The Early Development of Object Knowledge: A Study of Infants' Visual Anticipations During Action Observation

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The Early Development of Object Knowledge: A Study of Infants' Visual Anticipations During Action Observation

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This study examined the developing object knowledge of infants through their visual anticipation of action targets during action observation. Infants (6, 8, 12, 14, and 16 months) and adults watched short movies of a person using 3 different everyday objects. Participants were presented with objects being brought either to a correct or to an incorrect target location (e.g., cup to mouth, phone to ear vs. cup to ear, brush to mouth). When observing the action sequences, infants as well as adults showed anticipatory fixations to the target areas of the displayed actions. For all infant age-groups, there were differences in anticipation frequency between functional and nonfunctional object–target combinations. Adults exhibited no effect of object–target combination, possibly because they quickly learned and flexibly anticipated the target area of observed actions, even when they watched objects being brought to incorrect target areas. Infants, however, had difficulties anticipating to incorrect target locations for familiar objects. Together, these findings suggest that by 6 months of age, infants have acquired solid knowledge about objects and the actions associated with them.

Keywords: object knowledge, predictive looking, infancy, tool use

Over the course of our lives, we acquire conceptual knowledge about objects that is essential to the successful planning and performance of goal-directed actions. This knowledge involves information about what an object is used for and how it is used. As a consequence, our knowledge about, for example, a cup might comprise not only that it is hollow or has a handle but also that it is used for drinking, is usually grasped in a certain way (i.e., by the handle), and is brought to the mouth (cf. Rosch, 1978). In accordance with this embodied approach to knowledge representation, it could be shown in adults that action knowledge is an integral part of object concepts (see, e.g., Beauchamp & Martin, 2007; Rueschemeyer, Lindemann, van Elk, & Bekkering, in press; van Elk, van Schie, Lindemann, & Bekkering, 2007).

Young children watch others acting on objects from early on in life, and these repeated observations of others' everyday object use are thought to be one of the sources of their own functional object knowledge. The second important mechanism through which infants learn about objects and objects' functions is their own action experience. Their concrete experiences with objects (e.g., being fed with a bottle or a spoon or feeding themselves) are thought to support the acquisition of knowledge about the functions of these objects (see, e.g., Barrett, Davis, & Needham, 2007; Gredebäck & Melinder, 2008), and their object use skills are thought to emerge in a continuous and gradual process of exploration and discovery (Lockman, 2000). Furthermore, it has been suggested that young children might have a particularly strong tendency to view objects and events from a teleological–functional perspective and to perceive them as being "designed for a purpose" (Kelemen, 1999; Piaget, 1929). These predispositions, which are possibly present early in development (Gergely & Csibra, 2003), might also support infants' emerging object knowledge. To date, however, it is largely unknown how knowledge concerning the functional use of objects develops in young children.

A number of studies on early object use have investigated infants' ability to grasp everyday objects in a functional way and to bring them to a correct goal location. Learning how to use a spoon for feeding has been studied as one of the earliest tool-use skills (see, e.g., Connolly & Dalgleish, 1989; Gesell & Ilg, 1937; McCarty, Clifton, & Collard, 1999). However, the ability to effectively and reliably use a spoon to eat develops only during the course of the second year of life. In accord with this, McCarty and colleagues (1999) showed that infants tended to bring different objects, such as a spoon, a brush, or a hammer, to the correct target area using an appropriate grip not before 14 months of age.

From observational studies on the development of infants' spontaneous object play we know that infants start to exhibit some knowledge about object functions when they are approximately 1 year old. At this age, young children can be observed playing with everyday objects by handling them in a way they are normally used (e.g., bringing a cup to the mouth, trying to insert keys into a lock, rolling a ball, stirring a spoon in a bowl). The emergence of functional–conventional play (Casby, 2003; Piaget, 1951) marks a significant change in infants' play: Around 12 months of age, infants' object play changes from simple exploration and manipulation to a form of play that involves functional knowledge

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about the object. Moreover, in an imitation study, Killen and Uzgiris (1981) showed that 10- and 16-month-old infants were more likely to imitate actions demonstrated with appropriately matched objects (such as driving with a car) than with inappropriate objects (such as driving with a cup; also see McDonough & Mandler, 1998). The importance of this early awareness of the conventional use of objects has been emphasized in the context of language acquisition and infants' developing cultural knowledge (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Bates & Dick, 2002; Buresh & Woodward, 2007).

Taken together, these studies present broad evidence that it is not before the end of the first year of life that infants demonstrate their conventional object knowledge through the active use of objects, through nonfunctional recognitory gestures, or in their free play. To date, however, infants' developing object knowledge has mainly been studied in action execution paradigms (e.g., tool use studies, imitation studies, observational studies of free play). We argue that infants' knowledge about how to use an object and for what purpose might start to emerge much earlier than the point at which infants are able to perform the appropriate actions.

Attention and eye movements are important measures of infancy research (for a review, see Hunnius, 2007), and during the last decade, a nonintrusive and easy-to-apply method for precise measurement of eye movements in infants has become available (Haith, 2004; Hunnius & Geuze, 2004). Eye movement behavior, the way in which visual displays are scanned, can reveal specific information about how infants process and interpret complex stimuli, for example, through measures of fixation locations, fixation durations, and the occurrence of anticipatory eye movements (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Johnson, Amso, & Slemmer, 2003).

In adults, short anticipatory, rather than reactive, eye movements predicting the course of an observed action have been found during the observation of a block-stacking task (Flanagan & Johansson, 2003). This eye movement pattern during task observation appears to be highly similar to the gaze–hand coordination during the active execution of the task, and the occurrence of proactive eye movements during action observation is thought to indicate the mapping of the observed action onto an internal representation of that same action. It is interesting to note that comparable predictive eye movements directed to the target location of an action have been found in 12-month-old infants who were observing a simple action (putting balls into a bucket; Falck-Ytter et al., 2006). Moreover, infants do not show anticipatory eye movements when they watch "impossible" actions (balls jumping into a bucket by themselves).

