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Perspective matters in goal-predictive gaze shifts during action observation: Results from 6-, 9-, and 12-month-olds and adults



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ABSTRACT

Research on goal-predictive gaze shifts in infancy so far has mostly focused on the effect of infants' experience with observed actions or the effect of agency cues that the observed agent displays. However, the perspective from which an action is presented to the infants (egocentric vs. allocentric) has received only little attention from researchers despite the fact that the natural observation of own actions is always linked to an egocentric perspective, whereas the observation of others' actions is often linked to an allocentric perspective. The current study investigated the timing of 6-, 9-, and 12-month-olds' goal-predictive gaze behavior, as well as that of adults, during the observation of simple human grasping actions that were presented from either an egocentric or allocentric perspective (within-participants design). The results showed that at 6 and 9 months of age, the infants predicted the action goal only when observing the action from the egocentric perspective. The 12-month-olds and adults, in contrast, predicted the action in both perspectives. The results therefore are in line with accounts proposing an advantage of egocentric versus allocentric processing of social stimuli, at least early in development. This study is among the first to show this egocentric bias already during the first year of life.

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Introduction

The world around humans is filled with a plethora of visual information. For instance, an infant might observe how his or her mother grasps a kettle in order to prepare a cup of tea while a dandelion seed flies through the kitchen window. Already in infancy, humans are able to differentiate between random movements across time and space, like the dandelion seed flying by, and goal-directed actions heading toward a goal, like grasping the kettle. Evidence for encoding the goal of an action comes from different research paradigms such as looking time studies (e.g., Woodward, 1998), imitation studies (e.g., Carpenter et al., 2005), and predictive gaze studies (e.g., Falck-Ytter et al., 2006). In particular, research on infants' predictive gaze behavior shows that from about 6 months of age, infants shift their gaze toward a goal object before the moving agent arrives at its goal, but only when the observed movement is suggestive of being goal-directed (e.g., Ambrosini et al., 2013; Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011). The onset of these goal-predictive gaze shifts relies on infants' experience with the observed action and agent (e.g., Cannon & Woodward, 2012; Kanakogi & Itakura, 2011; Melzer et al., 2012) and their familiarity with the displayed action (Kochukhova & Gredebäck, 2010; see also Gredebäck & Melinder, 2010). These goal-predictive gaze shifts also rely on perceivable information that is indicative of the goal-directedness of the unfolding action such as salient action effects (e.g., Adam & Elsner, 2018; Adam et al., 2017). However, little is known about the role of infants' perspective toward the observed action. This is surprising given that in real life infants observe their own actions from an egocentric perspective and often observe others' actions from an allocentric perspective. Therefore, the observation of an action presented from an egocentric perspective, which is especially linked to own action execution and experience, might play a special role in infants' goal prediction. This study was designed to investigate this aspect of action perception in more detail by contrasting infants' goal-predictive gaze shifts during the observation of egocentric and allocentric simple grasping actions.

There are different accounts that explain why infants start to show goal-predictive gaze shifts at around 6 months of age. Based on the direct-matching hypothesis, goal-predictive gaze shifts are enabled via a matching process of the observed action onto own motor representations of this action (e.g., Falck-Ytter et al., 2006; Rizzolatti & Craighero, 2004; Rizzolatti et al, 2001). Therefore, when an observer does not have any corresponding motor representations to match the observed action to, the observer mainly fixates the moving agent, which results in tracking or reactive gaze behavior (i.e., the observer's gaze arrives at the goal object simultaneously with or after the agent, respectively). Indeed, this is supported by the typical findings that infants show goal-predictive gaze shifts more easily when observing human actions compared with actions that are performed by non-human agents. The same tendency to show goal-predictive gaze shifts occur for actions that are in the infants' motor repertoire, such as grasping an object, compared with actions that infants at the given age do not perform themselves, such as touching an object with the back of the hand (e.g., Cannon & Woodward, 2012; Kanakogi & Itakura, 2011; Melzer et al., 2012). Regarding the role of the perspective of the observed action, this account raises the question of whether matching onto own motor representations and thus goal anticipation is facilitated by an egocentric or allocentric perspective.

Another account proposes that goal-predictive gaze shifts rely not only on infants' action experience and motor representations but also on perceivable information about the unfolding action, resulting in an interaction between these two factors (e.g., Adam & Elsner, 2018; Adam et al., 2017; Ambrosini et al., 2013; Elsner & Adam, 2020; Henrichs et al., 2012). For example, 7-month-olds showed goal-predictive gaze shifts when a familiar action (i.e., grasping performed by a human hand) was followed by a salient action effect (i.e., lifting the grasped object), but they showed tracking gaze when that action did not result in such an effect (i.e., the hand stood still after having grasped the object) (Adam & Elsner, 2020). This means that even in conditions where action experience and matching motor representations are identical, the addition of a salient action effect can help infants to predict the action goal. However, 11-month-olds showed goal-predictive gaze shifts for a grasping hand independent of the presentation of an action effect (e.g., Adam & Elsner, 2020; Henrichs et al., 2012). This indicates that additional visual information is no longer needed when infants' advanced

action experience enables them to predict the probable goal upon observing the start situation (i.e., the hand and a graspable goal object) and the beginning movement of a familiar action (Elsner & Adam, 2020)

