2004; Gredebäck & von Hofsten, 2007; von Hofsten, Kochukhova, & Rosander, 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 & 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 (von Hofsten, Kochukhova, & Rosander, 2007; Spelke & von Hofsten, 2001); see also Gredebäck & 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 (Falck-Ytter et al. 2006; Eshius, Coventry & Vulchanova, 2009; 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, Kochukhova, & Rosander, 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, Kochukhova, & Rosander, 2007) whereas action anticipation studies usually present fully visible and non-obstructed movement paths. For examples of this, see Falck-Ytter et al., 2006; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Hunnius & Bekkering, 2010; Kanakogi & Itakura, 2011); for exceptions, see Costantini, Ambrosini, & Sinigaglia, 2012; Elsner, Falck-Ytter, & Gredebäck, 2012; Elsner, D'Alusio, Gredebäck, Falck-Ytter, & Fadiga, 2013). However, in these latter action prediction studies, the occluder was not placed in the middle of the object path as in object representation studies, but at the end of the object path. No study to date has controlled for these variables.

In this study, 6-month-olds, 10-month-olds, and adults viewed videos showing a human actor moving balls to a goal (Hand condition) or balls moving independently to a goal (Ball condition) while their gaze latencies to the goal were measured. The study controlled for the stimuli differences described above: In both conditions, the balls moved in a straight linear manner and stayed on the table in order for extrapolation of the movement path to be possible; an occluder at the center of the movement path of the object trajectory was present in both conditions; and a human actor was present in both conditions, either moving the balls in the Hand condition or just sitting behind the table in the Ball condition.

The aim of the present study was to directly compare object representations and action anticipation paradigms in order to assess whether the above-described discrepancies are related to stimulus differences between the paradigms or whether different processes govern the ability to predict events, depending on the context. If the discrepancy depends on stimulus differences, we hypothesized that controlling for these should reveal equivalent anticipation ability i.e. a similar degree of anticipatory gaze shifts for human actions as well as for self-propelled objects. If, on the other hand, different processes are used to anticipate human actions and self-propelled objects, then there should be a discrepancy even when controlling for the differences between paradigms, as outlined above.

We hypothesized that there are two anticipatory processes that infants can use. The tendency to anticipate self-propelled objects depends on the degree to which these actions can be extrapolated (as described in the object representation literature). Infants can extrapolate linear motion from an early age and this process should help infants anticipate objects moving on linear trajectories. Independent of this, we argue that direct matching operates exclusively in the presence of human actions and should further facilitate anticipation of human action goals only when the observer has the ability to perform the perceived action. According to this hypothesis gaining motor experience should enable the use of one additional process (in addition to extrapolation) helping infants anticipate future events. Thus, the differences in anticipation ability between different contexts should be greater in younger infants who have less experience and, thus fewer processes available. For older infants and adults the difference between contexts should be smaller since they should be able to anticipate both types of events.

2. Material and methods

Participants

The study included the following subjects in the final analyses: 6-month-old infants, Hand condition, 12 infants (7 girls; mean age=184 days, SD=8.1); Ball condition, 14 infants

(5 girls; mean age=179 days, SD=7.1); 10-month-old infants, Hand condition, 13 infants (5 girls; mean age=297 days, SD=6.7); Ball condition, 14 infants (9 girls; mean age=307 days, SD=5.7); and adults, Hand condition, 14 adults (12 women; mean age= 27.6 years, SD=5.2); Ball condition, 14 adults (9 women; mean age=31.5 years, SD=10.5). An additional eight 6-month-old infants were excluded, 3 due to calibration problems, as were fourteen 10-month-old infants, 1 due to a calibration problem. Excluded infants did not meet the inclusion criteria (see data analysis section), and the main reason was fussiness. Four adults were excluded due to failing to meet the inclusion criteria. All infants were healthy and born within 2 weeks of the expected birth date.

Stimuli and apparatus

Gaze was measured using a Tobii T120 Eye Tracker (Tobii Technology AB, www.tobii.se). The subjects were presented with videos on a 17-inch monitor that was placed 60 cm from each infant. The system recorded the reflection of near infrared light in the pupils and the corneas of both eyes at 60 Hz (accuracy = 0.5°, spatial resolution < 0.3°).

