

The Role of Frequency Information and Teleological Reasoning in Infants' and Adults' Action Prediction

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This study investigates the contribution of frequency learning and teleological reasoning to action prediction in 9-month-old infants and adults. Participants observed how an agent repeatedly walked to a goal while taking the longer of 2 possible paths, as the shorter and more efficient path was impassable. In the subsequent test phase, both paths were passable. In the 1st test trial, infants and adults anticipated the agent to take the longer path. Unlike adults, infants kept anticipating movements to the longer path even after observing that the agent now took the more efficient path, indicating that the frequency of previous observations dominates action prediction. These results provide evidence, contrary to existing claims in the developmental literature, that frequency learning underlies action prediction in infancy, whereas teleological reasoning might gain importance later on in life.

Keywords: social cognition, action perception, infancy, statistical learning, teleological reasoning

The ability to predict others' actions is an important human capacity. It allows for timely planning of one's own reactions to others' actions and is a significant component of proper functioning in a dynamic social environment. Central to the investigation of this ability are the mechanisms humans of different ages rely on to predict others' actions. Moreover, findings about the mechanisms, which subserve action prediction, inform us about how humans perceive others' actions and offer insight into the development of social understanding (cf. Carpendale & Lewis, 2006; Hauf, 2007; Moore, 2006).

One of the prominent cognitive mechanisms of infants' social understanding proposed in the literature is that of teleological reasoning. The teleological stance theory postulates that humans normatively evaluate actions by applying the principle of rational action (Gergely & Csibra, 2003). According to this principle, humans tend to expect actions that they infer to be most efficient for achieving one's aims based on the situational constraints (Csibra & Gergely, 1998). It has been suggested that this principle is a core principle that forms "the initial state of the infant's naive psychological theory . . . that is as yet 'uncontaminated' by the associations established later in development" (Csibra, Gergely, Bíró, Koós, & Brockbank, 1999, p. 262). Support for this view

comes from experimental studies with both adults (e.g., Brass, Schmitt, Spengler, & Gergely, 2007; de Lange, Spronk, Willems, Toni, & Bekkering, 2008) and infants (e.g., Bíró, Csibra, & Gergely, 2007; Csibra, 2008; Csibra, Bíró, Koós, & Gergely, 2003; Csibra et al., 1999; Gergely, Bekkering, & Király, 2002; Gergely, Nádasdy, Csibra, & Bíró, 1995; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Sodian, Schoeppner, & Metz, 2004). Furthermore, computational models of action prediction based on the rationality principle have been shown to fit human predictions for adults in several tasks (e.g., Baker, Saxe, & Tenenbaum, 2009; Baker, Tenenbaum, & Saxe, 2006).

Importantly, most evidence for infants' reliance on the principle of rational action to understand and predict others' actions comes from studies in which infants are habituated to an animated agent (e.g., a ball) or a human that is passing an obstacle (e.g., jumping over a barrier) to reach its goal (e.g., Bíró et al., 2007; Csibra, 2008; Csibra et al., 2003, 1999; Gergely et al., 1995; Kamewari et al., 2005; Sodian et al., 2004). In a subsequent test phase, two possible test trials without the obstacle are presented to the infants. In the one test trial (the old event), the agent continues to perform the jumping movement, although not justified by the situational constraints, as the obstacle has been removed. In the other test trial (the new event), the agent takes the direct route to its goal. Infants tended to look longer in the old event test trial compared with the new event test trial, and it has been suggested that infants show surprise about the agent's inefficient action, as it would have been more efficient, and hence by the principle of rational action also more likely, to take a direct route (cf. Gergely & Csibra, 2003).

Notwithstanding the appeal of this original explanation, it is important to note that the finding can also be explained differently. More specifically, the finding may be the result of long-term frequency learning by infants based on the actions and events they observe in their social and physical environments. In daily life infants observe that humans and other agents very rarely perform sudden jumps during their movements. Similarly, when infants