Using a predictive looking paradigm, we examined the development of object knowledge in infancy in the present study. By presenting infants (and a comparison group of adults) with short movies of functional and nonfunctional actions with a number of everyday objects, we studied their expectations about how these objects are used. Infants between the ages of 6 and 16 months were tested. As it is known from action production studies that infants begin to exhibit functional knowledge about objects from the beginning of the second year of life, we expected that the older infants would exhibit more profound knowledge about more different objects than would younger infants. More important, we hypothesized that infants also would display knowledge about everyday objects at younger ages, when they cannot yet be observed producing the appropriate actions.

Method

Participants

There were 283 infant participants in the final sample: fifty-eight 6-month-olds (33 boys), fifty-six 8-month-olds (31 boys), fifty-five 12-month-olds (29 boys), fifty-seven 14-month-olds (31 boys), and fifty-seven 16-month-olds (34 boys). The infants' age within each age-group ranged from 2 weeks younger to 2 weeks older than the respective target age. Participants came from a sample of families who responded to an invitation letter sent to all families living with infants of appropriate age in the area of Nijmegen (a Dutch city with approximately 160,000 inhabitants). Therefore, participants were mostly Dutch, had been exposed mostly to Dutch in the home, and had mixed socioeconomic backgrounds. The participants were healthy, full-term infants without any pre- or perinatal complications. Several infants were excluded from the study, due to inattentiveness, fussiness, or equipment failure. Parents gave informed consent for participation of their child in the study. Additionally, a group of 54 adult participants (14 male, mean age = 21.4 years) was tested. The adult sample consisted of students of the Radboud University Nijmegen. They received monetary compensation or course credit for their participation. Infant as well as adult participants were assigned to the experimental conditions in a random fashion.

Stimuli

The stimulus material consisted of short movies (approximately 5 s in duration) in which a female model acted on three different everyday objects: a cup, a brush, and a mobile phone. The model demonstrated the use of the objects in either a functional way (bringing the cup to her mouth, the phone to her ear, and the brush to her hair) or a nonfunctional way (bringing the cup to her ear, the phone to her hair, and the brush to her mouth). The objects used in this study were all common, everyday objects with clearly distinct target locations (mouth, hair, and ear). All movies had the same duration, and the different action steps (reaching for the object, grasping and lifting it, and bringing it to the goal location) had approximately the same timing. The looking behavior of the model was kept constant, and she avoided looking into the camera during action execution. Figure 1 shows several key frames from the six movies.

Experimental Setup and Procedure

During the experiment, the infant was seated in an infant seat on the lap of his or her parent, who was sitting on a chair. All participants were tested at a viewing distance of approximately 60 cm. Light conditions were kept low to minimize visual distraction. During the experiment, the gaze of both eyes was recorded using a corneal reflection eye tracker (Tobii 1750, Tobii Technology, Stockholm, Sweden). The Tobii eye-tracking system is integrated in a 17-in. TFT flat-screen monitor on which the stimuli are shown, and the apparatus records gaze data at 50 Hz with an average accuracy of 0.5° visual angle. The monitor was mounted on an adjustable arm, so that the screen could always be positioned

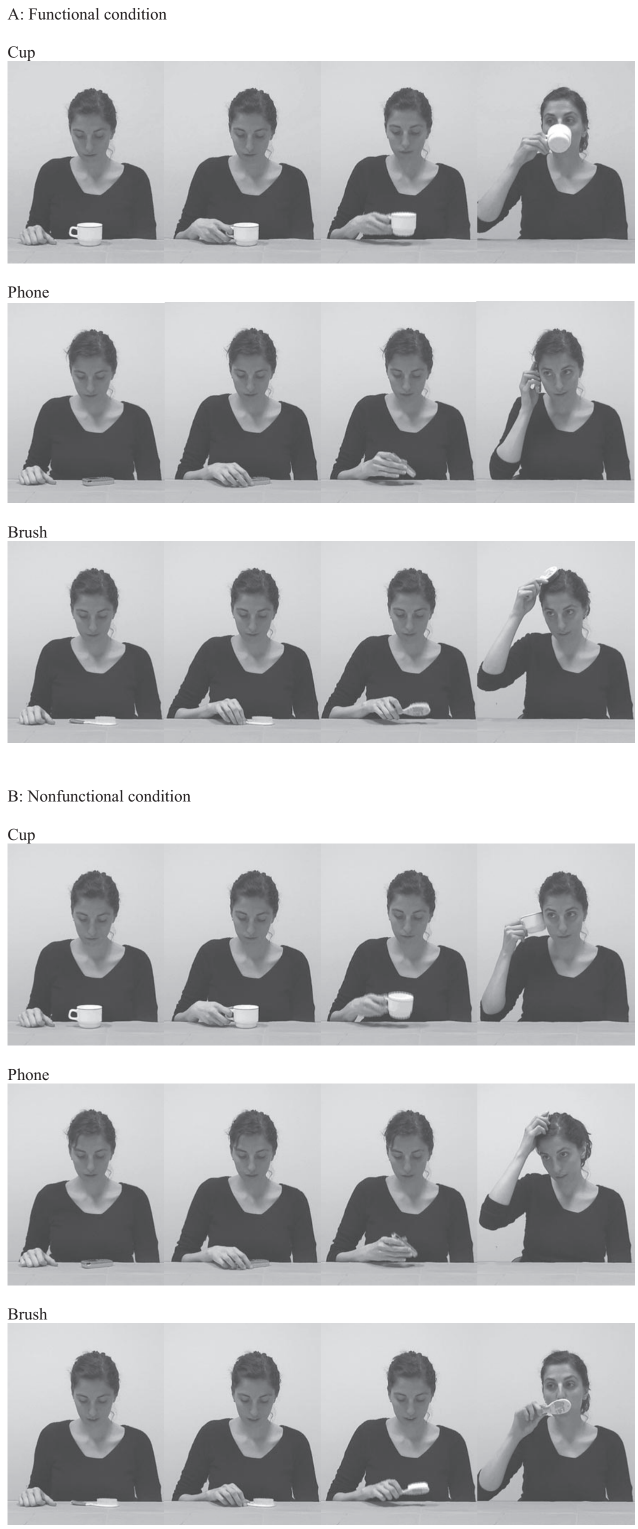

Figure 1. Four key frames from each stimulus movie for the functional (A) and the nonfunctional (B) condition. The individual whose face appears here gave signed consent for her likeness to be published in this article.

at the correct distance and kept fronto-parallel to the participant's face.