When it comes to the visual information during action observation—be it own actions or others' actions—the perspective from which we view these actions also plays a crucial role. For example, own actions are usually experienced from an egocentric perspective. In contrast, others' actions can be viewed from many angles, with a dominance of the allocentric perspective (Ge et al., 2018). Therefore, the perspective from which an action is presented might be relevant for the matching of this action onto own motor representations and action experience. Indeed, when adults were presented with pictures of a hand in different perspectives, they took longer to judge certain aspects (e.g., the hand's laterality) the more the hand was rotated from the egocentric viewing position (Conson et al., 2010; Cooper & Shepard, 1975; Ní Choisdealbha et al., 2011). In addition, functional magnetic resonance imaging studies revealed stronger activation in the frontoparietal mirror neuron network and the visual cortex when adults observed actions from an egocentric perspective compared with an allocentric perspective, combined with faster imitation behavior for the egocentric stimuli (Ge et al., 2018; Watanabe et al., 2013). These results indicate that the egocentric perspective is linked more closely to the sensorimotor system, which enables direct matching of observed actions, and to the perspective of a "self" compared with the allocentric perspective that is more linked to the idea of "other" (Ge et al., 2018).

From a developmental perspective, predicting goal-directed behavior from an egocentric or allocentric perspective might be related to how infants develop an understanding of the self and of other persons. Some theorists favor the idea that infants first develop an understanding of own actions before they transfer this understanding to making sense of others' actions (e.g., Elsner & Adam, 2020; Meltzoff, 2005). Based on these egocentric-first accounts, infants should predict the goal of an action observed from an egocentric perspective at an earlier age than from an allocentric perspective. In contrast, allocentric-first accounts suggest that infants develop an understanding of own actions and the own perspective only after they are able to understand others' behaviors (Prinz, 2013; Southgate, 2020). Prinz (2013) suggested that so-called mirror games in which parents imitate their infants contribute to this developmental order. Picking up the idea of a looking-glass self (Cooley, 1902/1967), infants are supposed to perceive themselves through the eyes of another person. Likewise, Southgate (2020) proposed that understanding of own behavior is linked to self-awareness, which emerges only around 18 months of age, and that prior to that age action understanding is primarily concerned with actions of others. Hence, based on these allocentric-first accounts, infants should predict action goals at an earlier age when observing actions from an allocentric perspective as compared with an egocentric perspective.

Notably, research on infants' action–goal prediction has mostly presented actions from an allocentric perspective (e.g., Adam et al., 2017; Ambrosini et al., 2013; Cannon & Woodward, 2012; Falck-Ytter et al., 2006; Henrichs et al., 2012). As an exception, Kanakogi and Itakura (2011) presented the action from an egocentric perspective, and only they reported goal-predictive gaze shifts for a grasping hand already in 6-month-olds. Other studies that presented human grasping from an allocentric perspective found goal-predictive gaze shifts only for infants who were some months older (e.g., Adam & Elsner, 2020, Gredebäck et al., 2018). However, no study so far has experimentally manipulated the perspective when investigating infants' goal-predictive gaze shifts.

From 3 months of age, infants differentiate between displays of own movements that are presented from different perspectives in that they preferentially looked at a display of their legs that did not match their egocentric perspective (Rochat & Morgan, 1995). However, when 3- to 5-month-olds had the opportunity to kick a ball, they preferentially looked at an egocentric display, possibly because this facilitated the coordination of their behavior (Rochat & Morgan, 1998).

To our knowledge, only one study has investigated the influence of perspective on infants' perception of others' goal-directed actions (Daum et al., 2008). Here, 6- and 9-month-olds differentiated between plausible and implausible action outcomes only when the action was presented from an allocentric perspective, but not when it was presented from an egocentric perspective. The infants watched stimuli presented on three monitors. First, the upper central monitor displayed a video of a hand reaching toward one of two goal objects, but the action was interrupted halfway by presenting

a black screen. Following this pause, each lower monitor displayed a picture of the hand having grasped one of the objects: left monitor–left object, right monitor–right object. Based on the hand's prior grasping trajectory from the upper screen, one of these outcomes was plausible and the other was implausible, with the location of plausible counterbalanced across trials. Infants at both ages who observed the actions and outcomes from an allocentric perspective (i.e., hand moving toward the infant) looked longer at the implausible outcome than at the plausible outcome, but other infants who observed the egocentric perspective (i.e., hand moving away from the infant) looked equally long at the two outcomes and thus did not differentiate between them. Based on the research with adults described above, this is surprising because the processing of egocentric information should be easier and more closely linked to own motor experience compared with allocentric information (e.g., Ge et al., 2018). However, Daum et al. (2008) took their findings to indicate that infants start out with an allocentric bias when perceiving goal-directed actions, perhaps because they do not yet possess self-awareness that would allow reflecting on own actions (Southgate, 2020).