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observe objects that move over surfaces (e.g., a ball), these objects usually move linearly along the surface in a straight path without making sudden jumps or swerves. Importantly, this explanation is in line with findings that statistical and associative learning plays a central role in infants' (e.g., Kirkham, Slemmer, & Johnson, 2002; Lany & Gomez, 2008; Paulus, in press; Saffran, Aslin, & Newport, 1996; Smith & Yu, 2008) as well as adults' information processing (e.g., Hasher & Zacks, 1984). In particular, it has been suggested that from early on in life humans use frequency information to process perceptual events and actions (e.g., Boseovski & Lee, 2006; Haith, 1993; Hunnius & Bekkering, 2010; Kochukhova & Gredebäck, 2007; von Hofsten, Feng, & Spelke, 2000). Infants come into an experimental session with some expectations about the movements of agents and objects, which they have acquired through observation in their daily life. It is thus possible that infants might have looked longer at the old event trials of the above-cited studies, as they infrequently observe agents who perform suddenly jumping movements or moving objects that do not follow linear routes on surfaces (cf. Luo, Kaufman, & Baillargeon, 2009). In other words, the inefficient action (old event) happens to be an action that is very infrequent in the real world, and the infants' reaction to these stimuli might thus be a novelty response to an event they rarely observe. As the inefficient action presented in the old event trials is also the more infrequent action, the impact of statistical learning and teleological reasoning on infants' action prediction cannot be disentangled in these studies.

The present study was designed to disentangle the contributions of frequency learning and teleological reasoning to infants' and adults' action anticipation. To this end, we constructed stimulus material in which an animated agent moved from one side of a computer screen to the other to get to another agent. In a learning phase, the agent repeatedly took the longer of two paths, as the shorter (and hence more efficient) path was impassable. In a subsequent test phase, both paths were open and could be used. If infants and adults rely on frequency information in their action prediction, they should anticipate the agent to continue using the longer path. If they, however, rely on the principle of rational action to predict the agent's actions, they should anticipate that the agent would use the shorter path as soon as it is passable again, as taking this path would be the most efficient way to get to the other side. To examine participants' action anticipations, we measured their overall looking times (Csibra et al., 1999) as well as their proactive eye movements (Eshuis, Coventry, & Vulchanova, 2009; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Hunnius & Bekkering, 2010; cf. Aslin, 2007).

Method

Participants

Participants were 20 nine-month-old infants ($M = 9$ months 25 days; range: 9 months 16 days–10 months 2 days) and 14 adults (range: 19–32 years). An additional 19 infants did not complete the experiment due to fussiness ($n = 9$), interference of the parent ($n = 1$), procedural or technical errors ($n = 4$), or insufficient data in the test trials or not reaching the habituation criterion ($n = 5$).¹ The infants were recruited from birth records. Parents gave informed consent for participation and were given a book or mon-

etary compensation for their visit. The adults participated in the experiment in return for €5 or course credit.

Stimuli

The stimulus materials consisted of introductory movies, learning movies, and test movies. All movies had a size of 1200×1024 pixels and were created with Adobe ImageReady 7.0. Three introductory movies were made and showed a horizontal path on a green background that led from the right side of the computer screen to its middle. In each movie, a cow walked along the path from the right side to the middle, where the path ended, and back. One introductory movie showed how the cow walked along the path, another one showed the same movement of the cow with a transparent oval occluder in the middle of the path, and a third one showed the movement with an opaque occluder (see Figure 1A). The movies were designed for two purposes: First, they enabled the participants to get acquainted with the occluder and to learn that the cow continued its path behind the occluder and reappeared from behind it. Second, participants learned that the cow always moved on the yellow paths and not over the green surface, as in every movie the cow walked to the end of the path and subsequently returned to its initial position.

The learning movies showed two paths leading from the left to the right side of the screen. At both ends, the paths converged into a single path (see Figure 1B). One of the paths was obviously longer, as it was U shaped. Importantly, the shorter path did not lead to the other side, as it was interrupted by a gap in the middle. The same transparent occluder as in the introductory movies overlaid the crossroad between both pathways on the left side. We introduced an occluder to elicit anticipatory eye movements (cf. von Hofsten, Kochukhova, & Rosander, 2007) to one of the paths rather than fixations on the moving agent. In other words, as, due to the occluder, participants could not perceive which path the cow was going to take, their predictive eye movements to one of the two paths would tell us about their action anticipation. On the left side of the screen, a cow was standing on the path; on the right side of the screen, there was a sheep. After a short period the sheep wiggled, waited shortly, and moved away to the right until it was off-screen. Subsequently, the cow wiggled as a response to the sheep's wiggling. After this interaction between the characters, the transparent occluder gradually turned opaque. The cow started walking along the path and disappeared under the occluder that overlaid the crossroad. After 1.5 s the cow appeared again, walked along the long pathway to the other side, and went off the screen after the sheep. The movie ended with a black screen and took altogether 12 s. Two versions of this learning movie were made, as the path location was counterbalanced, such that the short path appeared on the upper part and the lower part of the screen in an equal number of times.