Prior to testing, we calibrated the gaze of each infant participant. We used a 9-point calibration procedure, in which an expanding–contracting circle accompanied by a sound appeared in every position of a screenwide 3 by 3 grid of calibration points on a black background. If seven or fewer points were calibrated successfully, the calibration was repeated for the missing calibration points; otherwise, the experiment was started.

During the experiment, each infant watched either functional actions or nonfunctional actions. Every stimulus movie was repeatedly presented nine times in row, and this resulted in three blocks of nine movies. After five repetitions of the movie and between stimulus blocks, short attention getters (e.g., a colorful geometric stimulus accompanied by an attractive sound) were presented. The order in which the movie blocks of each object were shown was randomized.

Analysis

For each movie, areas of interest were defined for the different target areas (mouth, ear, and hair region). These areas of interest were square in shape and had the same size and position for all six stimulus movies (see Figure 2A). Furthermore, the stimulus movies were divided into different phases: the grasping phase, the lifting phase, and the goal attainment phase. During the first phase of the stimulus movie, it could be seen how the model lifted her hand and grasped an object that was placed on a table in front of her. The next phase, the lifting phase, started after the model had grasped the object and begun to lift it and ended before object and hand entered the target area. The goal attainment phase started when the target area was reached and lasted until the end of the stimulus movie. Fixations to the different areas of interest throughout the stimulus movie were registered. To examine anticipatory looks, we first selected those trials in which infants paid attention to the displayed action and then analyzed whether infants looked at the different target areas during the lifting phase of the stimulus movies. An anticipatory look was defined as a look to one of the target areas during the lifting phase (i.e., before the model in the movie entered the goal area with the object or her hand). Figure 2B shows examples of anticipatory looks.

Results

Frequencies of Anticipatory Looks

First, we examined whether infants showed different frequencies of anticipatory looks to the target area of the observed action when they watched a functional versus a nonfunctional object–goal combination. In other words, the frequency of anticipatory looks to the mouth when the actor was lifting a cup was compared to the frequency of anticipatory looks to the mouth when the actor was lifting a brush. Likewise, the frequency of anticipatory looks to the ear when the actor was lifting a phone versus a cup and the frequency of anticipatory looks to the hair when the actor was lifting a brush versus a phone were included in this analysis. The averaged frequencies of anticipatory looks to the mouth, ear, and hair area for the different objects are displayed in Figures 3A, 3B, and 3C.

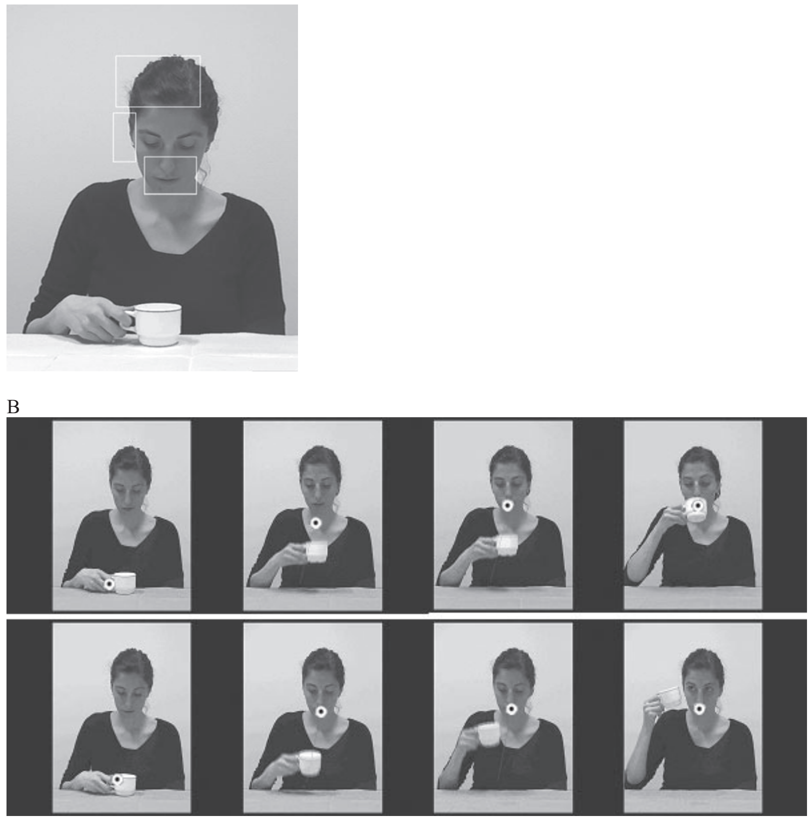

Figure 2. A: The areas of interest for the three target areas (mouth, ear, and hair region); B: Examples of an anticipatory look during observation of a functional (top) and a nonfunctional (bottom) action. The dot indicates the fixation location. The individual whose face appears here gave signed consent for her likeness to appear in this article.

A $3 \times 2 \times 5$ (Goal Area $\times$ Functionality of the Observed Action $\times$ Age) analysis of variance (ANOVA) was carried out with the relative frequency of anticipatory looks as the dependent variable. The analyses revealed a significant main effect of functionality of the observed action, $F(1, 270) = 13.96$, $p < .001$, with more anticipations occurring when a functional action rather than a nonfunctional action was observed. Moreover, a main effect of goal area, $F(1.53, 413.20) = 121.24$, $p < .001$, and a marginally significant main effect for age, $F(1, 270) = 2.30$, $p = .06$, were found. Pairwise comparisons using *t* tests demonstrated that significantly more anticipatory looks occurred to the mouth than to the ear and hair, $t(280) = 11.01$, $p < .001$; $t(280) = 12.39$, $p < .001$, respectively, and to the ear than to the hair, $t(270) = 2.34$, $p < .05$.