The beginning of each video shows a woman sitting behind a table (Fig. 1A). Three colorful balls are lying on one side of the table, and on the other side there is a red cone-shaped container. After 3 seconds, a dark grey screen (horizontal size, 4.3 visual degrees) slowly slides down all the way to the lower edge of the video frame (Fig. 1B and 1C). After the screen stops moving, in the Ball condition the balls start to move on their own, one at a time, in a straight path along the table, never lifting off of it. The motion trajectory starts from the side of the table where the balls are lying. Each ball passes behind the occluder, reappears, and then disappears into the red cone, which was the goal of the motion. In the Hand condition, the woman takes a ball, places it on “the starting point,” and moves the balls to the goal in the same straight way, never lifting the balls off the table. In this way, the balls are moved one at a time to the goal. Each condition included six 16-second videos; every other video was mirrored, showing the action/event starting from the left or from the right side of the screen. The videos were edited using Sony Vegas. Table 1 lists the duration of the different phases of the stimuli.

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2.1. Procedure

Participants were recruited by mail, and the parents of the infants or the adult participants signed a consent form prior to participation. Once in the lab, each family was provided with a verbal description of the study, its purpose, and the methods used. The study was performed in accordance with the ethical standards specified in the 1964 Declaration of Helsinki. During the study, infants were seated in a safety car seat on the parent's lap in front of the eye tracker. Before the experiment started, a calibration procedure was carried out. Each infant participant was presented with one of the two possible conditions. The experimental session included six consecutive videos that were separated with brief animations designed to orient attention to the screen. The entire experimental session lasted around 3 min. The families received a gift certificate (~10€). The procedure for the adult participants was the same as for the infants except that the adults were sitting on a chair in front of the eye tracker. Adults were not given instructions but were just encouraged to “look at the screen.”

2.2. Data analysis

One area of interest (AOI) was defined around the goal and one around the balls (Fig. 1A). The time at which a subject first looked at the goal AOI was subtracted from the time at which the object first reached this area. This time difference was called gaze latency. Gaze latency was considered predictive if the participant's gaze reached the goal AOI before the moving ball (a positive gaze latency value) and reactive if the participant's gaze reached the goal AOI after the moving ball (a negative gaze latency value). In order to be included in the analysis, subjects had to 1) fixate on the ball AOI for at least 150 ms before the ball started moving and/or follow the ball when it started to move; 2) look at the goal AOI, but not before the ball started moving; 3) fixate on the goal area for at least 150 ms but not later than when the next ball starts moving, and 4) produce at least three gaze latencies according to the above listed criteria.

In addition, anticipatory gaze shifts to the reappearance side of the occluder (but not to the goal further along the trajectory) were also analyzed. Since these analyses only showed an age effect, with adults showing faster gaze latencies than infants and no effects between conditions, they are not described further.

Univariate ANOVA was performed, with gaze latency to the goal as the dependent variable and age (6-months, 10-months, or adult) and action type (Hand condition and Ball condition) as independent variables. The ANOVA analysis was followed by separate analyses between conditions for each age group. This is because we would expect, especially in the youngest age group, that different processes might underlie anticipation and thus we might find differences between the two conditions. In order to see if subjects looked to the goal ahead of the action, t-tests against zero were also performed, where zero was the time that the object arrived at the goal.

3. Results

3.1. Descriptive data for goal-directed gaze shifts

Table 2 lists the descriptive data for the trials, including the mean percentage of anticipations of ball movement to the goal for the different age groups and conditions.

----- Insert Table 2 about here -----

3.2. Latency of goal-directed gaze shifts

No order or learning effects were found in any of the conditions for the mean gaze latency of the first ball, second ball, and third ball in all videos; all data points were thus aggregated).

Univariate ANOVA analysis with age (6-months-old, 10-months-old, and adult) and action type (Hand or Ball) as independent variables and gaze latency as the dependent variable demonstrated a main effect of age, $F\ (2,81)=8.89$, $p<.001$, $\eta^2_{part}=0.19$. Post-hoc comparisons (Tukeys HSD) demonstrated that adults shifted their gaze to the goal earlier than 6- and 10-month-old infants ($p<.001$). Six- and 10-month old infants did not differ in latency of goal directed gaze shifts ($p=.800$). There was also a main effect of action type, $F(1,81)=4.24$, $p<.05$, $\eta^2_{part}=0.05$. Gaze shifts to the goal were faster in the Ball condition (M= 369 ms, SD=297 ms) than in the Hand condition (M=241 ms, SD=376 ms) (Fig. 2).

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To investigate whether the latency of participants' goal-directed gaze shifts relative to the arrival of the ball were predictive, single sample t-tests against zero were performed. These showed that adults shifted their gaze to the goal before the ball arrived in both conditions: Ball t(1,13)=5.61, p<.001 and Hand t(1,13)=5.59, p<.001. Ten-month-olds looked anticipatorily to the goal for the Ball condition t(1,13)=3.56, p<.01, and there was a marginally significant effect in the Hand condition t(1,12)=1.80, p=.097. Six-month-olds also looked anticipatorily to the goal in the Ball condition t(1,12)=5.85, p<.001, but they did not in the Hand condition t(1,11)=.14, p=.892.