The test movies differed from the learning movies insofar as there was no gap in the short pathway, so that both pathways were now passable and connected the left and right side. The old action movie (see Figure 1C) resembled the learning movie, as the cow took the long pathway to get to the sheep. In the new action movie,

¹ Although this dropout rate seems to be high, it is comparable to other habituation-based studies with similar designs (cf. Csibra et al., 1999).

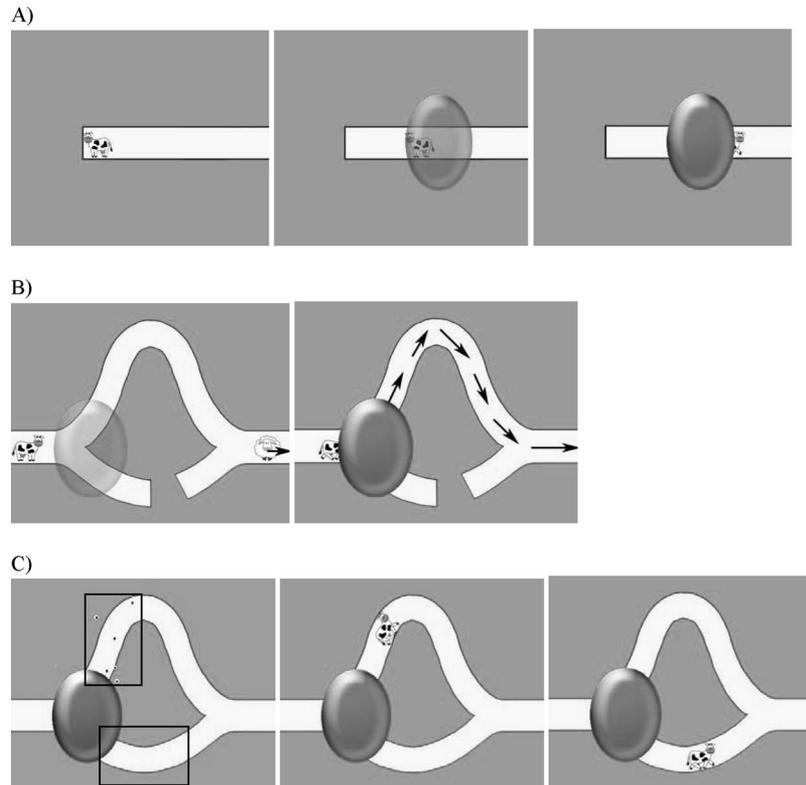


Figure 1. Figure 1A shows examples of the three introductory movies. Figure 1B gives two key frames from the learning movies. The arrows indicate the movement direction. Figure 1C gives in the first picture a projection of infants' first anticipation in the first test trial. The second and third picture show one frame from the old action movie and one frame from the new action movie. The rectangles in the first picture illustrate the approximate position and size of the regions of interest.

however, the cow took the short pathway. Four old action movies were combined to form the old action test bloc; four new action movies were combined to form the new action test block. Two versions of both test blocks were made to counterbalance path location.

Experimental Setup and Procedure

The adults were seated on a chair in front of a monitor. The infants were seated in an infant seat on the lap of their parent who was sitting on a chair in front of the monitor. All participants were tested at a viewing distance of approximately 60 cm from the monitor. Light conditions were kept low to minimize visual distraction. During the experiment, the gaze of both eyes was recorded with a corneal reflection eye-tracker (Tobii 1750, Tobii Technology, Danderyd, Sweden). The eye-tracking system was integrated in a 17-in (43.18-cm) TFT flat-screen monitor on which the stimuli were shown. The apparatus recorded gaze data at 50 Hz with an average accuracy of 0.5° visual angle. The gaze of each participant was calibrated with a 9-point calibration procedure. If 7 or fewer points were calibrated, the calibration was repeated; otherwise the experiment was started.

Infant procedure. Infants participated in a habituation-based experimental procedure that was programmed with Presentation (Neurobehavioral Systems, Albany, CA). Once started by the

experimenter, the program ran the experiment automatically. It registered the participant's eye movements, calculated looking times, and controlled the stimulus presentation on the basis of the participant's looking behavior.