The analysis also yielded two significant interaction effects: the two-way interaction of age and goal area, $F(6.12, 413.20) = 2.36$, $p < .05$, and of functionality of the observed action and goal area, $F(1.53, 413.20) = 6.96$, $p < .01$. These interaction effects were further examined with three 2×5 (Functionality of the Observed Action $\times$ Age) ANOVAs. Here, the relative frequencies of anticipatory looks to the three action target areas (mouth, ear, and hair) were analyzed separately. These analyses revealed significant effects of functionality for anticipations to the mouth area, $F(1, 272) = 6.86$, $p = .01$, and to the ear area, $F(1, 272) = 23.98$, $p < .001$, whereas there was no significant effect for anticipations to the hair area, $F(1, 272) = 1.51$, $p = .22$. These effects indicate that infants exhibited more anticipatory looks to the mouth area and to the ear area when they watched the correct object being lifted than when they observed the unrelated object being brought to this goal area. The analyses also revealed that there was an increase in predictive looks for the mouth area as infants grew older, $F(4, 272) = 3.32$, $p < .05$, whereas there was no effect of age for the other target areas (all *p*s $> .40$). No significant interaction effects were found (all *p*s $> .60$).

Also, the adult control group showed frequent anticipations when watching the model as she was bringing different objects to different target areas in her face. *T* tests for independent samples showed that the frequency of predictive looks was significantly higher for adults than for all infant age-groups (all *p*s $< .01$). A 3×2 (Goal Area $\times$ Functionality of the Observed Action) ANOVA for the adult group yielded a significant main effect of goal area, $F(1.48, 77.05) = 93.58$, $p < .001$, as adults anticipated most frequently to the mouth ($M = 66.5\%$ of the trials, $SE = 3.6$) and less frequently to the ear ($M = 20.5\%$, $SE = 2.5$) and the hair area ($M = 17.4\%$, $SE = 2.4$). However, it revealed no significant main effect of functionality of the observed action, $F(1, 52) = 0.80$, $p = .38$, and no significant interaction effect, $F(1.48, 77.05) = 2.04$, $p = .15$. Adults thus visually anticipated to the target areas of the observed actions regardless of whether they

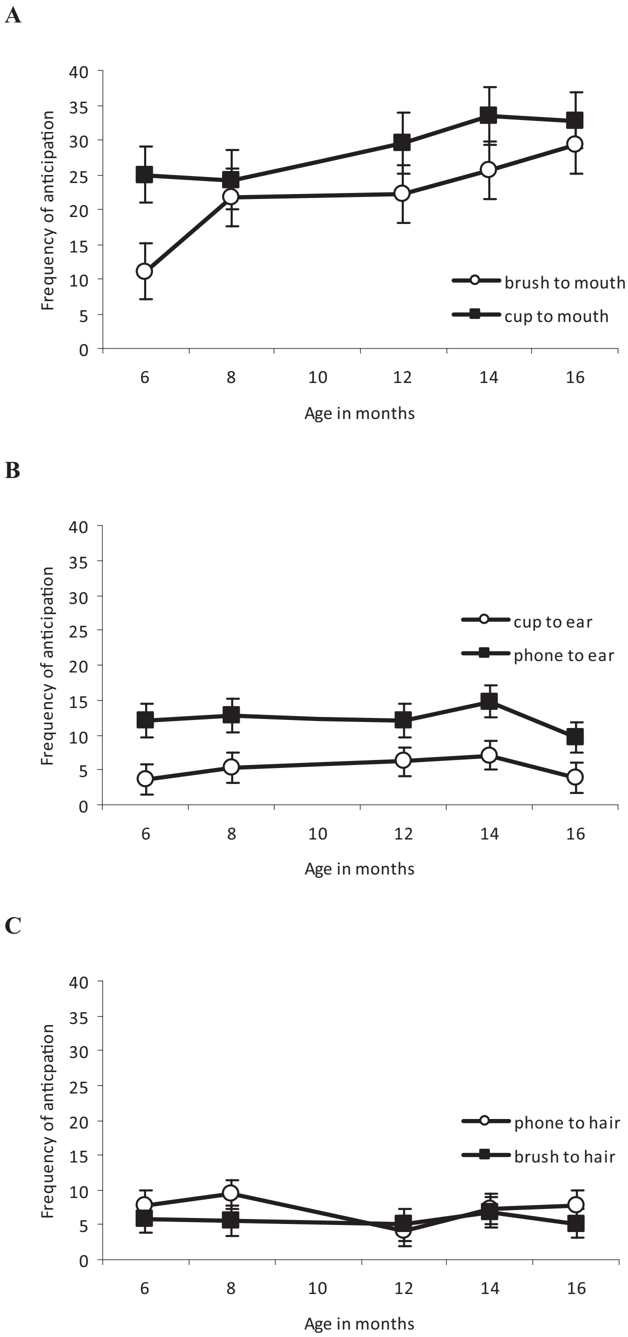

Figure 3. The averaged frequencies of anticipatory looks to the mouth (A), ear (B), and hair area (C) for the different objects. Error bars indicate the standard error of the mean.

were watching a set of functional or nonfunctional actions. This suggests that adults learned quickly about the target areas of the actions they observed and flexibly anticipated even when they watched objects being brought to incorrect target areas.

Anticipatory Looks During First Movie Presentation

Second, we analyzed whether the effect of more anticipatory looks to the goal area for correct objects that was found in infants was already present during the first of the nine presentations of the stimulus movie. The percentages of infants who showed predictive looks to the target area of the action for the different objects and areas when watching the movie for the first time are displayed in Figures 4A, 4B, and 4C.