Taken together, only few infant studies have directly compared presentations from different perspectives, and the evidence for the influence of perspective on infants' processing of observed actions is still inconclusive. For displays of own movements, 3-month-olds' attention was elicited stronger sometimes by the egocentric perspective and sometimes by the allocentric perspective (Rochat & Morgan, 1995, 1998). For the observation of others' actions, Daum et al. (2008) found longer looking to the implausible outcome than to the plausible outcome only in the allocentric perspective but not the egocentric perspective. However, in that study no complete natural grasping actions were used as stimuli (i.e., grasping was interrupted halfway), and the study measured preferential looking times to pictures displaying potential action outcomes. Although such studies also require infants to form an expectation about an action outcome, their results usually do not match the ones obtained when measuring infants' goal-predictive gaze behavior. This is because looking-time studies afford a post hoc evaluation of the complete action, whereas action-prediction studies afford an online evaluation of the ongoing action and the forming of an expectation based on incomplete information (Elsner & Adam, 2020). Thus, these paradigms likely test different cognitive processes (Daum et al., 2012).

The current study therefore aimed to contribute to closing this gap by investigating infants' goal-predictive gaze shifts during the repeated observation of a human grasping action presented from an egocentric or allocentric perspective in a within-participants design. If infants indeed have an allocentric bias early in life (Daum et al., 2008; Prinz, 2013; Southgate, 2020), we should find goal-predictive gaze shifts more for allocentric stimuli than for egocentric stimuli. However, if infants understand own actions before others' actions (Meltzoff, 2005), and if egocentric stimuli are more relevant to the "self" perspective and to sensorimotor matching (Ge et al., 2018), we should find goal-predictive gaze shifts more for egocentric stimuli than for allocentric stimuli. This would match results found in adults using different measures (e.g., Conson et al., 2010; Cooper & Shepard, 1975; Ge et al., 2018; Ní Choisdealbha et al., 2011; Watanabe et al., 2013). In addition, based on experience-based accounts for infant goal prediction (e.g., Cannon & Woodward, 2012; Elsner & Adam, 2020; Kanakogi & Itakura, 2011; Melzer et al., 2012), the egocentric perspective should be especially beneficial for infants around 6 months of age who have only little experience with grasping. For these infants, the egocentric perspective may provide additional visual information that could facilitate the matching of the observed action onto own motor representations (Falck-Ytter et al., 2006; Rizzolatti & Craighero, 2004) and thus support the prediction of the action goal for the ongoing action based on incomplete information (Daum et al., 2012; Elsner & Adam, 2020). In contrast, older infants should be able to rely on their advanced action experience, enabling them to produce goal-predictive gaze shifts for the highly familiar grasping action regardless of the observed perspective.

We tested 6-, 9-, and 12-month-old infants, as well as adults as a control group, because the second half of the first year after birth is marked by an increase in action experience and by a rapid development of goal-predictive gaze shifts (e.g., Adam & Elsner, 2020; Kanakogi & Itakura, 2011). We recorded the participants' eye movements while they observed repeated presentations of the same simple grasping action performed by a hand, seven filmed from an egocentric perspective and seven from an allocentric perspective (within-participants design). First, we analyzed the timing of the participants' gaze behavior during the observation of these actions. Goal-predictive gaze shifts occur when participants' gaze is directed to the goal before the agent's hand has reached the goal. Second, we

investigated how participants' goal-predictive gaze shifts changed across trials due to potential learning effects.

At 6 months of age, infants are still relatively inexperienced at grasping and therefore should be the ones to benefit most from an egocentric presentation of the action. So far, there is the idea that infants have an innate bias toward the perspective of others when processing actions (Southgate, 2020). In contrast, infant studies on goal-predictive gaze shifts during the observation of grasping actions suggest that action prediction develops in tandem with increasing experience of own grasping (Ambrosini et al., 2013; Adam & Elsner, 2020). This led us to assume that the egocentric perspective of a grasping action facilitates goal-predictive gaze shifts. Here we expected goal-predictive gaze shifts for egocentric presentations but expected tracking or reactive gaze behavior for allocentric presentations as well as faster gaze-arrival times in the egocentric condition than in the allocentric condition. At 9 months of age, the perspective might still play a role, but given that at this age infants are already quite experienced with grasping actions, we would expect goal-predictive gaze shifts for both perspectives but still faster gaze-arrival times for the egocentric condition as compared with the allocentric condition. At the end of the first year of life, infants are known to anticipate non-human grasping actions from non-egocentric perspectives (e.g., Adam & Elsner, 2020). Accordingly, we expected no effect of the perspective for both the 12-month-olds and the adults. The additional analyses regarding potential learning effects across trials were conducted on an exploratory basis because learning effects tend to be difficult to predict (e.g., Henrichs et al., 2012).