The experiment started with the presentation of the introductory stimuli. The familiarization stimulus without any occluder was shown once; the stimulus with the transparent occluder and the stimulus with the opaque occluder were both shown twice. Thereupon an unrelated movie was presented for 10 s to attract the infant's attention (attention getter), and the habituation phase was started with the presentation of the first learning movie. The learning movie was presented repeatedly (learning trial) and was stopped when the infant looked away for more than 2 s or when the trial reached its maximum duration of 1 min. Then, again, an attention getter was presented. When the infant looked at the screen, the next trial was started.

The program computed the average looking times of the first three trials and compared this value online with the last three looking times. The habituation criterion was reached when the average looking time of the last three trials was less than 50% of the average looking time of the first three trials, and this criterion had to be met twice in a row (cf. Csibra et al., 1999). Accordingly, the minimal number of habituation trials was seven. The maximal trial number was set to 15.

When the habituation criterion was reached, a 30-s break was introduced during which a short, unrelated movie was presented. Then the test phase was started, which consisted of the presentation of the new action test block and the old action test block. Both movies had a fixed length of 44 s. The order of presentation was balanced between infants. Note that the first 6.5 s of both the old action block and the new action block were identical, as the cow started walking and disappeared under the occluder. To ensure that the looking times toward the test movies reflected infants' response to the nature of the stimulus, we included only participants who watched the stimulus long enough to be able to see which of the two paths the cow actually took. Therefore, all participants were excluded who stopped watching the test trials within the first 6.5 s.

Adult procedure. The adults' experiment was run with ClearView (Tobii Technology, Danderyd, Sweden). The familiarization stimulus with the opaque occluder (see Figure 1A) was shown once. Then the learning movie (see Figure 1B) was presented eight times in a row, as, for adults, usually no habituation-based procedure is used. Subsequently, the new action test block was presented (see Figure 1C).

Measures

Looking times. To analyze infants' dishabituation responses to both test events, we summarized their looking times in the new action test block and the old action test block.

Anticipations. Two same-sized regions of interest were defined around the areas where the paths reappeared from behind the occluder (see Figure 1C). A visual anticipation was defined as the first eye movement directed onto one of the two regions of interest during the time the cow was hidden behind the occluder. To analyze anticipations statistically, we calculated a difference score (DS; for a similar procedure see Corkum & Moore, 1998; Moore & Corkum, 1998). To this end, an anticipation to the long pathway was given the value 1; an anticipation to the short pathway was given the value -1 ; and if no anticipation occurred, the movie was coded with the value 0 (e.g., when participants kept fixating on the occluder or directed their gaze elsewhere on the screen). Data were processed with MATLAB and ClearView.

Results

Infants: Looking Times

Infants completed on average 10.7 ($SD = 3.0$) habituation trials. The looking times during the test phase were analyzed by a repeated measures analysis of variance with the within-subjects factor Test Block (old action, new action) and the between-subjects factor Order of Presentation (i.e., counterbalancing of the old action and new action test blocks). This analysis resulted in no significant effect (all $ps > .31$), suggesting that infants did not spend more time looking to the new action test block ($M = 23.5$ s, $SD = 7.3$) or the old action test block ($M = 24.5$ s, $SD = 9.2$).

Infants: Anticipations

We were interested in examining to which path infants would anticipate in the first movie of the first test trial, as this was the first

incidence that both paths could be used. Note that while the cow was under the occluder, there were no perceptual cues about whether the cow actually would take the long path (old action) or the short path (novel action). Of all infants, 65% showed an anticipatory look in the first test movie, and 92% of them anticipated to the long pathway. A one-sample t test with DS as dependent variable showed that the average value of .55 was significantly different from zero, $t(19) = 4.067$, $p = .001$.

For further analyses, the group of infants who first watched the novel action (i.e., the block in which the cow takes the short pathway) was selected, as infants in the other group first watched an action that was incorrect with respect to the predictions of the teleological stance theory (i.e., the cow kept taking the long path, although the shorter could be used as well). The DS for each of the four movies was separately calculated (see Figure 2A). A repeated measures analysis of variance with DS as the dependent variable and the within-subjects factor Movie (Movie 1, Movie 2, Movie 3, Movie 4) revealed no effect of movie ($F < 1$), indicating that infants' anticipation behavior did not change over the four test movies. Accordingly, we averaged the DS over all movies. A one-sample t test showed that the average DS of .25 was significantly different from zero, $t(9) = 3.000$, $p < .05$, and infants thus tended to anticipate to the long path over all test trials.