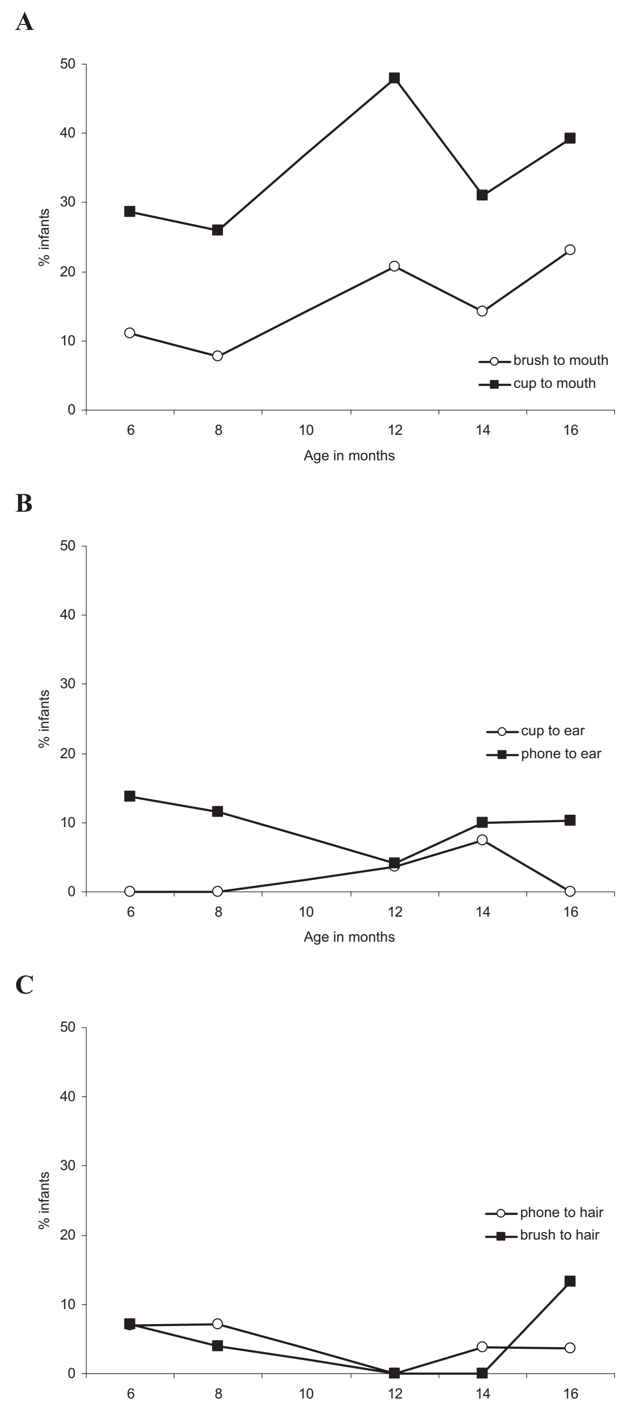

Figure 4. The percentage of infants who showed anticipatory looks to the mouth (A), ear (B), and hair area (C) for the different objects during the first presentation of the stimulus movie.

Chi-square tests revealed that more infants showed visual anticipations to the mouth area when they observed a cup being lifted than when they watched a brush being grasped and lifted for the first time, $\chi^2(1, N = 271) = 13.53, p < .001$. Moreover, relatively more infants anticipated to the ear area when the model grasped and picked up the phone for the first time than when the model reached for the cup to bring it to the ear, $\chi^2(1, N = 272) = 6.64, p < .05$. There was no significant difference, however, between the number of infants who showed predictive looks to the hair area for the brush and for the phone, $\chi^2(1, N = 271) = 0.14, p = .70$.

Looks to Correct Target Areas During Nonfunctional Trials

We further investigated infants' and adults' expectations about the objects' target locations by examining anticipatory eye movements to correct target areas during nonfunctional trials. These looks to the correct target area of an object, although the model did not bring the object there and repeatedly demonstrated an action to another target area (i.e., cup being brought to the ear, phone being brought to the hair), can be considered an additional measure of object knowledge.

On the basis of the earlier analyses on infants' predictive looking, we examined only the anticipatory looks for the mouth and the ear area. To study infants' perseverative looks to correct target locations also in nonfunctional trials, we applied $2 \times 2 \times 7$ (Functionality of the Observed Action $\times$ Object $\times$ Age) ANOVAs to investigate whether the three-way-interaction yielded significance. The analyses yielded significant three-way interactions among age, object, and functionality for anticipatory looks to the mouth, $F(5, 322) = 6.05, p < .001$, and to the ear area, $F(5, 322) = 2.95, p < .05$.

A closer look at Figure 5 illustrates these effects: In the functional condition, there was a clear effect of object for both target locations (see Figures 5A and 5B, upper graphs). Anticipatory looks to the mouth area, for example, occurred more frequently in infants of all ages as well as in adults when participants observed how the cup was grasped and picked up than when they watched the brush being handled (see Figure 5A, upper graph). For the nonfunctional episodes, however, an interesting change in the pattern occurs. Here, the participants watched how the model repeatedly brought the brush to her mouth, whereas the cup was brought to the ear instead of to the mouth (cf. Figure 1). Whereas the adults appeared to adjust to the unusual actions and showed an