Method

Participants

The final sample consisted of 24 6-month-olds (M = 5.9 months, SD = 0.3, range = 5.4–6.4; 16 girls), 24 9-month-olds (M = 9.1 months, SD = 0.4, range = 8.4–9.9; 13 girls), 24 12-month-olds (M = 12.1 months, SD = 0.3, range = 11.5–12.5; 11 girls), and 24 adults (M = 21.7 years, SD = 2.5, range = 19.0 35.9; 24 women). The sample size of the infant age groups was calculated via G*Power for analyses of variance (ANOVAs) with repeated measures (alpha = .05, power = .95). The calculated sample size per age group was n = 22, and we set the sample size to n = 24 for counterbalancing. An additional 26, 14, 8, and 7 participants in the 6-month, 9-month, 12-month, and adult groups, respectively, needed to be excluded due to a lack of valid trials (see criteria below). The lack of valid trials was caused by fussiness (ns for 6-, 9-, and 12-month-olds and adults = 13, 5, 1, and 0), eye-tracker lost track of the eyes (ns = 9, 9, 4, and 4), not enough valid trials in both perspectives (ns = 4, 0, 3, and 1), and experimenter error (2 adults). Participants were randomly assigned to one of four conditions (n = 5–7 per age group in each condition), with counterbalanced order of the perspective (first 7 videos egocentric vs. allocentric) and order of the goal objects (first 7 videos monkey vs. lion). Parents and infants were recruited from a database the parents had signed up for prior to the experiment, and participants mostly came from white middle-class families in a densely populated German area. Adult participants were students from the University of Dortmund. At the lab, parents and adult participants signed informed consent and received 5 € plus a small toy (infants) or credit points (adults) as reimbursement. The study was approved by the local ethics committee of the University of Dortmund).

Stimuli, apparatus, and procedure

Participants saw 14 videos in total, and these videos were presented in two blocks (one egocentric and one allocentric) containing 7 videos each. The order in which the perspectives were presented (e.g., first 7 trials egocentric vs. allocentric) and the identity of the goal object in the first block (blue toy monkey or yellow toy lion) were counterbalanced among the four conditions. The allocentric videos were created by mirroring the egocentric videos on both the horizontal and vertical axes to demonstrate the same right arm movement in both perspectives.

Each video started with a still frame of 1000 ms depicting a goal object (monkey/lion) in either the upper (egocentric) or lower (allocentric) middle of the screen in front of a black background filmed

from above (see Fig. 1). Then a hand entered the scene from either the lower (egocentric) or upper (allocentric) middle of the screen and approached and finally grasped the goal object (duration = 3600 ms). Following the grasp, the screen froze for 1000 ms, resulting in a total runtime of 5600 ms for each video. Between the 14 trials, attention-getter videos were presented in order to keep the infants entertained and to redirect their attention to the center of the screen at the start of each new trial.

Infants sat on their parent's lap while watching the videos, and adult participants sat on a chair. All participants were placed 60 cm away from an EyeLink 1000 Plus eye-tracker (SR Research, Ottawa, Ontario, Canada), which was mounted to a 17-inch screen with a resolution of 1280 by 1024 pixels. Gaze behavior was recorded with a tracking rate of 250 Hz. The experiment began with a 5-point calibration with manual point acceptance. The calibration stimulus was a slightly pulsating duck that made quacking noises. The experiment lasted approximately 3 to 4 min.

Data handling

For each video, two areas of interest (AOIs) were defined: a static AOI covering the goal object and a dynamic AOI covering the moving hand (see Fig. 1). Following similar studies (see, e.g., Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011), gaze-arrival times were calculated by subtracting the time (in ms) when the participants first fixated the goal AOI from the moment when the hand entered the goal AOI (t = 3600 ms). This was 2600 ms after the onset of the action. Therefore, gaze-arrival times represent fixations to the goal object before (positive values; goal-predictive gaze shifts), at the same time as (0 ms; tracking gaze), or after (negative values; reactive gaze) the hand arrived there. For a trial to be considered valid, participants first needed to fixate the moving hand for at least 200 ms before the fixated goal object. In addition, gaze-arrival times of −1000 ms or below were excluded from further analyses because values in this range indicate that the participants did not sufficiently attend to the relevant aspects of the grasping action (see Henrichs et al., 2014, for the same criterion). Overall, participants needed to have at least 2 valid trials in each of the two perspectives (resulting in a total of at least 4 trials) to be included in the analyses. Mean gaze-arrival times for each participant were then calculated by averaging across the 7 trials per block. Participants contributed on average 5.4 (SD = 1.6) valid trials in the egocentric perspective [M (SD) for 6-, 9-, and 12-month-olds and adults = 5.2 (1.7), 5.1 (1.8), 5.6 (1.3), and 5.7 (1.4)] and 5.3 (SD = 1.7) valid trials in the allocentric

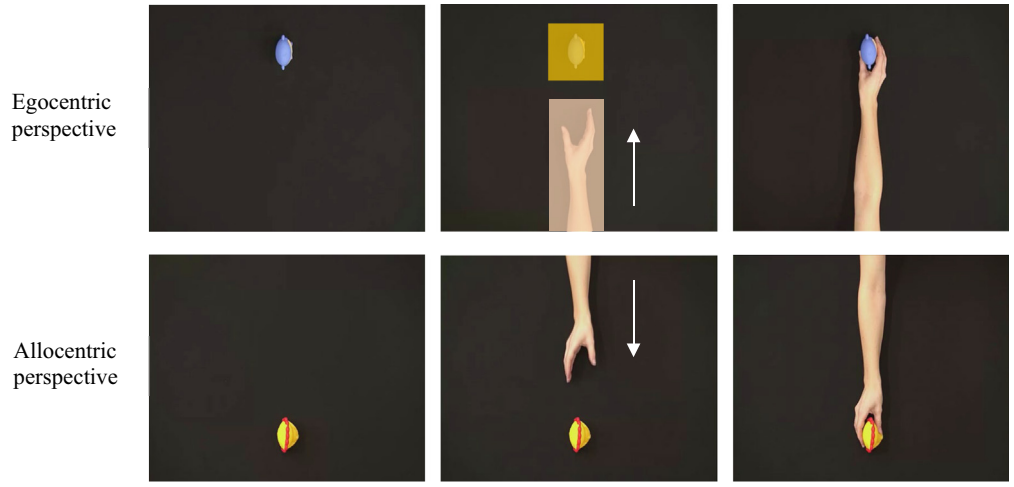


Fig. 1. Stills taken from the stimuli depicting an example for the egocentric videos (upper row; goal object blue monkey) and the allocentric videos (lower row; goal object yellow lion). The two squares in the middle picture in the upper row represent the areas of interest (not visible to the participants).