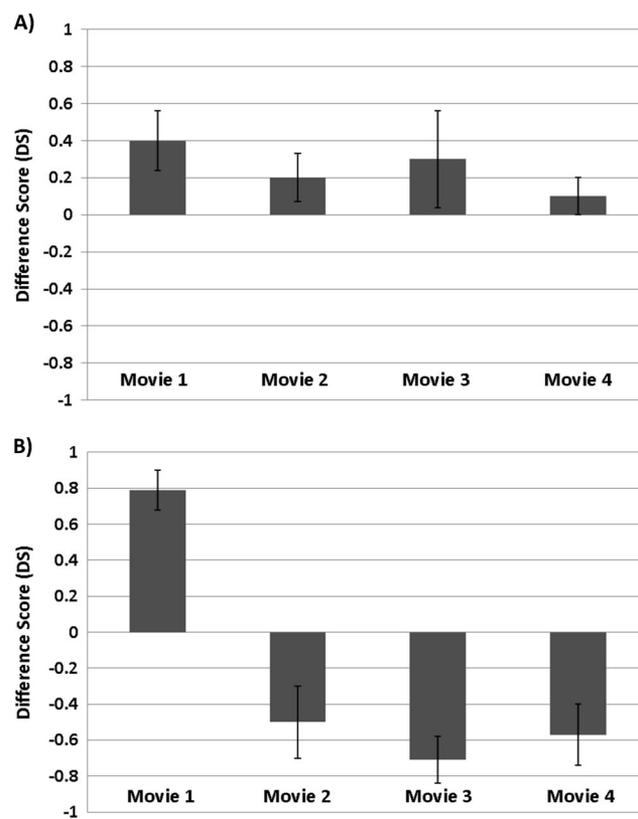


Figure 2. Average difference scores of the anticipations in each movie of the new action test block. Positive scores indicate anticipations to the longer path, negative scores to the shorter path, respectively. Error bars indicate standard error. Figure 1A shows the results of the infant participants. Figure 2B shows the results of the adult participants.

To further examine whether infants' tendency to anticipate to the long path could be due to a failure to perceive the gap in the habituation phase or to perceive the lack of the gap during the test phase, we analyzed the relation between the time infants spent looking to the location of the gap and their test performance. To this end, a region of interest was defined around the position of the gap, and infants' looking times at this region were calculated. On average, infants spent 12.3 s ($SD = 9.7$) during the habituation phase looking at the gap. A correlational analysis between the time infants spent looking at the gap and their anticipation behavior in the first test trial ($M = 0.45$, $SD = 0.60$) as well as their performance over all four test trials ($M = 0.25$, $SD = 0.26$) revealed no significant relation ($r = .15$, $p = .54$, and $r = .18$, $p = .63$, respectively). During the test phase, infants spent on average 436 ms ($SD = 589$) looking at the location where the gap had been (though no fixation was found in the seconds directly prior to the occlusion event of the first test trial). There was no significant correlation between infants' looking to the previous location of the gap and their performances in the first test trial or their performances over all four test trials ($r = .21$, $p = .56$, and $r = -.12$, $p = .75$, respectively).

Adults

Of all adults, 71% displayed an anticipatory look in the first test movie, and 100% of them anticipated to the long pathway. A one-sample t test showed that the DS of .79 was significantly different from zero, $t(13) = 6.904$, $p < .001$. We further calculated the DS for each of the four movies over all adults (see Figure 2B). A repeated measures analysis of variance with DS as the dependent variable and the within-subjects factor Movie revealed a significant effect of movie, $F(3, 10) = 30.028$, $p < .001$, $\eta_p^2 = .891$. Post hoc paired-samples t tests indicated that the frequency of anticipations differed between the first movie and the following movies (all $ps < .001$), which were not significantly different from one another (all $ps > .38$). We subsequently averaged the DS over the last three movies. A one-sample t test showed that the average DS of $-.59$ was significantly different from zero, $t(13) = -6.853$, $p < .001$, indicating that the adults tended to anticipate to the short path during the last three movies.²