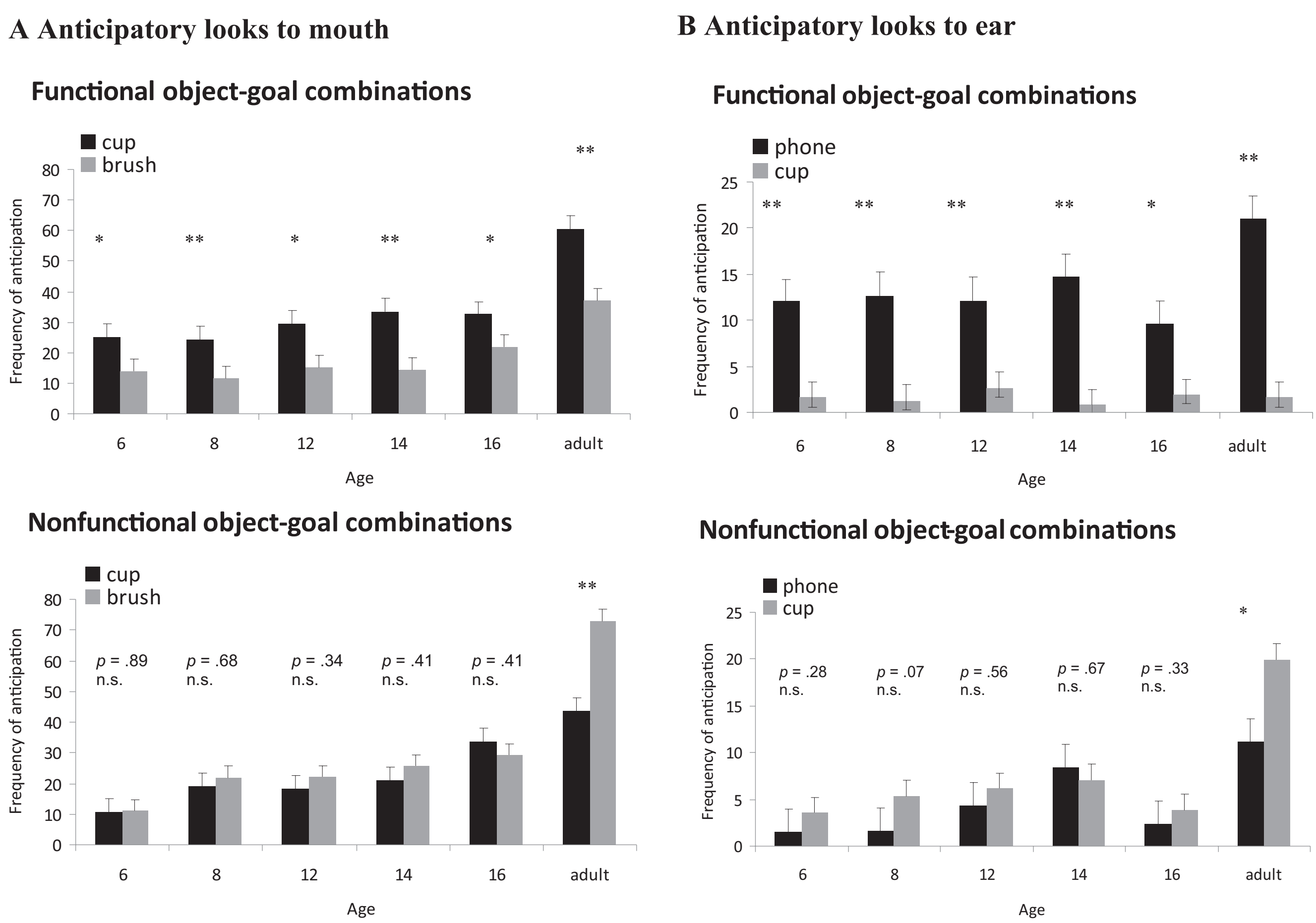

Figure 5. The averaged frequencies of anticipatory looks to the mouth (A) and ear area (B) for functional and nonfunctional object–goal combinations. Error bars indicate the standard error of the mean.

inversion of the looking pattern of the functional condition, infants anticipated less readily to the targets of an observed nonfunctional action. For example, in the functional condition infants showed a clear pattern of more frequent anticipations to the mouth when they saw the cup being grasped and lifted versus the brush (see Figure 5A, upper graph); in the nonfunctional condition, however, their anticipations to the mouth were not more frequent for one of the two actions (brush being brought to the mouth vs. cup being brought to the ear; see Figure 5B, lower graph). This finding is reflected in the pattern of significant effects that emerged from paired comparison *t* tests: For both looks to the mouth and looks to the ear, there were clear significant differences for the adult group in the functional as well as in the nonfunctional condition (all ps $<$ .05), whereas for the infants, there were significant differences only in the functional condition (all ps $<$ .05) and not in the nonfunctional condition (all ps $>$ .05; see Figures 5A and 5B for details).

Discussion

This study investigated the early development of infants' object knowledge. Infants were presented with functional and nonfunctional actions with three different everyday objects, and their predictive looks to the target areas of the presented actions were examined. For two of the three object–goal combinations, infants showed significantly more visual anticipations to the target area when observing a functional compared to a nonfunctional action: They anticipated more frequently when they watched a cup rather than a brush being brought to the mouth, and they performed more predictive looks when shown how a phone rather than a cup was brought to the ear region. Whereas previous evidence from infants' object use or symbolic play studies suggested that infants start displaying knowledge about the conventional use of objects only around the beginning of their second year of life (see, e.g., Killen & Uzgiris, 1981; McCarty et al., 1999), our findings demonstrate that infants know how functional objects are used long before their first birthday. In the present study, infants as young as 6 months of age exhibited clear indications of knowing which actions are associated with which objects for at least two everyday objects, a phone and a cup. This significant difference was found in infants from 6 months of age on and persisted throughout infancy until the age of 16 months.

Previous research has shown that from early in development on, the inner features of a face attract attention easily, whereas looks to the edge of a face are less frequent (Hunnius & Geuze, 2004). In the current study, we were able to replicate these results, as infants anticipated to the mouth of the model most frequently, looked to the ear area less often, and performed anticipatory looks to the hair area seldom. Despite these general differences in the probability of attracting attention to the three goal areas, anticipation frequencies to the mouth and to the ear area differed significantly for functional versus nonfunctional actions.

Our study revealed little developmental change between infants from the different age-groups. From 6 months on, infants associated two of the objects with functional movements, and there was no indication that they started to acquire knowledge about the third object, a brush, over the following months. From parents' reports, however, we learned that many infants, independent of their age, were not familiar with using a hairbrush in general or with a brush as we presented it in our stimulus movie (i.e., a white baby brush). The only significant change that occurred with age was that infants exhibited increasingly more anticipations to the mouth area as they grew older. One possible explanation for this effect might be that throughout infancy, the habit of purposefully bringing something to the mouth—food or an object like a spoon or a feeding bottle—becomes more and more established. There was no such effect for the other two target areas, and for all three areas, there was a significant difference in the frequency of predictive looks between the oldest infants of the sample and the adult participants. Adult-like patterns when observing actions to the hair and to the ear thus appear to emerge only later in development, possibly together with the ability to actively and purposefully bring objects to these target areas.