perspective [*M* (*SD*) for 6-, 9-, and 12-month-olds and adults = 4.2 (1.8), 4.9 (1.5), 5.7 (1.7), and 6.3 (1.0)]. The data are available in the following data repository:https://osf.io/83q2k/?view_only=f8847c39b6214b6291bae5403d72cbc9.

To test our hypotheses, we performed mixed ANOVAs and paired *t* tests in order to compare the mean gaze-arrival times between the two perspectives (within participants) and across the four age groups (between participants). Furthermore, we conducted independent *t* tests against 0 ms for each age group separately to classify the gaze behavior in each perspective as predictive, tracking, or reactive. We also performed exploratory regression analyses for each age group and perspective with curve fitting for a linear, logarithmic, or quadratic function to investigate potential learning effects across the 7 trials per block.

Results

The mixed ANOVA on mean gaze-arrival times with the within-participants factor perspective (egocentric vs. allocentric) and the between-participants factor age group (6 vs. 9 vs. 12 months vs. adults) yielded a significant main effect for perspective, $F(1, 92) = 5.90$, $p < .017$, $\eta_p^2 = .06$. Overall, participants showed faster gaze-arrival times in the egocentric perspective ($M = 406$ ms, $SD = 435$) than in the allocentric perspective ($M = 306$ ms, $SD = 551$). There was also a main effect of age group, $F(3, 92) = 35.40$, $p < .001$, $\eta_p^2 = .54$. Post hoc independent-samples *t* tests revealed that the mean gaze-arrival times (averaged across both perspectives) did not differ between the 6-month-olds and the 9-month-olds, $t(46) = 0.69$, $p = .50$, $r = .09$, but were significantly slower for the 6-month-olds than for the 12-month-olds, $t(46) = 3.79$, $p < .001$, $r = .49$, and the adults, $t(46) = 8.88$, $p < .001$, $r = .79$, as well as for the 9-month-olds than for the 12-month-olds, $t(46) = 3.32$, $p < .001$, $r = .44$, and the adults, $t(46) = 8.69$, $p < .001$, $r = .82$, as well as for the 12-month-olds than for the adults, $t(46) = 4.73$, $p < .001$, $r = .57$.

These main effects were qualified by a significant interaction of perspective and age group, $F(3, 92) = 4.80$, $p < .004$, $\eta_p^2 = .14$ (see Fig. 2). For the post hoc tests, we used a Bonferroni-corrected value

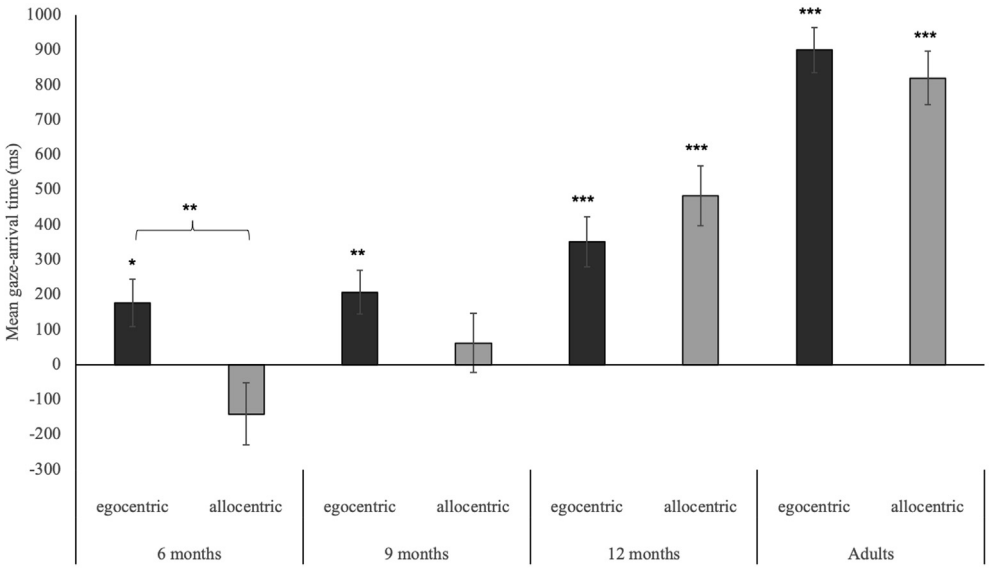


Fig. 2. Mean gaze-arrival times in the egocentric and allocentric videos for the 6-, 9-, and 12-month-olds and adults. Positive values indicate that the participants' gaze arrived at the goal object before the hand arrived there. Error bars represent standard errors. Asterisks above the single bars represent mean gaze-arrival times that significantly differ from the value of 0 ms (i.e., simultaneous arrival of gaze and hand at the goal object). $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