Discussion

This study examined the mechanisms on which infants and adults tend to base their predictions of others' actions. In particular, the impact of frequency learning and teleological reasoning on action prediction was investigated. To this end, 9-month-old infants and adults observed an agent repeatedly taking the longer of two paths to get to its goal, as the shorter path was impassable. In a subsequent test phase, the shorter path was passable, and a more efficient action was possible. In the first test trial, participants still expected the agent to take the longer path, which shows that infants and adults relied on frequency information (i.e., on previously observed actions) to predict an upcoming action. After having watched the agent taking the shorter, more efficient path, adults quickly adjusted their expectations. The infants, however, kept anticipating to the long path, which suggests that statistical learning is the dominant mechanism of action prediction in infancy rather than the application of the principle of rational action

(Gergely & Csibra, 2003). Adults, on the other hand, quickly adjusted their predictions when their predictions based on frequency failed.

It is interesting that even adults relied on frequency information in the first test trial. This result is consistent with empirical findings (cf. Boseovski & Lee, 2006; Hasher & Zacks, 1984) as well as long-standing theoretical approaches (e.g., Hume, 1748/1974) stressing the fact that humans tend to form expectancies on the basis of frequency information and use these expectancies as a default mode of prediction without necessarily reflecting on them. It remains subject to further investigation whether adults relied on the frequency information (i.e., expected the agent to act as before) despite being aware of the changes or because they overlooked (the relevance of) those changes. Importantly, after having observed that the agent changed its behavior when a more efficient action had become possible, adults rapidly considered the novel circumstances and adjusted their expectations. This suggests that adults can overcome this default mode after experiencing a failure to predict actions on the basis of frequency information. Further research is needed to examine whether adults' action anticipations in such novel circumstances are based on their application of the principle of rational action (Gergely & Csibra, 2003) or on other mechanisms.

One might argue that infants' repeated anticipations to the long path during the test phase might also be interpreted as resulting from an A-not-B error (cf. Marcovitch & Zelazo, 1999). However, it is very unlikely that our findings can be sufficiently explained by that. First, studies have suggested that the A-not-B error is predominantly found in young children's reaching movements but not their looking behavior (e.g., Diamond, 1991; Hofstadter & Reznick, 1996). Second, and more important, these kinds of errors have been reported to occur only when A trials are directly followed by B trials, which is not the case in our study, as we introduced a 30-s break between the learning and testing phase. Therefore, it is unlikely that our task shows the characteristics that are typical for A-not-B errors. The break is furthermore important, as it has been suggested that the "motor memory" of the preceding actions plays a critical role in this task (Diedrich, Thelen, Smith, & Corbetta, 2000). As the infants watched and visually scanned an unrelated, though interesting, movie during the break, we can conclude that the motor memory of the crucial effector (in our case the eyes) was interrupted in this break by the visual fixations and

²To examine, if the effect was mainly driven by trials in which no anticipations occurred, we disregarded all the trials without anticipations and conducted additional analyses. Ten out of 11 infants showed an anticipation to the long path. A binomial test revealed that this pattern was significantly different from chance ($p = .01$). Likewise, 11 out of 11 adult participants displayed an anticipation to the long path ($p < .001$). Next, we analyzed differences between trials. As this data structure does not fulfill the requirements for a chi-square analysis (e.g., not every participant contributed data in each trial), we implemented a permutation method to test the significance of differences between groups. Permutation methods allow the calculation of the probability that an observed data set can be explained by the null hypothesis without relying on further assumptions (cf. Good, 1999). For the infants, the permutation test yielded no significant differences between trials (all $ps > .23$). For the adults, the analysis showed that the first test trial differed from the others (all $ps < .001$), which differed not significantly from each other (all $ps > .21$).

eye movements on the unrelated display. Thus, it is unlikely that the visual anticipations in the test trials were driven by a simple repetition of a previously executed motor program, but rather they were the result of a learned association between the cow and the path it had been taking.