3.3. Latencies of goal-directed gaze shifts for each age group

Planned comparisons in the form of independent sample t-tests for each age group separately were performed. In the 6-month-old group there was a significant difference in goal-directed gaze latency values between the Hand condition (M=10 ms, SD=252 ms) and the Ball condition (M=325 ms, SD=208 ms): t(24)= -.28, p<.01. That is, 6-month-olds anticipated the goal earlier in the Ball condition than in the Hand condition. We performed the same analyses for 10-month-olds and adults, but there were no significant differences.

4. Discussion

The aim of the present study was to investigate the mechanisms underlying the discrepancies in anticipation between action understanding and object representation studies. This was done using an experimental set-up in which the objects always moved in the same linear manner and an occluder, a goal, and a human were all present. The only thing that varied was whether the objects moved by themselves or if a human actor moved them.

The results showed that 6-month-olds shifted their gaze to the goal earlier when observing self-propelled balls than when observing human actions. Further, 6-month-olds and 10-month-olds anticipated the goal when the objects were self-propelled but not when the human actor moved them. Adults anticipated the goal in both conditions. Overall, adults looked to the goal significantly earlier than infants.

The discrepancies reported in the literature remained after controlling for stimulus differences, suggesting that different processes mediate the ability to anticipate future events in object representation versus action anticipation studies. The difference between conditions was largest in the young age group, which is in line with the hypothesis suggesting that different processes are used to anticipate human actions on one hand and self-propelled linearly-moving objects on the other.

When infants observe self-propelled linearly-moving objects, extrapolation of the movement path is possible, and infants use this mechanism to anticipate the future path of the object. Here, infants anticipated the goal in the Ball condition, which is in line with results from object representation studies that have demonstrated extrapolation abilities even in infants who are just 3 months of age (Rosander & von Hofsten 2004). The reason that infants have not anticipated the goal of self-propelled objects in previous action anticipation studies should depend on the more complicated, non-linear paths for the objects used in these studies. A different anticipation mechanism is needed when a human actor is moving the ball, even though the movement path is linear. More specifically, we assert that direct matching processes facilitate the anticipation of human action goals if the observer has the ability to perform the perceived action. Six-month-old infants have not yet started putting objects into containers (Brunner, 1970; Falck-Ytter, 2006; Rosander & von Hofsten, 2011) and hence they did not, in this study, anticipate the goal of the actor.

In the present study, the infants' experience with the task was not tested directly. However, several studies show that infants' experience with a particular task is related to their gaze latencies during observation of the same task (Claxton & McCarty, 2003; Gredebäck & Melinder, 2010; Kanakogi & Itakura, 2011; Rosander & von Hofsten, 2011). We argue that the six-month-olds in the present study did not anticipate the goal of the human action because they do not yet have a motor schema of putting objects into containers.

We found that the ability of 10-month-olds to anticipate the goal in the Hand condition was only marginally significant. However, this result actually fits rather well with results from previous studies. Rosander & von Hofsten (2011) found that 10-month-olds looked anticipatorily to the goal while observing as well as while performing a containment action. The study had a live situation design, and the authors selected 10-month-olds because pilot tests showed that younger, 8–9-month-old infants did not consistently grasp toys in order to move them to a goal. In the present study, stimuli were presented on a computer screen. It is probable that the difference in experimental setting could explain the slightly different results between the Rosander & von Hofsten (2011) study and our study. Further, if the ability to put objects into containers develops around 10 months of age, differences in the experimental setting might have a big impact.

We did not manipulate the movement path in this study. One reason for this was to keep the path constant between conditions and to make the stimuli more comparable to object representation studies. Another reason for this was that the stimuli in this study were highly similar to the stimuli used in the Falck-Ytter et al. study (2006) except for the movement path of the object. If the path of the ball had been curved in the present study as well, we would expect infants to be reactive in the Ball condition, in line with the results from the Falck-Ytter et al. (2006) study. In the present study, however, infant anticipation should depend on the linear movement path of the object. When it comes to human actions, on the other hand, our results are in line with the Falck-Ytter et al. study (2006). This suggests that when it comes to human actions, the movement path does not seam to matter for anticipation to occur, but in the case of self-propelled objects, the movement path does matter.