of $p = .0125$ because we conducted four tests. The post hoc paired t tests for each age group separately yielded significantly higher mean gaze-arrival times in the egocentric perspective compared with the allocentric perspective at 6 months of age, $t(23) = -3.38$, $p < .003$, $r = .58$. In all other age groups, mean gaze-arrival times did not differ significantly between the two perspectives [9-month-olds: $t(23) = -1.61$, $p = .12$, $r = .32$; 12-month-olds: $t(23) = 1.77$, $p = .09$, $r = .35$; adults: $t(23) = -1.07$, $p = .32$, $r = .22$]. Except for the 9-month-olds, these results were in line with our hypotheses.

The one-sample t tests against the value of 0 ms for each age group and perspective separately (see Fig. 2) revealed that, consistent with our hypothesis, 6-month-olds showed goal-predictive gaze shifts in the egocentric perspective, $t(23) = -2.59$, $p < .016$, $r = .48$, and tracking gaze in the allocentric perspective, $t(23) = 1.59$, $p = .125$, $r = .31$. Despite the nonsignificant difference in the mean gaze-arrival times between perspectives, 9-month-olds also showed goal-predictive gaze shifts in the egocentric perspective, $t(23) = -3.32$, $p < .003$, $r = .68$, and tracking gaze in the allocentric perspective, $t(23) = -0.74$, $p = .47$, $r = .15$. This result contradicted our expectation of goal-predictive gaze shifts in both perspectives (and faster gaze shifts in the beneficial perspective) in 9-month-olds. Confirming our hypotheses, 12-month-olds showed goal-predictive gaze shifts in both the egocentric perspective, $t(23) = -4.86$, $p < .001$, $r = .71$, and the allocentric perspective, $t(23) = -5.67$, $p < .001$, $r = .76$, and so did the adults (with significantly larger means than those of 12-month-olds): egocentric, $t(23) = -13.98$, $p < .001$, $r = .95$, and allocentric, $t(23) = -10.61$, $p < .001$, $r = .95$.

The regression analyses on mean gaze-arrival times across Trials 1 to 7 for each age group and perspective separately revealed only a significant fit of a logarithmic function for the 12-month-olds in the allocentric perspective, $y = 204.08\ln(x) + 287.60$, adjusted $R^2 = .68$, $F(1, 5) = 13.63$, $p < .014$. All other analyses yielded no significant fits (all $ps > .08$) (see online supplementary material).

Discussion

The main goal of the current study was to investigate whether and how 6-, 9-, and 12-month-olds' goal-predictive gaze behavior during action observation, as well as that of adults, is affected by the perspective from which the observed action is presented. Via eye-tracking, we measured the timing of participants' gaze behavior while they watched repetitions of a simple grasping action performed by a human hand, seven presented from an egocentric perspective and seven presented from an allocentric perspective. Matching our hypotheses, one of the perspectives was more beneficial for the younger infants' action processing; we found goal-predictive gaze shifts (i.e., the gaze arriving earlier than the hand at the goal object) in the egocentric perspective for all age groups and in the allocentric perspective for 12-month-olds and adults, but we found tracking gaze (i.e., gaze and hand arriving at the same time) in the allocentric perspective for both the 6- and 9-month-olds. However, only at 6 months of age, but not in the older age groups, was the difference in mean gaze-arrival times between the perspectives significant. This indicates that the effect of perspective had declined at 9 months of age. As expected and consistent with previous research (e.g., Adam et al., 2017), the 12-month-olds and the adults showed gaze-predictive gaze shifts with no difference between the two perspectives. This result is also in line with the idea that by the end of the first year of life, infants' experience with grasping is sufficiently strong, enabling the prediction of the probable goal based on still incomplete information for a familiar ongoing action, which the infant has frequently performed and observed from different perspectives (Elsner & Adam, 2020). Thus, additional visual information such as presentation from the egocentric perspective that matches own motor representations and thus can facilitate sensorimotor matching is no longer necessary. With respect to the gaze behavior across the 7 trials, we found a significant fit for a logarithmic function only at 12 months of age in the allocentric perspective, showing that the gaze shifts became increasingly more predictive. As is discussed below, the inconclusive results regarding learning across trials match those of the few studies that have conducted such analyses (e.g., Adam & Elsner, 2020; Adam et al., 2017; Henrichs et al., 2012).

The finding of goal-predictive gaze shifts in the egocentric perspective but tracking gaze in the allocentric perspective for the 6-month-olds provides evidence for the expected impact of the perspective on predictive gaze behavior early in development. This is in line with research in adults (using more complex tasks than in the current study) showing that egocentric presentations are linked to a

stronger activation of the sensorimotor system compared with allocentric presentations, which in turn facilitates the matching of the observed action to own motor representations (e.g., Ge et al., 2018; Ní Choisdealbha et al., 2011). In addition, our results provide an explanation for some seemingly contradictory data from previous research: On the one hand, 6-month-olds were reported to show predictive gaze behavior for human grasping actions (Kanakogi & Itakura, 2011). On the other hand, these results could not be replicated in other studies, showing tracking gaze behavior in 6-month-olds for similar human grasping actions (e.g., Adam & Elsner, 2020; Gredebäck et al., 2018). However, Kanakogi and Itakura (2011) presented the infants with stimuli filmed from an egocentric perspective, whereas the other studies presented stimuli filmed from an allocentric perspective. The results of the current study suggest that the different findings resulted from the beneficial effects of the additional information provided by the egocentric perspective on the action processing of 6-month-olds who have just recently reached the motor milestone of grasping (Adam & Elsner, 2020; Adam et al., 2017; Elsner & Adam, 2020).