Compared with the infants, the adult group showed a clearly different pattern of visual behavior. As mentioned above, adults anticipated more frequently to the target areas of the actions they observed. However, adults were much less affected by the functionality of the actions and showed no differences in the frequency of predictive looks when they observed functional or nonfunctional object–goal combinations. Instead, it seems that they adapted their predictive looking to the nonfunctional actions and showed great flexibility in anticipating functional and nonfunctional actions. Previous research on adults' looking behavior during action observation has demonstrated that predictive eye movements can frequently be observed when adults monitor actions. The presence of hand–object interactions (Falck-Ytter et al., 2006; Flanagan & Johansson, 2003) or even the possibility of identifying an autonomous agent that causes the observed movements (Gesierich, Bruzzo, Ottoboni, & Finos, 2008) plays an important role in the occurrence of such proactive eye movements. Even when adult observers watch unpredictable actions during a block-stacking task, they show proactive eye movements, but their target fixations occur later than do observations of predictable actions (Rotman, Troje, Johansson, & Flanagan, 2006). The results of the present study are in accord with these earlier findings, as the adult participants in the nonfunctional trials probably made use of the kinematic information that was present in the actor's movement and, as the actions were repeated, flexibly attuned their gazing behavior to the unfamiliar action.[1]

Infants, on the contrary, had difficulty adapting their predictive gazing behavior when they observed objects being brought to incorrect goal locations. Whereas adults started to anticipate quickly also to unfamiliar target areas, infants appeared to be reluctant to accept unfamiliar locations as the action targets. This finding suggests that during the second half of their first year, infants are already equipped with solid knowledge about objects and the actions associated with them. It is consistent with evidence from action production studies that prior knowledge about and experience with objects strongly influences infants' and young

[1] Because anticipatory looks to the target locations were overall rather infrequent, especially for locations other than the mouth and in the infant samples, we did not carry out analyses on the anticipatory gaze latencies. It is possible, however, that for the adults, who did not show differences between correct and incorrect object–target combinations for the frequency of predictive looks, there might have been differences in the anticipation latencies.

children's subsequent handling and use of these objects (Barrett et al., 2007; Casler & Kelemen, 2005). Barrett et al. (2007), for instance, demonstrated that the actions of 12- and 18-month-old infants with a familiar tool (either an everyday object or a tool they have been trained with) are less flexible than their actions with a completely novel tool. Taken together, these findings suggest that from very early on infants start to acquire knowledge about how to use objects and that this knowledge guides their expectations about other people's actions as well as, later on, their own actions.

How do infants acquire expectations about how an object should be used, and which processes underlie their anticipations when they observe object use in others? Different mechanisms probably play a role here: On the one hand, the impact of infants' own action experience for their understanding of other people's actions has been emphasized (Sommerville, Woodward, & Needham, 2004; Woodward, Sommerville, & Guajardo, 2001). Predictive eye movements during action observation have been linked to direct matching processes between the observed action and its internal representation and to mirror neuron activity, as anticipatory looks primarily occur when a human actor is observed (Falck-Ytter et al., 2006; Flanagan & Johansson, 2003). On the other hand, infants might acquire knowledge about objects and the actions associated with them through observation. According to the ideomotor principle, infants are thought to first observe perceptual consequences of actions (e.g., that one can drink after bringing a cup to the mouth) and to learn consequently to control their own motor system to achieve the anticipated consequences themselves (Hauf & Prinz, 2007). In accord with this, it has been shown that infants watch other persons and their actions carefully and detect regularities between these actions and their effects from an early age (Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Woodward, 1998).

In the present study, infants probably exhibited visual anticipations on the basis of both the processes sketched above. Their own action experience might have subserved their predictive looks during action observation, and this might have been the case particularly for the older children, who were gaining increasing experience with objects. The younger infants, however, were very unlikely to have active action experience with cups or phones. In these infants, learning through observation might have played a more important role, and they might thus have anticipated to the target area of the action on the basis of their associative knowledge about objects. Furthermore, the fact that we found anticipatory looks in infants as young as 6 months of age and for actions they had little-to-no experience with suggests that predictive eye movements might be less experience dependent than has previously been suggested (Falck-Ytter et al., 2006). Researchers should examine in more detail which processes are subserving infants' expectations about the course of observed actions in studies that tap indicators of these processes in a more direct way. In the future, EEG studies might provide more insight into this topic (cf. Nyström, 2008; Reid, Csibra, Belsky, & Johnson, 2007; Reid & Striano, 2008; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008).

Different interpretations are possible when it comes to what kind of knowledge the infants in our study exhibited when they anticipated to the target area of an observed action. Knowing where an object should be brought in order to use it properly is part of functional object knowledge. Predictive looks might also occur as a result of lower level representations, such as visual associations or statistical learning. Recent studies have suggested that during infancy, complex cognitive representations can emerge from statistical learning about the co-occurrence of phenomena, for instance, in learning about visual scenes (Fiser & Aslin, 2002) or in language acquisition (Altmann, 2002; Saffran, Aslin, & Newport, 1996). However, our findings provide strong evidence that from a young age on, infants have clear-cut representations of which action is associated with which object for a number of objects from their everyday environment.

Our findings also demonstrate that investigating visual anticipations is a powerful measure with which to study infants' cognitive development. For the present study, we analyzed the occurrence of predictive eye movements to action target areas; to date, this measure has mostly been used to examine direct mapping processes during action observation or infants' expectations about the reappearance of occluded objects (see, e.g., Falck-Ytter et al., 2006; Flanagan & Johansson, 2003; von Hofsten, Kochukhova, & Rosander, 2007). By completing an observed action with their gaze, however, infants reveal information about their expectations and their knowledge about the world. Therefore, the visual anticipation paradigm can be an important addition to the habituation-based looking measures that are traditionally used in infancy research. The suitability of habituation-based looking methods for the investigation of complex cognitive processes has been questioned (Haith, 1998; Schöner & Thelen, 2006), as these overall looking measures are unspecific and global and allow only indirect conclusions about cognitive processing. Compared to habituation-based looking measures, the anticipatory looking paradigm thus has several advantages: It does not require a habituation or learning phase, it directly assesses the infant's expectations about observed actions and events, and it can in principle be employed with older children or adults.

In summary, the present study shows that by the second half of their first year of life, infants have already developed a solid knowledge about how a number of everyday objects should be used. This knowledge might provide the basis for their emerging active tool-use skills, which start to unfold over the course of the second year of life.

References

Altmann, G. T. M. (2002). Statistical learning in infants. *Proceedings of the National Academy of Sciences, USA, 99,* 15250–15251.

Barrett, T. M., Davis, E. F., & Needham, A. (2007). Learning about tools in infancy. *Developmental Psychology, 43,* 352–368.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy.* New York: Academic Press.

Bates, E., & Dick, F. (2002). Language, gesture, and the developing brain. *Developmental Psychobiology, 40,* 293–310.

Beauchamp, M., & Martin, A. (2007). Grounding object concepts in perception and action: Evidence from fMRI studies of tools. *Cortex, 43,* 461–468.