A question still remains: why don't infants use the successful extrapolation principle, when possible, for human actions? One reason could be that the movement path of human manual actions usually is not linear and cannot be extrapolated in the same way as the movement of physical objects. The hand is simply free to move in many ways. That is, the movement path of human actions is much more flexible as well as much more unpredictable since there are many ways to arrive at the same goal. Thus, relying on extrapolation principles when a human actor is moving the ball may not be the most effective strategy. For example, Grossman, Cross, Ticini, & Daum (2012) (see also Kilner, Friston, & Frith, 2007; Cross et al., 2012) argue that from a Bayesian perspective, the observation of highly unusual or unfamiliar actions, and not only familiar ones, could lead to motor system activity. This would demand more from the responsible neural networks in that they are trying to process, predict, and learn from actions that the observer has no prior (physical) experience with. This interpretation is in line with studies that show greater activity in motor areas for less familiar actions (Stapel, Hunnius, van Elk, & Bekkering, 2010) as well as for highly familiar actions (van Elk, van Schie, Hunnius, Vesper & Bekkering, 2008). In terms of the present results, this interpretation suggests that the motor system will always activate when processing human actions. In the case of actions that are not familiar to the infant, this would lead to higher demands on the system while trying to process the action, which could thus disturb or involuntarily inhibit other processes, like, for example, extrapolation. At first glance, having the motor system take over other efficient processes may seem to be an inefficient way to process events. On the other hand, it might be more efficient in the long run if using the more appropriate process, even when it is not yet developed, is a precondition for learning and interpreting human actions. One could say that extrapolation is not used, even when it might be possible to use it, in order to give the brain opportunities to develop the most efficient process for interpreting a certain type of event. Here, manual action and the process used thus involve one's own motor system (direct-matching). In the present study, this may explain the discrepancies in anticipation ability depending on the context.

5. Conclusions

To summarize, even when controlling for stimulus differences between the studies described, the discrepancy in anticipation ability was still there. In other words, the current study demonstrates that 6-month-old infants, even though the path is linear in both cases, anticipate self-propelled objects but not human actions. This suggests that different processes mediate the ability to anticipate future events in object representation versus action anticipation studies. The results indicate that extrapolation can be used to anticipate the future path of an object as long as it is moving in a linear path. In self-propelled object studies in which the objects mimic the non-linear path of human actions (Falck-Ytter et al. 2006), anticipation has not been possible. On the other hand, extrapolation is not used for human actions, even if the path is simple. In the case of human actions, extrapolation could be inhibited or just not used, possibly to allow a more reliable process to be used to interpret these kinds of actions. We would like to argue that to anticipate human actions, own experience with the observed action is required, as postulated by the direct matching hypothesis (Rizzolatti et al. 2001; Flanagan & Johansson, 2003; Rosander & von Hofsten, 2011; Elsner, D'Alusio, Gredebäck, Falck-Ytter, & Fadiga, 2013). Our results suggest that early in development, different mechanisms are used to anticipate future events depending on the presence of a human actor (direct matching) versus self-propelled objects (extrapolation).

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Table 1. *Mean duration of the different phases of the stimuli.*

	Ball starts to move; ball disappears*	Ball is occluded	Ball reappears; ball goes to goal	Total movement duration
Ball condition	1279 ms	723 ms	1001 ms	3003 ms
Hand condition	812 + 918 ms	662 ms	767 ms	3159 ms

*In the Hand condition, each ball is lifted from the table and placed in a starting position. The first time (812 ms) is the time from lifting the ball until it is placed in the starting position, while the second time (918 ms) is the time from the starting position of the ball until it disappears behind the occluder. In the Ball conditions, the ball starts to move after the hand lifts the ball (Hand condition) but before it is placed on the table (Hand condition), reflecting the shorter total duration of this part of the action in the Ball condition.

Table 2. *Mean percentage of attended trials and mean percentage of anticipations of the goal during the trials for the two conditions in the indicated age groups.*

	Attended-trials			Anticipations		
	6-month-olds	10-month-olds	Adults	6-month-olds	10-month-olds	Adults
Ball	52%	48%	89%	65%	68%	95%
Hand	38%	39%	87%	40%	42%	90%

Figure 1. Photos showing the two conditions. First, an actor was shown sitting behind a table (A). After 3 seconds, a screen slid down, covering the central part of the action. In the Hand condition (B) the actor moved the balls one at a time to the goal (red container). In the Ball condition (C) the balls moved to the goal in a similar way, but by themselves. The gray rectangles (A) demonstrate the Goal and Ball AOIs used in the analysis.

Figure 2. Mean gaze arrival latency times to the goal relative to the arrival of the object for the two conditions. The arrival of the object at the goal is represented by a horizontal line at 0 ms. The y-axis depicts latency in milliseconds, with positive numbers indicating that the participants looked at the goal before the ball reached it. Error bars indicate the standard errors of the mean.