Our findings fit to a recent theoretical model (Elsner & Adam, 2020) that explains the development of infants' ability to generate goal-predictive gaze shifts based on an inverse relation between top-down processes driven by infants' action experience and bottom-up processes driven by the visual information provided by the observed action. For example, infants' experience grows and becomes more variable over time while infants learn that hands typically move in a certain way and approach goal objects to manipulate them. At first, when the infants have only limited experience with grasping (or hands in general), they rely more on the visual information provided by the unfolding action (e.g., familiarity of the agent, trajectory and speed of the movement). Tracking the agent enables infants to sample this information and to build a cognitive action representation. Each performance or observation of a similar action strengthens associations between the stored features of the agent, movement, and the goal state. Once these associations have become sufficiently strong, they enable the prediction of the typical goal based on the observation of only the agent, goal object, and beginning movement. In this model, additional visual information leads to stronger bottom-up activation of the stored action representation, increasing the likelihood of an activation of the associated goal features, which then enables goal prediction via top-down processes. Based on this idea, less experienced observers need more visual information about the observed action in order to perform goal-predictive gaze shifts, whereas more experienced observers can just rely on their own experience and do not need to draw on additional visual information. Indeed, 7-month-olds only showed goal-predictive gaze shifts when observing a grasping action that was accompanied by a salient action effect (Adam & Elsner, 2020). Such additional information might also be provided by familiar means–end relations. For example, when observing manual self-directed actions of a person displayed in a frontal view, 6-month-olds showed goal-predictive gaze shifts only for a familiar action (i.e., putting a spoon to the mouth), but not for an unfamiliar action (i.e., bringing a comb to the head) (Kochukhova & Gredebäck, 2010; see also Gredebäck & Melinder, 2010). The current study indicates that the perspective from which an action is presented can also provide additional visual information that can facilitate goal-predictive gaze shifts in the 6- and 9-month-olds with still limited action experience. In contrast, the 12-month-olds performed predictive gaze shifts also for the allocentric perspective, indicating that they gathered sufficient experience with grasping actions. Yet, further research is needed on the assumed interplay of bottom-up information and experience-based top-down processes, including on which type of visual information supports younger infants' goal prediction.

The 9-month-olds showed a similar pattern as the 6-month-olds, with goal-predictive gaze shifts in the egocentric perspective but tracking gaze in the allocentric perspective. However, the difference between the two perspectives was not significant, and therefore the data need to be interpreted with caution. When looking at the means, it seems that the gaze-arrival times of the 9-month-olds and the 6-month-olds were similar in the egocentric perspective but were higher (and above zero) for the 9-month-olds in the allocentric perspective. This was still not enough for the 9-month-olds as a group to be predictive, but it is interesting to see how only performance for the allocentric stimuli increased at this age. Taken together, the results from both the 6- and 9-month-olds are not in line with the idea of an allocentric bias in early development (Prinz, 2013; Southgate, 2020) and fit better to the idea that egocentric presentations of actions are linked stronger to own motor representations compared with allocentric presentations (e.g., Ge et al., 2018; Ní Choisdealbha et al., 2011).

The current results are also not compatible with the findings by Daum et al. (2008), who reported better encoding of videos of grasping actions from an allocentric perspective compared with an egocentric perspective in a between-participants design at 6 and 9 months of age. However, that study differed in several aspects from the current one. First, Daum et al. (2008) showed incomplete actions and pictures of plausible/implausible action outcomes. Second, they presented the action video and the two outcome pictures on three monitors. Third, they measured infants' evaluation about the action outcome via looking times after the action had been performed and not via goal-predictive gaze shifts during the observation of an ongoing action as we did. Therefore, it is difficult to draw direct comparisons between the two studies. An alternative explanation for the results by Daum et al. (2008) could be that the infants in the egocentric perspective looked equally long at the plausible and implausible outcomes, particularly because the egocentric stimuli were more closely linked own motor representations. From their experience, infants know that they sometimes redirect their movement to a different goal in the middle of a reach, so they could evaluate the outcome of grasping the left or right object as equally plausible for any of the observed interrupted reaching actions. However, it is possible that in the allocentric perspective, the infants were surprised when the actor changed the movement in the middle of the reach because the actor had always directed the action in the same direction. Another explanation could be that in the allocentric condition the hand on the upper monitor moved toward one of the lower monitors, whereas in the egocentric condition it moved away from one of the lower monitors. Thus, it could have been easier for the infants to extrapolate the motion path and to evaluate the plausibility of grasping the left object (displayed on the left lower monitor) or the right object (displayed on the right lower monitor) in the allocentric perspective. For the time being, these explanations remain speculative, and more studies on this topic need to be conducted to get a clearer picture on the cognitive processes that underlie infants' goal-related gaze behavior.