Importantly, a closer analysis of infants' visual behavior shows that they looked at the location of the gap during the habituation trials and the test trials. This suggests that the infants perceived the presence of the gap during the learning phase as well as its absence during the test phase of the experiment. Furthermore, to exclude the possibility that infants did not look long enough to process the information about the presence of the gap in the learning trials or the absence of the gap in the test trials, we performed additional correlational analyses and found no relation between the time infants spent looking at the gap location and their anticipation performance in the test trials. This finding is especially relevant, as one could argue that infants' failure to anticipate to the short path during the test phase could be due to the possibility that they did not see that the short path was initially blocked and therefore assumed that the cow had a preference to take the long path. Additionally, one could argue that infants did not anticipate to the short path because they—even though noticing that there was a gap during the learning trials—did not perceive that the short path was passable in the test trials. However, if these alternative explanations were true, one would expect that the infants who looked longer at the location of the gap (i.e., long enough to process the information) should anticipate to the short path or at least should not show anticipations to the long path anymore. Likewise, the infants who did not look long enough should show continued anticipations to the long path. Therefore, if this interpretation would be true, a correlation between infants' looking times and their test performance should be expected. However, we found no correlation between the time infants spent looking at the location of the gap and their test performance. Yet, most important is the fact that the participants observed from the first test trial on that the cow was now taking the short path. In particular, that the cow was moving on the short path from one side of the screen to the other side provides compelling evidence that the short path was passable. Taken together, the facts that infants looked at the location of the gap during the test trials, that there was no correlation between the time they spent looking at the location of the gap and their test performance, and that they observed during the four test trials how the cow was moving on the short path render it very unlikely that infants' anticipation behavior could be explained by the assumption that they did not discover that the short path was now available.

Infants' dishabituation responses revealed no significant difference in their looking times between blocks. This finding may at first seem to contradict existing findings in habituation experiments that have suggested that infants rely on teleological reasoning in their action prediction. Within the context of our experimental design, the absence of dishabituation effects can be explained by noting that the two measures (i.e., dishabituation times, anticipations) represent two kinds of underlying processes. Whereas anticipatory eye movements reveal infants' ability to predict an action, dishabituation times represent infants' "surprise reaction" based on a retrospective evaluation of the deviation of the observed behavior from what one would expect (cf. Gredebäck & Melinder, 2010). Whereas one can

assume that humans quickly acquire an expectation about others' actions, it takes more to be really surprised about an action. For example, knowing that a colleague usually drinks coffee allows one to anticipate what she will drink during her break. Nonetheless, one would not be surprised if one day she takes a glass of water, even if not having anticipated that. However, if she would opt for a glass of vinegar, one would be surprised, as this action is totally unexpected given one's experiences about what humans normally drink. In the same vein, it has been shown that infants display surprise reactions for events that not only are not anticipated but violate physical laws (e.g., Baillargeon, 2004; Luo et al., 2009; see also Kochukhova & Gredebäck, 2007). As our experimental stimuli were specifically designed to exclude such nonnatural actions, we might thus not find clear surprise effects in the infants' dishabituation times. Importantly, though, we do find that infants' predictive looking behavior revealed infants' action anticipations based on statistical regularities that were built up during the course of the experiment.

The essential finding of our study is that the 9-month-old infants kept anticipating to the longer, inefficient path, even though it would have been more efficient for the cow to take the shorter path and negative evidence had been provided on preceding trials. Accordingly, our results provide evidence that infants do not yet predict actions of others based on the principle of rational action but rather rely on frequency information in forming action predictions. This finding contradicts the interpretation of previous studies (cf. Bíró et al., 2007; Csibra, 2008; Csibra et al., 2003, 1999; Gergely et al., 1995) but is rather in line with the view that statistical and associative learning forms an important mechanism in infants' early cognitive and social-cognitive development (e.g., Paulus, in press; Saffran, Pollak, Seibel, & Shkolnik, 2007; see also Barresi & Moore, 1996) and corroborates recent studies on infants' imitation that show limits of infants' ability to rationally assess the actions of others (Paulus, Hunnius, Vissers, & Bekkering, in press). This leaves us with the question of how the ability to evaluate others' actions in terms of efficiency develops. Further research is needed to investigate this in more detail.

Comprehending the mechanisms underlying our ability to predict others' actions is central to explaining the social basis of human cognition and behavior. Key mechanisms are our ability to predict future actions based on past observations, based on our own experiences with these actions, and based on their efficiency (Csibra & Gergely, 2007). Whereas the action prediction and understanding literature has mainly focused on motor and cognitive processes and their relative importance (e.g., Brass et al., 2007; Csibra, 2007; de Lange et al., 2008; Eshuis et al., 2009; Gredebäck & Melinder, 2010; Paulus, Hunnius, Vissers, & Bekkering, 2011; Paulus et al., in press; Sommerville & Woodward, 2005), our results make clear that more attention needs to be given to the role of perceptual processes and frequency learning in human action perception and prediction.

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