Buresh, J. S., & Woodward, A. L. (2007). Infants track action goals within and across agents. *Cognition, 104,* 287–314.

Casby, M. W. (2003). Developmental assessment of play: A model for early intervention. *Communication Disorders Quarterly, 24,* 175–183.

Casler, K., & Kelemen, D. (2005). Young children's rapid learning about artifacts. *Developmental Science, 8,* 472–480.

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill. *Developmental Psychology, 25,* 894–912.
Falck-Ytter, F., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience, 9,* 878–879.
Fiser, J., & Aslin, R. N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences, USA, 99,* 15822–15826.
Flanagan, J. R., & Johansson, R. S. (2003, August 14). Action plans used in action observation. *Nature, 424,* 769–771.
Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences, 7,* 287–292.
Gesell, A., & Ilg, F. L. (1937). *Feeding behavior of infants: A pediatric approach to the mental hygiene of early life.* Philadelphia: Lippincott.
Gesierich, B., Bruzzo, A., Ottoboni, G., & Finos, L. (2008). Human gaze behaviour during action execution and observation. *Acta Psychologica, 128,* 324–330.
Gredebäck, G., & Melinder, A. (2008, March). *Goal prediction during observation of rational and irrational social events.* Paper presented at the 16th International Conference on Infant Studies, Vancouver, British Columbia, Canada.
Haith, M. M. (1998). Who put the cog in infant cognition: Is rich interpretation too costly? *Infant Behavior and Development, 21,* 167–179.
Haith, M. M. (2004). Progress and standardization in eye movement work with human infants. *Infancy, 6,* 257–265.
Hauf, P., & Prinz, W. (2007). The understanding of own and others' actions during infancy: "You-like-me" or "Me-like-you"? In P. Hauf & F. Försterling (Eds.), *Making minds: The shaping of human minds through social context* (pp. 211–226). Amsterdam: John Benjamins.
Hunnius, S. (2007). The early development of visual attention and its implications for social and cognitive development. *Progress in Brain Research, 164,* 187–209.
Hunnius, S., & Geuze, R. H. (2004). Developmental changes in visual scanning of dynamic faces and abstract stimuli in infants: A longitudinal study. *Infancy, 6,* 231–255.
Johnson, S. P., Amso, D., & Slemmer, J. A. (2003). Development of object concepts in infancy: Evidence for early learning in an eye tracking paradigm. *Proceedings of the National Academy of Sciences, USA, 100,* 10568–10573.
Kelemen, D. (1999). The scope of teleological thinking in preschool children. *Cognition, 70,* 241–272.
Killen, M., & Uzgiris, I. C. (1981). Imitation of actions with objects: The role of social meaning. *Journal of Genetic Psychology, 138,* 219–229.
Király, I., Jovanovic, B., Prinz, W., Aschersleben, G., & Gergely, G. (2003). The early origins of goal attribution in infancy. *Consciousness and Cognition, 12,* 752–769.
Lockman, J. J. (2000). A perception–action perspective on tool use development. *Child Development, 71,* 137–144.
McCarty, M. E., Clifton, R. K., & Collard, R. R. (1999). Problem solving in infancy: The emergence of an action plan. *Developmental Psychology, 35,* 1091–1101.
McDonough, L., & Mandler, J. M. (1998). Inductive generalization in 9- and 11-month-olds. *Developmental Science, 1,* 227–232.
Nyström, P. (2008). The infant mirror neuron system studied with high-density EEG. *Social Neuroscience, 3,* 334–347.
Piaget, J. (1929). *The child's conception of the world.* New York: Harcourt, Brace Jovanovich.
Piaget, J. (1951). *Play, dreams and imitation.* Melbourne, Australia: Heineman.
Reid, V. M., Csibra, G., Belsky, J., & Johnson, M. H. (2007). Neural correlates of the perception of goal-directed action in infants. *Acta Psychologica, 124,* 129–138.
Reid, V. M., & Striano, T. (2008). N400 involvement in the processing of action sequences. *Neuroscience Letters, 433,* 93–97.
Rosch, E. H. (1978). Principles of categorization. In E. Rosch & B. Lloyd (Eds.), *Cognition and categorization* (pp. 27–48). Hillsdale, NJ: Erlbaum.
Rotman, G., Troje, N. F., Johansson, R. S., & Flanagan, J. R. (2006). Eye movements when observing predictable and unpredictable actions. *Journal of Neurophysiology, 96,* 1358–1369.
Rueschemeyer, S.-A., Lindemann, O., van Elk, M., & Bekkering, H. (in press). Embodied cognition: The interplay between automatic resonance and selection-for-action mechanisms. *European Journal of Social Psychology.*
Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996, December 13). Statistical learning by 8-month-old infants. *Science, 274,* 1926–1928.
Schöner, G., & Thelen, E. (2006). Using dynamic field theory to rethink infant habituation. *Psychological Review, 113,* 273–299.
Sommerville, J. A., Woodward, A. L., & Needham, A. (2004). Action experience alters 3-month-old infants' perception of others' actions. *Cognition, 96,* B1–B11.
van Elk, M., van Schie, H. T., Hunnius, S., Vesper, C., & Bekkering, H. (2008). You'll never crawl alone: Neurophysiological evidence for experience-dependent motor resonance in infancy. *NeuroImage, 43,* 808–814.
van Elk, M., van Schie, H., Lindemann, O., & Bekkering, H. (2007). Using conceptual knowledge in action and language. In P. Haggard, Y. Rossetti, & M. Kawato (Eds), *Attention and performance XXII: Sensorimotor foundation of higher cognition* (pp. 575–599). Oxford, England: Oxford University Press.
von Hofsten, C., Kochukhova, O., & Rosander, K. (2007). Predictive tracking over occlusion by 4-month-old infants. *Developmental Science, 10,* 625–640.
Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69,* 1–34.
Woodward, A. L., Sommerville, J. A., & Guajardo, J. J. (2001). How infants make sense of intentional action. In B. F. Malle, L. J. Moses, & D. A. Baldwin (Eds.), *Intentions and intentionality: Foundations of social cognition* (pp. 149–169). Cambridge, MA: MIT Press.

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