As expected, the 12-month-olds and the adults showed goal-predictive gaze shifts regardless of the perspective of the observed action. This is in line with previous research showing that when observers have sufficient experience with the observed action, additional visual information is no longer required for the observer to show predictive gaze behavior (e.g., Adam & Elsner, 2020; Adam et al., 2021). Adults were faster than 12-month-olds in their goal-predictive gaze shifts, which shows that the development of action processing and the control of eye movements (e.g., disengaging the gaze from a moving agent) continue beyond the first year of life.

Regarding the explorative regression analyses across the 7 trials, only the data of the 12-month-olds in the allocentric perspective yielded a significant fit, and this was for a logarithmic function, suggesting a continuous increase of the gaze-arrival times across the 7 trials. These learning effects across trials tend to show up irregularly (e.g., Adam & Elsner, 2020; Henrichs et al., 2012) or are not reported at all (e.g., Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011), which makes it difficult to interpret these results. In the current study, the seven repetitions of the action per perspective might not have been sufficient to induce stable learning effects. For example, the gaze-arrival times of the 9- and 12-month-olds in the egocentric condition increased across the first few trials, and those of the 9-month-olds in the allocentric perspective increased across the last few trials, but these patterns did not result in a significant fit for a linear, logarithmic, or quadratic function. Implementing more than 7 trials might be necessary to investigate whether learning effects occur in younger age groups.

It might be argued that the perspectives used in the current study do not constitute "real" examples of egocentric and allocentric actions because in real life we usually do not see actions from a bird's-eye view. First, the chosen perspectives were based on methodological considerations. That is, when measuring gaze behavior, the use of spatial depth in the presented stimuli makes it more difficult to show a straight movement of the agent toward the goal object because the agent not only moves on the measurable x-axis and y-axis of the screen but also moves on the z-axis. In addition, the greater depth of the stimuli makes it more difficult to distinguish exactly where participants are looking, which is why we opted to use stimuli with as little depth information as possible. Second, previous research with adults has also used stimuli showing human hands from a bird's-eye perspective, sometimes even with line drawings of hands, and an important factor in this context seems to be whether the fingers of the current hand point upward (egocentric perspective) or downward (allocentric perspective) (e.g., Cooper & Shepard, 1975; Ní Choisdealbha et al., 2011). In sum, the perspectives

used in the current study should sufficiently capture the essential information needed to constitute an egocentric or allocentric perspective without the need for additional depth information.

Another concern might be that the effects for the younger infants might be explained by a general mechanism that makes it easier for the oculomotor system to initiate upward eye movements to the goal object at the top of the monitor (egocentric perspective) compared with downward eye movements to the goal object at the bottom of the monitor (allocentric perspective). However, Kenward et al. (2017) investigated standard saccadic reaction times of infants aged 9 to 15 months and reported slower upward saccades compared with downward saccades. If this general effect of saccadic latency would also apply for goal-predictive gaze shifts, we should have found faster mean gaze-arrival times in the allocentric perspective compared with the egocentric perspective, which was not the case. Therefore, the current results cannot be attributed to general effects regarding the oculomotor system and even indicate that the presented perspective seems to overwrite infants' general propensity to show slower upward saccades.

One might argue that the duration of the grasping action (3600 ms) in the current study was longer than that in previous studies (e.g., Adam & Elsner, 2020; Falck-Ytter et al., 2006). However, several issues need to be considered. First, the speed of the hand in the current study was similar to that in Adam and Elsner (2020), but the hand moved across a longer distance, namely across the entire screen instead of stopping at the screen center. In addition, in Adam and Elsner (2020), the picture was much more zoomed-in, resulting in an even shorter distance between the edge of the screen and the goal object. Second, the actual time period in which participants could produce goal-predictive gaze shifts was 2600 ms in our study. In the remaining 1000 ms, the hand had already entered the goal AOI, slowed down, and grasped the object. This detailed analysis of the demonstrated action reveals that Kanakogi and Itakura (2011) probably used a similar duration given their description of the movement part and the grasping part of the displayed action: "[the agent] moved towards one of the two toys (2 s), and stopped at the target toy (1 s)" (p. 6). This matches the current 3600-ms duration, in which the hand moved to the object, stopped there, and grasped the object. Admittedly, the longer action duration may have helped infants' goal prediction (e.g., because they could track the agent longer before moving their gaze to the goal object), but if so then this would apply to both perspectives and cannot explain the condition difference.

Taken together, the current study is the first to show the influence of the perspective of an observed action on infants' and adults' goal-predictive gaze shifts. The results from the 6- and 9-month-olds are consistent with research in adults showing an advantage of stimuli presented from an egocentric perspective compared with an allocentric perspective. This study advances our knowledge of the factors that influence infants' processing of goal-directed actions across the first year of life. In addition, the results from the 12-month-olds and the adults show how the influence of the perspective decreases with growing experience of the observers. Our different findings in the age groups could be attributed to the interplay between action experience and the reliance on presented visual information during the observation of goal-directed actions.

CRediT authorship contribution statement

Maurits Adam: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Birgit Elsner:** Writing – review & editing. **Norbert Zmyj:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2024.106075.

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